NASA/SP-2015-626

Science Training History of the Apollo Astronauts

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Apollo 17 crewmembers Gene Cernan and Harrison Schmitt conducting a practice EVA in the southern Nevada Volcanic Field near Tonopah, NV (NASA Photograph AS17-S72-48930).

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Cover photographs: From top: Apollo 13 Commander (CDR) James Lovell, left, and Lunar Module Pilot (LMP) Fred Haise during a geologic training trip to Kilbourne Hole, NM, November 1969 (NASA Photography S69-25199); (Center) Apollo 16 LMP Charles Duke (left) and CDR John W. Young (right) during a practice EVA at Sudbury Crater, Ontario, Canada, July 1971 (NASA Photograph AS16-S71-39840); Apollo 17 LMP Harrison Schmitt (left) and CDR Eugene Cernan (right) during a practive EVA at Lunar Crater Volcanic Field, Tonopah, Nevada, September 1972 (NASA Photograph AS17-S72-48895); Apollo 15 CDR David Scott (left) and James Irwin (right) during practice geologic EVA training at the Rio Grande Gorge, Taos, NM, March 1971 (NASA Photograph AS15-S71-23773)

ACKNOWLEDGEMENTS

When I retired from NASA several of my coworkers, particularly Dave McKay and Everett Gibson, suggested that, given my past role as the coordinator for the science training of the Apollo astronauts, I should put together a history of what was involved in that training. Because it had been nearly twenty-five years since the end of Apollo they pointed out that many of the persons involved in that training might not be around when advice might be sought for future missions of this type. The difficult lessons learned during that training should be made available in print for the benefit of any similar programs in the future. With financial aid from NASA the work got underway with interviews, collection of files & photos, visits to archives, and assembly of notes from individuals who were involved. Thanks are due to: Mike McEwen, Dave McKay, Gordie Swann, Bill Muehlberger, Gene Shoemaker, Jack Sevier, Jim Head, Farouk El-Baz, Gerry Schaber, Jack Schmitt, John Young, and John Dietrich for taking the time to discuss with me their roles in and assessments of the training as well as providing copies of documents and photos that were crucial to the accuracy of the history; Ray Zedekar for providing the detailed daily schedules of the various Apollo crews; Paul Lowman for providing several documents regarding early astronaut training; and Gary Lofgren, Fred Horz, and Don Morrison for providing copies of the detailed schedules that they kept as science trainers for the Apollo 15, 16, and 17 crews respectively. Special thanks go to Uel Clanton who allowed me to spend a few days with him at his home going through his extensive collections of recordings and documents as well as his personal recollections of the early training. Two other persons who deserve special thanks are Jodie Swann who led me through the maze of USGS documents to glean the useful ones and Pat Patnesky, the official NASA photographer throughout the training, who helped select a few photos from the thousands that he had taken. Thanks are also due to the helpful staffs during my visits to the National Archives Pacific Region at Laguna Niguel, California and The University of New Mexico Libraries at Albuquerque. Their aid in finding the proper boxes in their storage areas and copying and mailing to me the selected documents was invaluable. And finally the persistence of Dean Eppler in getting the completed history out of limbo and off to publication is greatly appreciated.

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Section I: GENERAL OVERVIEW

1. Background and Rationale

The science that had been accomplished in space up to the selection of the original astronauts on April 9, 1959 consisted mainly of solar and atmospheric physics studies from balloons and sounding rockets. The assignment of astronauts to the newly formed NASA had nothing to do with the development of scientific exploration of space. Their main objective was to surpass the Soviet Union in all aspects of manned spaceflight from the first man in space to manned orbital flights to whatever else was possible. Future scientific studies of space were expected to be conducted by means of unmanned spacecraft. But on April 12, 1961, when the Soviets became the first nation to put a man in space by sending Yuri Gagarin into one complete orbit of the Earth, President Kennedy was forced to look for a dramatic event that would spur the U.S. space program to a position of unmistaken leadership in the space race. By May 25, 1961 President Kennedy had decided on the nature of this dramatic event when he presented his famous message to Congress calling for a manned lunar landing to be accomplished before the end of the decade, to be known as Project Apollo.

Although the initial goal of Apollo was stated only as landing a man on the Moon and returning him safely a question soon arose about what might be done by a man once he was on the lunar surface. Max Faget, the director of engineering at the Manned Spacecraft Center (MSC), is quoted as saying “it wouldn’t look very good if we went to the Moon and didn’t have something to do when we got there” (NASA SP-4214, p. 20-22). There had already been some discussions about the use of unmanned spacecraft and instruments to scientifically study the nature of the Moon. Therefore, the immediate answer to the question was to conduct scientific studies such as collecting samples, deploying instruments, and taking photos that would help scientists understand the origin and evolution of the Moon. Despite the reluctance of most space scientists to accept the use of manned missions to conduct space exploration, it soon became clear that Apollo was going to accomplish such exploration. As the planning for Apollo proceeded, the manned lunar landing evolved into several lunar landings to be followed by even more elaborate lunar bases, mobile laboratories, and flying machines that would be undertaken throughout the 1970s.

As the Apollo plans progressed both the direction and speed of NASA’s efforts began to change. New spacecraft had to be designed to test many aspects of manned flight including more than one man in the spacecraft, orbital rendezvous techniques, physiological effects of long-duration flights, and many other things. The urgency for planning and developing rockets, spacecraft, guidance, communications, and operations to meet the needs of Apollo gave these efforts the highest priority. At this stage science efforts were given low priority, except where they applied directly to the success of the Apollo missions. Clearly, some unmanned spacecraft were also needed to map the lunar surface from lunar orbit and to determine the nature of the lunar soil by landing on the surface. All of these requirements that had to precede a lunar landing required drastic modifications in NASA’s organization, staffing, budget, and facilities. In addition, there was a need to consider what type of training was necessary for the astronauts.

At first, the initial training for the astronauts, whose task was primarily to fly spacecraft, was thought to be similar to that of test pilots who needed to learn how to use the controls and instruments required to fly their craft. As more thought was put into the nature of the training required for flying spacecraft a training program was designed to include some of the scientific needs that might be necessary in this new endeavor. The first of these science training programs started in May 1959 and included mechanics and aerodynamics, space physics, principles of guidance and control, navigation in space, elements of communication, and basic physiology. Each astronaut also spent time at a planetarium studying star recognition and celestial navigation.

As the time for John Glenn’s first orbital flight approached in early 1962 scientists were beginning to suggest various types of observations that might be attempted by man from Earth orbit: taking photos, describing cloud cover, observing lightning in squall lines, looking for comets, noting frequencies of meteor flashes, sketching the zodiacal light relative to star background, and describing auroral observations. On December 8, 1961 John Glenn, Scott Carpenter, and Wally Schirra, the astronauts scheduled for the next three Mercury missions, met with the Astronomy Subcommittee of NASA's Space Sciences Steering Group to hear about the suggested observations that they might make from orbit. This was the very first scientific briefing for mission experiments that might be carried out by the astronauts. During John Glenn's 5-hour Mercury flight of February 20, 1962 he was able to make many of the suggested astronomical observations as well as provide photos of Earth with a camera that he had purchased at a local drug store. He took photos of cloud formations, dust storms in the Sahara Desert, sunsets, and many other features. This led Homer Newell, who was in charge of the Office of Space Science at NASA Headquarters, to form the Ad Hoc Committee on Scientific Tasks and Training for Man-in-Space. This committee suggested numerous observations and experiments that could be carried out by the astronauts. Throughout the remainder of the Mercury Program the astronauts conducted many of these experiments and took some excellent photos of several terrestrial features, some of which were in areas that had not been explored previously.

The success of the experiments in the Mercury Program led to an RFP for experiments to be carried out during the Gemini Program. The Manned Space Flight Experiments Board (MSFEB) was formed in January of 1964 to evaluate experiments proposed for both Gemini and Apollo. More than 50 experiments in astronomy, biology, atmospheric sciences, medicine, radiation effects, micrometeoroids, space environment, and Earth sciences were carried out during the one and a half years of the 10 flights in the Gemini program, which ended in November 1966. During Gemini there were many opportunities for the investigators to spend time with both the astronauts and the supporting crew members. Clearly, by the end of the Gemini program the science experiments program was developing rather rapidly. The cooperation of astronauts, flight controllers, and principal investigators (PIs) was a major accomplishment and contributed to extremely successful results.

In the midst of the Mercury Program a second group of astronauts was brought on board in mid-September 1962 and another basic science training program was designed. Because the new program would be more extensive than the earlier one and because there would be much more additional material, both the original astronauts and the second group were to participate in the new program. From October 1962 through January 1963 this science program covered astronomy; aerodynamics; space physics; selenology (mainly lunar geology); propulsion; physics of orbital flight; computers; medical aspects of space flight; navigation and guidance; a two-day trip to a planetarium for navigational aspects of astronomy; and a two-day field trip to Flagstaff, Arizona, to study Meteor Crater and volcanic features and observe lunar features by telescope.

While the early science training was being accomplished through January 1963 the role of science for the Apollo program was being discussed and taking many different directions, involving many different groups, including the newly formed MSC in Houston, NASA Headquarters, and the United States Geological Survey (USGS). Most importantly, in September 1961, the Space Task Group (STG) at Langley was assigned to move to Houston which had been selected as the location for MSC and was to be the focal point for all of the manned spacecraft activity. Initially there was little interest at MSC in any aspects of science outside of what was required for the operational aspects of a lunar mission which included such items as the nature of the lunar surface temperatures, the extent of the lunar vacuum, and all of the other pertinent conditions of the lunar surface environment, and how they changed during the course of lunar day and night. Scientific expertise was required also to help set up training facilities that simulated lunar conditions for use to test equipment to be used on the lunar surface, to test the mobility and comfort of spacesuits, and to provide training programs for astronauts.

Starting in late 1961 NASA Headquarters began readjusting its science programs to accommodate the precursor studies needed for Apollo. Over the next few years various committees, working groups, and summer studies were convened by Headquarters to propose guidelines for the science to be accomplished during Apollo and the training that the astronauts would need. As planning for Apollo science experiments and the associated training for the astronauts got under way at NASA Headquarters in 1962, there were concerns about the manner in which both of these activities should be conducted, especially from the engineers and operations personnel at the newly formed MSC in Houston. These concerns were elaborated in a series of memos during 1963. Two memos written by Homer Newell indicated that MSC management did not appreciate what space science and manned spaceflight could do for each other and, in his opinion, the few scientists who were at MSC served only in support roles providing data to the engineers. These MSC scientists were almost exclusively recent graduates who were relatively inexperienced in research and had no scientific research under way. Starting in early 1963 Newell urged both NASA Headquarters and MSC to support the development of science research facilities and a more research-oriented program for space science in general at MSC. MSC was generally unresponsive to these suggestions until 1970 when several significant additions were made to the research facilities and personnel.

The USGS had programs of lunar mapping and crater studies well under way by the early 1960s. In addition they commenced a study in July 1964 under the title Manned Lunar Explorations Investigations, containing five separate projects: 1) Lunar Field Geological Methods, 2) Lunar Field Geophysical Methods, 3) Lunar Field Surveying

Methods, 4) Electronics Investigations for Field Systems, and 5) Documentation for Lunar Field Systems. By 1965 the USGS had formally proposed most of the types of equipment considered essential for samp1e selection, collection, and documentation on the lunar surface, including a scoop, extension handle, core tubes, hammer, scriber/brush, hand lens, sample bags, and a tool and sample carrier. (MSC had already started development of most of these tools through a contract with Martin Marietta in 1964.) The USGS also had developed radio and television (TV) communication systems between field crews and a central control facility. In addition the USGS, along with personnel at MSC, conducted many geological tests in pressure suits to determine the extent to which mobility and exhaustion would affect the ability to conduct geologic activities on the lunar surface. Furthermore, they began developing equipment and procedures for a more extended exploration program to follow Apollo.

It was during the growth of these organizations that the detailed plans for further training of the astronauts were developed. Clearly all of the astronauts for the early Apollo flights would have test pilot backgrounds. Because it was becoming rather obvious that most of the lunar surface activities would be geologically oriented, and the test pilots had no background in this subject, the crews would require a significant amount of training in geology. Throughout early 1963 at MSC there was a growing consensus among the science group, and perhaps a few others in the Engineering Directorate, that they needed to set up a training program for the astronauts, largely in geology, but also including some of the other pertinent sciences. Meanwhile at NASA Headquarters Gene Shoemaker, who was detailed from the USGS to NASA, was trying to develop better communications and collaboration between the Manned Spaceflight Office and the Science Office. During his time at Headquarters Shoemaker had taken the first two groups of astronauts on their two day field trip to Flagstaff, Arizona in January 1963 to study Meteor Crater, volcanic features, and observe lunar features by telescope. The positive response that he received led him, in early 1963, to set up an unofficial arrangement between the USGS and NASA to have USGS personnel conduct the geologic training of the astronauts. The USGS personnel were to be in residence at MSC in Houston where they would develop and execute the training program. Shoemaker and Headquarters were unaware that MSC personnel were also proceeding with plans to set up a similar training program. When the first of the USGS personnel arrived at MSC in early July 1963 it was rather a shock for them to discover that MSC personnel were already under way on the same task that they were to develop.

Because of this unexpected turn of events and the lack of any formal agreements regarding the respective roles of the USGS vis a vis MSC it was not clear who was to do what. Although there had been some discussion among the MSC group about this situation before the arrival of USGS personnel no specific details had been agreed upon. The MSC group expected that both groups would participate in all aspects of the astronaut training and in some of the hardware discussions equally. After the arrival of the USGS, however, it was agreed that the training would be split into three separate parts. The USGS would handle the ‘typical geology,’ or the basic lectures. The NASA geologists would handle the mineralogy/petrology part of the coursework. And the USGS group and the NASA group would work cooperatively to put together the field trips. This arrangement allowed both NASA and the USGS to cooperate equally in the training program. Once this division of responsibilities was agreed upon the groups started planning a program of lectures, labs, and field trips.

For the geologically oriented training there was no question that field observations were to be a major part of the experience, but some basic knowledge of geological principles, processes, structures, descriptive terms, and rock types were felt to be necessary before the field experiences could be meaningful. Furthermore, a continuing joint development of the details and concepts of geology along with the field observations was considered necessary. In retrospect some of those involved would have preferred to have had more of the geologic principles and processes taught in the field rather than the classroom. The outcome of all the planning and discussion was a very ambitious and extended geology program that, in the first draft (December 1963), consisted of six four-month programs: Series I through Series VI, the concluding program, which was the specific crew training for Apollo missions.

A third group of astronauts had now been selected and they were scheduled to take a similar overall science training program as the first two groups, plus the newly designed geology curriculum. Because the first two groups of astronauts had not taken any detailed geology courses the astronaut office agreed that the first two groups of astronauts would join the third group for the new geology segment of the curriculum. A total of 29 astronauts participated in Series I of the geology training which lasted from February 3, 1964 through June 15, 1964.

At this point the animosity that had developed between some of the USGS and MSC personnel led to the withdrawal of the USGS contingent from Houston to the USGS offices in Flagstaff, Arizona, on July 1, 1964. It was agreed that the USGS would continue to participate in the training in the manner that was agreed upon the previous year, but they would not be in residence in Houston. Under these conditions the continuation of training for the first three groups of astronauts in Series II and III commenced in September 1964 and continued through November 1965. Science training for the fourth and fifth groups of astronauts, with a total of 24 participants, began in May 1966 and continued through September 1967 using the same geology training series as the first three groups.

The sixth group of astronauts, who arrived in August 1967, received drastically different training from that of the previous groups. One of the reasons for the change was that several scientists were among this group of astronauts and they could evaluate better the nature of any science training. A second reason involved the cancellation of some of the Apollo missions as well as all of the follow-on programs for lunar exploration after Apollo. Clearly, this sixth group was not going to be trained for any of the Apollo lunar missions, and the role of any particular science in whatever they were to accomplish was undetermined. The scientists in this group became heavily involved in planning the training for the group, as well as in the teaching itself. Although all participants in the prior training agreed that the field trips had been the most useful parts of the curriculum the new plans did not include any field trips because of the uncertainty about what this group of astronauts would be doing. Furthermore the extensive geology coursework of the earlier training was now included in only a few lectures titled “planetology” that were taught almost entirely by instructors who had not been involved in the earlier training. Class work for this group took place from October 1967 to March 1968. This was the last of the group training efforts before the program changed completely to the mode that treated each Apollo crew individually.

The MSC and USGS scientists were also involved with the development of areas that could be used as simulated lunar surfaces for developing and testing the various hand tools, instruments, and procedures that were to be used on the lunar surface during the actual Apollo missions. The first of these was created in 1963 in a room in one of the oldj converted barracks at Ellington Air Force Base (AFB). The walls were painted black and a light with variable intensity was placed in one corner of the room. Suited astronauts or other test subjects were brought into the room to determine what minimum light conditions were necessary to conduct surface tasks. A larger room with a higher ceiling was then used to allow the light to come from a point nearly overhead, a more realistic simulation. Next came the "rock pile" which was installed at MSC in late 1964 to early 1965 as a place to run suited subjects and/or astronauts over a simulated lunar surface having a 63 feet diameter. It had two large craters and several smaller ones and a concrete ridge that represented mountains on a fairly rough surface of volcanic rocks and cinders. As more information about the lunar surface became available it became clear that the surface of the “rock pile” was not as lunar as it should be for the best available simulations. By 1968 a new “rock pile” was constructed at MSC with 188 craters ranging in size from 3 to 60 feet in diameter. It covered 2 acres with a diameter of 328 feet. At Kennedy Space Center (KSC) there was another area referred to as the “sand pile” for trying out hand tools and other scientific gear and to practice setting up various instruments on the lunar surface. Some craters were dug in the sand to make the area a bit more Moon-like, but it was not quite as realistic as the facilities in Houston. One disadvantage of this area was its near sea-level elevation which resulted in the partial filling of the craters with water at some high tides.

Other training facilities at MSC included a large vacuum chamber where it was possible to duplicate lighting intensity and temperature under the proper vacuum conditions, a large pool of water in which the test subjects could be suited and weighted in such a manner that neutral buoyancy could be obtained, and a harness arrangement that would support various proportions of a person's weight allowing the person to simulate action at various g-levels. There was also an aircraft that could fly parabolas to produce various levels of reduced gravity for tens of seconds and contained large open volumes in which testing could be accomplished. All of these facilities were used extensively by astronauts and other test subjects to practice and modify procedures and determine the facility with which tools and instruments could be used under lunar conditions. The aircraft was considered to be the most realistic of the low gravity testing facilities.

The USGS also developed some training facilities starting with a man-made crater field that was produced between July and October of 1967 by explosive blasts in the Cinder Lake area, 7½ miles northeast of Flagstaff, Arizona. This was in a relatively flat area underlain by several layers of volcanic cinders. Forty-seven craters ranging from 5 to 43 feet in diameter were produced in a 500-feet by 500-feet area. The USGS produced a second crater field in the Cinder Lake area during 1968. This one was 1700 feet by 1700 feet and had more craters than the original one, some up to 100 feet in diameter. This area continued to be used extensively throughout the Apollo program. Another crater field was produced during February 1970 at Black Mesa in the Verde Valley near Cottonwood, about 60 miles southwest of Flagstaff. This was a 35 acre site in which 850 tons of TNT and 43 tons of ammonium nitrate were used to create 380 craters ranging in diameter from 6 to 82 feet and was first used for training by the Apollo 13 crew in March 1970.

Before any actual science training for the specific Apollo missions could begin the detailed nature of the science experiments to be conducted, and the tools and instruments to be used required adequate definition. Several committees and summer studies were convened to help with this challenge, and the USGS began developing its own set of suggestions for hand tools to be used on the lunar surface. As might be expected, conflicts developed between NASA centers and Headquarters offices over who was to manage the contracts for developing the tools and instruments. Eventually these conflicts were resolved by subdividing the responsibilities between Headquarters and the Centers.

The complex nature of the science associated with the Apollo missions required the inputs of many science groups and organizations. There were at least 43 science experiments that were eventually selected and conducted on the Apollo missions. In addition, there were also about 350 Principal Investigators (PIs) selected to study the returned samples. Furthermore, the mission planners, the engineers associated with tool and instrument development, and the flight directors all had to be involved in the science training in order to familiarize all relevant personnel with the nature of the constraints, objectives, and development of timelines and their associated contingencies. For the field exercises there were also support groups for cameras, tools, vehicles, radios, recording devices, etc., all of which had to be transported to the training locations and maintained in good operating condition during the training. Because scientists were included in the support rooms of Mission Control for both the orbital and surface science activities during the actual missions there were numerous pre-mission simulations that integrated the science efforts with all of the other Mission Control operations and communications.

All of these activities had to be accomplished within an organizational framework. This framework included organizations within the NASA structure, other government agencies, outside advisory committees, and the U.S. Congress. In the early 1960s an evolutionary process began that eventually involved numerous organizational elements within NASA, many of which had an impact on the science activities of the Apollo missions and the resulting training of the Apollo crews. The growing pains that accompanied the birth and development of science throughout the Apollo Program produced many conflicts between various offices and NASA Centers. Growth of personnel and organizations was rampant throughout most of the 1960s. NASA Headquarters nearly doubled in size in 1963, and the newly formed MSC in Houston expanded from 750 people to 14,000 in a period of four years while gradually changing locations from several buildings scattered throughout southern Houston to a new set of buildings 20 miles south of Houston. Such growth was accompanied by almost continuous reorganization making it nearly impossible to keep up with the changes in personnel, organizations, and locations. Who was in charge of what, who was doing what, and who was supposed to be doing what became rather confusing. Such rapid development led to the same things being done by more than one group, lack of knowledge that certain things were already being done, and confusion among outside contractors and scientists about which NASA office was managing their projects.

The major issue that produced a long-standing conflict throughout much of the Apollo was the question of who would have control over development of science objectives, instruments, specifications, contracts, construction, testing, procedures, deployment, training, and other aspects of the science-related parts of Apollo and the anticipated follow-on lunar missions. The conflict originated between the Manned Spaceflight and Science Offices at NASA Headquarters but was complicated by the creation of MSC in Houston to oversee the day-to-day, nuts-and-bolts operations of the manned part of the program. This provided another location where both science activities and manned operations were to be dealt with. As a result there developed not only local conflicts between the groups at the new center but also with their counterparts at NASA Headquarters. In addition to both Headquarters and MSC independently forming geology training groups, as mentioned above, the guidelines for Apollo science were also set up independently at MSC and Headquarters. MSC engineers tried to exclude Bellcomm engineers, a group contracted by Headquarters, from meetings by keeping the meeting schedules under wraps until it was too late for the Bellcomm engineers to schedule trips from Washington to Houston. There were also conflicts at MSC between personnel in the Science Directorate who were trying to develop the science instruments, and those in flight crew operations who were trying to develop procedures for the instruments.

There were other events that drastically influenced the activities in the Apollo Program. By the late 1960s and early 1970 the impact of the Vietnam War on budgets and the concern about safety as well as waning public interest in the space program caused Congress and NASA Headquarters to eliminate three Apollo missions in 1970. The follow-on missions had already been cancelled in late 1967. These modifications, in turn, produced a change in the types of missions and the consequent training. The seven landing missions that were being planned in mid-1970 were reduced to only four. Clearly, the site selections, science activities, and associated science training, all of which were already under way for the originally planned missions, required substantial revisions.

Another issue related to astronaut training was site selection for the Apollo missions. There were different objectives to be met by operations groups and scientists, and also between different scientists. The operations at any landing site would be limited by life support systems, fuel supply, physical hazards in the landing area, the weight of instruments that could be landed on the Moon as well as the weight of samples that could be returned, communications, medical concerns, and maneuverability in pressure suits, among others. Through 1964 no single organization was responsible for collecting the needed data to evaluate landing site selection. In the spring of 1965 Homer Newell of the Office for Space Science and Applications (OSSA) organized a Surveyor/Orbiter Utilization Committee to use the expected data and photos of the lunar surface in scientifically acceptable fashion. Shortly thereafter (mid-1965), in order to centralize the inputs for landing sites, George Mueller of the Office for Manned Space Flight (OMSF) formed the Apollo Site Selection Board (ASSB) whose mission was to evaluate and recommend landing sites to Mueller. To meet the various requirements and suggestions the ASSB was chaired by the Apollo Program manager in OMSF and its members were from OMSF, OSSA, MSC, KSC, and Marshall Space Flight Center (MSFC).

The scientists' interests for landing sites varied from deciphering the origin of various surface features, to understanding the interior structure of the Moon, to analyzing samples from different lunar units, to use of the Moon as a base for studying solar and galactic radiation, and other basic science problems. Although there were many interesting landing sites that were of scientific interest it was rather obvious that the site for Apollo 11 would be determined primarily on the basis of safety and operational constraints with only minor input from the science community. Once the capability to land on the Moon and return safely had been demonstrated, the scientific interests could be further employed in the selection of landing sites and, in fact, became the major factor in selection of the last four landing sites.

It should be emphasized that all of this planning for site selection for the early lunar missions was being accomplished during late 1967 and early 1968 before Apollos 8, 9, and 10 flew during late December 1968 through early April 1969, and even before the crews for Apollos 11 and 12 were assigned on January 9, 1969 and April 10, 1969. Selection of sites required at least a one-year lead time in order to: select the adequate and available sets of lunar orbital photos that met the landing constraints, use the photos to prepare the precise three-dimensional mosaics required for simulator training for any given site, set up the mosaics for both the Command Module and Lunar Module (LM) simulators, and accomplish the extensive simulator training required by both the prime and backup crews. Adding to the problem was the fact that the Apollo 11 and 12 crews had to train for the same three potential landing sites in case the planned launch dates were delayed and alternative sites would be used to meet the requirement of landing within the decade of the 1960s. Once Apollo 11 demonstrated that the landing could be accomplished and Apollo 12 further demonstrated that the landing could be accomplished within a preplanned, nearly pinpoint location, the selection of sites allowed much more input based on science objectives.

Once the landing sites were selected there was a need to plan the traverses and tasks along with priorities for each activity at each site. On Apollo 11 there was very little planning of actual traverses. Because the landing site for Apollo 11 was designated as a rather large elliptical area, no specific point from which to run traverses was designated. There were some instruments to be placed, some outlines of procedures associated with photos of the landing site and the types of samples to be taken, and it was left up to the crew to determine where and when to accomplish these tasks. Shortly before the Apollo 12 mission some members of the geology team were at the Cape and Pete Conrad suggested that they sit down together and lay out some traverses. They picked four possible landing sites in the vicinity of the area where they hoped to land and designed traverses from each of those landing sites. Those were the first planned traverses that included time and activities at each station.

Following the successes of Apollos 11 and 12 the extent of the traverses and tasks became more extensive with each mission and heavily dictated the nature of the training. When planning the first two landing missions there had been uncertainty about whether all of the instruments would be ready, whether the procedures could be carried out under lunar conditions, and whether they had the ability to land at a specific point. Once these uncertainties were resolved and the traverses became longer in both time and distance the items of equipment became more numerous and complicated, the use of a Lunar Rover introduced many new experiments as well as constant TV coverage by a camera on the Rover, and the orbiter carried additional remote sensing devices for longer periods in orbit. Also the longer times and distances produced more competition for amounts of time and locations for the various PIs' experiments. The sample analysts wanted more special procedures for specific types of samples, the Apollo Lunar Surface Experiments Package (ALSEP) and other instrument PIs wanted more time as well as traverse locations for making measurements, and the geologists wanted more time for taking special photos and visiting a variety of surface features.

By the final three missions the planning of traverses had evolved to a very practical and systematic procedure. There were certain people who had been involved in site selection discussions and were well aware of the science objectives, the instruments to be deployed, and the requirements of each of the PIs on a specific mission. Once a landing site was selected these people started the traverse planning process by posing the question “where is the best place to land at this site?” To answer this question they developed traverses from several possible landing points within the overall landing site to illustrate what could be done to meet the science requirements by means of traverses from each of those sites. A memo with the traverses from the different landing points was distributed for comments to various science groups, operations personnel, flight controllers, crew members, and others who had interests. At this stage one or two people had to interface with the groups who would overlay all of the operational constraints on the traverses to evaluate each of the possible landing points operationally. They would also interface with the science working groups who were interested in meeting the science requirements. Once all of the inputs had been evaluated a landing point was selected to best optimize the all of the requirements. Then the development of detailed traverses would commence with specific tasks and time lines. This involved further iterations with all of the same groups that were involved in the earlier discussions. At some point the detailed traverses were further amended by a Lunar Traverse Planning Team that included representatives from each of the groups. The detailed traverses might be modified by the crew up to the last few days before each mission as the crew members huddled with the geology team and discussed the details of the final traverse plans. The final detailed traverses would then be entered on cuff checklists to be used by the astronauts when accomplishing their tasks on the lunar surface.

As landing sites were selected for individual missions both the surface training and orbital training could become more focused. When the lunar surface traverses and timelines became better specified the training exercises could be made more similar to the lunar missions in terms of specific terrains, surface features, rock units, and other problems. It was understood by the scientists and the astronauts that the science activities were to be accomplished by the astronauts by means of well-planned and -practiced procedures. Also it was agreed that the nature of the collected data and samples and its importance to lunar science should be provided to the astronauts. The training, therefore, involved field exercises to develop experience with the use of the hand tools and practice in verbal descriptions of geologic features, lectures on the basic science of the missions, recognition of rocks and minerals, flyovers of terrestrial features for developing acuity in orbital observations, practice in setting up of instruments, lectures on specific experiments by each PI, and a few other activities. Although all of these aspects of training were well developed by the end of the Apollo program they all evolved with time as the missions became more science-oriented and the scientists developed better insights into what data they needed and what the astronauts were capable of accomplishing both on the lunar surface and from orbit.

The field training was perhaps the most emphasized of all of the science efforts because it involved most of the extravehicular activity (EVA) time on the lunar surface. Such training was necessary to develop the proper procedures required for photography and sampling as well as keeping track of location and time. These techniques had to be so ingrained that very little thought would be required for the routine procedures thereby leaving plenty of time for the astronauts to observe and describe the terrain and devise approaches to studying each station on their traverses. This required that the astronauts perform simulated traverses in locations that were similar to their respective landing sites on the Moon and of similar duration to their lunar traverses. The simulations emphasized: selecting proper locations to stop and conduct sampling, collecting representative rock and soil samples, digging trenches and sampling different levels of the trenches, driving core tubes into the soil and extracting them without losing the contained soil, describing the geologic features verbally, photo documentation of the sampling activities, overlapping panoramic photos of each stop, setting up instruments on the surface, keeping track of locations on maps, adequately labeling the samples for later recognition, etc. All of these activities had to be practiced over and over as well as critiqued in debriefings for more than a year for each crew. For the surface component alone there was one field trip of two or more days per month for each crew after Apollo 11. Add to this the briefings by PIs, lectures on the progress of lunar science, studies of returned lunar samples, practice in setting up instruments, and debriefings for the field procedures after the field trips. It adds up to several days of science training per month.

Setting up the field trips was a major activity for the geology trainers. A few geologists would visit a potential field site. Although prior information might suggest that an area was appropriate close examination might indicate that the site was unsuitable because of poor exposures, inaccessibility, difficult topography, etc. During some of the initial searches for potential field locations notes were taped and photos were taken. These were used to determine times, mileage, morphology, tasks, etc. for the possible field exercises. In some cases, one of the geologists – who was a pilot – took aerial photos of the potential areas. As the training progressed some of the locations were used for more than one crew and the traverses required little modification but always needed to be checked out for unexpected changes that might have occurred during the intervening few months between exercises.

During the actual field exercises the crews would be in voice communication with the Capcoms in makeshift backrooms that were set up in the field and all conversations were taped. Upon completion of each exercise a walk-through debriefing was carried out for all participants in the exercises to determine how well the crews did on the exercise, how well the tools and other equipment performed, and how well the procedures worked. Upon return to Houston, or elsewhere, the collected samples were laid out, the tapes were transcribed, and the photos developed in preparation for a detailed critique with the astronauts. The photos and transcripts were correlated with the samples and further related to the geologic features that were studied. This would include notes on the evaluation of photography, adequacy of samples, and completeness of descriptive information. The field exercises also provided an opportunity to fine-tune any problems with the hand tools, cameras, and other equipment. During the field exercises there were personnel to provide and maintain the hand tools and cameras. Problems with these instruments were always documented and either corrected on the spot or slated for further study upon return to Houston.

Through Apollo 12 all of the field training for the Apollo crews had been planned and executed by the geologists at MSC. A substantial change took place in the field exercises at the initiation of Apollo 13 training. Scientist-astronaut Jack Schmitt had observed that the enthusiasm for field exercises was not as great as he thought it could be. He felt that the introduction of more experienced and charismatic instructors could help develop more enthusiasm and competence among the crews. Schmitt contacted his former professor at Caltech, Lee Silver who had spent many years doing field work and was known as a great teacher with a great deal of energy and enthusiasm that he seemed to impart to his students. Schmitt convinced Silver to try a several-day test in the field with the Apollo 13 crew. Apparently the Apollo 13 astronauts were looking for a change in the training that would develop more enthusiasm and competence for their geologic objectives because this was not an official trip. The astronauts paid their expenses out of their own pockets and took the trip out of their vacation time. Silver's enthusiasm and ability to excite the astronauts about geology worked well. Apollo 13 Commander Lovell was so favorably impressed with Silver and his method of approach that he and the crew agreed to continue with Silver as their mentor. The backup crew, Young and Duke, who were also on this trip and would go on to be the prime crew for Apollo 16, were also hooked on this type of procedure and asked Silver to do the same for them on Apollo 16. Schmitt recalls this trip as a major milestone in the field training: “a real breakthrough where the guys really started to learn.”

Although MSC geologists continued to be involved in the scheduling and logistics of field exercises the planning of the locations and traverses gradually became the responsibility of the mentors and the USGS. By the start of Apollo 15 training, for all of the field locations and traverses were planned by the mentors and/or the USGS. Study of returned samples and scheduling of lectures and PI briefings continued to be the responsibility of MSC.

Orbital science training for the Command Module Pilot (CMP) on the earlier missions was directed primarily toward describing geological features on the lunar surface and taking handheld photos of important lunar features that were to be overflown along the orbital track. This required lectures on lunar surface features, the ability to use aerial or orbital photos, and proper camera angles. Starting with Apollo 13 terrestrial flyover exercises to observe analogs of lunar features were scheduled regularly in T-38 jets at high altitude and small planes at low altitude. During these flights the astronauts taped descriptions and took photos that were later critiqued with the geologists. For the final three missions the CMPs also required numerous briefings on the scientific nature of new remote sensing packages as well as the operation of the associated instruments. As with the field training for the lunar traverses a mentor for the orbital training eventually evolved and became one of the crewmembers’ most trusted teachers. For the CMPs this person was Farouk El-Baz. His role increased with time and his interest and dedication to the observations that could be made from orbit led to substantial inputs from the CMPs.

Although there was a need for scientists to train the Apollo crews in the procedures and scientific background for the tasks on the lunar surface there was also a need for training the scientists in how to train the crews. After all, the astronauts were going to perform tasks under drastically different conditions and constraints than are encountered during similar studies here on Earth. Not only did the scientists have to recognize how to use new types of tools and equipment but they also had to learn entirely new means of communication and operations that were necessary for conducting missions on the lunar surface. During an actual mission several scientists were to be present in a Science Support Room (SSR) in Mission Control to keep track of the astronauts’ locations and activities both on the lunar surface and from orbit. They also were expected to make any helpful suggestions that might be used by operations personnel or passed on to the astronauts by the capsule communicator (CapCom). It took a few missions before an efficient and effective communications system developed between the scientists and the other groups in Mission Control. For the first four Apollo missions the scientists for the surface activities began learning the nature of the communications and operations through a pre-mission simulation for each crew in which the pertinent scientists gathered in the SSR in Mission Control as the crew conducted a traverse in a field area while in radio communications with Mission Control through a CapCom. By Apollo 14 the SSR had begun to develop a reasonable system of tracking the surface activities and communicating with the CapCom. By Apollo 15, in addition to the field simulation, there were paper sims and math model sims that brought together scientists, flight controllers, and engineers, who were to participate jointly in solving problems that might arise during a mission. The paper sims consisted of presenting a set of anomalies that might occur during lunar EVAs and asking combined teams of scientists, flight controllers and engineers to re-plan the traverses to overcome the anomalies and still meet the main objectives of the traverses. The math model sims used the actual facilities and personnel of Mission Control and followed the planned traverses for each mission, but would introduce numerous problems that would require modifications of the original traverses and procedures. The problems might range from rather simple, such as the loss of a film magazine, to very serious, such as failure of the Rover. In these simulations the science team that would be on duty during the actual mission in the SSR of Mission Control had to work with the appropriate operations and equipment personnel to reach a satisfactory solution that would preserve as much of the scientific data as possible without compromising the safety of the crew. There were several such paper sims and math model sims for each of Apollos 15, 16, and 17. Such simulations provided an excellent basis for developing the respect, trust, and familiarity needed among all the personnel involved in the missions as well as for developing contingency plans for the actual missions.

2. Recommendations

During the initial stages of planning for any such manned planetary exploration missions such as Apollo it is absolutely essential that there be a committee that includes representatives from all mission activities. Such a committee must include PIs, astronaut trainers, traverse planners, site selection representatives, equipment personnel, an astronaut crew representative, Apollo Spacecraft Program Office personnel, flight controllers, and representatives from any other groups that have a need for input to the missions. It must meet at least once a month at the location where most of the detailed planning activities are concentrated and where information bearing on operations and equipment can be obtained easily. This allows the operations folks to develop a much better appreciation for what the science folks are trying to do,; and, at the same time, the science folks begin to get a real appreciation for the real operational constraints.

The importance of selecting the right individuals to fill the roles of the critical personnel on the committee cannot be overemphasized. Most important is the chairman who must be able to anticipate problems and discuss them with cognizant personnel before meetings. With that capability the chairman can listen to everyone's input, provide solutions, get a consensus, and make a decision on the spot rather than getting a half dozen different alternatives and having someone else study them before making the decisions. The chairman must also have the respect of his contacts and the committee members as well as the management who must rule on any final decisions.

The second most important individual is the liaison person, essentially the person who does the legwork, who maintains contact with traverse planners, scientists, trainers, management, and other operations personnel. Much of this person's job involves recognizing problems ahead of time, contacting the relevant personnel in order to understand all the ramifications of each problem, and keeping the chairman informed of what progress has been made. This allows many, if not most, of the problems to be solved before the meetings. Such a person can make detailed presentations at the meetings and provide enough background material to reach a consensus. This person requires knowledge of the scientific objectives and the training that has been completed to meet these objectives as well as the engineering and operational constraints, and very importantly, must know who to talk to for the details of each activity. And such a person must have the perfect personality for this liaison role. He must be easygoing but intense. He should have a laser-like vision of what needs to be done and how to do it but with a completely comfortable and easygoing manner about him. Because of the detailed knowledge and experience that is essential for these two positions it would be highly desireable for one or both to have been an astronaut.

Classroom training need not go into the details of each of the sciences for all the astronauts. All the crew members do not need to know how to identify a wide variety of minerals and rocks, understand solar physics, calculate internal structures of planets, understand the evolution of many geologic structures and petrologic processes, etc. The best way to cover these scientific details is to have a combination of astronauts who are experts in these fields.

For all crew members, however, there is a need for lectures on the general nature of the overall problems associated with any form of planetary exploration as well as the current stage of understanding of these problems. Such lectures provide a basis for what type of data is required to solve the problems and develop a better understanding of what can be done by the exploration crews to provide the necessary information.

Field training serves as an essential introduction to geology or most other exploratory sciences and also provides practice for mission-related activities. Field training is generally considered to be the most meaningful and efficient means to learn the basic perspectives of the various geologic, geophysical, geochemical, and many other scientific objectives. A few very basic introductory lectures combined with a few field trips should suffice for the geology training. Although a cursory knowledge of minerals, rock names, petrology, structures, and geophysical objectives is useful, there is no need for all astronauts to know the details of each of these topics. The scientists who are experts in these fields, whether astronauts or not, are the ones who can best handle the detailed knowledge of such topics. Simulations for field activities, including setting up instruments and sampling techniques, should be commonplace for all crew members in the training. All astronauts should be cross-trained in these deployments in case of the need for ingenuity in unforeseen circumstances. The field training should be set up to replicate, as closely as possible, the communications, personnel, procedures, and traverses that will occur on the actual missions.

Field training locations and the associated objectives should be planned and executed by people who have experience both as good teachers and as researchers. They must also have the energy and infectious ability to enthuse and teach the crews in a friendly and jovial manner. These are the people who are best able to develop an excellent rapport with the crews as well as other personnel involved in the missions. Such people are best able to use their experience and contacts to set up the best replicas of field situations for realistic simulations, and also provide experienced leadership for the field trips. They are most likely to receive the respect and attention of astronauts, other scientists, flight controllers, and NASA management. All field training should include representatives from all pertinent areas. Flight controllers, management, engineers, and a variety of science disciplines should be included from the very beginning to develop a mutual understanding of the constraints and objectives of all relevant personnel. Debriefings after each field exercise should involve representatives from each of these areas to best develop familiarity with the terminology and communications that will be used during missions.

Flyovers for orbital observations should be included in the training of all crew members who will be describing and photographing surface features from orbit. Both high-level overflights to experience the types of observations possible from orbit and low-level flights to better understand the details of features seen from high levels should be included. As with the field activities the procedures for photography and descriptions should be practiced and debriefed until they are second nature, and the crew can spend time thinking about the science activities rather than how to accomplish the procedures. As with the field training good teachers are a necessity. They must have the energy and infectious ability to enthuse and teach the crews in a friendly and jovial manner while also commanding the respect and attention of astronauts, other scientists, flight controllers, and NASA management.

Simulations should be as realistic as possible with exact replicas of the tools and instruments to be used on the actual mission, and involve all the relevant personnel: scientists, flight controllers, medical personnel, mission planners, life support systems experts, etc. Similarly, the procedures for use of these tools and instruments should be developed jointly by the PIs, engineers, flight controllers, and traverse planners before presenting them to the crews for simulations. All such procedures should be tested and modified as required in suited and lunar gravity conditions before asking the crews to spend time doing what could have been accomplished already by the cognizant personnel. This recommendation would also apply to robotic mechanisms that might be developed as well as to laboratory procedures if labs are to be set up on other planetary surfaces. Once the procedures are perfected the crews should practice them and undergo debriefings until the procedures become second nature and their exploration time can be spent thinking about the science activities rather than how to accomplish the procedures.

As actual mission time approaches and plans for the missions are reasonably well established, there should be several simulations that closely follow the plans for the missions but with numerous problems introduced to train the flight controllers, engineers, scientists, and other personnel in Mission Control on how to communicate and react in real time to provide solutions for any troubles that might arise. Debriefings after such simulations should include personnel from all these areas. Such simulations and debriefing discussions provide an excellent basis for contingency planning, which should be a joint effort among all mission participants. Such tests and communications develop the respect, trust, and familiarity needed among personnel from all the fields involved in the missions.

Section II: EARLY GENERAL TRAINING

1. Introduction (Setting the Stage)

When the original seven astronauts, known as the Mercury astronauts, were assigned to NASA on April 9, 1959 there was only one objective in each of their minds: to climb aboard a spacecraft atop a rocket and become the first person to be launched into space. They were part of Project Mercury, the NASA program designed to overtake the Soviet space program and put the first man in orbit around the Earth. At that time any suggestion of their performing science experiments while flying in space would have seemed about as remote as their performing major surgery. After all, these were the most accomplished of test pilots who lived for the excitement and competition associated with proving that new, record-breaking exploits could be accomplished, even at the risk of their lives. They were mainly interested in flying into space. True, they all had college backgrounds that included science and engineering that provided the foundation of knowledge necessary for understanding the technical basis of the new machines that they flew as test pilots. But to them the extent of the science considered necessary was whatever they really needed as test pilots. Furthermore, the overriding motivation of NASA in bringing these people on board had nothing to do with science. It was primarily to select the best candidates for surpassing the Soviet Union in all aspects of manned spaceflight, from the first man in space to manned orbital flights to whatever else was possible. The match of objectives, attitudes, and backgrounds between the astronauts and NASA was ideal. The possibility that astronauts might spend thousands of hours training to be scientists or that astronauts might be selected on the basis of their scientific accomplishments was not even considered at this time. Section II of this history traces the growing pains associated with the development of such training in the early years of manned space efforts.

The science that had been accomplished in space up to this selection of the original astronauts consisted mainly of solar and atmospheric physics studies from balloons and sounding rockets. Following the famous October 4, 1957 Soviet launch of Sputnik the first satellite to be placed in Earth orbit, the U.S. space program got into high gear and tried to speed forward. The first U.S. attempt to launch a satellite into orbit on December 6, 1957 resulted in an explosion of the first stage of the Vanguard rocket at the launch pad; and the rest of the rocket collapsed into wet sand. The first unmanned U.S. satellite to be placed successfully in orbit was launched on January 31, 1958 and it carried on board a Geiger counter that made the first discovery of the Van Allen radiation belts (NASA SP-4201, p 29). Although the concepts for conducting further scientific studies from orbiting satellites had been considered the implementation of such studies was barely getting started. But, at that time, all such scientific studies were expected to be flown on unmanned spacecraft that were to be launched by unmanned expendable rockets. There was no reason to believe that future scientific studies of this type would require manned spacecraft. After all, the communications, weather, and military reconnaissance satellites that were being planned at that time were to be launched on unmanned spacecraft and there were no future plans for such activities that included the participation of astronauts. Essentially all space activities to this time were under the supervision of military organizations. Furthermore, the military had already studied the potential use of humans in space and had not come up with any credible manned missions. Therefore, President Eisenhower, in 1958, assigned all future manned space activities, whatever they might turn out to be, to the newly created NASA (NASA SP-4214, p. 3).

But the participation of astronauts in scientific studies in space was to change drastically over the next decade. This study is the story of the ensuing changes, the reasons for the changes, the consequences of the changes, and the lessons that were learned. There were many groups that played roles in this constantly changing drama: the science community with its various inroads to NASA managers and astronauts, the organizations at NASA Headquarters along with their numerous advisory committees, the USGS and its growing cadre of planetary geologists working under NASA contracts, the scientists at NASA's Manned Spacecraft Center in Houston, the engineers, both within NASA and with private contractors, who were developing the hardware and mechanics of manned missions, the astronauts themselves, the U.S. Congress with its controls over the purse strings for NASA's programs, and, very importantly of course, the accomplishments of the Soviet space program.

When, on April 12, 1961 the Soviets became the first nation to put a man in space by sending Yuri Gagarin into one complete orbit of the Earth, President Kennedy was forced to look for a dramatic event that would spur the U.S. space program to a position of unmistaken leadership in the space race. He asked Vice President Johnson to chair a quick study that would make recommendations on something spectacular that would provide American preeminence in the future. Fortunately, some space enthusiasts at NASA's Langley Research Center had been thinking seriously for nearly three years about sending people around the Moon and back (even before the existence of NASA). Such a mission was looked upon as an end in itself and required no contribution to some larger goal such as planetary science. Clearly, it would demonstrate the nation's superiority in the space race (NASA SP-4214, p. 4). The enthusiasts for such a mission had started to look seriously into its feasibility in 1959, and by the end of 1959 NASA's ten-year plan included manned circumlunar flights by the late 1960s. The concept of actually landing men on the Moon was further down the line, sometime in the 1970s. Such a landing was considered as a legitimate end in its own right. It had nothing to do with planetary science and was not based on politics, economics, or any other external forces (NASA SP-4203, p. 24-25). NASA had even awarded some contracts in October 1960 to further study the feasibility of such a lunar mission. In fact, near the end of the Eisenhower presidency NASA Administrators Glennan and Dryden had asked Eisenhower to approve a manned mission to the Moon, but he turned them down (Collins Liftoff, p. 63). Langley's manned lunar project was given an official name in July 1960. It was known by the now-familiar name of "Apollo" (NASA SP-4203, p. 23-24). Although most of the efforts through 1960 were aimed at lunar orbital missions a decisive new direction began to take shape at the January 5-6, 1961 meeting of NASA's Space Exploration Program Council. The first day of the meeting was devoted to discussions of a manned lunar landing. George Low, Chief of Manned Space Flight in NASA's Office of Space Flight Programs, and his team immediately got to work on this effort and submitted a report to Associate Administrator Seamans in early February 1961. The concepts in this report began to dominate NASA's lunar mission planning (NASA SP-4203, p. 28-29). Therefore, immediately after Gagarin's orbital flight of April 1961, when Congress and the President's office began the search for a dramatic response to the Russians, the manned lunar landing of "Apollo," which had already received a fair amount of study, became one of the prime candidates.

On May 8, 1961, less than a month after the Gagarin flight, the results of Lyndon Johnson's quick study resulted in a report to the President drafted by both NASA and the Defense Department. The report recommended a manned lunar flight similar to the earlier study at Langley that had been termed Apollo as their choice for the dramatic mission that the president had envisioned. The report further recommended strengthening the civilian space program, in particular the development of much more powerful launch vehicles. It chose a manned landing on the Moon because "It is man, not mere machines, in space that captures the imagination of the world" (NASA SP-4214, p. 6-7). On May 25, 1961 President Kennedy settled any uncertainties by presenting his famous message to Congress calling for a manned lunar landing to be accomplished before the end of the decade.

Chris Kraft recounts a story related to Kennedy's decision as told to Kraft by Bob Gilruth several years later. According to Kraft's account on May 8, 1961, three days after Alan Shepard accomplished America's first manned flight into space, President Kennedy invited Gilruth, Shepard, James Webb, George Low, and a few others to the White House for a presentation of the NASA Distinguished Service Medal to Shepard. Kennedy spoke to Gilruth and Low and wanted to know more about what NASA was planning for the future in the space program. Gilruth and Low proceeded to tell him of the upcoming plans in the Mercury program and also happened to mention the manned circumlunar studies that had been under study. Kennedy's response was "Why aren't you considering landing men on the Moon? .... Don't we need to do something more that just flying around the Moon?" As Gilruth tried to explain the complexity of landing on the Moon, Kennedy asked, "What do you need?" Gilruth responded, "Sufficient time, presidential support, and a Congressional mandate." When the president asked, "How much time?", Gilruth and Low briefly talked it over and gave the answer: "Ten years," (Kraft, p. 142-143)

Apollo, however, was not what the newly developing group of space scientists had in mind for future programs in space science. The science advice to both Presidents Eisenhower and Kennedy had eschewed manned flight in favor of unmanned spacecraft. The President's Science Advisory Committee, in a 1958 report titled "Introduction to Outer Space," had indicated that "scientific questions come first" and science should form the basis by which "we measure the value of launching satellites and sending rockets into space." There was a great concern among scientists that any manned program would evolve into attempts "to present spectacular accomplishments in space as an index of national strength," which is how James Killian, former chairman of the President's Science Advisory Committee, described the Soviet's space exploits as of 1960 (Logsdon, 1970). Killian further stated that "many thoughtful citizens" were of the opinion "that the really exciting discoveries in space can be realized better by instruments than by man." The research chief of Bell Labs, John Pierce, who was one of the most prominent figures in communications satellites, made the following argument for automated, unmanned satellites: "All we need to louse things up completely is a skilled space pilot with his hands itching for the controls (NASA SP-4201, p. 174)."

Furthermore, there was a concern that the extremely expensive manned programs would divert nearly all of NASA's funding to such efforts, thereby relegating science to an insignificant role. In fact, President Eisenhower apparently had developed skepticism about the advantages of manned space efforts as indicated in his final budget message to Congress in 1960 in which he stated that further study was necessary "to establish whether there are any valid scientific reasons for extending manned spaceflight beyond the Mercury program" (NASA SP-4214, p. 4). This same opinion carried on into the Kennedy administration in which Jerome Wiesner, who chaired Kennedy's ad hoc Committee on Space, shared Killian's views. Wiesner recommended to Kennedy: "We should stop advertising Mercury as our major objective in space activities [but rather search for] effective means to make people appreciate the ... importance of space activities other than space travel" (NASA SP-4214, p. 4). Wiesner's recommendation also indicated that NASA should avoid the risk of major failures in the manned program by emphasizing the successful science and applications programs and the tangible benefits to be expected (NASA SP-4214, p. 4). Some scientists, however, were willing to back off from this position in recognition of the fact that non-technical factors might be vital to public acceptance of a space program. This position was acknowledged when the Space Science Board of the National Academy of Sciences in late 1961 adopted the position that human exploration of the Moon and planets would be "potentially the greatest inspirational venture of this century." The Board further stated that "there seems little room for dissent that man's participation in the exploration of the Moon and planets will be essential" (NASA SP-4214, p. 6).

In an interview Gene Shoemaker, one of the scientists who championed manned exploration of space, describes the tripartite division of space scientists who were involved in these arguments: 1) the particles and fields types who rely almost exclusively on instrumental measurements in space and can do everything unmanned, 2) the chemical and physical properties types who require samples for laboratory studies and must have returned samples by either unmanned or, preferably, manned procedures, and 3) the observational types who observe in-situ the structures, stratigraphy, time relationships and regional variations on a three-dimensional basis and must have first-hand observations, preferably by direct eyeball viewing (Shoemaker interview with Compton, 1984). Through 1961 only the first of these three groups had been involved significantly with NASA's space flight programs.

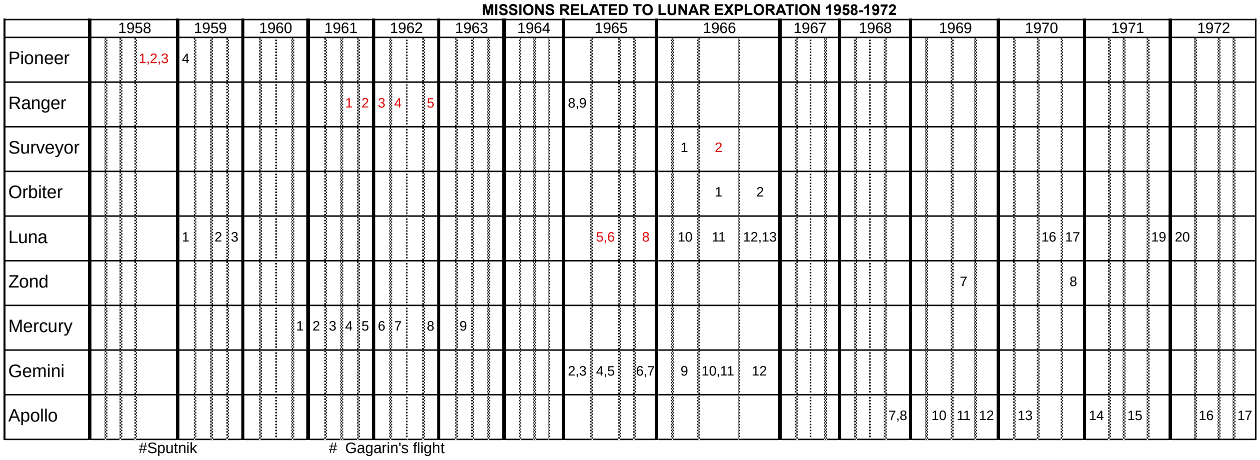
It is unlikely that any of the scientist's arguments, no matter which side they argued for, had any significant bearing on Kennedy's decision to land men on the Moon. Although much of the science community was not happy with the decision to follow the course of Apollo it, ironically, resulted in a gigantic spur of science activities in NASA over the next decade. Major increases in funding for NASA over the next few years were primarily designated for the Apollo program, but the other space science programs continued to develop. Much of the money in the Apollo program was used for the development of instruments and techniques that greatly improved science studies of all types. There is no evidence that the increase in NASA's allocations for manned projects would have been approved for similar increases in unmanned science projects if there had been no manned projects. My impression from talking with many folks in the science and NASA communities is essentially unanimous agreement that such a transfer of allocations would not have happened. In fact, it is quite possible that the space sciences, in general, probably fared better as a result of Apollo than if there had been no Apollo.

Before the Kennedy pronouncement of a manned lunar mission within the decade there had been little detailed study of what would be the purpose for manned missions beyond simply getting man into space. Although there had been discussion groups, meetings and colloquia whose main topic was lunar and planetary exploration, these were mainly to present ideas or potential science discoveries that might be associated with such general concepts as manned exploration of space, colonization of the Moon or other planets, and laboratories and habitats in space. The only real detailed study of the mechanisms for a manned mission beyond Earth orbit had been the feasibility study at Langley of a circumlunar manned mission, as mentioned a few paragraphs above. However, this study had concentrated on the technical aspects of rockets, spacecraft, guidance, communications, and the like, rather than what else the astronauts might do other than fly spacecraft. As NASA geared up for Apollo, and as many as ten lunar landings were contemplated, it became apparent that once the astronauts got to the Moon it would be prudent to have them accomplish something on the lunar surface. Max Faget, the director of engineering at MSC is quoted as saying “it wouldn’t look very good if we went to the Moon and didn’t have something to do when we got there” (NASA SP-4214, p. 20-22). Scientific tasks were an obvious response to this challenge. Fortunately, the approach to these tasks was not to be considered in a total vacuum. To manage the science side of NASA's programs, the initial organization of NASA had included a Space Science Division. A Theoretical Division was added to it in late 1958, and both were administratively under the Office of Space Flight Development, with Abe Silverstein as Director (NASA SP-4210, p. 14-15).

When Homer Newell, a researcher at the Naval Research Laboratory, was brought to the newly formed NASA in 1958 as Assistant Director for Space Sciences under Silverstein his task was to set the direction for programs in space sciences. He was the one responsible for creating the Theoretical Division as a companion to the Space Science Division to devote attention to basic research in cosmology, astronomy, and planetary sciences (NASA SP4210, p. 14-15). Robert Jastrow, an upper atmosphere physicist from the Naval Research Laboratory, whom Newell had picked to head the Theoretical Division, visited Nobel Prize recipient Harold Urey in late 1958 to gain insight into what Jastrow should do in his new assignment. At this meeting Urey explained his view of the "unique importance" of the Moon for understanding the origin of the Earth and other planets. As a result of this meeting Jastrow became a champion of lunar exploration and invited Urey to come to Washington the following week in December 1958 to talk with Homer Newell. From this talk was born a serious unmanned program of lunar exploration. Before this the Air Force and the Army had planned to launch five lunar probes named Pioneers 0 through 4, which were designed for the study of particles and fields near the Moon rather than for study of the solid body. (Although, initially, a small TV camera for imaging the lunar surface was to be on one of these flights it was replaced eventually by radiation detectors.) By March 3, 1959 all five of these probes had been launched. Four of them failed and the fifth passed the Moon at a distance of, 37,500 miles gathering no useful information about the Moon (Cortright interview, 1968).

Following his meeting with Urey, Newell appointed an ad hoc Lunar Explorations Working Group in January 1959 to commence a dialogue between scientists at NASA and in the academic community. The main tasks of this group were to design experiments and select instruments to be assembled into one or more payloads for lunar missions (still unmanned at this stage). However, as time went on Newell found that progress on these experiments as individual payloads did not occur as rapidly as had been expected. He, therefore, recommended in late August 1959 that the group be renamed the Lunar Science Group. He hoped that working groups who were to design experiments and select instruments to be assembled into one or more payloads, as originally planned, would eventually come into being (Memo: Newell to Silverstein, Aug. 26, 1959).

Meanwhile, there was some internal maneuvering to determine which of NASA's centers would be responsible for developing the instruments and managing the potential lunar missions. In December 1959 W. H. Pickering, Director of Jet Propulsion Laboratory (JPL), requested, in a letter to Dr. Silverstein that the name of this group be "expanded to include the consideration of planetary and interplanetary science." This change was clearly meant to solidify and expand JPL's role in the development and operation of flight instruments for all types of planetary missions as indicated by the following statement: "In view of the recent decision of NASA Headquarters that the Jet Propulsion Laboratory undertake responsibility for the planning and execution of lunar and interplanetary space exploration program [sic], it is recommended that the Chairmanship of this committee be assigned to a member of the Laboratory's staff." (memo Pickering to Silverstein, December 17, 1959) Silverstein responded by replacing the Lunar Science Group with a NASA Steering Group on Lunar, Planetary, and Interplanetary Exploration, consisting entirely of NASA and JPL employees and a chairman from NASA Headquarters. In addition, however, he also established a NASA Committee on Lunar, Planetary, and Interplanetary Exploration consisting primarily of scientists from outside NASA and JPL. The purposes of the NASA-JPL Steering Group included: (1) review the scientific recommendations of the NASA Committee on Lunar, Planetary, and Interplanetary Exploration, the Space Science Board, and other inputs from the science community; and (2) develop an integrated program for exploring



MISSIONS RELATED TO LUNAR EXPLORATION 1958-1972

	1958	1959	1960	1961	1962	1963	1964	1965	1966	1967	1968	1969	1970	1971	1972
Pioneer	1,2,3	4													
Ranger				1 2	3 4 5			8,9							
Surveyor									1 2						
Orbiter									1 2						
Luna		1 2 3						5,6 8	10 11 12,13				16 17	19	20
Zond												7	8		
Mercury			1	2 3 4 5	6 7 8	9									
Gemini								2,3 4,5 6,7	9 10,11 12						
Apollo											7,8	10 11 12	13	14 15	16 17

#Sputnik

Gagarin's flight

red = failed flight

Figure 1. Schedule of unmanned lunar missions and manned U.S. spaceflights that had a bearing on the development of science training for the American astronauts.

the Moon, planets and interplanetary space (letter, Silverstein to Pickering: January 26, 1960.) The second group, the NASA Committee of outside scientists, had among its charges recommending (1) specific experiments as well as their relative priorities and (2) responsible scientists for specific flight programs, including those experiments to be placed in orbit around the Moon or landed on its surface. Again, it should be emphasized that in the context of the thinking in 1959 and 1960, these were to be unmanned missions. Over the following months the latter Committee recommended a seismometer, a gamma-ray spectrometer, a magnetometer, and an X-ray fluorescent spectroscope to be flown on rough-lander missions (this type of lander is somewhere between uncontrolled impacts and soft-landers, and would require protective capsules). Proposals for the design and development of these instruments were to be sent to Newell's office (NASA SP-4210, p. 18).

As the year 1959 moved along the Soviets had once again spurred the direction and speed of U.S. efforts. In January Luna I passed close to the Moon (within 3,125 miles). In September Luna 2 crashed on the surface of the Moon. In October Luna 3 sent back the first photos of the far side of the Moon (Figure 1). These Soviet efforts caused NASA to further focus its planetary exploration on the Moon. In mid-1959, in response to Administrator Glennan's emphasis on an unmanned lunar exploration program, Silverstein asked Ed Cortright, who had been on the Task Group that helped set up NASA and was currently directing projects in meteorology and communications in the Advanced Technology Division, to put together a Lunar and Planetary Office and Program. In January 1960 Newell became Deputy Director of the Office of Space Flight Programs in which was formally established a Lunar and Planetary Program Division with Ed Cortright as its head (NASA SP-4214, p. 15, Cortright interview, 1968). The first major effort to be planned by this office was the Ranger Project, a series of hard impactors, followed by rough impact landers (see above) whose initial plans (mid-1960) included payloads that would measure particles and fields, perform gamma-ray measurements of lunar surface materials, land a seismometer, and send back high-resolution photos of the lunar surface before crashing into the lunar surface. By July 1960 a second project, Surveyor, was under way. This ambitious second project had the objective of soft-landing large instrument packages on the lunar surface and telemetering chemical and physical data back to Earth. The Surveyor Orbiter (which later became Lunar Orbiter), Mariner, and Voyager projects were all constituted during this same period (Cortright interview, 1968). Although the Apollo Program would not be initiated by President Kennedy for almost another year these prior unmanned lunar and planetary exploration missions and the results of these working groups and committees would provide an excellent background for much of the science and instrumentation to be considered for the Apollo missions.

As the above programs and studies progressed Kennedy's announcement of the Apollo initiative changed both the direction and speed of these ongoing unmanned lunar efforts as well as the nature of the manned Apollo efforts. A new intermediate spacecraft between the Mercury capsule and Apollo had to be designed to test many aspects of manned flight, including more than one man in the spacecraft, orbital rendezvous techniques, and physiological effects of long-duration flights. The urgency for planning and developing rockets, spacecraft, guidance, communications, and operations to meet the needs of Apollo placed these efforts in highest priority, whereas science efforts were placed in a low position of priority except where they applied directly to the success of the Apollo missions.

Even JPL was asked to examine how they would re-direct the science-oriented Ranger Project to satisfy the needs of Apollo. "Before that job (Ranger) got too far it became fairly clear that we were going to have to support the manned landing. We began to look at other payloads that Ranger could deliver that would give more information on the lunar surface. This included accelerometers to get impact loads and a photographic system. We felt that the most important thing that we had to do was see the surface." (Cortright interview, 1968) The planned seismometers, gamma ray spectrometers, and other instruments were dropped from the Ranger plans and photos of the surface became the main objective. But there was a growing groundswell of interest and excitement among the science community as many scientists from different organizations were now becoming concerned with the obvious problem of what science could be accomplished by the astronauts both on the surface of the Moon and from lunar orbit. As we shall see, once the engineering problems were overcome the science that was proposed became very extensive, but the question of who could do it best and what training was necessary became serious concerns. These problems formed the basis for a question that raged for the next several years: Would the tasks be best accomplished by scientist-astronauts who would be trained in spacecraft piloting or by test-pilot-astronauts who would be trained in science? Until the final Apollo mission this question was always resolved in favor of the latter option.

2. Early attempts at science in space on manned flights

The development of science experiments on manned flights was not given much serious thought in the early years of 1958 to mid-1961. Getting a rocket launched successfully and putting a manned spacecraft into an orbital flight trajectory and getting it back to Earth safely were the first, second, third, etc. priorities. The only important science was that related to the development and flight of the hardware. That soon changed as the requirements for Apollo evolved. Brainerd Holmes, Director of NASA's Office of Manned Space Flight, issued a document in June 1962 specifying the science information needed to fly the Apollo missions, i.e., the radiation environment, physical properties of the lunar soil, the Moon's topography, and photos and maps that would allow selection of landing sites (NASA SP-4214, p. 19). These science goals dominated much of the science activities associated with the Apollo program for its first year or two. Nevertheless, the first phase of science training for astronauts began in 1959, shortly after the astronauts arrived at NASA and nearly two years before the Apollo program was announced by Kennedy. It consisted of a series of academic studies in the newly emerging field of space science.

Dr. Robert Voas, a Navy lieutenant and clinical psychologist assigned to Langley Research Center, designed a science training program for the Mercury astronauts. Voas had designed the criteria for the Navy to choose men for hazardous duty and had also put together much of the testing regimen for selecting the Mercury astronauts. Starting in May 1959 the training of the seven new astronauts included about 50 hours of lectures given by the senior members of Langley. The lectures included mechanics and aerodynamics (10 hours), space physics (12 hours), principles of guidance and control (4 hours), navigation in space (6 hours), elements of communication (2 hours), and basic physiology (8 hours). Each astronaut also spent about 8 hours at the Morehead Planetarium (University of North Carolina) studying star recognition and celestial navigation (NASA SP-4201, p. 241). In John Glenn's book (Glenn, p. 217) he particularly recalls that training and reflects that the planetarium added a special enclosure to provide a view of the stars through a simulated Mercury spacecraft window. Some believe that this set of training lectures was introduced because there was little else for the new astronauts to do while simulators, hardware, and other aspects of planning for the Mercury program were in the very preliminary stages. By early 1960 simulators were developed, various test facilities for weightless or neutral buoyancy training became available, and also, by this point, the astronauts were becoming involved with the development of hardware at the contractors' plants. There was no further group training in science for nearly three years. The astronauts did not relish book-learning once these other more exciting activities got under way (NASA SP-4201, p. 240). For the next year and a half most efforts were directed toward hardware development and simulations.

By September 1961, after the first two suborbital Mercury flights of Shepard and Grissom, Voas was attempting to determine man's potential for navigational observations in space as well as the physiological effects of space flight on humans. He began to design some experiments for the astronauts to conduct during their Mercury missions. The navigational observations included detection limits for the smallest landmarks that could be observed, effects of weather on visibility, and precise descriptions of the occultation of stars by the Earth's atmosphere. He also suggested tests to examine the pilots' sensory perceptions while in orbit to compare with similar tests on the ground. Some of these latter tests were met with wariness by the pilots because there were suggestions for conducting movements in the cramped spacecraft with eyes closed. This proposal produced some fear among the astronauts of accidentally hitting controls on the panel. Voas also suggested other experiments, including taking photos, describing cloud cover, and looking for lightning in squall lines on the day side of the orbits, and then repeating these tasks and observing the aurora and luminescence of clouds on the night side. Observations of stars, the Milky Way, and the Moon were also suggested. This was one of the first serious attempts to develop a place for science into the manned spaceflight program. Voas shared his suggestions with the astronauts in the fall of 1961 and received favorable comments from some of them (NASA-SP-4201, p. 414). He then approached NASA Headquarters with his suggestions in the hope of gaining a broader base for science activities in manned space flight. Newell and Nancy Roman, who was setting up an astronomy program at NASA Headquarters, responded by forming an ad hoc committee to look into astronomical tasks for the Mercury pilots. Jocelyn Gill, an astronomer at NASA Headquarters, was assigned as the committee chairperson.

Gill and Voas began to work closely with the Astronomy Subcommittee of NASA's Space Sciences Steering Group to develop the astronomical tasks. Following a meeting of the Subcommittee on October 30-31, 1961 ten tasks that an astronaut might accomplish without integrating any new equipment into the Mercury Spacecraft were suggested. These included looking for comets, noting frequencies of meteor flashes, sketching the zodiacal light relative to star background, and describing auroral observations. Gill called the first meeting of an ad hoc committee on December 1, 1961 to plan the scientific observations that John Glenn might make on the next Mercury flight scheduled for January 1962. At this meeting the Committee and MSC representatives sought to organize the suggested astronomical observations into a workable order as well as plan the background information that the astronauts would need. On December 8 a second meeting of the committee included John Glenn, Scott Carpenter, and Wally Schirra, the astronauts scheduled for the next three Mercury missions. Point by point the suggested observations were explained to the three astronauts over a period of several hours. This was the very first scientific briefing on mission experiments that the astronauts received. From the interest exhibited by the astronauts Gill concluded that such briefings of an even more detailed nature should be provided periodically and also just before flight time (NASA SP-4201, p. 414-418).

On January 18, 1962, shortly before the Mercury flight of John Glenn, Gill and Roman briefed Voas and astronauts Slayton and Schirra on a list of astronomical tasks that could be accomplished by Mercury astronauts (minutes of March 16 meeting, Ad Hoc Committee on Scientific Tasks and Training for Man-in-Space). The first attempt at actually accomplishing any science on a manned flight was that of John Glenn in his five-hour Mercury flight of February 18, 1962. In addition to attempting the astronomical observations that had been suggested Glenn thought it would be good to have a camera along to take pictures from orbit. A 35mm camera was bought at a local drugstore, and he used it on his flight (Collins, Liftoff, 1988 p. 45).

As Glenn tells the story (Glenn, p. 250-51): "At that stage of Project Mercury cameras were considered too great a distraction to an astronaut. They would keep him from performing his array of scientific tasks. .... The slide rule and computer contingent lacked the imagination to see the value of photographs that would help translate an astronaut's experience for anyone who saw them. They had their checklists and that was all that was important." Glenn went to Bob Gilruth and complained, "This is ridiculous. I need to take some pictures because people are going to want to see what it looks like to be an astronaut." Gilruth agreed and the search for a suitable camera commenced. It had to be small enough to fit in one hand, allow the advance of the film with the thumb and snap the shutter with one finger, all of which could be manipulated while wearing a pressure glove. The machine shop tried to adapt several cameras to the requirements but, according to Glenn, "nothing worked very well." While Glenn was in a drugstore at Cocoa Beach he saw a small Minolta camera in a display case. “I picked it up and thought 'Jeez, it’s got automatic exposure.' That was brand new at the time. You didn't have to fiddle with light meters and f-stops. I bought it on the spot for $45. .... It turned out to be more readily adaptable than any of the others." It was the one he used on his flight. According to Jack Schmitt (Schmitt interview, 1995) Alan Shepard also bought a camera for his suborbital flight the previous year, but there is no documentation regarding the nature or use of any photos that he may have taken.

Following Glenn's mission it was clear that he had been able to respond well to many of the requests for astronomical observations as well as provide photos of Earth. He had taken photos of cloud formations, dust storms in the Sahara Desert, sunsets, and many other features. As a result Newell decided that the science of manned space flight and the training for it should now become the responsibility of a formal committee. In mid-March 1962 the Ad Hoc Committee on Scientific Tasks and Training for Man-in-Space was set up with Gill as its chairperson. Within two days she had called a meeting of scientists from various disciplines to outline objectives, review past activities, analyze the scientific aspects of Glenn's debriefing, and outline tasks for the next meeting. The new committee also decided to devise a training curriculum that would provide the astronauts with the best information about the spatial phenomena they might observe. The committee suggested several experiments to the newly formed MSC in Houston for inclusion on future Mercury flights. In response to this the Mercury Project Office at MSC set up a Mercury Scientific Experiments Panel to evaluate any proposed experiments from an engineering standpoint as well as their suitability for orbital flight. This Panel decided on some experiments for which Scott Carpenter, the pilot for the next Mercury flight, would receive special training, i.e., photographing the horizon through red and blue filters to better define the horizon, towing a balloon to measure drag, observing the behavior of liquid in a bottle, taking weather photos with a handheld camera, studying the airglow layer, and using a light meter designed to measure the visibility of a ground flare (NASA SP-4201, p. 418).

During Scott Carpenter’s May 24, 1962 Mercury flight he attempted to conduct all the suggested experiments. Some observations were more successful than others. The ground flares were not observed at all because they were in areas completely covered by clouds at the time the spacecraft passed overhead. In fact, after Carpenter's flight, he remarked that he had never realized how much of the Earth was covered by clouds at any one time. His celestial observations were hampered by light from a clock on the instrument panel. The balloon did not fully inflate making its movements unpredictable, but Carpenter did obtain a few drag measurements. He was able to provide excellent descriptions and photos of the airglow phenomena (NASA SP-4201, p. 448-452).

Before Carpenter's flight Paul Lowman of Goddard Spaceflight Center (GSFC) had requested through his GSFC colleague John O'Keefe, who was on the Ad Hoc Committee on Scientific Tasks and Training for Man-in-Space, that photos of North American and African surface features be taken on upcoming Mercury flights. This information was passed on to Carpenter and he was able to provide descriptions and excellent photos of several terrestrial surface features. Lowman was aware that several hundred terrain photos had been taken from sounding rockets at near-orbital altitudes before the beginning of manned flights. These photos had suggested that orbital photos might have value for geological purposes. Similar thoughts had occurred to scientists at the U.S. Weather Bureau, who requested that photos be taken for meteorological purposes. As a result of Carpenter's photos Lowman was asked to provide a three-hour briefing on terrain photography to the pilots of the final two Mercury flights, Wally Schirra and Gordon Cooper. The briefing included a one-hour introduction to the basic elements of geology and the remaining 2 hours were spent discussing areas to photograph and the best angles from which to photograph them. This was the first training in geology and photography of terrestrial surface features given to the astronauts. Because of the problems with cloud cover and sun angles at various stages of orbits over potential photographic targets it was difficult to build specific targets into the time line of a flight. This led Lowman in his briefing to introduce the term "targets of opportunity" for taking photographs whenever the combination of weather, orbital position, and surface phenomena was appropriate. According to Lowman the use of this term received agreeable nods as would be expected from military pilots. Shortly afterward, however, he received a rather frantic call from NASA's office of International Affairs asking him to please refrain from using such a war-like term (letter from Lowman, July 1995 and Lowman, 1974).

Schirra's Mercury flight on October 3, 1962 was almost entirely devoted to engineering tasks with no real science experiments built into the timeline. He, like his predecessors, was unable to see any ground flares because of cloud cover. He attempted to photograph some areas in Brazil, but there was too much cloud cover to provide useful terrain information. However, he thought it might aid the Weather Bureau in continental cloud analyses (NASA SP-4201, p. 481). Because the total mission time was less than half a day and there were many other engineering tasks to accomplish, there was no time for any other photography.

On the final Mercury flight (May 15-16, 1963) Gordon Cooper had 11 experiments built into his timeline during the 22-orbit flight. For most of these the investigators had briefed Cooper on the nature of their experiments as well as the role he was to play in conducting them. While in orbit he launched and photographed a small sphere to test visual acuity; finally spotted the ground flares that had been cloud-covered during previous flights; measured radiation inside the capsule; photographed the zodiacal light and night airglow; took infrared weather photos; took his blood pressure and temperature; collected urine specimens; photographed parts of South America, Africa, and India; and gave very detailed visual observations of Tibet (Collins Liftoff, p. 58 and NASA SP-4201, p. 495-500). Lowman developed a detailed terrain photography plan with an accompanying flight map with the aid of Carpenter who coordinated the experiment time line for the mission. The handheld photography was accomplished with a 70mm Hasselblad camera using an 80mm f2.8 lens and Ansco color transparency film. Most of Cooper's 29 color photos, mainly of Tibet and southern Asia, were superb and were used as a basis for developing formal proposals for terrain photography as part of the upcoming Gemini experiments package.

It would be nearly another year before the first unmanned flight of the Gemini Program on April 8, 1964 and nearly two years before the next manned space flight of the Gemini Program on March 23, 1965. The science capabilities of the astronauts during manned missions had been well demonstrated in the Mercury flights, especially during Cooper's 22-orbit mission, the final flight of the Mercury program. Clearly, there would be extensive further development of experiments for the Gemini flights, although no one seems to have given much thought to science in the Gemini program until after completion of the Mercury Program in mid-1963 (NASA SP-4203, p. 229). At that time the Office of Space Science at NASA Headquarters began looking for proposals. In a joint effort with the Office of Manned Space Flight in August 1963 they set up a Panel on In-Flight Scientific Experiments. This Panel was superseded in January 1964 by the MSFEB, which was to decide which experiments would go on which mission for Apollo as well as Gemini. In July 1963, almost simultaneously with the formation of the Panel on In-Flight Scientific Experiments at Headquarters, MSC had also set up a mechanism to evaluate experiments for Gemini. At MSC timing was becoming a critical factor because the spacecraft for the first few missions were already being designed and built. In fact, the spacecraft for the first manned Gemini mission had already been built, and the MSC panel stressed that any experiments to be proposed would largely have to conduct themselves and be already designed. Despite this rather late start over 50 experiments in astronomy, biology, atmospheric sciences, medicine, radiation effects, micrometeoroids, space environment, and Earth sciences were carried out during the one and one half years of ten manned flights in the Gemini program, which ended in November 1966. This extensive experimental effort was in large part due to the deletion, in late 1963, of the paraglider landing system for the Gemini spacecraft. The paraglider system took up much space and 360 kilograms of extra weight. Experiments began to encroach on this newly found bonus of space and weight, especially after the formation of the MSFEB in January 1964 (NASA SP-4203, p. 148).

Although the original seven astronauts had received some academic training in 1959 at Langley while waiting for the simulators and hardware to be developed for the Mercury project, a second group of astronauts, commonly referred to as the Gemini astronauts, had been brought on board in mid-September 1962, and the need for another basic science training program was important. Because the new training program would be more extensive than the earlier one and there would be much additional material, both the original astronauts and the second group were to take the new course. The first intensive classroom training program in science for the first two groups of astronauts began in October 1962 and continued through January 1963. This program of academic coursework occurred during the last few months of the Mercury Project and ended more than two years before the first manned Gemini mission. This basic science program for both the Mercury and Gemini astronauts, totaling 16 students, covered astronomy; aerodynamics; space physics; selenology (mainly lunar geology); propulsion; physics of orbital flight; computers; medical aspects of space flight; navigation and guidance; a two-day trip to a planetarium for navigational aspects of astronomy; and a two-day field trip to Flagstaff, Arizona, to study Meteor Crater and volcanic features and to observe lunar features by telescope (see Appendix A for details). Of the 178 hours of lectures nearly one-third of the time was spent on navigation and guidance (NASA SP-4214, p. 60-61, and Ray Zedekar's calendars of daily training schedules). Throughout the remainder of 1963 and 1964 the overwhelming majority of the Gemini training was in the simulators, and any further science training, other than some rather short briefings by experimenters, was of relatively minor importance. There were some serious arguments over the extent to which the military would control the Gemini program, and this led to some concern among scientists in the U.S. and abroad about the dissemination of data from the science experiments. These arguments were settled at very high government levels, and NASA assured the world that the Gemini science data would be made widely available, and there would be no military personnel in NASA's foreign network stations except on the medical staffs (NASA SP-4203, p. 117-138).

The three science experiments flown on the first manned Gemini flight, Gemini III, on March 23, 1965 were left over from Mercury 10, which was not flown. These experiments were selected because they were self-contained and largely conducted themselves. One was an examination of the effects of radiation on human blood samples. The blood samples were self-contained and required only the twist of a handle by the copilot to expose them to radiation. Another twist would stop the exposure to radiation. There was a bit of trouble experienced with turning the handle, but the experiment was completed. A second experiment to test the effect of weightlessness on cell development used sea urchin eggs that were to be fertilized at the start of the experiment and compared with cells on the ground that were fertilized at the same time. Again, the experiment was self-contained and required only five turns of a handle at half-hour intervals by the pilot. Unfortunately the handle broke when it was first turned and this experiment was a failure. The third experiment was to test the effect on radio communications of adding fluid to the ionized plasma in the vicinity of the spacecraft. A water expulsion system had been installed and was self-contained except for a starting switch to be thrown by the copilot. Water was emitted into the surrounding plasma for two minutes while ground stations monitored the radio reception. Little training was required for experiments of this type. But the crew believed that the troubles that did occur with the experiments stemmed from differences between the packages that were flown and those that they had trained with (NASA SP-4203, p. 235). It became apparent that any training devices should be exact replicas of the flight hardware.

Gemini IV, which made 62 orbits of Earth over a period of about 98 hours on June 3-7, 1965, was the real beginning of manned science efforts in space. There were 11 experiments on board and the PIs and their NASA Technical Monitors were on hand in Mission Control to monitor their experiments and provide any necessary input. This was the first American mission to resemble the manned, space-science laboratories that NASA had envisioned for the future. Although many of the experiments were either self-contained or required little more than the flip of a switch or turn of a handle some experiments took advantage of the astronauts' capabilities and initiative by requiring handheld sextant measurements for evaluation as a celestial navigation tool, photography of weather patterns and other terrestrial surface features, conducting of physical exercises with a bungee exerciser, and use of red and blue filters for photography of the Earth's limb (NASA SP-4203, p. 251-253).

For Gemini IV and all of the ensuing Gemini missions each of the PIs was given an opportunity to brief the crew members on the nature of their experiment and the role that the crew would play in conducting it. Lowman provided each Gemini crew at least one two- to three-hour briefing on his experiment, the Synoptic Terrain Photography Experiment (S005). He reflects that not only the backup crews but also other Gemini astronauts were interested enough in these sessions to attend. In addition it was common for members of the Flight Crew Support Division, other support personnel, and scientists from related experiments with an interest in terrain photography to attend. Lowman says that some of the briefings became rather crowded, but he felt that such attendance gave all those involved a better understanding and interest in the experiment which contributed greatly to its success (Lowman, 1975). The importance of such attendance and interest again was recognized in the later Apollo missions when flight and support personnel as well as scientists from other experiments attended the field simulations of the EVAs.

Briefings for Lowman's experiment included orbital photos from previous missions, geologic maps of the areas to be overflown, and the relevant flight path maps. He emphasized the need for the use of good photos for geologic, geographic, and oceanographic studies, displaying photos from previous missions. Most of the briefing time was occupied by discussions of the areas to be photographed with special emphasis on the importance of each in order of priority. The requirements became more specific as time progressed because requests began to arrive from cooperating scientists from universities and government agencies. Because the Gemini astronauts had very little background in geology and oceanography the scientific rationale for each set of photos was stressed in some detail. It was felt that such background information would develop a greater interest and initiative in the subject and lead to observations of potentially important targets that had not been discussed in the briefings. Also, if for some reason planned targets could not be photographed because of cloud cover, fogged windows, etc., there might be other possible opportunities for photos along other segments of the flight path. The photographic techniques were generally covered in other preflight briefings by R. W. Underwood of the Photo Technology Laboratory at MSC. These included camera settings, sun angles, stereo techniques, vertical vs. oblique angles, and data to record either on tape or in writing. Good and bad examples of previous photography were used to emphasize the usefulness of the photos. The flight crews were encouraged to study the previously taken photos on their off-duty time and during aircraft flights. Eventually a notebook of the best and worst photos from Mercury and Gemini was prepared and kept in the offices and quarters of the crews at Merritt Island for occasional informal study by the crews (Lowman, 1975).

The Gemini V mission in late August 1965 made 120 orbits over a period of 191 hours and upped the number of onboard experiments to 17. For the first time the crew demonstrated that it was possible to track and photograph celestial bodies. They took the first good photos of the zodiacal light and Gegenschein, and their photos of the Zagros mountains in Iran provided more detail than was available on the official Geologic Map of Iran. They also provided a pictorial history of the clouds associated with tropical storm Doreen and, with the cloud-top spectrometer, proved the feasibility of making cloud-altitude measurements from spacecraft (NASA SP-4203, p. 259-260). The training and experience for manned science activities in space were beginning to gain credibility in some fields of science. Gemini VII, which lasted for 14 days, carried 20 experiments, the most of any Gemini mission. All but three of these had been flown previously, so the experience from previous missions could be incorporated into the training for repeat performances (NASA SP-4203, p. 278-279). Although Gemini VIII encountered serious operational problems and returned to Earth without accomplishing its scientific experiments, Dave Scott describes some of the science training procedures. He and Neil Armstrong flew T-38s on night flights to practice an experiment that was to observe the zodiacal light that could be photographed just after sunset or just before sunrise. They also flew at night on a Navy plane to practice activating a low-light-level TV camera to take photos of the Earth at low light levels. The camera was to be turned on and off at predetermined locations for comparison with a variety of map features. Scott states that they found these flights to be "really enjoyable" (Scott, p. 151-152). On flights IX and X, various operational constraints developed and modifications had to be made to the flight plans in real time to get the most out of the science experiments. To accomplish this the PIs were brought in during the flights to help the flight controllers redesign the flight plans. These real-time flight changes could not have been accomplished in unmanned flights and would not have been done in earlier manned missions (NASA SP-4203, p. 351). On the final Gemini mission photos were taken of a solar eclipse, and a witness plate was exposed to the space environment to intercept micrometeoroids during the flight and then collected during an EVA to provide measurements of the micrometeoroid flux.

The results of the S005 photography experiment exemplify the advantage of the basic science training of the astronauts provided by the experiment team. Lowman states that "despite the fact that many of the planned terrain target areas were not covered for various reasons, the gaps were more than compensated for by coverage of unplanned areas or features." As an example he points out the photos taken on Gemini IV by McDivitt and White of a circular structure in Mauritania. Although they had not been briefed on this structure they instantly recognized it as an important feature and obtained excellent photos. These photos stimulated a field investigation that resulted in a publication that settled the origin of a major problem in the geology of Mauritania. Lowman considers that the greatest improvement in crew training during Gemini was the opportunity for the investigators to spend more time with both the astronauts and the supporting crew members (Lowman, 1975). Clearly, in late 1966, by the end of the Gemini program the science experiments program was developing toward maturity. The cooperation of astronauts, flight controllers, and PIs was a welcome achievement. The stage was set to begin getting ready for Apollo both mission-wise and science-wise.

3. The influence of Apollo commences

President Kennedy's announcement in May 1961 to send men to the Moon by the end of the decade spurred much activity throughout NASA. Throughout late 1961 and 1962 the role of science in the Apollo program was taking many different directions and involved many different groups. By November 1961 an Office of Space Science (OSS) was established and now included the Lunar and Planetary Programs Office. The Space Sciences Steering Committee which had been formed mainly to oversee tasks for astronomy and space physics was now asked to establish an ad hoc working group to recommend scientific tasks for lunar missions. A Joint Working Group was established as a combined effort between OMSF and OSS to develop a detailed program of scientific exploration for Apollo. Three organizations that were to play major roles in the science achievements and the science training of the astronauts were just beginning to search for their roles and exert their influence in the Apollo program. By late 1961 the USGS had programs of lunar mapping and crater studies well under way; NASA Headquarters was readjusting its unmanned lunar science programs to accommodate the precursor studies needed for Apollo,; and very importantly, in September 1961, the STG at Langley was assigned to move to Houston, which had been selected as the location to set up the MSC. This new NASA Center was to be the focal point for all manned spacecraft activities as well as the home of the astronauts and the center for most of their training activities. A review of the activities of these three organizations and their interactions, and lack of interaction, during 1962 to 1965 is necessary to better understand the evolution of astronaut science training over the next decade.

Manned Spacecraft Center, Houston

As the STG started developing its programs in Houston during 1962 there was little to no interest among the MSC management at that time to develop a science capability for its own sake. There was a recognition, however, that scientific expertise was required for a variety of reasons. To develop the operational constraints for a lunar landing there was a need to provide scientific information about the lunar environment such as the nature of the lunar surface temperatures, the extent of the lunar vacuum, and all the other pertinent conditions of the lunar surface environment and how they changed during the course of lunar day and night. Scientific expertise was required also to help set up training facilities that simulated lunar conditions for use both in testing equipment to be used on the lunar surface andthe mobility and comfort of spacesuits, and to provide training programs for astronauts.

However, there was little interest at MSC in any aspects of science outside what was required for the operational aspects of a lunar mission. Uel Clanton recalls that when he arrived in March of 1963 the concept being pushed by MSC was strictly a landing mission with no science activities. He states, "There were only two or three people at MSC at the time who were really thinking or planning any sort of a science-type activity on the Moon. I rather vividly recall one of the earlier conversations with people really high in the structure where the suggestion was made that one might want to pick up some rocks from the Moon and return them. And the question was, 'Why?'. And after an explanation period the people involved seemed partially satisfied. When again the comment was made that on the next mission we would probably also wish to pick up rock samples for return the question again, in astonishment, was "Why? You have already picked up one set, doesn't that tell you all you need to know about the Moon?'." Gordie Swann remembers a similar conversation and his recollection of the response was "Why do you want to do that again? You've already done that experiment." (Swann interview, 1995) The general sense of the response is the same in both cases and illustrates the point quite well. Clanton continues: "With this background several of us at NASA, at the local level of the Manned Spacecraft Center, began some agitation for the science activities to go on. After a series of discussions, primarily with Jack Eggleston of NASA's Manned Spacecraft Center, part of the point was made, and perhaps – like it or not – through his activities and the contacts with the other people here at the Manned Spacecraft Center the science community got what they wanted in the way of space and equipment aboard the LM" (Clanton tapes, 1975).

Gene Shoemaker gives credit to Jack Eggleston's boss, Max Faget, Director of Engineering at the new MSC, for recognizing the need for a science capability at MSC and for bringing that capability to MSC (Shoemaker Interview, 1995). In 1962 the Lunar Surface Technology Branch of the Space Environment Division (SED) at MSC was the home for the scientists who were involved in these efforts. John Dornbach was the Branch Chief, and among the earliest of the scientists were Bob Jones, a photometry expert; Curtis Mason, a geologist; Don Flory, a chemist; and

Bob Musgrove, a mathematician. At the Geological Society of America Annual Meeting in Houston during October 1962 Clanton, a geology graduate student at the University of Texas, met Dornbach and Mason (Clanton knew Mason as a former fellow student at the University of Texas) who encouraged him to visit them at MSC and consider coming to work there (Clanton interview, March 1995). In January 1963 Clanton visited them and was given an employment application in the hope that he would soon join them in Houston with the charge of taking on the responsibility of developing geologic training for the astronauts. Clanyon arrived in March of 1963 while in the midst of completing a PhD thesis in geology at the University of Texas. Among his first acts was ordering multiple sets of numerous rock and mineral specimens as a means of teaching the astronauts to recognize various materials that might be encountered on the surface of the Moon (Clanton interview, 1995). Clanton continued as one of the prominent members of the science training program throughout much of the Apollo program. Other scientists who joined the branch within the next few months were Wendell Mendell, who arrived in June 1963, having just completed a B.S. in physics at CalTech; Elbert King, who arrived in mid-August 1963, in the midst of completing his PhD at Harvard, his interests being in meteorites and tektites; and Ted Foss, who came in October 1963, after completing his PhD in geology at Rice University. One of the major tasks for which Foss was hired was to be the NASA liaison with the USGS. Both King and Foss became highly involved in the training program for the next few years although King, in 1965, was assigned the duty of developing what was to become the Lunar Receiving Lab and curtailed most of his training activities.

Throughout early 1963 at MSC there was a growing consensus within the science group, and perhaps a few others such as Faget, that they needed to set up a training program for the astronauts, largely in geology, but also including some of the other sciences. At about this time in 1963 the point was being made quite clearly that science would be important on the Apollo missions (Clanton tapes, 1975). Clanton points out that as this somewhat secondary role for science developed, the spaces for samples and scientific equipment were being parceled out all over the LM and/or Command Module at unusual places. "I remember specifically that one of the initial sample return spaces was a somewhat elongated, triangular wedge underneath one of the Command Module seats. This area essentially was inaccessible and the original seat just about had to be removed in order to get into it to place the samples. It was along about this time that Jack Eggleston began to put his foot down, and also, based on the input from the scientists on board at that time (which consisted primarily of myself, later on Elbert King, Ted Foss, Bob Musgrove, Wendell Mendell, people like this), that management here at the division level began to see the need for a science-oriented mission. The point was made, and made repeatedly, that you could only sell a program as a lunar landing mission once, perhaps twice. From then on the science community and the total community of the United States would have to be shown that there would be some tangible benefit."

By that time, furthermore, it had become clear that once the Apollo crews reached the Moon, if there was any science that could be accomplished by astronauts, it would be highly related to geologic activities. Whether it was collecting samples, taking photographs, describing the structures that they saw, or whatever, it was certainly going to be very highly oriented toward acquisition of geologic information. The scientists were well aware that all of the astronauts at that stage were test pilots. Although all of the astronauts had bachelors' degrees, or more, in science or engineering they had essentially no geologic training. Therefore, the obvious training that was to be supplied to the astronaut group at that time was geologic in nature. That was one of the main reasons that Clanton was hired in early 1963. As soon as he arrived he began searching catalogs for sets of rocks and minerals that would provide the optimum laboratory materials for teaching people with no geologic credentials and very shortly thereafter he started ordering sets of rocks and minerals. Because he had taught mineralogy and hand specimen petrology at the University of Texas he had some ideas for the best sources of materials and the types of storage facilities, cabinets, trays, etc. that would be needed for classroom activities. Thus, in the early days of training the program of study for hand specimens of rocks and minerals was not unlike what would probably be found in most freshman geology labs in any college or university across the U.S. Clanton was unable to find any appropriate trays in the ready-to-buy category, so he talked the University of Texas at Austin out of one of their trays that had been used for the sophomore course in hand specimen mineralogy and petrology. He brought the tray over to the Tech Services Division at MSC and had them build 100 similar trays. Then, when the class time came, just like in any freshman or sophomore geology or hand specimen petrology course, he could place the required number of specimens into the trays and distribute the trays around the classroom to each student.

There was one glitch in the procurement of samples as a result of Clanton's unfamiliarity with government procedures. When he had studied the various catalogs of rocks and minerals there was one company that clearly could provide the best specimens and he specified that company on the purchase request. The procurement office, however, sent the request out for bids and subsequently had ordered the specimens from the lowest bidder. When

Clanton went to the receiving dock to verify that the proper specimens had arrived he noticed that the company name on the boxes was that of the wrong supplier, in fact the one that he had considered least desirable. A look at the samples soon convinced Uel that his initial selection of suppliers was well justified, and he refused to accept the specimens. This resulted in the president of the company coming to Houston to accompany Clanton on an inspection of the samples and to determine specifically what was wrong with them. Apparently, the company president did not realize that Clanton had an excellent background in mineralogy and petrology because he was embarrassed when shown that many of the samples were not what they were supposed to be or were highly unrepresentative. The shipment was returned and Clanton's first choice was then ordered (Clanton Interview, 1995).

By mid-1964 the role of science at MSC had begun to develop a foothold. On June 15 and 16, 1964 there was a Manned Lunar Exploration Symposium at MSC and the contributions from MSC scientists were substantial. Of the eleven contributions by MSC personnel six dealt with some aspect of the science program, and a seventh by Neil Armstrong discussed the astronaut training program and started off with a discussion of the academic subjects, especially the geological part, which he pointed out would continue until completion of the lunar missions. John Eggleston discussed the various scientific instruments that the astronauts would use on the lunar surface and how the instruments were integrated into the spacecraft capabilities. Curtis Mason and Elbert King showed how the astronauts would spend their time on the lunar surface, especially emphasizing the nature of the science tasks that would be carried out during EVAs. Ted Foss described the astronaut training course that was nearing completion, especially Series I in the geology part of the program. John Dornbach reviewed the numerous in-house and contractual studies that were under way to determine the best scientific equipment, procedures, sampling plans, drilling operations, sample containers, cameras, and the like that could be developed for lunar exploration. He also reviewed the various simulation facilities that were being provided for testing the equipment and procedures. Jim Sasser provided a view of the science that could be accomplished from lunar orbit, ranging from photography to geophysical measurements and geochemical data by various forms of spectral measurements. Dallas Evans emphasized the experiments that could determine the composition and physical aspects of the lunar atmosphere with an eye toward understanding the formative processes of planetary systems (Contributions of MSC personnel to the Manned Lunar Exploration Symposium, June 15 and 16, 1964). Clearly, the scientists at MSC had come a long way during their first year and a half as part of the MSC society. But the basic, in contrast to applied, research accomplishments that were necessary for recognition and acceptance as bona fide scientists in the eyes of the academic community and research organizations were still lacking at MSC. In view of the extensive efforts of the MSC scientists in astronaut training and other operational and planning efforts that were required to meet the many aspects of preparation required for Apollo the difficulty of accomplishing basic research is readily understandable.

NASA Headquarters

NASA Headquarters, meanwhile, began setting up guidelines and requirements for science investigations on the Apollo missions and science training of the astronauts. As planning for Apollo science experiments and the required training for the astronauts got under way in 1962 there was some concern at NASA Headquarters about the manner in which it should be conducted. These concerns were elaborated in a series of memos during mid-1963 in which Newell indicated that MSC management did not appreciate what space science and manned spaceflight could do for each other and, in his opinion, the few scientists who were at MSC served only in support roles providing data to the engineers. These scientists were almost exclusively recent graduates who were relatively inexperienced in research and had no scientific research under way (SP4214, p. 32). As mentioned earlier, there had been some initial attempts at NASA Headquarters, starting in October 1961, to set up committees for suggesting the nature of experiments for the Mercury and Gemini flights as well as the training necessary for the astronauts to conduct these experiments. With these activities for manned spaceflight already under way, Newell set up a Space Sciences Steering Committee in March 1962. Also, in March 1962 OMSF decided to establish their own scientific input for Apollo and asked the Space Sciences Steering Committee to establish an ad hoc working group to recommend scientific tasks to be performed on the Moon by the Apollo crews and the associated science training for the Apollo astronauts. This was known as the Ad Hoc Working Group on Apollo Scientific Experiments and Training and consisted of several NASA personnel from Headquarters, Ames, JPL, and Goddard (but not MSC), and several non-NASA scientists from universities, the USGS, and the National Science Foundation. The work of the group, which came to be known as the Sonett Committee, was to consist of outlining: (1) the scientific problems requiring solutions, including justification; (2) means of using Apollo in terms of experiments, measurements and operational aspects; (3) the science support needed from unmanned programs and ground-based research; and (4) the education, selection and training of the astronauts for scientific tasks (minutes of Sonett Committee on Apollo Scientific Experiments and Training, April 23, 1962). OMSF indicated that it would attempt to tailor the flights and flight equipment to meet these needs. There was also a statement that welcomed suggestions for astronaut selection procedures with respect to scientific background with the comment that one or more members of the crew could be professional scientists trained as test pilots (NASA SP-4214, p. 20). Although the final report of this Committee is dated as December 15, 1963 a draft report was submitted for review in July 1962. Following a favorable review at a 1962 summer study at Ames, Iowa (the first of several summer studies of the NASA space science program conducted by the Space Science Board of the National Academy of Sciences for NASA Headquarters) the report remained essentially unchanged in its final version. Although manned space programs were not the main concern of the Ames study there were two working groups that examined the subject: one on lunar and planetary exploration and another on the role of humans in space, and that considered the recommendations of the Sonett Committee. Although several suggestions were made regarding lunar science emphasis was given to the need for scientific competence among the astronauts who would land on the Moon. The portion of the report dealing with astronaut training (Sonett Committee Report, p. 52-64) is covered in the following paragraphs.

One of the strong recommendations of the Sonett Committee as well as the Space Science Board was that "at least one member of the crew should be a professional scientist and that the other members (of the crew) should have extensive training in suitable scientific subjects." The professional scientist was to have a PhD and five to ten years of experience. Furthermore, in recognition of the fact that the scientific discipline that deals most directly with planetary surfaces is geology it was recommended that the principal scientific training and experience of a scientist-astronaut who would land on the lunar surface be in "hard rock geology" and, further, that the person had been a "practicing geochemist" with an "understanding of solid body geophysics" and "able to interpret observations in the field." However, the scientist-astronaut should also have additional training in "other pertinent disciplines such as high vacuum physics, radio and classical astronomy." It might be noted that Nobelist Harold Urey weighed in on this topic in a letter of January 1964 to Jay Holmes at NASA Headquarters in which Urey states, "I am sure that only the most experienced hard rock geologist could possibly do anything about the subject satisfactorily. I urge strongly that all astronauts be well-trained hard rock geologists" (Beattie, p. 17).

The Sonett Report further recommended the general nature of the training for both scientist and non-scientist-astronauts. For the non-scientist-astronauts, the recommended training should include setting out instruments and making readings from them. These could include "running a seismic profile or making astronomical observations with a theodolite." Other more routine functions such as collecting samples, digging trenches, or taking drill cores should also be included in the training. In addition to these specific tasks the non-scientist-astronauts should receive general instructions in problems related to the lunar surface and in methods of field geology. This training should be thorough enough to "provide them with sufficient understanding of the problems so that they could proceed with the scientific observations" without the aid of the scientist-astronauts, if necessary, but "with Earth-based guidance."

The recommended training for the scientist-astronauts was to be very intense in a variety of fields and to require hands-on experience in a number of topics. For the scientist-astronauts the report recommended that their training should include involvement in the preparatory investigations for the lunar landings as well as use of the results in follow-up studies after their return. It also recommended that up to the final stages of intensive flight training for the missions the scientist-astronauts should spend at least 50% of their time working in the field of lunar science, more specifically (1) the stratigraphy and structure of the lunar surface and (2) the processes occurring on the lunar surface. The latter would include such topics as the phenomena associated with hypervelocity impacts of solid interplanetary particles and the effects of solar radiation. Even more specifically, the report recommended that they be familiar with the behavior of rocks and minerals during fusion and crystallization in melts and under shock loading as well as their response to high-energy radiation and hard vacuum. It was recognized that until the first landings the principal source of information for these topics was astronomy with its various types of radiation sensors.

The report recommended "The lunar scientist-astronaut needs experience in all these fields." It further stated "He should know and preferably have contributed to the working out of the stratigraphy and structure of the lunar surface and understand fully the nature of the problems involved in their solution." Furthermore, he should have experience with terrestrial igneous rocks, various types of meteorites, volcanoes, terrestrial impact craters, and impact metamorphosed rocks, as well as the effects of hypervelocity impact, high-energy radiation, and hard vacuum. Their training should also include "work with high-vacuum systems...the interpretation of many physical and astronomical phenomena, and a rapid facility in order-of-magnitude calculations concerning a diversity of physical effects." For each landing site the scientist-astronaut should know the details of the surrounding terrain by heart and should have a detailed program of observations in mind and a broad spectrum of landing site problems for which more detailed information is needed. The report pointed out that the ability to integrate a wide variety of such observations into a coherent picture, which in turn would lead to further observations, is exactly what is accomplished by an experienced field geologist. Therefore, it recommended intensive training in field geology to strengthen the required abilities. A further recommendation was that the scientist-astronauts serve as the principal instructors for the scientific training of the other astronauts. Although it was recognized that, as mission times approached, greater amounts of time would be spent on spacecraft activities, it was recommended that work on, and review of, the scientific tasks should occupy part of each day for all astronauts.

As a final comment related to science training the report recommended that different research groups should pool their scientific and intellectual resources for the purpose of training astronaut-scientists. This was to be accomplished by a formal organization, established under NASA, headquartered at one specific geographic location, at which a staff of lunar scientists and scientist-astronauts could assemble and carry out major parts of their personal research. There should be adequate laboratory and observational facilities for all phases of lunar science as well as office space for a large proportion of visiting scientists from cooperating institutions. Such a research facility could also provide excellent research opportunities for graduate students from cooperating institutions. Scientist-astronauts would be part of the permanent staff while they were training for a lunar mission. The facility would also serve as the training center for the non-scientist-astronauts.

Many recommendations from this report were eventually implemented. However, only on the final Apollo mission did a scientist-astronaut participate in the lunar landing; and, as recommended, he was a field geologist with a "hard rock" background. The Apollo astronauts eventually became involved in planning traverses and learned the details of the geology at their respective landing sites. Some of the scientist-astronauts did take part in the training as instructors. Training in field geology became the major part of Apollo crew training for all astronauts after 1968. Hands-on studies of rocks, meteorites, geophysical instruments, and eventually, the returned lunar samples were part of the training for all astronauts. In the final weeks before the last three Apollo missions the astronauts and scientists spent several hours each evening reviewing and modifying the lunar traverses. In 1969 a Lunar Science Institute was set up for visiting scientists from all over the world next to the MSC where excellent laboratory facilities for the many aspects of lunar science were being installed. These facilities at MSC would be available to the visiting scientists. It would appear that the writers of the training portion in the Sonett Report were rather perceptive and merit more credit than they have received. In actual fact, though, it does not appear that the implementation of the actual training was a direct result of the report. Rather, it would appear that much of what occurred was more a result of recognition of what was practical during the evolution of the Apollo program, especially by the astronauts and the people involved in the training. The similarity between the report and the actual training in geology may result in part from the fact that Gene Shoemaker was a member of the Sonett Committee and later was the initiator of the joint effort between NASA and the USGS to set up a geology training program for the astronauts. As will be seen from later discussions of Shoemaker's philosophy regarding science training for astronauts his influence on the training recommendations of the Sonett Committee Report was substantial.

Over the next few years, following the formal release of the Sonett Committee Report, many individuals and study groups considered the training needs and made inputs of various types. It is not clear whether these formal inputs from Headquarters had much influence on the training program which was managed almost entirely by MSC personnel and others, particularly USGS geologists, who were involved directly in the day-to-day training. In the 1962 summer study at Ames, Iowa one of the working groups recommended creating an institute for Advanced Space Study in which participants would be trained as scientist-astronauts. The idea of an institute for the academic training of astronauts gained further interest when Congressman Teague of Texas proposed in bill H. R. 10476 that an academy be set up for the training of U.S. astronauts. The details for this part of the bill were prepared by Dr. Heber Moore (memo from Gerathewohl, July 31, 1964) of NASA Headquarters. S. J. Gerathewohl, a scientist in the Office of Science and Applications, reviewed the documents related to Teague's proposal and responded to Homer Newell in a memo dated July 1, 1964. The memo states that no complete curriculum exists for the training of astronauts engaged in our program. He attributed this to: (1) the lack of information on the tasks to be accomplished during the Apollo exploration and (2) the lack of competent personnel within NASA who could develop the requirements, academic standards, and appropriate training program. Gerathewohl goes on to recommend that a contractual study for a thorough analysis of this problem "be initiated with a competent institution of undisputed reputation in the field of higher learning and academic training." He suggests that the main emphasis for science background and training at first should be on "geology, selenology, geophysics, astrophysics, astronomy, geochemistry, atmospheric physics, and other Earth environmental sciences." It would appear that Gerathewohl knew nothing of the academic program already under way at MSC. These are precisely the subjects that were included in the 240 hours of lectures and labs, 12 days of geologic field exercises, and 2 days of planetarium studies that had just been completed at MSC by all astronauts (see Appendix A). This lack of knowledge about the activities at MSC by Headquarters and vice versa was a continuing problem as will be demonstrated throughout this study.

At a 1965 NASA summer conference on lunar exploration and science in Falmouth, Massachusetts, on July 19-31 there was serious consideration of the astronaut training program as well as the nature of the scientific instruments and studies to be associated with the Apollo program. In attendance were the newly selected group of scientist-astronauts and Walter Cunningham, a pilot-astronaut. The training discussions considered not only what was required for the Apollo program but also the needs of post-Apollo training. There seemed to be general agreement that the nature of the science training program that was already under way was quite reasonable to prepare the current group of astronauts for the Apollo missions. The recommendations seemed to be aimed at more field exercises on a more advanced level and participation of the astronauts in some of the geological research activities. What was really of more concern was the nature of the lunar exploration program after Apollo. The consensus was that an important factor in further selection of astronauts should be their abilities as field geologists, at least for some of them. A further concern was the continued scientific proficiency of scientist-astronauts. "Unless means can be found to permit him to continue in a productive research program, his qualifications as a scientist after a few years will deteriorate" (NASA SP-88, p. 156-160).

At about the same time as the Falmouth Conference, a study group was formed by Alex Dessler of Rice University to study the science training of astronauts. Among the main recommendations of this report were: (1) scientist-astronauts should be allowed to continue in active research by devoting one full week per month to research and one day on each other week to discussions, seminars, etc.; (2) scientist-astronauts should devote part of their time to in-house tutoring of other astronauts; (3) the science interests of astronauts should be stimulated by declaring that scientific proficiency shall be a prime requisite for at least one member of each flight crew; and (4) more scientist-astronauts should be brought into the program to provide more depth and breadth in science fields related to the space program (Report on Space Science Training for Astronauts, Study group at Rice, Nov. 1965).

MSC Director Gilruth's reaction to this report seemed generally positive but displayed a few rather defensive comments, as the recommendations had neglected the problem of integrating the scientists into a predominantly pilot culture. On the suggestion that scientist-astronauts should devote part of their time to in-house tutoring of other astronauts he responds, "the scientist-astronauts can also learn something from the test pilots." He responded identically to a suggestion that the scientist-astronauts should be integrated into the faculty that taught the regular science courses of the astronaut training program. He also reacted to the amount of time that should be spent on training with the comment, "We must not lose sight of the need for adequate flight training type of preparation for the scientist-astronauts. Witness the recent Soviet admission of nausea, disorientation, etc. of their relatively untrained scientific cosmonauts." (letter: Gilruth to Dessler, Dec. 22, 1965) This latter comment turned out to be immaterial as it became quite clear over the next few years that the amount of training had little, if anything, to do with the nausea and disorientation.

At another NASA summer conference on lunar exploration and science at Santa Cruz, California, from July 31 to August 13, 1967 the topic of astronaut selection and training was again a major topic of discussion. Among the main recommendations of the conference was the concept that ability in field geology should be the next most important criteria after ability in flight operations for selection of crew members for lunar exploration. A second recommendation was that astronauts should be provided time to engage in research activities within their professional fields. The geology group at this conference emphasized that the highest scientific value should be placed on the ability of the astronaut "to recognize and analyze the unexpected and then to formulate tests and additional observations that place on record a new and unforeseen contribution to knowledge." To this end, the "astronauts must be freed from all but absolutely essential tasks while on the lunar surface." Although there seemed to be general satisfaction with the direction of the training up to that point there was a recommendation by the geology group that a new aspect of training be introduced, namely orbital science. It was argued that this new aspect was important because a trained human eye can be used as a scanning and data-selection system in a more efficient manner than instruments. The geophysicists also emphasized the need for field geology training, including field work with geophysical instruments. They also stressed the need for close contact between astronauts and PIs. Only the bioscience working group at Santa Cruz seemed unhappy with the science training. They felt that bioscience had not been implemented in the training program despite recommendations to do so at previous conferences (NASA SP-157, p. 19, 107-110, 195, 283-284). Although medical aspects of space flight had been a regular part of the training to this point biological science had not. In the next set of classes in 1968 16 hours of biology were added to the training program.

It is not clear that the various committees and study groups had much effect on the science training. The initial two courses in 1959 and 1962 were nearly identical except for the addition of 10 hours of selenology and a one-day field trip, both instructed by Gene Shoemaker (see Appendix A). In 1963, through the efforts of MSC geologists, as well as Shoemaker and the USGS, a substantial amount of geology was added to the training programs that had been given in 1959 and 1962 (see Appendix B). Further iterations of the science training program remained unchanged through mid-1967 when Jack Schmitt convinced Alan Shepard to have the Astronaut Office take control over the training as it already did for other flight activities. Schmitt suggested to Shepard and the flight crews that field simulations be conducted on real geologic problems related to specific missions. He also suggested that more senior researchers who were excellent teachers be brought into both the field and classroom instruction. The science training program in late 1967 and early 1968 was drastically different from any of the earlier programs. Other than a few specific mission experiments on Mercury and Gemini it does not appear that the input from Headquarters, and its committees and study groups, had much influence on the science training of the astronauts in the early years from 1959 through 1968.

US Geological Survey

While MSC was developing a cadre of scientists for the Apollo program and NASA Headquarters was trying to set up an administrative structure and develop a direction for science on Apollo, the USGS was also heavily involved in lunar projects. Wilhelms discusses some of the early USGS activities in geologic mapping of the Moon starting about 1959 (Wilhelms, p. 38-42 and 46-48) and the study of impact craters (p. 40-49). One of the leaders in these efforts was Shoemaker who convinced the USGS to form an Astrogeologic Studies Group in August 1960, which became the Branch of Astrogeology in September 1961 with Shoemaker as its chief. One of its major efforts throughout the 1960s continued to include lunar mapping and crater studies. As the Apollo program began to develop, however, the USGS expanded its Astrogeology Branch as it began to consider the types of geological efforts that might be proposed for lunar surface activities during an Apollo landing. With funding from NASA Headquarters it also became heavily involved in astronaut training and was the center for the Lunar Field Geology Experiment during the Apollo missions. This Branch also provided some of the prominent people who eventually went with NASA such as Mike Duke, who became Curator of lunar samples and Chief of the Solar System Exploration Division; Jack Schmitt, who became the only scientist-astronaut to land on the Moon; Joe Boyce, who became a program manager for some of the lunar programs at NASA Headquarters; and Robin Brett, who became chief of NASA's Geochemistry Branch at MSC.

In addition to heading the Branch of Astrogeology Shoemaker was one of the most influential of the USGS geologists in the early efforts to develop lunar geology programs. He had been interested in exploration of the Moon ever since his days as a Caltech student and his first job with the USGS in 1948. In his own words "One couldn't help but be impressed with the incredibly rapid advance of technology at that time. And I just made up my mind that there was going to be manned exploration of the Moon in my professional lifetime. And so I decided that would be the most exciting thing I could conceive of being involved in" (Shoemaker interview with W. D. Compton, March 17, 1984). His main goal during his first few years with the USGS was to become "the best damn field geologist that I could be because that's what you'd need if you were going to send a scientist to the Moon."

Shoemaker's work with the USGS led him to study explosive volcanoes and their associated craters on the Colorado Plateau as well as the nuclear craters at the Nevada Test Site (NTS). Gordie Swann, one of Shoemaker's early co-workers who had worked with him quite a bit on the Colorado Plateau, said that Shoemaker would put an alidade out on the hood of the jeep in the '50s and look at the Moon and say "Some day somebody's going there and I'm going to be one of them." Also during the 1950s Shoemaker had visited essentially all of the so-called cryptovolcanic structures that were recognized at that time. These were controversial structures whose origins were quite uncertain. In Gene's words "I had taken a hard look at them and concluded that those things really were impact structures." He had a list of the ones that ought to be geologically mapped and studied in detail. He got some students started on some of them for PhD theses and he was going to do the Sierra Madera structure in West Texas himself. Also during this period he commenced a detailed mapping study of Meteor Crater in Arizona. This concentration on craters was associated with his desire to understand the processes that could be involved in the formation of the craters on the Moon. When the Apollo program was announced and it was intimated some scientist-astronauts might be sent to the Moon Shoemaker was confident that he might be chosen. This was about the time that he started flying an airplane, in part to prepare for applying to be an astronaut. But in the midst of this he came down with Addison's disease and was not able to apply (Swann interview, 1995).

As mentioned above, Shoemaker was one of the USGS scientists who had been interested enough in the geologic exploration of the Moon to set up a new Branch of Astrogeology within the USGS. He also played a role in setting directions for the science activities at both NASA Headquarters and MSC. The NASA connections began in a serious way when Gene attended the Ames summer study in space science at the University of Iowa from June 17 to July 31, 1962. At this meeting, attended by both NASA officials and active research scientists, scientists had opportunities to set forth their various concerns and try to clear the air of developing problems. Homer Newell indicates that "it appeared that the scientists approved of much of what NASA had been doing but urged more attention to problems that continued to be a worry throughout the years" (NASA SP-4211, p. 207).

One of the most contentious of these problems was the great cost of manned spaceflight which many scientists felt would drain most of the money away from space science. Most of the scientists saw very little science resulting from the manned programs, although some prominent scientists tried to argue that the exploration that would result from manned spaceflight was itself science. Also from this meeting came the recommendations that scientist-astronauts should be included in the program and that NASA should create an institute for training astronauts in science to be administered by either a university or within NASA by the office responsible for the space science program. Shoemaker left that meeting "utterly dismayed" because he sensed that the attitude the MSC representatives conveyed was, "We don't need your help; don't bother us" (NASA SP-4214, p. 32). Because of his concern that there was going to be a problem getting any science done on Apollo Gene spoke about this problem with Oran Nicks who was head of the Office of Lunar and Planetary Programs in the Office of Space Science at NASA Headquarters. Shoemaker's major point was that there was no planning under way for any science to be done on Apollo. Furthermore, he felt that Brainerd Holmes, the director of NASA's Office of Manned Space Flight, "didn't want science in the way." As a result of the discussion with Nicks Nicks and Newell invited Shoemaker to spend a year at NASA Headquarters, starting in fall 1962, to set up some kind of an organizational unit that would bridge the gap between space science and manned spaceflight.

At about this same time in mid to late 1962 at MSC some thought was being given to what the astronauts would do once they were on the Moon. According to Shoemaker, Max Faget, director of Engineering at MSC, was the person with more interest and vision in the possibility of doing something scientific than anyone else at MSC at that time. "Max was interested in trying to get some science started for Apollo. He was the one who had the vision for this. In fact, he designed the landing module with some pretty big bays in it with the idea that there would be scientific instruments in there. He wanted to get the thing going. I think a lot of credit should go to Max for that vision. I think he was the only one, really, at MSC who had that idea that there was some science to do when you got to the Moon" (Shoemaker interview, 1995). In fact, in mid-1962 Faget tried to hire Shoemaker at MSC to develop a science program. In August 1962 Shoemaker was doing field work at Sierra Madera in West Texas and Faget invited him to visit MSC to discuss the possibility of him coming to work there. So Shoemaker drove to Houston (in the hottest part of the summer) to meet with Faget. In Shoemaker's words "Max wanted me to come and work for him, straight out, to build up a geology group, to do research, to train the astronauts, and to build up the whole thing for science on the Moon." Although he was seriously tempted to accept this offer as a way to get science under way in the Apollo program Shoemaker decided to first check with the folks at NASA Headquarters to see what activities and directions they would be willing to support. So he went to see Homer Newell at NASA Headquarters. According to Shoemaker, Newell said "Well, the first thing that's got to be done is we've got to set up something here at NASA Headquarters to get the funding organized and get the funding to support for the science." At that time Newell was having some difficulties establishing the role of science with Brainerd Holmes who was the administrator of the manned program. According to Shoemaker "Homer wanted to establish some kind of a joint arrangement with Brainerd so there would be science embedded in the Apollo project, in the manned effort." Newell convinced Shoemaker that the first thing he should do was come to NASA Headquarters and set up a bridge between the OSS and the OMSF at Headquarters, and that is where Shoemaker went for a one-year assignment in the Office of Space Science.

Shoemaker left his Menlo Park, California, home base in September 1962 to fill a one-year appointment at NASA Headquarters in Washington, D.C. As was often the case in the planning for science activities several offices were planning things that others were also planning, with no one aware of the duplication. In Gene's words:

> *So I went in and worked directly with Oran Nicks who was Director of Lunar and Planetary Programs. He was really the daddy of Planetary Exploration. And was the daddy of the Unmanned Flight Programs. Tremendously good guy to work with, he really was good. So the idea was that I would work with Oran and then we'd try to set up a new directorate that would be responsible both to Newell and to Brainerd Holmes. We got that going. The interesting thing is that Holmes had sort of*

> *had an idea to get somebody himself. It turns out that he brought Fred Eimer from JPL to NASA Headquarters to do it for him. Well of course that sort of thing had to be thrashed out at the level of Newell and Holmes. Well, as it turned out, the thing was worked out that we go ahead and set this up kind of the way Newell was planning. I guess Newell said, well you know we're responsible for science; that was his job at NASA, he was the science king. So we went ahead and set up the directorate. I served as its interim director then, when it was established, and recruited a staff. Fred went out and ultimately ended up in the disarmament activities. I kind of lost track of him."*
> (Shoemaker interview, 1995)

Thus Shoemaker succeeded in setting up an organizational unit, the Manned Space Sciences Directorate, to provide the desired bridge between OSS and OMSF. On July 30, 1963, when Shoemaker was about to return to the USGS, Newell reorganized this group as the Manned Space Science Division.

While at NASA Headquarters Shoemaker continued to be concerned about the training, or lack of training, in geology among the astronauts. As many people had begun to realize, the tasks of the astronauts on the lunar surface would be heavily weighted toward geological and geophysical activities. Newell and his deputy Nicks were also sensing that the Apollo activities would be influenced by geological studies. This observation was not lost on Shoemaker. During his term at NASA Headquarters Shoemaker argued that the astronauts who would perform the field studies on the Moon were mostly test pilots. (At this point the first two groups of astronauts had been selected and they were all test pilots.) He made the logical point that it should be the task of earthbound geologists to train them in the methods of geology, especially field techniques, if there were to be any successful science accomplished while on the lunar surface. Wilhelms states that "our" point of view (apparently referring to Shoemaker and some of the other USGS geologists) was that "the Moon is made of rock, and a large block of relatively inexpensive shirt-sleeve time on Earth might be the key to choosing the most important samples during those precious hours on the Moon" (Wilhelms, p. 78-79). Shoemaker decided to propose a brief introduction to the type of training that he felt would be necessary for astronauts who would travel to the Moon and spend time there either in orbit or on the surface. He suggested that a group of astronauts be selected for a short two- or three-day course of lectures, field excursions, and telescope-viewing on topics related to the Moon. This proposal was negotiated with the Astronaut Office at MSC with the understanding that if it worked out well a future program of similar training might be developed. In January 1963 Gene took the nine astronauts of the second group on an intensive two-day field trip in and around the USGS facilities at Flagstaff, Arizona (Wilhelms, p. 76). The group included astronauts Armstrong, Borman, Conrad, Lovell, McDivitt, See, Stafford, White, and Young. The astronauts were accompanied by several other personnel from MSC to provide further evaluation of the potential for a training program.

The training commenced on the morning of January 16 with an excursion to Meteor Crater followed by investigation of the Sunset Crater cinder cone and associated lava flows of the San Francisco volcanic field near Flagstaff, Arizona. These two areas were meant to emphasize the diversity of origins and the criteria for determining the origins of circular structures many of which had been mapped on the Moon. During the evening and on until about 3:00 a.m. the next morning additional work was carried out with the reflector and refractor telescopes at the Lowell Observatory, the U.S. Naval Observatory, and The Atmospheric Research Laboratory at Arizona State College. These night-time studies included observations of the geological features on the lunar surface, an examination of Mars, and a discussion of the problems involved in lunar topographic mapping. The following morning Shoemaker presented a lecture summarizing what was known about the geology and possible processes bearing on the character of the lunar surface (Ray Zedekar's calendars of daily training schedules).

Don Wilhelms (Wilhelms, p. 76) indicates that the astronauts were favorably impressed by this first geology training trip and seemed eager for more. Shoemaker had already discussed with Faget and Eggleston at MSC the possibility of assigning some USGS personnel to Houston to conduct the geologic training. According to Shoemaker "When I talked to Max initially [August 1962], I said, 'well I think I could recruit or bring a top bunch of people from the Survey down directly to Houston and get this thing going.' That's the thing I discussed directly with Newell when I got there [NASA Headquarters]." The field trip and its apparently favorable response allowed Shoemaker to further develop the idea of geologic training for the astronauts among his NASA Headquarters contacts where he again suggested that USGS personnel could provide much of the training through a cooperative arrangement with NASA. As a result of these suggestions Newell met with Thomas Nolan, Director of the USGS, in late January 1963, over lunch in the NASA Headquarters cafeteria. In fact, for at least two months before Nolan's and Newell's meeting Shoemaker had already been discussing with Newell some of the details for assigning a group of USGS personnel to MSC. At the lunch meeting they discussed an arrangement in which Nolan committed the USGS to support the training of the astronauts while Newell agreed that it would not be necessary "to build up within the agency another little Geological Survey" (NASA SP-4211, p. 292). Newell points out that this was an informal agreement and never went to the NASA Administrator's office for his blessing.

Further discussion with Uel Clanton, one of the MSC scientists hired in early 1963, sheds a bit more light on the background of the MSC-USGS agreement: "It was clear at that time both from an engineering point of view – and from the astronaut's point of view – that there was a major reluctance by both management and the astronaut group that any person other than a test pilot be allowed to fly and participate in the missions. For this reason it became apparent that any science that would be done, at least in the first few missions by the test pilot type astronauts, and the scientific return from these missions would come from these people and from the training that was developed around them." Clanton continues by stating "It was also during this period of time while Shoemaker was in NASA Headquarters as an advisor there was pressure at the Headquarters level to the local [MSC] level that the Geological Survey, or at least some people from the Geological Survey, be brought in to the program. Because of the reluctance of some of the scientific community to accept NASA as an organization that would provide scientific input to the community as a whole one of the thoughts was that by bringing in the Geological Survey this would add some credibility to the task and offer a resource of talent that could be used. Through a series of discussions at the *local level* [emphasis is the writer's] this relationship was formulated" (Clanton interview, 1995). It should be understood that this arrangement was completed by letters between Gilruth at MSC and Nolan of the USGS. There was never any formal interagency agreement that involved officials from NASA Headquarters. Following is the documentation that was involved in this arrangement.

A letter of January 10, 1963 from Shoemaker to Vince McKelvey at USGS headquarters in Washington, D.C. contains a draft of the details for the suggested arrangements. On February 2, 1963 Shoemaker sent a draft of a letter with these same arrangements, essentially unchanged, to Jack Eggleston, the Assistant Chief of the SED at MSC, for Faget's approval and for Dr. Gilruth to send to the Director of the USGS. A letter from Robert R. Gilruth, Director of MSC, to Thomas Nolan, Director of the USGS, dated March 29, 1963 contains the details of the proposed arrangement with essentially no changes from Shoemaker's drafts in early January and February. Nolan returned a letter agreeing to the arrangement on April 24, 1963. The timing of these drafts and acceptance of the agreement is important. The initial draft was written by Shoemaker in early January, the draft to Eggleston was sent in early February, the letter from MSC to the USGS at the end of March, and the response from the USGS in late April; a total period of nearly four months. Why it took nearly two months from the time of Shoemaker's letter to MSC and the sending of Gilruth's letter is not clear. Gilruth's letter points out that the functions of the MSC SED currently included development of environmental data and models for the design and operation of spacecraft, but it was planned that this division would also help "develop the requirements and specifications and tests for qualification, the scientific instruments to be carried on manned space flights, and will assist in the training and instruction of the astronaut crew for the scientific missions to be carried out on the Moon."

Specific arrangements for the USGS activities included: (1) six geologists and geophysicists to be assigned to the Chief of the SED at MSC on full-time duty with residence at MSC for two years and to serve, in effect, as full-time NASA employees although still as members of the USGS and subject to its policies; (2) backgrounds of the assigned personnel should include exploration geophysics (one person), field geology (two people), petrology (one person), lunar geology (one person), and impact cratering (one person); (3) functions of the group were to a) guide in equipping a geological laboratory with the necessary instruments and facilities for research and teaching; b) help develop the model of the lunar surface used for engineering and operations; c) help evaluate scientific instruments for use in lunar exploration in the Apollo project; d) help work out profiles of the scientific program on the lunar surface, in conjunction with the Flagstaff office, including various lengths of stay on the lunar surface and time and motion studies of what can actually be done (this was to include mobility studies in spacesuits in the natural terrain around Flagstaff with radios, cameras, etc.); and e) instruction the astronauts in basic geology, geophysics, and lunar geology, to include mineralogy and hand specimen petrology in Houston, field geology in the Flagstaff area, lunar geology in Houston and Flagstaff, and geophysical field techniques in the Flagstaff area. The USGS group was to take up temporary residence at Ellington AFB while the permanent facilities for MSC were under construction.

The letter from Nolan to Gilruth dated April 24, 1963 responds to Gilruth's letter indicating that "the proposed arrangements are satisfactory" and that the USGS "will try to assemble the staff in Houston by July 1 or shortly thereafter." It further indicated that Dr. E. Dale Jackson would be in charge of the USGS group and that Jackson's "association with this program will provide capable leadership in planning a comprehensive program *to establish at Houston a fully equipped facility for the distribution, control, and analysis of lunar and other space samples* [emphasis is the writer's] obtained by flights of manned and unmanned spacecraft." Clearly, the latter statement includes among the duties of the USGS Houston office, the establishment of what later became known as the Lunar

Receiving Laboratory. Apparently Nolan interpreted function 3a of Gilruth's letter, "to guide in equipping a geological laboratory with the necessary instruments and facilities for research and teaching," in a very broad manner, perhaps not in the way that Gilruth intended.

Clearly, this request from Gilruth and response from Nolan includes much more than just the training of the astronauts, but it is not clear how the assigned USGS personnel were to interface with the MSC personnel who were already doing (or, at least, planning to do) the same things. Furthermore, MSC was continuing to hire personnel to expand their capabilities in these areas. One clue to this overlap is a comment in Gilruth's letter stating that "at the present time the staff of the SED is small and Mr. Faget has been seeking qualified scientists to carry out the functions of the Division." Gilruth goes on to state that “the assignments [of USGS personnel] will be for a period of two years.” He also stated that the assignments could be renewed at the option of the Survey and MSC. It is not clear, but perhaps is implied, that a build-up of NASA's scientific personnel in a lunar science program within MSC was to accompany a phasing out of the USGS personnel. Clanton, one of the MSC scientists hired in early 1963, adds further input for this situation: "The decision was made in perhaps January or February of 1963 that a group [of NASA personnel] would be built up in-house at the Manned Spacecraft Center to train the pilot-astronauts in the level of geology and the other sciences that would be used in lunar exploration such that the scientific community could gain, if not maximum benefit, at least a major benefit from the lunar exploration." Clanton then makes it clear that building up a group of scientists at MSC was not easy to accomplish: "One of the first tasks that I had when I came with NASA in March of 1963 was to start building and collecting information for the astronaut training program. It was in this same period of time that additional people were being recruited, and I must admit that quite often the recruiting was with some difficulty, because in 1963 the scientific community as a whole did not really believe that we were going to the Moon. Quite often considerable persuasion had to be used to convince the scientists to participate in the program" (Clanton interview, 1995). This statement agrees with the comment in Gilruth's letter but further amplifies it by pointing out that recruiting was difficult. It should also be emphasized that the science facilities at that time were located in some converted barracks at Ellington AFB several miles from the Clear Lake City site where the new MSC facilities were being built, and at that time it was not clear when, if ever, new and adequate science facilities would be built. Also a factor in this was the observation that, at this stage of MSC’s development, whatever scientific and research competence an expert scientist might have, it would be afforded little opportunity for development at MSC for a few years as the management and development of the training, hardware, landing sites, and other operational aspects of Apollo were evolving. A similar situation also presented a problem at NASA Headquarters, as discussed by Newell (NASA SP-4211, p. 213). Such conditions certainly did not aid in recruiting top-notch scientists.

4. Apparent conflicts

There are numerous indications that MSC, Headquarters, USGS, JPL, and university scientists were all heading in different directions, often without knowing what the other was contemplating. The scientists who had been influential in setting NASA's early research directions with unmanned spacecraft were generally against the manned program. So rather than helping to develop a coherent science program they were trying to scuttle it, leaving a few scientist-managers at Headquarters to try and mend the fences between the groups. And there was another group that did not find space science to be necessary at all. Gene Shoemaker provides this tripartite division of the attitudes of the scientists: (1) the whole business of space exploration was a waste of time and money, (2) space science is okay when done unmanned, (3) manned exploration is necessary. Obviously, only the last of these groups had any interest in the Apollo program. Further complicating this was another tripartite division among those who were in favor of conducting science in space: (1) Black-box instrument people who want numbers from in-situ locations, (2) laboratory scientists who want to work on samples by analysis of chemistry, isotopes, etc. (3) big-picture or synthesis folks who need observations on a regional or global basis to understand time sequences of events and history (Shoemaker interview with Compton, 1984). Many space scientists still did not accept the fact that Apollo was really going to happen and continued to rail against it as though they could stop it. All of these conflicts and different directions of efforts were present during the 1962-63 time frame as the Apollo program was being organized and getting under way.

Some of the difficulties that developed between MSC scientists and the USGS contingent that arrived at MSC in July 1963 were mentioned above. Apparently, Shoemaker, who set up the arrangement, was not aware of what was happening at MSC in the several months after he first discussed the arrangements with Faget and other MSC management. In an interview in 1995 Shoemaker indicated that he would not have made arrangements for the USGS contingent to be in residence at Houston had he known that MSC intended to build up its own science capability. "What happened in the meantime was that Max wasn't going to wait around. He decided to go ahead and recruit staff directly. In fact, had I known that Max was just going to go ahead and get another independent group I wouldn't have done that because that made a very awkward situation. By the time Dale (Jackson) and Gordon (Swann) and Eggleton and Wilhelms got there our expectation, and that's what Dale went down with, was that this would be a group that would work there directly at MSC and get the science going in-house there and it would be a contingent from the USGS that would be there to do it. That was a real fast way to get under way. But I guess Max had other ideas after that." When asked if Newell was aware of what Faget was doing when Newell indicated to Nolan that he did not wish to set up a little USGS within NASA, Shoemaker's response was "Well no, not at that point. So Max just went on independently. He recruited Uel and the other guys who were there at that time. So, it made for kind of a funny and awkward situation by the time Dale actually came on board." Exacerbating the problem was the fact that many of the USGS personnel were older and more experienced geologists than the MSC group.

Despite Newell's statement to Nolan that there was no need to build up a little USGS within NASA that is precisely what appears to have occurred. It should be pointed out that from the time of Faget's first meeting with Shoemaker in August 1962 at MSC it was nine months before the discussions and exchange of letters between Gilruth and Nolan finally resulted in an agreement of a plan for the USGS to train astronauts and to develop other science activities at MSC (letter from Nolan of the USGS to Gilruth, April 24, 1963). The program was not to start until July 1, 1963. At the August 1962 meeting in which Faget offered Shoemaker the science job at MSC Faget had indicated to Shoemaker that he wanted to start building a science capability at MSC for a number of reasons including training the astronauts. But Shoemaker delayed his decision until he had time to determine Headquarters's response regarding the future of science in the Agency. Clearly, hiring people to start this capability was on Faget's mind; and he began hiring scientists for these positions in late 1962 and on into 1963, well before the completion of any written agreement with the USGS.

It is of interest at this point to emphasize that Newell and others at NASA Headquarters had long recognized the need for more research to be accomplished by scientists within NASA. In fact, in early 1959 during a brief skirmish with the National Academy of Science over whether NASA should conduct its own space science programs Newell argued that "aside from wanting to be involved in the scientific work, the agency had to have a scientific competence to work properly with the outside scientific community. Were NASA to limit itself only to engineering and technical staffs day-to-day decisions in the preparation of satellites and space probes would have to be made without the insights into basic and sometimes subtle scientific needs that only working scientists could provide" (NASA SP-4211, p. 204). This seems to contradict Newell's January 1963 discussion with Nolan regarding the building of another little Geological Survey within NASA. Actually, by 1963 Newell was waging a campaign urging MSC to build up its scientific staff and even develop an organizational structure that gave more prominence to science. Following a visit with Gilruth at MSC on February 14, 1963 while there to present a seminar on space science to the astronauts Newell sent a letter to Gilruth asking for his participation in a meeting of the Space Science senior council in April to address the group on "How the Office of Space Sciences and the Manned Spacecraft Center Can Assist Each Other." In July 1963 Newell sent a memo to the administrator's office requesting support for building a science facility in Houston.

At MSC in September 1963 Newell and others from Headquarters met with Gilruth and others from MSC to discuss, among other science issues, a Space Science Institute closely connected with MSC in order to develop a strong manned space science effort there. This suggestion was part of a memo from Verne Fryklund (a detailee from the USGS to NASA replacing Gene Shoemaker as the liaison for Space Science and Manned Space Flight) to Newell (memo from Fryklund to SM, Sept. 27, 1963). A further topic of the memo dealt with the reluctance of MSC to follow Headquarter's science advice. One of the points under discussion at the September meeting was the fact that MSC Management Instruction 37-1-1 dealing with the center's conduct of scientific investigations did not conform with the existing Headquarters 37-1-1. A copy of the Headquarters version was left with Gilruth with the understanding that appropriate changes would be made. As an indication of the nature of the relations between Headquarters and MSC management Fryklund's memo ends with the following comment: "It would be appropriate to note that the meeting, which lasted more than 2 hours, was conducted in a friendly manner."

Following further discussions between Newell's office and MSC money for two scientific research projects was transferred to MSC in November 1963 over Newell's signature with a concluding comment from Newell to Gilruth: "hoping that you will rely heavily on the assistance of this office and the other Space Science centers as you continue to develop MSC's scientific capability." Newell and his science staff at Headquarters persisted for the next few years in their efforts to develop a stronger recognition for the science staff and research efforts at MSC. Finally the influence of Newell's efforts began to take form, first as a Space Science Office within MSC's Engineering

Directorate in early 1966; then as a Space Science Division, again in the Engineering Directorate; and finally in late 1966 with the establishment of a Science and Applications Directorate (S&AD) (see organizational charts). As Compton points out "At long last Homer Newell's view of the importance of science at MSC prevailed" (NASA SP-4214, p. 87). As these organizational changes occurred the location of the science training organizations also changed from a Branch within the Engineering Directorate to a Division within the Science Directorate (see Appendix F for detailed organizational charts). Fortunately, however, the personnel who conducted the training remained nearly the same and they remained as a coherent sub-unit thereby assuring the continuity of the training.

The continuing differences between Headquarters and MSC are illustrated in the following exchange. In December 1963, following a request from Gilruth that Headquarters withdraw the Apollo Scientific Guidelines that had been previously transmitted to MSC in early October 1963, a memo from Headquarters Manned Space Science Division to Newell in the Office of Space Science points out that these guidelines were established after extensive consultation with leading members of the scientific community. Furthermore, it suggests that these guidelines again be transmitted to MSC from Newell's Office in order that scientific planning for Apollo be undertaken as soon as possible. The memo further requests that a representative from Headquarter's Manned Space Science Division be assigned to MSC to be on Gilruth's staff with the responsibility of "managing science projects and for assuring the compliance with guidelines established in Headquarters" (memo from Foster to Newell, Dec. 19, 1963).

There were other conflicts between NASA centers and other government agencies involving several aspects of the developing programs. Shoemaker (1995 interview) explains how some of these finally led him to depart from active participation as a PI in the program. He had been dealing with JPL for support on the unmanned part of the program. He had been dealing with Headquarters for the mapping efforts. He had been dealing with MSC for support on the training and development of hand tools and procedures for lunar exploration. He had been dealing with MSFC for some of the surface mobility concepts for lunar exploration. All of these organizations were trying to keep as much for themselves as possible and not let other NASA Centers or other agencies get a part of their activities. As Shoemaker put it "I have to tell you, by before Apollo 11 I was really getting burned out. The whole NASA organization became this funny kind of feudal kingdom with some kind of a weak central king and all these powerful dukes each battling each other for turf and territory. And there were vassals under those dukes that were fighting their turf battles. That's the way NASA ran it. But those guys wanted the turf. They wanted the action. And that's sort of awkward. The place where your funding is coming through is where they want to push you out the door."

Why was there such a lack of agreement and communication between so many of the units involved? It is beyond the scope of this study to analyze this question in great detail, but some of the more obvious reasons seem rather apparent. One of the first things that is noticed in interviews and in some of the documents is the fact that very strong personalities were involved. The people who gained the decision-making levels were those who were forceful in their actions, had great confidence in their abilities, and knew how to gather a staff of loyal and capable employees. Such people seemed to prefer their independence and were not likely to accept the intrusion of others' influences unless it was absolutely necessary. Such independence can be manifested through stalling tactics, lack of communication, setting up roadblocks in the form of complex management and committee structures, or just plain refusals to cooperate.

It must be understood that NASA was formed from remnants of NACA (National Advisory Committee for Aeronautics) which consisted of relatively independent research centers, and JPL which, although not truly a NASA Center administratively, was also a quite independent entity. NACA was an agency devoted to applied research and had been at the forefront of applied aviation research for over four decades when it became the core of NASA on October 1, 1958. It was very good at applied research and spent very little effort on basic research. One of the problems that faced aeronautics in the 1950s was the effects of high temperatures on very fast moving aircraft and rockets. This had led NACA to focus its research on transonic and hypersonic flight with special emphasis on aerodynamic heating phenomena (NASA SP-4203, p. 7). It was from this background that NASA arose, and the STG which became the core of MSC was organized in October 1958 at the Langley Research Center, a former leader in the type of research applicable to manned spacecraft. The habits, viewpoints, styles, and biases of NACA did not vanish overnight but remained unchanged or changed very slowly. As Hacker and Grimwood (NASA SP-4203, p. 7) very cogently point out "The same NACA engineers, scientists, managers, and technicians who left work on September 30, 1958 were back on the job for NASA the next morning." These centers were suddenly placed under new management with many unknown new directions to consider. Clearly, the most reasonable thing to do at the local management level was to continue doing what you have been doing well for the past 40 years until receiving new direction. When NASA and the STG were formed the people in these groups were the ones who had already had the foresight and independent mindsets to be thinking about manned space flight. The STG started with 45 people who "had only one job: the most direct and speedy achievement of manned orbital flights" (NASA SP-4203, p. 7). Therefore, with the strong personalities and the various independent organizations that were involved in the first several years of NASA's development it is not surprising that many problems developed involving lack of communication and agreement on directions, organization, and procedures.

5. Facilities

The STG commenced the move to Houston in December 1961 shortly after the orbital flight of Enos, the monkey, on Nov. 29 but before John Glenn's first orbital flight on February 20, 1962. At first they were scattered about the south side of Houston in 11 separate locations near what was known as Gulfgate as well as in some surplus quarters at Ellington AFB, several miles to the south. A street map was necessary to get from one office to another. Throughout 1962 and early 1963 some of the activities, including the science training facilities and astronauts, gradually moved to buildings at Ellington AFB, which was located about 10 miles south of Houston. By mid-1963 the scientists' facilities were located in some converted barracks, Building 341, at Ellington. The personnel associated with the geological aspects of science training were organizationally located in the Lunar Surface Technology Branch within the SED of the Engineering Support Directorate (see organizational charts in Appendix F).

The facilities were far from adequate for a reasonable science facility and John Eggleston, chief of the SED to which the scientists, geologists, and others were assigned, pleaded with Headquarters to support them in a request to obtain better facilities. In a memo to Newell on July 24, 1963 Verne Fryklund, chief of the Apollo Scientific Program Office at Headquarters, requested that Newell support Eggleston's request to remodel these facilities into "usable office space and somewhat less usable laboratory buildings." He pointed out that Ellington was several miles from the Clear Lake City site where the new MSC facilities were being built and it was apparently the intention of MSC management to leave the SED at Ellington indefinitely. Fryklund's memo contains some rather pessimistic comments about the Houston situation. He argued that "The SED Branches are professionally weak and it is doubtful if they ever will be able to recruit top-notch people if they must work under second-rate conditions." He further stated that "We and SED together will have, at best, difficulty in fostering science on Gemini and Apollo. If SED remains off the main post its stature in the organization, and our stature, probably will be diminished in a significant manner." Fryklund's final comment is rather significant regarding the feelings that Headquarters had about MSC's attitude toward science: "Though one might question the wisdom of fostering a Space Sciences Division at Houston, as that is what it really is, I see no alternative in getting our work done." Newell sent a memo to the Administrator's office a few days later repeating these comments and requesting support for the science facility in Houston.

The initial classroom instruction for the astronauts at Ellington was in a one-story building right off the flight line next to the hangers. There were two small offices at one end of the building and there was a huge area, a couple of bathrooms, and a storage room at the back, with standard government-issue tables and chairs in the rooms. Around the walls of the storage room and at the back of the room, wherever there was space, were the rocks and minerals and some of the display specimens that were used in astronaut training (Clanton interview, 1995). Gilruth described the geology classroom at Ellington as a small museum of mineral science with collections of minerals, rocks, meteorites, globes of the Moon, models of lunar terrain, etc. (Nat. Geographic, January 1965).

In mid-1964 the SED science organizations were merged with those of the Spacecraft Technology Division to form the Advanced Spacecraft Technology Division, and the Lunar Surface Technology Branch was divided into three sections: Geophysics, Geology, and Geodesy (See Appendix F), with the Geology Section handling the science training. The science facilities remained at Ellington for a few years as other organizations gradually moved several miles to the south into the new Center at Clear Lake City. The shipping and receiving area at MSC was ready by mid-1963. Most other groups moved to the new MSC facility over the next two and a half years. The science activities, however, were split for several months as the Radiation Branch and the Geophysics and Geodesy Sections of the Lunar Surface Technology Branch moved to Building 16 at the new MSC site in 1965 while the Meteoroid Branch and the Geology Section of the Lunar Surface Technology Branch remained at Ellington.

Finally, in mid-1966 the Geology Section, with its training group along with all of the other science branches, moved into Building 31 at the new MSC site; Building 31 is still the center of physical science activities (in 2015). The new location contained a classroom facility (see Figure 2) and teaching laboratory as well as many new laboratories for research. The classroom for training was a fairly large area on the second floor. The room was expandable with a curtain so one could roughly double the floor space when necessary. The science trainers were able to use that area much better than the area at Ellington.

Figure 2. Part of the laboratory-lecture facility that was set up in Building 31 at the Manned Spacecraft Center. From mid-1966 through early 1970 this is where most of the classroom and laboratory training in geology took place. (NASA photo S68-36327)

Uel Clanton spent much time and effort developing a very high-class set of rocks and minerals. He bought a reference set of rocks and minerals from Wards Scientific. It was their top-of-the-line display specimens for reference work. Typically, when he was on one of the astronaut trips, or a dry-run for a trip, he would pick up 30 to 40 pounds of whatever the better rock types were in the area and ship them back to MSC or bring them back as airline baggage. The technicians would crack them up into hand-sized specimens, number them, and toss them into the collection to augment the Wards collection. He "lugged in 500 to 600 pounds of specimens from the central mineral region in Llano, west Texas." He also bought or personally collected museum-quality specimens for display and for show-and-tell with the astronauts. He remembers mailing back from Hawaii probably the best vesicular basalt specimen that he had ever seen. The tops of the cupboards were covered with these large display/museum-quality specimens. Then "if a question came up during the classes about rock types from the localities that had been visited on field trips one could go to the reference collection and pull out a specimen of whatever weird and wonderful rock that you wanted to talk about" (Clanton interview, 1995).

In addition to classroom and field training the MSC and USGS scientists were involved with many other activities that were related to science training, including developing areas that could be used as simulated lunar surfaces for developing and testing the various hand tools, instruments, and procedures that were to be used on the lunar surface during the actual Apollo missions. The scientists were also involved in various simulations of low gravity, again for developing and testing the various hand tools, instruments, and procedures that were to be used on the lunar surface. The principal facilities for these purposes are described in the following paragraphs.

Throughout the course of astronaut training several facilities were developed to simulate lunar surface conditions. The first of these, in an old converted barracks at Ellington in 1963, was dubbed the "Moon Room." There were several reasons for the creation of this room. In the early days of the Apollo program people had not figured out how to keep the astronauts cool under the high temperatures that would be expected on the lunar surface during the lunar daylight (temperatures on the order of 250 degrees Fahrenheit). Therefore, the plan was to land on the Moon during the lunar night and work in earthshine (sunlight reflected from the Earth). The engineers had trouble understanding just how good, or how poor, the light would actually be. Consequently, this room was set up to be similar to the conditions that the astronauts would experience. The room size was about 20 feet by 40 feet. The floor was covered with a very vesicular, dark pumice out of the Mono Craters area in California. The walls were painted black and a light with variable intensity was placed up in one corner of the room so you could adjust it to whatever brightness you wanted. Suited astronauts or other test subjects were brought into the room to determine the minimum light conditions necessary to conduct surface tasks (Clanton interview, 1995).

The first Moon Room, however, had a major limitation. The ceiling height was too low for simulating situations where the lighting could truly duplicate lunar conditions especially if one wanted the light to come from a point nearly overhead. Bob Jones, the lighting expert, and Uel Clanton did some scouting around the Ellington Base

Figure 3. The "Moon Room" in one of the buildings at Ellington Air Force Base. Simulated lunar surface conditions and lighting were used to test the astronauts' abilities under lunar lighting conditions. This facility was used during 1963 and 1964 until the new facilities were available at the Manned Spacecraft Center in 1965. (NASA photo S64-23391)

which at that time was semi-abandoned. They found the old parachute rigging building. It was roughly a three-story building where the parachutes were rigged after they had been used. The beauty of it was that the lights could be placed much higher in the building and the variable intensity would allow much better duplication of the lunar lighting conditions. Since the building wasn't being used NASA was able to use it. It was painted black inside, the rocks were hauled in from the old Moon Room, and a new Moon Room was created (Figure 3). According to Clanton it was quite impressive and there was a nearly continuous parade of people going through the building to see what the lunar surface was like and to study the problems of visibility. That particular location was photographed with one of the astronauts in a spacesuit using one of the early lunar hand tools and the photo was used as the cover on Houston phone books in 1964.

Once the move to the new Center commenced other training facilities were developed. The "rock pile" was initially installed in 1964-65 as a place to run suited subjects and/or astronauts over a 100-meter-diameter simulated lunar surface (Manned Lunar Exploration Symposium, MSC, June 15-16, 1964, p. 61). This was to try out boots, gloves, hand tools, and other scientific gear and to practice setting up various instruments on the lunar surface. It had two large craters and several smaller ones and a concrete ridge that represented mountains on a fairly rough surface of volcanic rocks and cinders (Figures 4 and 5). The rock pile underwent one reincarnation. It was intended that this area would be periodically updated as new information about the Moon became available. "We will keep improving this piece of the Moon as long as new information comes in," said Ted Foss, a geologist who was involved in astronaut training (Nat. Geographic, January 1965). The design of the first rock pile was based on lunar photos from Earth-based telescopes. As more information about the lunar surface did become available from Ranger, Surveyor, and Lunar Orbiters, it became clear that the surface of the rock pile was not as “lunar” as it should be for the best available simulations. A memo from Deke Slayton, Director of Flight Crew Operations (FCO) at MSC, dated Dec. 27, 1966, requested that the latest photos from the Surveyor and Lunar Orbiter flights be used to produce a new surface for simulations and crew training. In early 1967 Mike McEwen, one of the geologists involved with the science training of the astronauts, was given the responsibility of planning a revised rock pile that was more in keeping with what was known from the recent unmanned spacecraft visits to the Moon. The goal was to create a landscape that would be an actual scale model of a small area of the lunar surface. It was to be typical of what might be expected for an average Apollo landing site. McEwen performed a crater-size-distribution analysis based on the recent lunar photographs. The new rock pile was to have 188 craters ranging in size from 3 feet to 60 feet in diameter. He searched for material that was similar to what was believed to be a very dust-like lunar surface. He located some blast furnace slag that was about as close a simulant

Figure 4. The "Rock Pile" at the Manned Spacecraft Center as it appeared in 1965 with a mock-up of the lunar module. (NASA photo S65-24603)

as could be found in a bulk material that was available in amounts of more than the 2000 cubic yards needed for the simulation area. The area covered 2 acres, with a diameter of 328 feet. The old rock pile was leveled, the ridge removed, and a new moonscape was constructed in late 1967 and early 1968. Solar lighting was simulated at the rock pile by waiting until nightfall and shining large arc lights over the landscape (McEwen interview, 1995).

There was also a full-size mock-up of the LM on the rock pile allowing astronauts to practice exiting and entering the module and performing other tasks under lunar lighting conditions (Figure 6). According to Clanton "a lot of people spent a lot of time out there working in a spacesuit, doing simple tasks in the spacesuits, with people watching the blood, sweat, and tears involved. I share a bit of personal experience on the rock pile. This was in the days before the water cooled underwear was developed when you worked in a spacesuit which I did there and at other places. After about 30 minutes or so you usually had to pop the gloves and helmet off the subject and give him a chance to breathe and cool off. We did have air hoses flowing into the suits. There was some attempt to flow enough air through the suits to keep you cool and perhaps it did. But just about everyone I knew who worked in one of those spacesuits after 30-45 minutes could take off the gloves and pour a spoon or two of water out of the gloves. You were sweating that much. That was one of the more popular training areas. We worked it, the astronauts, the people involved in manufacturing and testing the spacesuits, all worked the rock pile. It was not like the Moon, but it was about as good a simulation as you could get for the Houston area." John Young recalls trying out an earlier model of the pressure suit on the rock pile: "Yeah, we used to work out there. I remember that. We ran around the rock pile picking up rocks and stuff like that. I think we were just testing out equipment, more or less; or doing some experiments as I remember. I was assigned to the pressure suit. We couldn't bend over in it. So I couldn't sit down in the Rover. So we had to go up and tell Dr. Gilruth why we had to spend all this money to build a pressure suit where you could bend over and sit in the Rover and do all of that stuff. A pretty tough sell" (Young interview, 1995).

There were other areas developed at MSC for simulations. Building 9 had at least two rooms, one of which was a sort of mini-Moon room. In Clanton's words:

> *"It was set up primarily as a place to test the lunar drill (Figure 7) which I worked on for quite a few years with Martin Marietta and Black and Decker. The crew systems people wanted to be able to simulate drilling, so we ended up building a big box of pumice and ground-up Knippa basalt, Knippa being a small city 60 miles or so west of San Antonio. The box was mapped in three dimensions so we knew that if you drilled x inches in from this side of the box we knew what you would drill through. The drill was designed to pull a 10-foot core. It was desirable to know that at this depth, there was a 2-foot boulder of dense basalt or over here there was a 2- or 3-foot boulder of vesicular basalt, etc. Then in another bay of that building we had a Rover track. As I recall, eventually there was a little bit of slag, primarily the tin slag out of the Galveston area. It was more like a light colored vesicular basalt. The color was not perhaps the best, but it was blocky and it was cheaper than anything else we could find."*


Figure 5. The "Rock Pile" being used in a test of a suited subject practicing ascent and descent from the lunar module. (NASA photo S65-22083)

This area was used for simulating the use of lunar hand tools, drill, instrument set-ups, and the Lunar Rover (Figures 8 and 9). There was also a large vacuum chamber that was used for some of the tests. It was set up mainly to test equipment in a location where it was possible to duplicate lunar lighting intensity and temperature under the proper vacuum conditions.

There was an extensive flat area of sand next to the astronaut training building at KSC. This area, known affectionately as the "sandpile," was used for trying out hand tools and other scientific gear and to practice setting up various instruments on the lunar surface (Figures 10 and 11). Throughout the first few years the sandpile was not very useful for practicing rock-sampling procedures. But during the Apollo missions it became apparent that simulations run at KSC were not realistic enough without some rocks to sample. Gordie Swann of the USGS, who was the PI for the Apollo Geology Experiment, was asked in early 1971 to bring in some rocks that would allow more realistic simulations. Swann remembers the situation quite well. He and Jack Sevier of the Apollo Space Program Office were together on an airplane trip and in the course of their conversation Sevier said "We've got some money and we need some rocks. Can you get some?" Swann replied, “Yeah, we sure can.” Near the USGS facilities in Flagstaff, where Swann was stationed, the Santa Fe railroad has a big cinder quarry used for ballast for their tracks. He arranged to ship two gondola car loads of this material, which included volcanic bombs as well as cinders, from Flagstaff to KSC. The Santa Fe railroad had another quarry in the San Gabriel anorthosites in California. A carload of anorthosite was shipped from there to KSC. And Swann had Bill Muehlberger of the University of Texas arrange for a 16-ton dump truck out of the Llano uplift in Texas to take some of the granites and other similar rocks from there to KSC. Three or four of the USGS geologists from Flagstaff then went down to KSC and scattered the rocks around the sandpile (Swann interview, 1995). John Young, in his usual sardonic style of humor, commented "They put all those exotic rocks down there at the Cape. I figure that a million years from now somebody will be trying to figure out what all those fancy rocks are doing in this sand" (Young interview, 1995).


Figure 6. The "Rock Pile" being used in training at night with lighting that simulates lunar surface conditions. (NASA photo S67-35312)

Three facilities were used to simulate low gravity while developing and testing the various hand tools, instruments, and procedures that were to be used on the lunar surface: (1) aircraft that could fly parabolas to produce various levels of reduced gravity for tens of seconds and contained large open volumes in which testing could be accomplished, (2) large pools of water in which the test subjects could be suited and weighted in such a manner that neutral buoyancy could be obtained, and (3) a harness arrangement that would support various proportions of a person's weight, allowing the person to simulate action at various g-levels.

Flying parabolas to simulate low gravity commenced with the first group of astronauts during 1959 in C-131s at Wright-Patterson AFB in Ohio. These early low-g experiences were primarily to familiarize the astronauts with the conditions of space flight (NASA SP-4201 p. 241). Later in KC-135s, also known as the K-bird or the “vomit comet,” flown out of MSC, instruments and procedures were tested at simulated lunar gravity (Figures 12 and 13). Several geologists from MSC and the USGS were involved in these efforts. Uel Clanton probably did more of this than any of the other scientists. He estimates that he flew 400 parabolas on the KC 135 between 0 g and 1/6 g while testing various tools and equipment in spacesuits. Clanton provided a bit of information about the history of these tests. Because the first spacesuits were incredibly crude, it was initially felt that "we would never get the mobility necessary to do the effective geological work nor could we keep the astronauts cool enough in the sunny conditions that would be on the lunar surface in order for him [sic] to work. Because of this much of the early work toward landing sites, geologic tools, spacecraft consideration, and so on were for a night landing in the dark of the Moon" (Clanton, 1975 notes). However, a major breakthrough in the design of suits allowed more mobility and a built-in cooling system; this allowed the astronauts to land under daylight conditions and work under sunlight conditions. Nevertheless, the development of the hand tools met many major stumbling blocks and took much more time than was necessary according to Clanton because of "the lack of people both in-house and out-of-house who could fully appreciate the problem of spacesuit mobility and mobility in 1/6 gravity" (Clanton, 1975 notes). His opinion is based not only on the flights in the KC-135 but also on the fact that he was a suit subject for many of the tests in other training facilities and monitored a contract with Martin Marietta for the development of the geologic hand tools and the lunar drill.

To illustrate the difficulties encountered in lunar gravity tests, Clanton relates the following story:

> *"The short scoop, as designed, was too short to use. The astronaut, under 1/6 g, could not get on his knees and dig the trench as proposed and hammer on the back of the small scoop as originally designed. (A suited subject could kneel but as the body approached vertical above the knees the spring-rate of the deformed pressure suit took over and returned the suit to the vertical, or standing, configuration thereby shooting the subject forward and face down in the dirt.) This information was presented in an early meeting between NASA and the PI for the field geology experiment, and this information was rejected. At that time I was both a suit subject and flight qualified, so Jack Slight (another suit subject who was flight qualified) and I put together a flight, flew on the KC 135 and demonstrated and documented with movies and stills the inability of a suited subject to go into the kneeling position while pressurized. This information was brought back and presented at the next meeting. At that time we were pushing for either a redefinition or a longer handle on the scoop. The field geology PI was still reluctant to accept the suggestions. As I recall, we made another flight, tried it again, and it still didn't work. Somewhere along the line there Jack Slight and I decided, 'Well, perhaps the only way to solve the problem was to get a couple of the Flagstaff (field geology) people flight qualified so that they too could do the testing.' As I recall, Tim Hait and Gordon Swann, it may have been someone else (in fact it was George Ulrich), got flight qualified and we flew them on the KC 135 using the collection of tools that had been proposed for the field geology experiment. Lo and behold, once again, nothing worked. Jack Slight and I came to the next meeting (Sept. 1966) all eager and thinking that we had solved the problem and could go on to other points. I recall meeting Shoemaker (the PI) at the front door, saying 'Gee, now we can go to a long-handle scoop, one that is long enough so that the astronaut does not have to kneel to use it'. At this time I was somewhat amazed to find out that the size and shape of all of the equipment again was like originally requested and that now, rather than using the small scoop in the kneeling position, that scoop was being used in a standing position to sample crater walls as you stood on the bottom."*

Figure 7. Uel Clanton conducting a suited test of an early version of the lunar drill in one of the Building 9 test facilities at the Manned Spacecraft Center. (NASA photo S66-20212)

Clanton goes on to emphasize that this situation was not unique to the field geology team. The same problem existed in some other areas. The basic problem, in his opinion, was that "the PI was unwilling to accept any other input on his experiment project. The people that were working with the suits and the procedures understood one part of the problem and the PI understood another part of the problem. I would suggest that both parties be a bit more tractable and appreciate the other point of view." The problem at this point was that MSC management had told the people managing the tool development and procedures to give the PIs what they wanted, but Slight and Clanton had data to show that the PI's demands would not work under lunar conditions. Shortly after this Clanton resigned from the Hand Tool Working Group and suggested that Slight and the tool designers get clearance to build the tools to satisfy the test results. Eventually when some of the astronauts began to participate in these tests the equipment was modified to suit their requirements which were more in line with what Slight and Clanton had suggested.

The swimming pool at Langley was used in 1959 and 1960 to provide the sensation of neutral buoyancy to the fully suited astronauts. At MSC a large water tank was constructed for training with various instruments and procedures under conditions that used the neutral buoyancy that could be achieved by balancing the weight of the astronaut and his suit against the air in the suit. It was possible to adjust the balance to achieve lunar gravity conditions. The water immersion simulations, however, did not produce as realistic a simulation for practicing under lunar gravity as the parabolas flown on the K-bird. In a memo comparing the simulations under both conditions astronaut Mattingly describes the drag effects in the water, even at a slow walking pace, as "more like swimming in SCUBA than walking in the KC-135 during 1/6-g parabolas." He also indicates that getting up from a face-down prone position could not be accomplished with the pushup technique that was possible in the KC-135. Furthermore, the ballast that was used to achieve proper buoyancy "resulted in an uncontrolled center of gravity and moments of inertia." Observers commented that on several occasions he appeared to use swimming motions as he became engrossed in a task and would unconsciously resort to whatever was necessary to complete the task (memo: Mattingly to chief of EVA Section, Nov. 6, 1967). In contrast, however, the time for simulations in the water could be hours rather than the few tens of seconds provided during the parabolas. The scientists involved in the testing of tools, instruments, and procedures worked primarily with the suited simulations in the K-bird for their evaluations.

Figure 8. Test subject in the Building 9 test facilities at the Manned Spacecraft Center simulating the unpacking and setting up of some of the lunar surface instruments. (NASA photo S69-18998)

The harness arrangement, or partial gravity (POGO) simulator, consisted of a platform with a gimbaled harness that could be adjusted to support any desired proportion of the test subject's weight (Figure 14). In a memo Mattingly compares this facility with the immersion tank and the K-bird. He found that the gimbal attachment forces an unnatural body posture, the inertia of the weight-supporting mass caused added problems in controlling motions, and the harness provided too much stability, thereby making it difficult to fall. Mattingly concluded that the POGO simulator provided a better lunar gravity simulation than the immersion facility but not as good as the K-bird (memo for record: Mattingly, May 20, 1968).

Geologists from MSC as well as Flagstaff were involved in many of the simulations with the hand tools that resulted from the USGS field tests described in the next subtopic. The simulations were run under various conditions: some in pressure suits at 1 g, some in shirtsleeves at 1/6 g, and still others in suits at 1/6 g. The various facilities of the previous paragraphs were used for the simulations. As a sample of the studies done on the individual tools that were to be used both in the Apollo missions and in the training a quick look at the results of an evaluation report, done at the request of a Preliminary Design Review Committee, is instructive. In December 1966 a rather thorough evaluation of the lunar hand tools was accomplished on the KC-135 under lunar gravity conditions with the test subjects wearing Apollo pressurized spacesuits. A box containing sand, slag, and rocks was used for sampling procedures. The report indicates that the gnomon and the staff would require little additional modifications but other tools required significant changes, and some failed badly. Use of the hammer for chipping samples was possible only in the prone position. This was awkward, time-consuming, and somewhat dangerous. The scoop did not work at all. It was impossible to keep a sample of soil in the scoop while in either a standing or kneeling position. The material would not stay in the scoop during the upward motion. It was suggested that a new design might be considered. It was already known that the sample bags did not work well and were in the process of being redesigned and the tests further verified this. The tool carrier was already in the process of being redesigned and tests of some new methods of attaching the tools were evaluated. The methods that were tried were not very satisfactory and "a more positive means of securing items will probably be required." An aseptic sampling tool could not be assembled with the components that were part of the design at that time. Several suggestions were made for redesign (Evaluation of Second Generation Hand Tools under 1/6 gravity, Dec. 27, 1966). It was not uncommon for several dozen specific problems and suggestions to result from these simulations.

Figure 9. Apollo 11 crew simulates use of lunar hand tools and camera during a training exercise in the Building 9 test facilities at the Manned Spacecraft Center. (NASA photo S69-32233)

6. Flagstaff simulations, time-motion studies, tools, etc.

About 1000 miles to the west of Houston, the USGS developed another set of facilities in the vicinity of Flagstaff, Arizona to develop and evaluate the various tools, procedures, and communications arrangements that could best serve the purposes of lunar exploration. This work was carried out under NASA contracts by the Branch of Astrogeology of the USGS with offices in Flagstaff, Arizona. Gene Shoemaker, after returning from NASA Headquarters in Washington, D.C., was in charge of this Branch and its activities. A detailed account of this work is provided in a USGS Open-File Report by Gerald Schaber (Schaber, 2005). Among the important equipment to be used by the astronauts on the lunar surface were the various hand tools that were common for geologic exploration. The USGS was heavily involved in the development of hand tools to be used on the lunar surface. The earliest documented attempt by the USGS to identify the basic tools required for geologic exploration of the Moon was a proposal from the USGS to NASA in March 1965 by several geologists, headed by Shoemaker. The document was entitled “Objectives of Apollo Geological Field Investigations and Proposal for Development of an Apollo Field Exploration System.”

Earlier discussions among geologists and other specialists from the USGS, NASA, and various contractors about the probable requirements for tools and sample containers preceded this proposal, and some ideas had been generated on the astronaut group field trips during the two and one half years before that time. At MSC, Clanton had a contract in place with Martin Marietta beginning in late 1963 or early 1964 for the development of lunar hand tools. Shortly after that he wrote a proposal for a lunar drill, also contracted to Martin Marietta. About a year later the two contracts were combined into a single contract. This latter contract resulted in a powered drill, hand tools, and a tool carrier. A spacesuit (pressure suit) was loaned to Martin Marietta to allow for design considerations to account for the restricted mobility in the suit. A significant problem at the time was the ballooning of the glove away from the hand thereby diminishing the feel of the tools through the palm of the glove. As an example of the problem Clanton mentions that after two or three strikes with a geology pick one might have to reorient the hammer in the glove to get a clean strike of the hammer. To overcome this problem Clanton had a rock hammer outfitted with strain gauges to compare the strike energy that could be delivered both in shirtsleeves and in a suit. These tests were repeated in both 1 g and 1/6 g (KC-135) environments.

A few months after the USGS proposal was submitted the requirements for hand tools were formally stated in a report by the Geology Working Group at the NASA 1965 Summer Conference on Lunar Exploration and Science. The types of equipment considered essential at that time for samp1e selection, documentation, and collection were: scoop, extension handle, core tubes, hammer, scriber/brush, hand lens, sample bags, tool and sample carrier, TV camera, stereometric and surveying camera, and a staff. About half of the geological instruments, tools, and sample containers that eventually flew on Apollo 11 were proposed in some form in the 1965 requirements. Items that were first proposed for the early missions but were not carried were a scriber-brush and hand lens for examining and selecting rocks on the lunar surface, a tool carrier that came into use on Apollo 12 and later missions, film cameras with stereometric and surveying capabilities on an instrumented staff, and a surveillance TV camera and periscope on the LM (Ulrich and Swann, 1974).

In addition, using several areas in the vicinity of Flagstaff, the USGS had already begun a study in July 1964 under the title Manned Lunar Explorations Investigations; it included five separate projects: (1) Lunar Field Geological Methods, headed by Jack Schmitt; (2) Lunar Field Geophysical Methods, headed by Joel Watkins; (3) Lunar Field Surveying Methods, headed by Yukio Yamamoto; (4) Electronics Investigations for Field Systems, headed by Ray Barnett; and (5) Documentation for Lunar Field Systems, headed by Hal Stephens. Let's listen to Shoemaker explain what he had in mind for all of these efforts.

> *"One of our mainline efforts here was to try to work out the most efficient and effective way that you could do human exploration. My notion, and this was the thing in the back of my mind all the way along, was to try to figure out a way to maximize the amount of science return, not just for the samples brought back, but to really try to get a maximum return on what the astronauts themselves could do on the Moon. And I wasn't thinking of ALSEP. I was thinking about what can the astronauts do as human observers. The basic notion in my mind was, and I put myself in the position of what would I want if I were the guy on the Moon, you want to off-load all of the "mickey mouse" stuff. Ideally, you'd like to track the astronaut with a little laser system mounted on the LM. So, you'd know every point accurately on the traverse. You'd like to have it set up so you'd have a very thorough visual record. So, you'd have video of the whole thing. But you'd also have control of it and you'd automatically record where the camera was pointing, not just the video but also the still photography. You'd know exactly where you are looking, and you'd know the orientation of the camera. And you'd also know where it is all the time. And you'd like to have a team of people keeping track of you and compiling all the time as you go. So, you'd have an up-to-date picture of what you've seen and you have a context, as nearly as possible, right up to the minute, as you go along. Unload from the astronaut every damn chore that you can so that he, the human observer, can do what he can do best, which is to use his eyes and his wits to see things because my notion was that you have a limited number of opportunities to show that you can really make discoveries with a human observer. So the idea was to try to get out of Apollo a test of the concept that it really made a difference to scientific discoveries by having a human being there. That's what we tried to figure out in practice here. And that*

Figure 10. Alan Shepard trains for the Apollo 14 mission on the “Sand Pile” at the Kennedy Space Center. He is adjusting a camera on the equipment transporter, which carried all the tools and film magazines that were needed on an EVA. (NASA photo S70-46191)

> *to me was what it was all about. Gradually I came to realize that that was not going to happen. If we'd had a few more missions it might have happened; but we never quite got there."*
>
> *"The ground rules at the start were that you couldn't hang anything on the astronaut. Later it turned out that they did, but that was the ground rule that we were working with at first. We said okay, we'll give the astronaut a staff that he'll walk around with and it would have everything that will do these things. It would have a transponder on it, corner reflectors so that you could track him, devices for determining the orientation, and it would carry a video camera and a stereo camera. Every picture you took you'd have in stereo. The idea was to use it a lot. All you'd have to do is squeeze a trigger and just keep going. And of course we thought about the tools and things that would be needed to take samples etc. But the real heart of it was how to get the best value out of a traverse"* (Shoemaker interview, 1995).

The plan was to develop a control center, or backroom, for the science activities where all of the TV and other data from the field simulations could be sent by telemetry for the scientists to evaluate and analyze. Shoemaker visualized the "backroom doing all of this stuff and following the guy who was actually doing the traverse, building a map as he goes, doing all of those things to try to understand how to get the maximum out of a traverse."

Figure 11. Aerial view of the "Sand Pile" near the crew quarters at the Kennedy Space Center. This area was used for many training exercises while the crews were involved with their last month of training before missions. Note the craters to provide a more realistic simulation. (NASA photo 116-KSC-71PC-423)

Shoemaker brought Jack Schmitt and Gordie Swann on board to get these activities under way. They became almost totally immersed in this activity in 1964 and 1965. In Swann's words he was first involved with "the business of trying to work out techniques on the Moon, that kind of stuff, field tasks, and some astronaut training. Kind of a hodge-podge. I never did do a lunar map which was a mistake. I avoided it because I didn't want to do one. I didn't want to sit at that damn telescope until two in the morning and freeze my buns off."

Jack Schmitt recalls being hired at Flagstaff by Shoemaker:

> *"[I was given the option of] working on Surveyor or setting up a project that was ultimately called the Lunar Field Geological Methods project, which in a sense was indirectly related to training because Gordon Swann and I, particularly, were trying to figure out what kind of procedures should they actually be learning in order to take samples and photographs and things like that. We started with really some very basic stuff; in fact, I even had a group of University of Arizona freshman geology majors that Spence Titley brought in, he was consulting for the Survey at the time, and not knowing what we were doing, we were just getting our feet wet, we had these kids acting like astronauts in certain types of sampling procedures and we were sort of doing time and motion studies trying to figure out just how well would certain things work, that is sampling and other things like that. So really in that 64-65 time frame some of the crowd of people that later was [sic] deeply involved in the actual Apollo missions were trying to figure out what the hell was this thing called lunar exploration. All of that fed ultimately into a lot of the things that happened later on, but it was purely getting your feet wet at that time"* (Schmitt interview, 1995).

When Shoemaker was shown Schmitt's comments, he continued on with his concept of what they were trying to do.

> *"That was a small piece of it. I'd forgotten about the students. That was all building up to it. We were really trying to figure out how do you really want to do lunar exploration. Also, a fair amount of our effort here was not just Apollo. We were trying to look beyond Apollo. What would you follow Apollo with? So that led to the Lunar Field Geology 'Experiment.' The science program as it got set up and run (in NASA) was the concept that you have an experiment with some danged instrument. But*

> *somewhere there had to be some responsibility for what the hell the astronauts did in honest-to-God field geology. That's what I was trying to get at. So that's how it got submitted and it got accepted as a form of 'experiment.' And of course, a part of that was trying to understand the details of each (potential Apollo landing) site as best we could beforehand"* (Shoemaker interview, 1995).

To get a better idea of the detailed tasks that were being studied in one of the projects, one can study a memo to the personnel of the Lunar Field Geological Methods project on October 13, 1964 in which Schmitt asks for volunteers in eight different topics that were being developed in the project. These were: (1) methods of geological description, including transmission and recording of data; (2) making of geologic maps by two men on the lunar surface; (3) purposes and methods of geological sampling on the lunar surface, including the role of a mobile laboratory; (4) applications of imaging systems to descriptions and mapping; (5) usefulness and application of petrographic, mineralogic, and analytical methods on the lunar surface oriented primarily toward mobile laboratory operations; (6) bearing of lunar excursion module (LEM) and pressurized suit design on geological field operations; (7) bearing of mobile laboratory and instrumentation on geological field operations; and (8) pertinence of unmanned lunar investigations to manned geological operations on the lunar surface. Bob Sutton was one of the people involved in these activities and he recalls "testing of a lunar surveying staff on which a portable television camera and sun compass could be used by an astronaut to aid in location and geologic descriptions" (Sutton personal notes, 1975).

Schmitt and Swann spent nearly all of their non-sleeping hours on efforts for the Lunar Field Geological Methods project. According to Swann,

> *"About 16 hours a day. We were sharing an apartment at that time. We had become very close friends even before he applied to become an astronaut. Technically, until he went to be an astronaut (in July 1965), I guess he was kind of my boss, if there was such a thing. We worked pretty closely on all that stuff. But Jack and I kind of pooled our energies and got the efforts out of the time and motion category and into the business of testing procedures and stuff, which I think made sense. Then I got more involved in – well remember at that time, NASA was planning these long-term laboratories, roving laboratories, those kinds of things. At that time I was pretty heavily involved with that kind of stuff. I was pretty involved with some of that and all of that was coming out of NASA Headquarters, not MSC. And a little out of Huntsville, but mostly Headquarters. We wrote reports and did these field tests. We'd go out and try different things and write these green-backed reports on them. But as those things began to kind of go down the drain I began to get more and more heavily involved with the Apollo stuff"* (Swann interview, 1995).

The progress of these efforts can be traced through monthly and quarterly reports to both NASA and the USGS. MSC arranged for a mock-up of the LEM to be sent to Flagstaff in 1964 for use at Hopi Buttes, Arizona, which was being set up as one of the test areas for the development of scientific mission operations. In addition to the tasks of the Lunar Field Geological Methods project, the other projects' activities began. The Lunar Field Geophysical Methods project ran gravimeter, magnetometer, seismic, and scintillometer traverses with time and information studies to determine the effects of operator experience and the amount of time spent on various aspects of the surveys. The Lunar Field Surveying Methods project conducted field tests with mobile surveying systems, including a truck-mounted laser ranging system. The Electronics Investigations for Field Systems project conducted field tests for transmission of slow and standard scan TV by microwave relay systems. This eventually was to be used to transmit video from the field sites to a control center, the Command, Data Reception, and Analysis (CDRA) facility that was set up in Flagstaff at which geologists at consoles could follow the activities of field crews. The Documentation for Lunar Field Systems project designed stereo cameras for the staff that was to be carried by the test subjects in the field. Several test sites were set up in geologically and topographically varied terrains in Arizona and Utah. The tests were conducted with two men in the field in contact with a remote base in an effort to be of direct value to the astronaut training program as well as the lunar missions. It was hoped that these studies could be directly integrated into the field training activities of the astronauts. On a later trip to Flagstaff when Jack Schmitt was an astronaut he was "surprised to learn...that there were people out there spending their time working on dual launches where a Rover would be launched on one Saturn V mission. Then the crew would come in and they would be doing these 1000-km traverses across the Moon. They were spending quite a lot of effort on it. I don't know whether that was Shoemaker's doing or not. Prior to that time they had planned on having their own control room out there. And actually controlling the surface mission from Flagstaff. I don't know when that got shot down but it was something that went on for some time before it got stopped. They had the thing outfitted and everything else" (Schmitt interview, 1995).

At the beginning of 1965 NASA arranged for more contracts with the USGS group at Flagstaff to evaluate the concept of a modified LEM that could serve as a laboratory for two men to explore the lunar surface for periods of up to two weeks. There was also the possibility of having a roving vehicle available. Various types of analytical instruments were to be evaluated as part of the equipment on board the modified LEM. Joel O'Connor and Swann made an extended trip to several laboratories in the southern and eastern U.S. to evaluate various types of equipment for petrographic, X-ray diffraction, X-ray fluorescence, and other analyses that might be accomplished on the modified LEM. This laboratory, when conducting field tests, was to be in contact with the CDRA.

By June 1965 the CDRA was operating and some of the field tests were being monitored at the control center in Flagstaff. The use of this facility required some electronic ingenuity. Hopi Buttes and Meteor Crater were as much as 90 miles away and the microwave system was good for only about 60 miles. Johnny Nuttall found that they could bounce the signal from Hopi Buttes and Meteor Crater off an intermediate ground location to the top of a mountain near Flagstaff where the receivers were and pipe the video down to the CDRA in Flagstaff (Schaber interview, 1995). There was also a mobile control center, according to Gordie Swann.

Figure 12. Alan Shepard trains for the Apollo 14 mission under 1/6 g on the KC-135. This test allowed him to simulate pulling the equipment transporter under similar gravity conditions as exist on the lunar surface. (NASA photo S70-53480)

> *"It was an old army surplus. One of those blue things still sitting out here. We had two of them on semis. One was what we called the mobile CDRA, and it was primarily a work space with some light tables and that kind of stuff. Then the other was an electronics trailer, actually electronics and some analytical stuff, a thin section machine and the old Surveyor diffractometer. And we ran some mission kind of things that were more advanced than Apollo. We actually did analyses. We were also using that portable outfit with just a TV capability. We did quite a bit of running around the rocks with a man on the TV camera following the guy and plotting his traverse"* (Swann interview, 1995).

By fall 1965 tests of the mobile laboratory were part of what was called the Apollo Extension Systems Investigations. A 14-day field test at Hopi Buttes is described in a monthly report for October 1965. The geologists in the field were monitored with both TV and audio which were transmitted to the LEM and then relayed to the CDRA in Flagstaff where the locations of the field geologists and the associated field data were plotted and evaluated. Studies of the samples were carried out in the mobile laboratory by microscope, X-ray diffraction, and magnetic susceptibility measurements. Gordie Swann pointed out that they even accomplished statistical point counting on thin sections by these relayed TV procedures. Tests of this type continued for the next two and one half years, and reports of the results were published by the USGS as a series of Technical Letters and Interagency Reports which were submitted to NASA. In one such test on January 26-27, 1967 astronauts Lind and Schmitt participated in an exercise in this mobile laboratory that involved remote study of rock samples by petrography, diffractometry, and spectroscopy using telemetered data.

Gerry Schaber recalls the pre-Apollo training in Flagstaff with pride and points out how useful it was as a predecessor for the actual mission training that commenced in 1968:

> *"When I first came here in 65 through 68, we had all of these simulations out at Hopi Buttes and all of those sites before the astronauts even got started. We had our own geologists in spacesuits. The ones I was in charge of were more oriented toward the field work because I was originally hired by Gordon to do later Apollo missions with analytical equipment. We made thin sections. We had a little spectrometer, a Californium spectrometer thing, we analyzed rocks out in the field in a little LM simulator. That was what many of those tests were all about. They were for later Apollo missions. I think that's an important part of the astronaut training, preparing for it. It was really good planning and training"* (Schaber interview, 1995).

Gordie Swann indicates that these tests were particularly designed "to try and figure out actual mission procedures. These did come back into astronaut training when we figured out which mission procedures would work. The photo documentation procedures, the rock documenting procedures, and all that, we practiced that quite a bit. And also Polaroid cameras. In fact, Jack Schmitt and I measured a section out at Hopi Buttes on Polaroid film and then measured it for real and we didn't do too badly. Except he kept dropping the Polaroid film in the sand with the jelly side down. You can tell him I said that. We just took some pictures of an exposure and then sat down and measured the section, and we did it by percentages. Then we measured the actual thickness of one layer and came back and converted the percentages into feet. Then we measured the whole section, it was about a 200-foot section, and we were within about 5% of correct thicknesses. And we even made pretty good guesses as to rock type. Well that's what we did on Hadley Rille (Apollo 15)." Even the control center, or CDRA, was used in the field tests in the same manner that the actual Apollo missions were run several years later. There was only one person in CDRA that the geologists in the field could talk to, as was the case with the CAPCOM during the Apollo missions. Schaber reflected on the success of the SSR activities in the Mission Control Building during the actual Apollo missions, referring to those early tests when he said, "That's why we got so good at it."

According to Swann, one of Gene Shoemaker's dreams in the early 1960s was to eventually have a separate Mission Control center in Flagstaff.

> *"Gene did envision actually running geologic missions from Flagstaff. But he was also envisioning year-long missions where he would have resident geologists here for long term. Actually Gene's concept, except for the turf problems, which maybe some day would have been overcome, would probably have worked. I mean, you could do the science part from here and the engineering part from Houston. And that would make some sense. At least the scientists would be living in a decent climate. There would be good support facilities, laboratories, photo facilities, photogrammetry capabilities, and all that kind of stuff in connection with them. Some of it was run that way, anyway. Huntsville interacting with the spacecraft, MSC running it, and the blockhouse at KSC controlling the launch, and all that kind of stuff. And those things worked but it would have been a long time to get through the turf wars that would have evolved out of all that."*

In 1965 some of the USGS personnel began training to use the spacesuits in their field tests. During June 1965 Swann and O'Connor spent time at MSC in an indoctrination program and arranged for the loan of some suits to use in the Flagstaff exercises. George Ulrich and Dave Schleicher also became involved in suited tests a bit later. Swann had a real interest in this activity.

> *"I ended up spending about 50 hours in a suit I guess; a couple flights on the 1/6 g aircraft and all that. I had a method in my madness. I think I really knew what I was doing in that suit. At that time I'd spent a lot more time in a pressure suit than most of the astronauts had. Not near as much time as Jack Slight, but I wanted to do two things. One was just to find out for myself what you can and cannot do in a suit. And, of course, most of this was in 1 g, so that changes things in a rather awkward suit. Some guys spent a lot of time in them. What we learned was pretty much that you can do about anything in a suit that you can without it. It just takes longer and it's harder work. But you can do it, usually. But something that might take five minutes in shirtsleeves might take 30 minutes or an hour in a suit. And might totally exhaust you, but still you could do it. And to do this, to get NASA-----, they became very cooperative on this because they were looking for guinea pigs. That was the, I'm trying to remember which directorate it was they had the suits in, Flight Operations, I guess. Or Flight Directorate. I don't think it was Engineering. It wasn't medical. It was either Flight Crew or Flight Operations, I think. Anyway, it doesn't matter, but that bunch became very cooperative because they wanted guinea pigs and we made a deal that we would go down there and do treadmill stuff and that kind of thing for them if they would send technicians and suits up here for us to go out and break*

rocks. It was a very happy relationship. It worked well. But the main thing that it did for me, more than learning what you can and can't do in a suit, was I became the scientist who was the expert in what you could do in a suit. And I could tell somebody like Lee Silver or Bill Muehlberger or Aaron Waters, the old time gravedigger, 'No you can't do that.' Or 'The hell you can't do it, I've done it.' And it turned out it was a worthwhile thing to do. It gave me more credibility in Zedekar's office (training office at MSC) and in his, whatever those monthly meetings were, and that kind of thing. So it was worthwhile doing. Although I surely didn't get any science out of it."

Figure 13. Astronaut Joe Engle testing the ability of the driver to move about adequately while driving the Lunar Rover under 1/6 g on the KC-135. (NASA photo S70-27154)

The suits were incorporated into the Flagstaff field tests starting in October 1965 and continued on until early 1968 when these tests ended and Apollo mission training got started. They used the old Gemini suits first, then switched to the Apollo suits, the hard type.

The suited field tests at Flagstaff were expensive and exhausting. They also involved a lot of technicians and advance planning. In a memo to some of the USGS folks who were to participate in the tests Swann warned them to handle the suits with great care because they were very expensive. A pair of gloves cost $1600 and three gloves had already been damaged by USGS personnel in tests. Also, eight 8 people and 2000 pounds of equipment had to be flown to Flagstaff from MSC for each test and everyone could expect to work 12 hours per day (memo Swann to Astrogeology Section Chiefs, October 28, 1965). Some of the tests could last for hours and were physically exhausting in the desert sun. Gerry Schaber remembers that "Schleicher, or somebody, passed out in a suit out in Hopi Buttes, it was so hot." During a 4-day suited test at Hopi Buttes the tasks included collection of soil and rock samples, penetrometer readings, photography, verbal descriptions of the geologic features, an active seismic survey and a magnetometer traverse. In the CDRA the scientists followed the traverse and produced geologic maps by means of TV imagery, verbal descriptions, and a staff-mounted camera. Detailed time and motion data were gathered on the subject's activities throughout the test.

Figure 14. Suited test of the deployment of a lunar television camera while using the partial gravity (POGO) system to simulate 1/6 g. Note the attachment at the top of the unit to support most of the subject's weight. (NASA photo S71-16442)

In order to make some of the field tests more realistic, craters were produced between July and October of 1967 by explosive blasts in the Cinder Lake area, 7½ miles northeast of Flagstaff. This was in a relatively flat area underlain by several layers of volcanic cinders. The craters were laid out to mimic, on a 1:1 scale, one of the proposed landing sites for the first Apollo landing mission in Mare Tranquillitatis. Forty-seven craters ranging from 5 to 43 feet in diameter were produced in a 500ft by 500ft area. In some of the tests in this crater field a mock-up of the LM was placed on the crater field and the test subjects, while scanning the crater field from the LM windows, were to locate themselves on orbiter photos of the lunar landing site. Test subjects who were accustomed to locating themselves on aerial photos generally did best on this part of the test (Interagency Report: Astrogeology 2, N. G. Bailey, Nov. 1967). A second crater field was produced in the Cinder Lake area during 1968. This one was 1700 ft by 1700 ft and had more craters than the original one, some up to 100 ft in diameter (Figure 15). This area continued to be used extensively throughout the Apollo program. Another crater field was produced during February 1970 at Black Mesa in the Verde Valley near Cottonwood about 60 miles southwest of Flagstaff. This was a 35-acre site in which 850 tons of TNT and 43 tons of ammonium nitrate were used to create 380 craters ranging in diameter from 6 to 82 feet (Astrogeology monthly report, Feb. 1970). This was first used for training in a simulation involving the Apollo 13 crew in March 1970.

By mid-1966 there were other developments being added to the tests. A June 15, 1966 letter from MSC to Shoemaker indicates that a more formal plan to integrate the various simulations and tests with hardware, procedures, suits, etc was being initiated with monthly meetings of an Apollo Lunar Surface Scientific Simulation Program Planning Committee (ALSSSP) to keep everyone informed of the progress. Also in this letter is a request that the USGS provide some subjects for the 1/6 g simulations, including flights on the KC-135 aircraft (letter R.S. Johnston to Shoemaker, June 15, 1966). Shoemaker replied with the names of Tim Hait, Gordie Swann, and George Ulrich as the lucky people who would ride the parabolas on the vomit comet (letter Shoemaker to R.S. Johnston, MSC, June 1966). Also at this time the design of hand tools was getting under way in earnest and several potential contractors were in attendance at the various simulations and field tests to determine exactly what was needed (memo: Mason to EC5 at MSC, June 8, 1966). In December 1966 a major, week-long set of suited tests at 1/6 g was accomplished involving ALSEP, lunar hand tools, lunar drill and other equipment that was to be used in future training programs (letter: R. Johnston, MSC, to Shoemaker, Nov. 10, 1966). At about this same time training with a roving vehicle had reached a stage where astronauts were participating in field tests. On November 7-10, 1966 Weitz, Engle, and Schmitt were the first astronauts to try the USGS “Trespasser,” a precursor to the Lunar Rover. They completed a geology traverse in which the vehicle navigated by means of a gyrocompass system developed at MSFC and communicated by means of a radio system with a simulated backroom (Bailey and Ulrich USGS TL, 1967).

By May 1967 things were really getting serious. The ALSSSP Committee was discussing tests for the integration of the EMU with field geology equipment and tasks. A first cut at procedures for lunar surface procedures was under way. A document for constraints on lunar hand tools was to be produced. Metabolic loads in suited tests on a treadmill were being conducted with George Ulrich of the USGS as a suited subject. A subcommittee was about to undertake the task of reorienting the science training to a new mode to deal with the individual Apollo crews (Minutes of May 19, 1967 meeting of ALSSSP Committee). At about this time Jack Schmitt put flight director Gene Kranz in contact with Gordie Swann and much of this preparatory work was incorporated into development of procedures. In November 1967 the experience with the CDRA in Flagstaff led to a plan for the design of a science control center for the Apollo missions. Suggestions for staff, equipment, and a floor plan were made in an internal Flagstaff memo from Schleicher to Hait on November 13, 1968. The science simulation facilities at both MSC and Flagstaff that had been in operation for nearly 4 years to develop procedures, hardware and training programs were now in the process of being reoriented to the specific training of Apollo crews which is the subject of SECTION III: MISSION-ORIENTED TRAINING.

7. Setting up the training by USGS and MSC

Dale Jackson arrived at MSC in July 1963 as the leader of the USGS group that was to develop the geological training for the astronauts as well as accomplish the other scientific duties discussed earlier in the MSC-USGS agreement that was detailed in the exchange of letters between Nolan and Gilruth. According to Wilhelms, Dale was surprised and upset to find that a group of NASA geoscientists was already in place in MSC's SED and commencing to do what Dale understood as USGS duties (Wilhelms, p. 77). Because of the unexpected turn of events in Jackson's expectations and the lack of any formal agreements regarding the respective roles of the USGS vis a vis MSC in the activities mentioned in Gilruth's letter to Nolan, it was not clear who was to do what. According to Clanton there had been some discussion among the MSC group about this before the arrival of USGS personnel but nothing in detail. "The local discussions centered around which area of activity that the Geological Survey would participate in. One of them was in the hardware development area; the other was within the scientific or geological training of the astronauts. The initial discussions were to ask the Survey to participate in both areas, and the NASA geologists would also participate in both areas. There was never any intent to completely separate

Figure 15. Apollo 15 crew riding a mock-up of the Lunar Rover in a field exercise at the Cinder Lake Crater field near Flagstaff, Arizona. (NASA photo S70-53283)

the two groups. Both groups were to participate in the astronaut training and in some of the hardware discussions equally" (Clanton 1975 notes). According to Wilhelms, Dale was to be the overall boss but would plan jointly with Foss (Wilhelms, p. 78). This arrangement, however, could not have come about immediately because Foss was not hired until three to four months after the arrival of Dale and the first contingent of USGS folks.

At the time Dale arrived the only other USGS person present was Dick Eggleton (July 1963). As time went on other USGS people joined the group (Wilhelms, p. 77-78): Al Chidester in August 1963; Don Wilhelms and Marty Kane in October 1963; and Gordon Swann and Dan Milton in March 1964. Eggleton left in the fall of 1963 to return to his USGS duties. On the NASA side both Elbert King and Ted Foss joined with Uel Clanton to develop the geological training program for the astronauts. It was these two groups that were responsible for developing the initial outline and detailed syllabus for the geological part of the training program (see Appendix B). Unfortunately, conflicts arose from the fact that two separate groups having different backgrounds and organizational associations were involved in this effort. Both personality and organizational clashes led to many difficulties; and, as will be seen below, much of the training was divided in such a way that the two groups were able to avoid working together in the classroom and laboratory activities. Fortunately, an agreement between Jackson and Schirra, who was in charge of the training for the first two groups of astronauts, allowed for the coursework to start when the third group of astronauts arrived in February 1964. This provided a cushion of several months in which the detailed training prospectus could be developed.

As a first priority it became necessary to discuss how the training was to be organized. There were many decisions to be made and details to be settled, dependent on these decisions. A syllabus had to be set up for the training to include topics, depth of detail in each topic, sequence of topics, instructors for the individual topics, laboratory requirements for each topic, number and length of lectures and labs for the various topics, nature and locations for various field exercises, nature of reference materials, texts, etc. Clanton recalls the process:

> *"I can recall some detailed discussions among some of the early people to arrive for the USGS and the other NASA geologists that were coming on board at that time about exactly what would be covered in the training course. ---- It was very apparent that the contact time we would have with the astronauts would be very limited; and a total course, as would be normally given in a university or college, would not be possible. From the geological sciences and geophysical sciences, the area that we would be responsible for, we would have to strip or glean from the total information available that which we thought was most applicable for their work or their training. At the same time, the decision was arrived at that the most effective method of instruction was by personal contact. The coursework would be as informal as we could make it and the personal contact as great as we could make it. ---- The decision was that the coursework would be split actually in three separate parts. U.S. Geological*

> *survey would handle the 'typical geology,' so-called, coursework, totally and with very limited input from the NASA side. On the other hand, the NASA geologists would handle the mineralogy/petrology part of the coursework, again separate for the most part from the work being done by the USGS. This was primarily because most of the geologists that NASA had at that time had a background in mineralogy/petrology and were somewhat lacking in the contacts we felt necessary to put together some of the better field trips that we had in mind. The arrangement was that the USGS group and the NASA group, primarily Al Chidester and Ted Foss would work together to put together the field trips. In this way it was felt that both NASA and the U.S. Geological survey were cooperating in the training program and that both organizations had equal responsibility in the formulation of the training and in the field trips. The group realized that contact time with the astronauts would be limited. Consequently, a considerable period of time by both groups was spent trying to determine what subject matter would be presented. Much of this was based on what we understood of the Moon at that time and what we thought we would gain from the Moon via the unmanned program"* (Clanton tapes from 1975).

One of the main problems that had to be considered was the extent of detail that would go into the lecture and laboratory training in geology. At the time that this training was being planned (late 1963 - early 1964) there was serious discussion of ten Apollo landing missions and several follow-on programs, including manned mobile laboratories on the lunar surface for several weeks at a time. Such missions were expected to continue throughout most of the 1970s. In particular, at this time, the Apollo Applications Program was being developed in which numerous laboratory and field capabilities were being considered for further manned exploration of the Moon after Apollo. These studies led to rather optimistic lunar exploration plans. As the training progressed over the next 2 years it seemed even more appropriate that the planned coursework include some very detailed science classes in lecture, laboratory, and field studies. In fact, by mid-1965 George Mueller was talking about current plans for extending the Apollo capabilities to include 28 days in lunar polar orbits and lunar surface missions of two men for up to 14 days (speech to International Astronautical Congress, Sept. 14, 1965). On March 21, 1966 Martin Molloy's planned Apollo schedule had charts showing 10 Apollo missions followed by at least 6 additional longer-term lunar missions to include landed, roving laboratories. With such possibilities it was tempting to design training courses that included much more detail than would be necessary for simply landing on the Moon and picking up a few samples as was done on Apollo 11.

Although no scientists had been selected as astronauts while the training was being developed it was fully expected that these more detailed later exploration missions would include scientists, but not necessarily with geologic backgrounds, to accomplish many of the science tasks. In fact, of the 18 astronauts chosen for their science and medical backgrounds during the Apollo program only two had geoscience backgrounds. Nevertheless, it was not expected that there would be scientists on the first several Apollo missions and any science capabilities for those missions would come from the training that was being planned. In an interview with Gordie Swann it was pointed out that some of the astronauts criticized so much of the detailed terminology being included in the rock and mineral part of the course. He was asked whether he agreed with them. He responded "I think so but that's a little in retrospect because we were looking at AEW missions and lunar laboratories and those kinds of things. I think if we had known back in the mid-60s that there wasn't going to be anything beyond six Apollos, I think we would have cut a lot more out of the hypidiomorphic granular terminologies. One thing I'm glad we didn't do was teach them about fossils. And I think there were those who would have wanted to, which would have been a real waste of time. We did emphasize volcanics a bit over crystalline and sedimentary rocks. And I think that turned out to be okay except I think the sedimentary thing would have been useful too because in some sense those (lunar materials) are sedimentary rocks." John Young feels that the extensive detail in some of the training wasn't too much out of line because no one knew at that time exactly where all of the exploration was headed. He felt that it's always better to know a lot more than you need to know rather than to get there and discover you haven't learned as much as you should have (Young interview, 1995).

When the initial teaching of hand specimen mineralogy and petrology to astronauts was being discussed the instructors were in a real quandary regarding the types of rocks and minerals to study for lunar exploration. Specifically, at that time, there were a couple of driving parameters for the Moon. One was the albedo of the Moon, around 7%. From the albedo measurement it was clear that whatever was picked up on the Moon was going to be very dark. Most likely it was going to be a gabbro or basalt, or the equivalent. The other known parameter was the bulk density of the Moon, and that was 3.4 to 3.5. Thus, the percentage of dark minerals couldn't be too high or they would exceed the bulk density. This presented the planners with a problem. If the minerals that they showed the astronauts were what they really thought the most representative specimens for the Moon would be, the rocks and minerals would be all so dark that one really couldn't demonstrate much of a range in physical properties. Consequently, in the mineral and rock selections the astronauts were shown many samples that would probably be found in a freshman geology course but not necessarily on the Moon. As Clanton explained,

> *"These were specimens that classically displayed some of the properties that you would like for the people to appreciate and understand. Like calcite for cleavage, galena for cleavage and metallic luster, quartz for hardness and conchoidal fracture, and so on. Some of the better rock specimens are the coarser grained ones like granites or quartz monzonite porphyries which have large crystals of both K-feldspar and plagioclase. So these were used in the early part of the instruction, not because we thought those were what they were going to see on the Moon but because this was a descriptive, a display, a learning specimen. And once you begin to be able to see the difference between the albite and the carlsbad twinning and so on, then when you begin to look at the darker and less visible differences in the feldspar you would be a little better equipped to look for and recognize some of these features. Fairly early in the game there were some extended discussions about what level of detail to give these people. We took essentially the sophomore course that I helped teach when I was at the University of Texas. We took that lab manual and kind of tailored it more specifically to the astronauts, to the level of knowledge that we thought they should have, and toward what we thought they might see on the Moon. Essentially what I did was take that book and edit it down. A lot of the terminologies were deleted. It was made more general, but the people didn't have to learn all the terminology. For instance, there were references, since we knew that they would be hearing them, to the mineral names for the different pyroxenes and amphiboles etc. But for the most part in class when we were talking to the people and we were using rock/mineral names we tried to use the more general terms, i.e. pyroxene or amphibole, rather than trying to differentiate which ones among the pyroxenes or amphiboles. Early on there was some attempt at usage of the names for different plagioclase minerals and indeed those names were used, albite, labradorite, bytownite, etc, but once used and exposed and showing the people that we could differentiate in hand specimens between the minerals, we moved very quickly into the usage of K-feldspar to represent the potassium feldspars and plagioclase to represent the Na-Ca feldspars. There didn't seem to be an awful lot of reason to differentiate between them."*

On the more geologically oriented part of the training there was no question that field observations were to be a major part of the experience, but some basic knowledge of geological principles, processes, structures, descriptive terms, rock types and a few other things were felt to be necessary before the field experiences could be meaningful. Furthermore, a continuing mutual development of the details and concepts of geology along with the field observations was considered as necessary. In retrospect, some people would prefer to have had more of the geologic principles and processes taught in the field rather than the classroom. Gene Shoemaker feels "You didn't need to go through the usual Geo 1, Geo 2 kinds of things. You can learn what you really need to learn in the field. And it's great to be able to go and see all these fantastic localities which Chidester and those guys organized. There was some value to that but I'd have rather seen the time spent with the guys going out individually and tackling a piece of geology and learning how to do it, learning how it should be done. That was really the issue." Gene felt that many of the astronauts had the ability to become good field geologists and he would like to have "created the situation where you could get the astronauts that had the aptitude and get them out so they could really learn to do field geology. Because that's really the guts of it if you're really going to learn how to see things. You learn to do that by practice. A bunch of those astronauts, given the opportunity, they were plenty bright enough and they had the right instincts and the right mental framework. You could make damn good geologists out of them. But they've got to have the opportunity—the time to go and really learn how to solve a problem in the field and figure things out." But he realized that this was impossible because of the time limitations on the astronauts. "My ideal was impossible under the circumstances, which was to peel these guys off for a month at a time and let them go do geology. Really learn how to do it. But it was a very hard thing to do given the constraints on the astronauts through the whole program." As Swann puts it "The fact is you can get an astronaut or a group of astronauts together for an hour in about an hour. To get them for an hour in the field took lots of hours of planning and travel and everything else. You had to carve out major blocks of time to get them out in the field for a day or two. So we had a lot more opportunity to get in an hour briefing than we did to get in a field trip. Therefore, much of the training was done in the classroom and a two to three-day field trip was scheduled every month." An even further complication was that crew members at the time of the initial coursework were in training for the Gemini flights making it difficult to gather all of the astronauts at one time and provide the same instruction for all astronauts, especially for the field training. Therefore, for each field trip it was necessary to run two trips (or even three in one instance) each with a different group of astronauts because it was difficult to get all of the astronauts together simultaneously for a three-day period.

The selection of field trip areas took up much time and discussion. According to Jackson both Slayton and Schirra preferred to schedule the trips as close to Houston as possible. But “location of suitable training areas on the Gulf coastal plain was too great a challenge for any geologist.” Jackson and others did spend two weeks scouring the Ouachitas, Wichitas, Llano uplift and Brazos Canyon as possible field areas but found them unsatisfactory and recommended that training areas further to the west would be more suitable (Jackson, 1975). The field trips were to be 2 -3 days in length and proceed from basic sites at first to more complicated areas later and eventually to some mapping exercises. The general approach was to start off by illustrating through simple observations of well-exposed rock units the major processes and principles of geology and not worrying too much about whether it was sedimentary or igneous, or whatever else. These first trips were to teach the major principles of stratigraphy, law of superposition, law of crosscutting relationships, some major kinds of structural types, etc. "The early training was to be orientated primarily toward observing only what you could see when you were on the outcrop. The relationships that were seen on the ground or in the outcrop would be similar in many respects to what would be reported from the Moon. Here is what you can see, this is what you would report from this outcrop or from this locality" (Clanton, 1995). On later trips the areas were chosen where the exposures of rocks involved more complex geology. These areas would allow the first attempts at geologic mapping. However, the selected areas must have enough exposures to provide an opportunity to make geologic interpretations that could be further tested when observations were undertaken in adjacent locations.

The procedure for conducting field trips consisted of a preliminary selection of a location by the USGS or MSC groups or both. Then Ted Foss and Al Chidester made contact with the local expert in each area and evaluated the locality as a training site in some detail, usually making a trip to the area with the local expert. If the area was deemed satisfactory the group of geologists who were to be involved in the training, including the local expert, went through a dry run of the field trip in a much more detailed fashion than was planned with the astronauts. This provided the benefit of the local expertise and discussions, sometimes heated, with the local experts and among the trainers. This gave the various instructors a chance to agree on a unified story to present to the astronauts during the field trip (Clanton tapes, 1975). Clanton has literally thousands of photos that were taken on some of the field trips with the astronauts and also from many of the field trips that were being scouted out but were not taken. He has many photos of the geology of places in California, Idaho, and other areas where they actually spent days looking over the outcrops and accessibility to plan traverses. In many cases there just was not good enough accessibility to get to the outcrops. Later some of the scouting for field trips was done by plane. Clanton and Dick Laidley, a pilot-geologist at MSC, flew over many potential field areas. Some they did not select for the training but others they did select. While Dick would fly the light plane on its wing Uel would be taking pictures out the window. They brought those photos back for development and enlargements to be used as aerial photos on which the astronauts during field trips would do their mapping and plotting of traverses etc. These also served as guides for some of the planned flyovers for the CMPs.

The first field trip that was discussed as a possibility was to the Arbuckle Mountains of Oklahoma. According to Clanton "Ted Foss and Al Chidester took off for about two weeks to drive through the area and set things up. They returned with somewhat mixed emotions. The rocks were great, the snow was deep, and the outcrops were really not all that well developed." This led to much discussion for several weeks during which there was a push for "Let's go to Oklahoma anyway." The discussions centered around whether there were better areas to show what they wanted to show. Two of the areas in question were The Big Bend area of west Texas and the Grand Canyon area of Arizona. Clanton recalls that "I was the one that pushed for the Grand Canyon. Eventually the idea of this location was accepted by the rest of the group, and the main argument was the super-exposure there plus the rock variety (Clanton tapes, 1975)." No field trip was ever made into Oklahoma to the Arbuckle Mountains.

The other area that had been under discussion at some length during the early stages was the west Texas area. This would become the second field trip and continue to emphasize stratigraphy but also would introduce some structural geology and volcanic rocks. The purpose of this field trip was to place more emphasis on cross sections and a bit of mapping on aerial photographs. Photographic documentation of both outcrops and sampling locations was also introduced. The third trip was planned in the Flagstaff, Arizona area to show relatively fresh volcanic features such as lava flows, maars, cinder cones, and spatter cones. It also provided the first opportunity to visit an impact crater, Meteor Crater, and compare the features of impact and volcanic craters. They also were to visit Kitt Peak

Observatory on this third trip and view images of the lunar surface. The fourth trip was to the Philmont Ranch in New Mexico to work with more complex geology that was more difficult to follow than on previous trips. It included mostly sedimentary rocks that had been intruded by some igneous rocks, some interesting structure, one non-fault, some landsliding, and some minor structural features in the Pierre shale. The planned exercises included orientation with geologic maps, measuring and describing stratigraphic sections, strike and dip measurements, recording of field notes, and an introduction to the use of geophysical instruments.

The outcome of all of the planning and discussion was a very ambitious and extended geology program which, in the first draft of December 1963, consisted of six 4-month programs named Series I through VI, to be concluded with Series VI, which was the specific crew training for Apollo missions (see Appendix B for a detailed outline of Training Series I and brief descriptions of the other Series). The primary concept behind the planning of Series I-VI was to develop the astronauts into competent observers for the geologic exploration of the Moon, one of the fundamental objectives of the Apollo Program. To accomplish this a gradual build-up of the concepts of geology was to take place over a several year training period and conclude with simulated lunar missions in terrestrial locations selected for their analogous lunar features. Series I was to introduce a basic understanding of the principles of geology including recognition of some of the more common rocks and minerals. This was accomplished in three simultaneous parts. One part was classroom lectures totaling about 30 hours on the basic principles of geology taught by USGS instructors. A second part was primarily laboratory study of rocks and minerals totaling about 30 hours taught by MSC instructors. The third part was a sequence of four field trips that integrated the lecture and laboratory materials, and was taught by both the USGS and MSC instructors. The field trips were working trips in which the astronauts eventually learned to combine exploration, note-taking, mapping, and sampling. The trips were keyed to lecture materials and followed a logical progression from areas of relative geologic simplicity to areas of greater complexity.

Training Series II was to place major emphasis on detailed studies of volcanic and impact-produced rocks and landforms. From available lunar photos taken through telescopes, the major hypotheses being argued for formation of the lunar surface involved both volcanism and impact processes. There were strong enthusiasts for both sides of the argument and, as expected in most arguments, some enthusiasts for a combination of both processes. Therefore, this series of the training was to combine lecture and laboratory studies of impact and volcanic rocks with field trips to classic areas of volcanic activity such as Hawaii, New Mexico, and Oregon as well as to areas displaying impact and explosion crater phenomena such as Meteor Crater and the NTS.

Training Series III was initially designed to develop an understanding of lunar geology and the applications of engineering geology and geophysics as an aid to solving some of the problems of lunar geology. It was expected that the results from the unmanned Ranger and Surveyor probes would be worked into the lunar geology part of the training program as the information was received. Also a working familiarity with some of the techniques and instruments for engineering geology and geophysics was planned. Training series IV and V were still somewhat less detailed at this time but would involve more detailed studies of sampling, documentation, and other field techniques particularly as they would apply to lunar exploration. Again, as the results from the unmanned Ranger and Surveyor probes were received they would be worked into the training. Training Series VI was to consist of briefings and field excursions for individual Apollo crews. The content of the briefings and locations of the field trips would be highly biased toward the geology and problems expected at the designated landing site for each crew. By mid-1964 the number of Training Series had decreased from six to five, as much of Series II and III were to be combined into a single series. By May 1965 the initial Series IV and V had been combined leaving a total of four Series in the overall geology program. Also by May 1965 the terminology had changed from Series to Phases (memo Foss to Dornbach, May 18, 1965). Phase I was identical to the original Series I. Phase II combined all of the old Series II with some of Series III still emphasizing volcanic and impact features. Phase III included all of the initial Series IV and V as well as the geophysical studies from initial Series III. Phase IV remained the same as initial Series VI, i.e., terrestrial simulations of Apollo missions. Thus, only the first three phases would be carried out as large group training efforts.

In addition to the content of the training classes and field trips there were many other books and materials that were required. Textbooks and reference materials were selected. Field equipment and camping gear were needed. Maps, photos, globes, slides and other visual aids were essential for classroom activities. A list of the supplies that were selected and ordered is included in Appendix C.

8. The training itself

The third round of science training took place from February 3, 1964 through June 15, 1964. The round was started in February to accommodate the newly arrived third group of astronauts which totaled 14 students. Studies for these astronauts included the same courses that were given to the other astronauts in earlier classes: astronomy, meteorology, upper atmosphere physics and some geology as well as engineering topics such as propulsion, guidance, navigation, and computers. Within this round of science training, however, was also Series I in Geology as the first part of the newly planned six-part series geology program that was now to be used for the first time. The detailed schedule, topics, and instructors for all of the science courses are given in Appendix A. The first and second groups of astronauts (16 total) had already taken most of the science courses one year earlier in the second round of science training and were not required to take the same courses over again. However, the earlier program had not included the extensive geologic training that was now included to accommodate the upcoming lunar exploration. According to Wilhelms, Dale Jackson spotted Wally Schirra, who was in charge of astronaut training, in the Ellington cafeteria one noon and discussed the subject of astronaut training in geology, especially the fact that the first two groups had taken essentially no geology training. Schirra indicated that all the astronauts "would gladly learn geology and the program could begin" (Wilhelms, p. 77). Therefore, the first two groups of astronauts were required to take the geologic part of the program as well as a new course on Gemini computers. In fact, Deke Slayton who was in charge of the astronaut office, required all astronauts, including himself, to attend all of the geology lectures and field trips unless excused for flight preparations or other unavoidable commitments. This meant that a total of 29 astronauts (John Glenn had left the program in January of 1964) could be expected for the geologic part of the training. At the first meeting of the 29 astronauts in the classroom the initial question was “Who has, at some time in their education, taken at least an introductory course in geology.” To the dismay of the instructors not a single hand was raised.

The training was presented and received in varied ways. One of the pitfalls of astronaut training was the difficulty of setting and maintaining training schedules. Clanton observed:

> *"For those who have not had the experience of astronaut training the schedules may require many modifications because the instructors must work around the astronaut's schedule. In many instances the time requirements for other scheduled activities required most classes be repeated at least twice." One of the somewhat frustrating facets of the instruction was that quite often they had set up schedules for specific classes in mineralogy, petrology, or physical geology several days, or in some instances, weeks, in advance. "Yet, not uncommonly, a few hours, or in some instances, a few minutes, occasionally a few days, before the class was to be given, we'd get a call, typically from Ray Zedekar, or one of his group, saying 'Because of such and such you have been rescheduled.' I might quickly point out that this rescheduling quite often slipped the date or the hour of your class to later in the day or the following day or the next week. But in many instances the slip was forward because someone who was scheduled could not show at a given time or a simulator was out of commission and you were asked to fill in very rapidly for 1, 2, or 3 hours. The word to the wise here is 'be prepared' and don't get your feelings hurt when the class or the field trip slips. The field trips also slipped and typically the field trips ran at least twice. I can recall some field trips that ran 5 times before we got everybody through."*

King (p. 27) pointed out that the quality of the geology, mineralogy, petrology and Moon lectures "was uneven: some were good, some were awful." When some of the astronaut students "complained about a few of the instructors the list of lecturers was revised accordingly." It was "made abundantly clear" that the astronauts "had many other training courses and things to do besides study geology." They "could not afford to waste their time with poorly prepared or badly presented material." Gordie Swann felt that some of the lectures were not only bad but misdirected. "In spite of it being one of the worst lectures I've ever heard, the talk on folds was just totally misdirected. I don't think anyone expected to see any folds on the Moon. I think maybe the entire subject could have been taken care of in the field. If there was an anticline out there you could say, 'there's an anticline. See it? You probably won't see one on the Moon but if you do that's what it is.' Let it go at that rather than a one or two hour lecture on the processes of folding." After the geology course was two-thirds complete a questionnaire was devised to determine the astronauts' reactions to the quality of the instructors and the course materials (see Appendix D). No results from this questionnaire could be located for this history.

The “Principles of Geology” portion started on February 3, 1964 with discussions of igneous activity, erosion, sedimentation, metamorphism, and impact processes with evaluations of the importance of each to both terrestrial

Figure 16. Astronauts on the first field trip to the Grand Canyon in March 1964. The various rock types are continuously displayed along the Kaibab trail and provide an excellent demonstration of geology for a first excursion into the field. (NASA photo S64-13727)

and lunar applications. The concept of geologic history was introduced with both terrestrial and lunar time scales. The processes used for both terrestrial and lunar geologic mapping were covered. Then there were detailed presentations of the processes that formed stratified rocks. Simultaneously, the study of rocks and minerals had started with the concept of classification and structure of minerals followed by the recognition and identification of the basic rock-forming minerals. This was followed by studies of the common rock types. After five general lectures on the geology topics by Jackson and Wilhelms and five lab sessions on rocks and minerals by Clanton, King, and Foss, the class was ready for their first field trip to the Grand Canyon where most of the concepts could be demonstrated. After an orientation to the Grand Canyon with geologic maps and aerial photos by Chidester in Houston the astronauts left in two groups for the field trips to the Grand Canyon, the first group on March 5-6, and the second on March 12-13, 1964 (Figure 16). On the first day, after an observation session from Yavapai Point led by E. D. McKee (USGS), everybody walked down the Kaibab trail in groups of two or three astronauts with a geologist, the groups being separated by 5-minute intervals. The geologist accompanying each group of astronauts described and discussed geologic features, history, rock types, and processes on the way down. The 9½-mile trip to the bottom took about 6½ hours. The group stayed overnight in the cabins at the Phantom Ranch at the bottom of the Canyon. On the second day the astronauts and geologists went up the Bright Angel Trail in the same groups as they had come down the day before. On the way up students were asked to identify and discuss the units in the perspective of the previous day's observations. At about 6½ miles of the trip back up the trail mules were made available for those who wished to complete the trip on mule-back. Some chose this type of transportation but many elected to walk the remainder of the way to the top.

Following two lectures on geologic structures and landforms as well as one more laboratory study of igneous rocks, a field trip was made to the Big Bend-Marathon region of west Texas (Figure 17). The planning for this trip included first a one-week visit to the area by two local experts, Bill Muehlberger, who had run the University of Texas summer field program at this location for several years, and Phil King, who had mapped the area several years previously, along with a NASA and a USGS geologist (Clanton and Chidester) who were part of the training group. After this advance group had decided on the details of the field trip a second trip was made, this time without Phil King, with several additional NASA and USGS geologists who would be the trainers (or teachers) during the astronaut field trip. This trip made sure that all trainers knew exactly what they were to see and the nature of the activities at each stop. Then the astronauts were brought along in two separate groups for the third trip through the field areas on April 2-3, and April 15-16, 1964. The trip continued the basic geology study by requiring interpretation and mapping of well-exposed structural and stratigraphic relationships. Also included was an introduction to volcanic rocks along the Rio Grande River west of Big Bend National Park. As on the Grand Canyon trip, two or three astronauts were assigned to a geologist. On the first day they mapped two folded and faulted structures on aerial photos. On the second day there were four stops, two at road cuts of layered volcanic lavas and ash flows, a third at Bee Mountain to study an igneous intrusion, and a fourth at Santa Elena Canyon to study a large fault scarp. A useful innovation on this trip was the use of radios that were used to communicate between the cars thereby allowing discussion of the geology while on the move.

Figure 17. Local expert Bill Muehlberger points out some of the geologic features to be studied on a field trip to the Marathon Basin in west Texas. (NASA photo S67-32752)

After two lectures on impact structures and one on an introduction to mapping lunar geology as well as two more lab sessions on igneous rocks, there was a field trip to Flagstaff, Arizona which included visits to Kitt Peak Observatory (Figure 18) and the Sunset volcanic field (Figure 19). Again the astronauts went in two separate groups on April 29,-May 2, and May 20-22, 1964. While at Flagstaff the astronaut groups were further divided into teams of five or six to allow for adequate space during the exercises. At Kitt Peak the telescope was arranged to project a 32-inch image of the Moon onto a table where the use of a small, hand-operated magnifying system allows selected areas of the lunar surface to be viewed in greater detail. The astronauts undertook these observations from midnight until 5:00 a.m. while the instructors pointed out the similarities of some of the observed features with both impact and volcanic structures on Earth. A second part of the trip involved flyovers of Meteor Crater and the San Francisco Volcanic Field in two four-place light aircraft. This provided an orbital perspective of some of the potential lunar landforms. A third part of the trip included field work at Sunset Crater and the Bonita Lava Flow north of Flagstaff where the students got a look at surface textures, cinder cones, spatter cones, and time relations of flows. They also spent some time mapping the flow and cinder units on aerial photos.

Following two additional laboratory sessions on igneous rocks, two more lectures on techniques of geological mapping on the Moon and on Earth, and one lecture on geophysical techniques for determining geologic structures, the fourth field trip was taken to the Philmont Ranch in New Mexico on June 3-6, 1964 (Figure 20). The Ranch was operated by the Boy Scouts of America and provided an opportunity to observe several different rock types and some rather complicated structures. A geologic study of the area had just been completed and a complete report had just been

Figure 18. Astronauts viewing projected image of the Moon through magnifying devices at Kitt Peak Observatory. (NASA photo S64-21987)

published by the USGS. The trip included both igneous and sedimentary rocks, orientation with geologic maps, measuring and describing stratigraphic sections, strike and dip measurements with a Brunton Compass, and recording of field notes. As on earlier trips to the Grand Canyon and west Texas the group was divided into two astronauts per geology instructor for three days. One day was spent sketching, describing, and defining the exposures on Slate Hill. Note-taking and section measurements were emphasized. A second day was spent trying to correlate vertically dipping units on two parallel traverses. Mapping of the units, dip and strike measurements, and note-taking were emphasized. Half of a third day was spent mapping a dike and sill. The other half was spent using the geophysical instruments that had been the subject of a recent lecture. The students took measurements with magnetometers, gravimeters, and seismometers in an attempt to determine subsurface structure. On the final day the entire group traveled by car and made several stops at significant geologic exposures for brief discussions. The trip finished at noon.


Figure 19. Instructor Dale Jackson discussing with astronauts one of their first attempts to use aerial photos as part of a field exercise at Sunset volcanic field near Flagstaff, Arizona, in early May 1964. (NASA photo S64-23731)

Phase I of the geology training was completed after two more geologic process lectures and two more lab sessions with rocks and minerals. The former consisted of a lecture on the use of geophysics to develop models for the internal structures of the Earth and Moon and a lecture on the engineering applications of geology and geophysics. The latter consisted of a session on the recognition and identification of metamorphic rocks and a session on meteorites and tektites. The last class was on June 15, 1964 and completed a 4½-month program.

King (p. 28) said that the intensive instruction on field trips was the most productive part of the geology training. The astronauts also much preferred this form of instruction to formal lectures and classes (King p. 30). Each instructor was assigned two or three astronauts for each field trip. The instructors and astronauts got to know each other well enough that the astronauts were not shy about asking questions, and the instructors got to know the strengths and weaknesses of the students. The Grand Canyon trip in March 1964 was an excellent first field trip for a group of people like this. There wasn't anybody who thought that the Moon was going to look like Grand Canyon. But it's a wonderful place to teach some of the very basic principles involving the various types of sedimentary, igneous, and metamorphic rocks and structures. As Clanton puts it, "To fully appreciate the impact of the field trip one almost has to have walked in and out of the Grand Canyon." The exposures there are exceptional. Again in Clanton's words, "They saw not only the big hole in the ground, but they also began to appreciate the geologic processes that formed it, and they began to appreciate the age of the rocks and the stories that the rocks told. The other idea behind the Grand Canyon at the time was that the type of rocks exposed there and the section throughout geologic time was a most excellent example." Clanton feels that if he were doing it all again he would still push for the Grand Canyon as the first trip because the diversity of the exposures was excellent and the story that could be told is unequal to any other field trip. In addition, there was excellent cooperation between NASA, Geological Survey, and the Park Service. The accommodations and food at the bottom were super.

Robert Gilruth, Director of MSC, wrote an article on the early days of the space program for National Geographic magazine in which he likened MSC in the early 1960s to a university for astronauts (Nat. Geog., Jan. 1965, p. 122-144). The staff of scientists and engineers was the faculty who taught both astronauts and each other and conducted advanced research. Gilruth emphasized the geologic training by describing the geologic field trips that served as a mechanism to gain firsthand acquaintance with landforms, rock strata, and the forces recorded in the rocks. He mentioned trips to the Grand Canyon, Big Bend, and Sunset Crater, and pointed out that the astronauts spent time observing the Moon, lunar craters, and the Sun at the 60” telescope at Kitt Peak National Observatory in Arizona.

One thing probably worthy of mention is that all of the astronaut training, not only the geology, but also orbital mechanics, propulsion, guidance, or whatever, was presented with no tests being given, so that the instructor really had no way of knowing how well the information was getting across. There was one advantage, though, that the geologists had on many of the other instructors and that was the field trips. Clanton recalls a discussion after the first field trip into the Grand Canyon. "The astronaut's comment was essentially, 'Well, for a couple of weeks now we've been sitting in class listening to you geologists bump your gums about rocks and minerals and various features that we could see. As we sat in class what you were trying to say did not really sink in. We could not see the importance of the use of it or how it could be used.' And yet, after the first field trip their comment was, 'Well, we've listened to you for two weeks and not understood. And one field trip has shown us the importance and the reasons for all of the discussion.' So the point that needs to be made here is that the field trips were productive, not only from an individual instructional point of view but also because you could extract information back from the astronauts and whether they realized it or not, they were being tested or questioned by the instructor in the field. This feedback was one way we found out how effective the classroom instruction was." As pointed out earlier in the comments of Shoemaker the point being made is that the best geologist or the best-trained astronaut is the one that has had the greatest and widest field experience. Along with Shoemaker, Clanton "would strongly push and recommend that the field trips not be slighted; in fact, if anything, be developed to a greater degree."

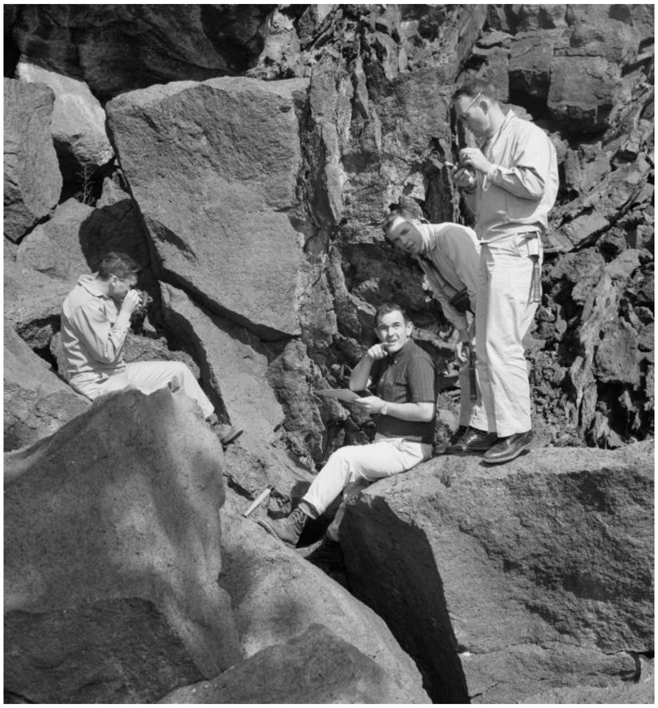


Figure 20. Instructor Dale Jackson discussing with astronauts the igneous rock formations at the Philmont Ranch, New Mexico. This was the final field trip of Series I of the geology training in June 1964. (NASA photo S64-21971)

Swann suggested that "the field trips should have been much more problem-oriented, especially in the early part of the training. Chidester and I really had some go-arounds about that. He was nominally in charge of it and he was going to take them out and put his finger on everything and tell them what it was. They went out and were told this is a this and this is a that. And see that over there? That's a thing. Now do you remember what we called this? And that was the way it was being done. But he was nominally in charge and I wasn't to say any more about it" (Swann interview, 1995).

A continuing logistical problem with all astronaut field trips was the accommodation of the press. Both local and national press had to be accommodated with information about the training exercises, photos, and press conferences. Generally a NASA Public Affairs Office (PAO) officer was along to try and control these activities. Also local politicians, civic groups, ethnic groups, and others wanted to be recognized. All of this got to be a major problem on some trips leading Deke Slayton to place a moratorium on public press gatherings for some trips.

9. Departure of USGS Group from Houston

The Philmont Ranch trip on June 3-6, 1964, and the last of the Phase I geology classes on June 15, closed out the first year of USGS participation in the training and also the residence of the USGS contingent in Houston. As mentioned earlier the continual conflict between the MSC scientists and the USGS scientists led to a withdrawal of the USGS group from MSC in July 1964, only a few months after the group had reached its full strength of six full-time personnel and one year before the completion of the agreement between Gilruth and Nolan. Wilhelms explains the departure as follows: By spring 1964 conflicts between the two geoscience groups "had proved intolerable. The animosity between Dale Jackson and his NASA counterpart, Ted Foss, was particularly severe." Furthermore, Dale could not forgive NASA for developing its own science group contrary to what he felt was in the original agreement.

As a result the USGS group decided to leave (Wilhelms, p. 80-81).

Shoemaker (interview, 1995) explains the departure as follows:

> *“It got to be kind of a sticky turfish thing there. When Dale agreed to go down, and I had committed substantial manpower and resources from Astrogeology so we could do it and get it under way and try to get the best people down there that would be good for it, we didn’t know that there was going to be another group. So it’s inevitable I think that—, in fact, I think it's remarkable that it worked as well as it did. But there were some young guys that were brought on there at MSC, and they thought they should have the responsibility for the whole thing. Dale went down and thought that he should have responsibility for the whole thing. So, it was just built into it that there was going to be a problem. After about a year or so it became evident that it would be much better for the Survey team just to back off."*

Gordie Swann recalls that he was sent there to fill one of the empty slots when MSC complained that the full complement of personnel called for in the contract was not present. His previous task with the Survey had been terminated in late 1963 and according to Swann,

> *"It was along about February of 64 that Jack Eggleston (the MSC person in charge of the training contract) started counting empty chairs. So I, on very sudden notice, got sent to Houston (in March) to fill one of those holes until July 1 which was when the beginning of the fiscal year would start over again."*

Gordie had not been involved in any of the Survey's lunar activities and

> *"It was just a matter of filling a hole and, to put it bluntly, I was not the best choice in the world. And I wasn't really needed. Those guys were doing the training just fine. But Gene had overestimated or oversold or something, I guess. I say Gene. Maybe it was Gene and Dale. I don't know who. I think Gene pretty much sold the program. So that's how I got plugged in to fill the hole. It was okay to do those two reports (this refers to two reports unrelated to the training) during that time because we had time. We didn't have a hell of a lot to do. The lecture system and who was going to do what between MSC and USGS was all set up and organized. Field trips were pretty much set up but there were places where Danny (Danny Milton, who also came in March) and I could help some on the field trips, which we did. But we weren't involved with any of the lectures. I don't think Danny was. I know I wasn't. It was just tagging along on field trips and writing these two reports."*

The departure of the USGS group was apparently not unwelcome from the MSC side. According to Clanton several incidents had set MSC management against the USGS folks. Clanton points out that, to begin with, one must realize that the hierarchy at MSC at that time and all the people in charge of everything at the newly developing MSC were all part of the Task Group that had come from Langley. It was a group that had been working together for several years on rockets, manned spacecraft, even manned flights to the Moon. So they were a tightly knit group and anything that one of them wanted or had as a complaint about anything that was going on, essentially all of them would know about it quite soon.

Within the first several months some things agitated Jack Eggleston, the Acting Division Chief. Particularly noteworthy was Dale Jackson's first introduction to Jack Eggleston, to whom they (USGS folks) were to act as consultants. When Dale was taken in to meet Eggleston, Dale sat on a chair in front of Eggleston's desk and put his booted feet up on Eggleston's desk and leaned back in his chair as though he owned the office. Eggleston immediately gave a glance to Clanton as though asking, “Who does this guy think he is?” That set Eggleston off in sort of an anti-Jackson mood from the very start. Before Jackson had even arrived an event had occurred that made Eggleston rather upset. Jack Eggleston's group of geologists including Clanton and Dornbach had been asked to attend a meeting where they were to discuss some topographic maps and scales and how they might apply to future maps that would be used for lunar activities. They had been given a very short lead time for this meeting and they were all trying to find some pertinent maps that might be available to show at the meeting. But they were not able to find any. At the time, Dick Eggleton of the USGS was already in residence and had been approached about the map problem. He had said nothing about any maps that he might have had available. They all went to the meeting. It was made clear at the meeting that they had had a rather short lead time and had not been able to get any appropriate maps. They tried to explain as best they could what the nature of the topographic maps would be. After leaving the meeting as they were all driving together back to the office at Ellington, or wherever they were housed at the time, Dick Eggleton happened to mention the fact that he had some of those maps back at his office. Jack Eggleston immediately turned to him and asked, “Well why didn't you tell us you had some so we could take them to the meeting?” And Eggleton's reply was, “Nobody asked me.” Knowing full well that Dick Eggleton had been present when they were talking about trying to get such maps for the meeting, Jack Eggleston turned to him and said, in effect, “We're all adult professionals here. We are not playing children's games. Let's not do that kind of thing again.”

A third thing that was not received too favorably was the less-than-agreed-upon USGS staffing. Once the USGS folks had arrived, although there were supposed to be six of them in residence full time, as stated in the agreement between Gilruth and Nolan, it was not until March 1964, nine months after the initiation of the agreement, that six USGS personnel were assigned to be there, and, in fact, it was unusual to have more that a couple of them there. In one particular instance when a meeting was called to include the USGS folks and the NASA folks to discuss some of the training that they were planning, only one USGS person showed up. And it was one of the people who was among the relatively late arrivals. In fact, he was one who had arrived several months after the USGS got started at MSC. So he was not as up to speed on a lot of things as Dale Jackson, or some of the other USGS people. When the meeting started and only one USGS person was there, the question was asked “Where are the rest of the USGS folks?” The response was that “only one USGS person was available at the time.” All the rest of them were off on travel or doing something else for the USGS. They had other things to do on some of the other projects that they were working on. Jack Eggleston was rather upset at that. He knew that there was a contract that NASA was funding for the USGS to provide six full-time people at MSC. Yet, at meeting after meeting, it seemed to be impossible to get more than one or two USGS people together and the excuse always seemed to be that the others had other USGS programs, or projects, on which they were working and could not be present at the meeting (Clanton interview, 1995). Clanton recalls discussing this with Don Wilhelms shortly after one of these meetings. When Clanton asked Wilhelms why he was on travel so much and missed several meetings Wilhelms responded that he was committed for 300% of his time. He was assigned to three projects, each for 100% of his time: one was a JPL project, a second was a NASA Headquarters project, and the third was astronaut training at MSC. As a result he often had to be in more than one place at the same time.

These were the kinds of things that contributed to not only the animosity that is mentioned between Ted Foss and Dale Jackson in Wilhelm's book but also the animosity that was developing in the management at MSC toward the USGS folks as a group. The general feeling was beginning to develop among the management at MSC that they would like to find some way for the USGS folks to leave and let the MSC folks take over with some sort of collaboration with the folks at Flagstaff. Therefore, when the USGS folks left there was a sort of mutual feeling that the USGS folks were happy to leave and the JSC management was also happy to see them leave.

As the relationships between the USGS and MSC scientists got worse there was an attempt to remedy the situation by replacing Jackson with a new leader for the second year of the USGS contract. Shoemaker and Fryklund met with Prof. Joe Peoples of Wesleyan University, Connecticut in an attempt to convince him to be the new leader for this contract. In a letter from Willis Foster to Peoples (June 12, 1964) the conditions of Peoples' assignment were that he would have an appointment as a member of the USGS, he would be assigned to MSC as the senior instructor and coordinator for all geological and geophysical training, and he would evaluate and review the previous geology course as well as the proposed continuation courses. The letter also points out that NASA's Science and Technology Advisory Committee was about to be assigned the review of the entire astronaut training program with the charge of making specific recommendations about the science training program. Peoples did not accept the position and apparently nothing came of the committee's review because the science training remained essentially unchanged until 1967.

Following the departure of USGS personnel from MSC a continuation of the collaboration in the geology training was arranged through discussions at a meeting on June 17, 1964 involving MSC and USGS geologists. Wilhelms says that a formal agreement (drawn up without Jackson's participation) spelled out that Chidester would recommend training areas and outside experts for the field areas, Foss would handle interactions with astronauts, and the press would be told that an outside expert was leading the trip. Chidester, rather than Jackson, continued to manage the USGS end of the agreement from Flagstaff (Wilhelms, p80-81). The MSC geologists would continue with the mineralogy and petrology aspects of the training. The geologic and lunar processes lectures would be given in Houston by visiting lecturers who generally were USGS folks involved in the previous training. Wilhelms' personal notes from this meeting of June 17, 1964 gave some indication of the strained feelings that existed at the time. The notes stated that for selection of field trip sites "USGS recommends site, subject to Ted Foss' perusal. If disagreement persists, Jack Eggleston referees. Can overrule Foss, or request consultation with Gene Shoemaker." Another comment concerning instructors from the USGS on field trips states that "MSC can raise doubts about individuals, but USGS has final choice." For comments to the press, "Press is informed that visiting expert is leading the trip. All other references to relation between USGS and MSC/NASA should be expressed as 'they are cooperating in giving the course' and the like" (from notes in Wilhelm's file). According to Clanton, the MSC geologists, however, recognized their shortcomings. They were all relatively young, new graduates, some with PhDs, but they lacked the professional contacts and breadth of field experience that was necessary for continuation of an optimal training program. Therefore, they wanted the USGS to continue collaborating in the selection and setting up of field trips as well as bringing in the local experts. It is interesting to note that the astronauts involved in the training did not recognize that there was any friction between the USGS and MSC during the training. In fact, John Young said that the first that he knew of it was when he read about it in Wilhelms' book in 1994. Jack Schmitt also does not believe that the astronauts were aware of it, at least he had not heard anyone mention it at the time.

10. Continuation of the training after USGS departure

Series II of the geology training commenced in September 1964 for the first three groups of astronauts and continued through May of 1965. Series III commenced in June 1965 and continued through November 1965 (see details of courses in Appendix A). This was a very active 14-month period for the astronauts who were assigned to Gemini flights, and it was not expected that the geology classes would be attended by these astronauts most of the time. For series II there were generally fewer than 15 in class at any one time and the field trips were generally run two or three times to accommodate the very full schedules of the crews. During Series III the Gemini program took away even more of the astronauts and never were more than 10 astronauts available for classes or field trips (Ray Zedekar's training schedules).

As previously planned the subject matter of Series II was directed primarily toward detailed studies of features with lunar applications: namely volcanic and impact-produced rocks and landforms. As in Series I, Series II also consisted of three parts: geology lectures, mineralogy/petrology labs, and field trips. The geology lectures in this series were directed much more toward the question of whether the Moon's surface was shaped more by volcanism or impacts. Fortunately, at this time, there was an additional source of information that bore on this question. As the first series of the geology training ended new information from the unmanned Ranger probes began to arrive. As a matter of fact, Ranger was returning the first close-up pictures of the Moon just a few weeks after Series I of the geology training was completed but before Series II commenced. The 4,300 photos returned by the first successful Ranger mission (there had been successive failures on the first six Ranger missions) in July 1964 improved the resolution of our view of the lunar surface from the previous 800 ft of telescopic views to less than 10 ft. This information was integrated into Series II. The data from two more Ranger missions in early 1965 were integrated into the continuation of the geology training in Series III as well as in the simulation facilities described earlier. Results from very recent studies of terrestrial impact craters and the discovery of shock features in their rocks and minerals was the subject of one of the lectures by Ed Chao of the USGS. Some of the most recent results of geologic mapping of the lunar surface with telescope photos were also included. The geology part of this series ended with a rather stimulating 3-hour debate on the relative importance of volcanism versus impact in shaping the lunar surface.

The people who were developing the mineralogy and petrology part of the training recognized the problems involved in rock and mineral identification and nomenclature. For the mineral studies they felt that some of the basic properties of minerals such as cleavage, fracture, and luster were necessary to recognize the different mineral groups. Although such properties might not be easily recognized on the Moon, it was felt that they should be presented to provide the basis for mineral identification. The classes were to be told that many of the minerals being used to illustrate these properties probably would not be present on the Moon. For the rock studies it was made clear that the hand specimen names based on an initial observation might not be the correct name when studied in detail under a microscope, but that a name would at least be a useful start to the process of understanding the nature of the collected material. The mineralogy and petrology part of Series II commenced with a concentrated effort to recognize and understand the origin for many volcanic rock types. This included laboratory study of pertinent samples. This part of the series then went on to brief introductions to metamorphic and sedimentary rocks over a total of 6 hours and finished with 12 hours of laboratory work involving study of thin sections under the polarizing petrographic microscope. Clanton explains that “the combined hand specimen, Prado projector (a special polarizing projector made especially for projecting thin sections onto a screen for group discussions), and petrographic microscope studies done in these later phases were an attempt to provide the astronauts some confidence in their hand specimen identification.” The thin sections and microscope work were the subject of some criticism later on because the Apollo program was not meant to include such work by astronauts. In defense of this work one can say that, in hindsight, the argument about the limited plans for the Apollo program may be true, but at the time of the training there were plans for follow-on missions that would have roving laboratories on the lunar surface and thin-section study under the petrographic microscope were included as part of those missions. Therefore, the argument is more properly directed toward the question: "For what time frame of exploration were the astronauts being trained?" It is not clear that this question was addressed at this time.

The field trips of Series II were meant to emphasize what is referred to as “supervised field exercises.” The field trips of Series I were referred to as “introductory field exercises.” The “supervised field exercises” of Series II were meant to introduce the astronauts to the basics of geological mapping under the tutelage of experienced field geologists with about a 3:1 ratio of astronauts to geologists. Although still in pilot training the five new scientist-astronauts of Group IV participated in some of these trips. It should be pointed out that many of the field trips were recorded on film. Documentary-type films of these field trips were made available to the Astronaut Office at MSC so that they could be viewed in lieu of the trips by those whose schedules made it impossible to attend. These films also could be used as references or refresher material by those wishing to review the field exercise.

Figure 21. Local expert Aaron Waters (holding box) discussing potential origins of some of the volcanic features with several astronauts at Newberry Crater, Oregon, in July 1966. Note the relatively recent dark volcanic flow in the upper center of the photo. (NASA photo S66-46669)

Series II started with trips to two different types of volcanic structures. The first trip was to Newberry Crater, a large (50-mile by 30-mile) shield volcano in Oregon (Figure 21). This is a complex of nested craters with an extreme range of differentiated volcanic rocks, obsidian flows, pumice cones, cinder cones, and tuff rings. To emphasize the problem of volcanism versus impact a day was spent at Hole-in-the-Ground, a 5,000-foot-diameter crater whose origin might be either volcanic or impact. Traverses were made across the crater with the objective of gathering data that would prove one origin or the other. The second trip was to the 15-mile by 22-mile Valles caldera in the Jemez Mountains of New Mexico, whose history is somewhat different from that seen at Newberry Caldera. Here there were rhyolite domes, pumice air falls, doming at the center of the caldera, active sulfur springs, and many different types of volcanic materials, including welded tuffs and ash flows. The third and final field trip of the volcanic segment was to Hawaii, where there exists an incomparable display of recent basaltic volcanic features including lava tree molds, gas and lava vents, spatter ramparts and cones, flank eruptions of aa and pahoehoe flows, fissure eruptions, lava tubes, lava lakes, lava blisters, Pele's tears and hair, Halemaumau fire pit, pit craters, cored volcanic bombs, and beach sands of eroded lava (Figures 22 and 23). An evening briefing used photos of the lunar surface that were analogous to features seen during the field excursions. On one of the days there were flyovers in a 12-passenger aircraft to observe the volcanic features from the air to give more of an orbital perspective of the features. To complete the field trip part of Series II the second side of the crater-origin debate was covered by two trips to impact and explosion craters. The first was to the NTS to see craters and depressions produced by nuclear blasts. This was the astronauts' first experience with non-volcanic craters to help prepare for the study of impact craters. It allowed a view of craters that were produced by a force more similar to the impacts that were thought to produce many of the lunar craters. The trip provided an opportunity to examine in detail the craters and ejecta formed by detonation of subsurface nuclear devices in lavas and unconsolidated sediments. In contrast to the volcanic craters the ejecta patterns provided a systematic set of samples from the underlying strata. Use of aerial photos for interpretation of this ejecta was introduced. In addition, the NTS is in a volcanic complex, the Timber Mountain Caldera, thereby allowing for a study of volcanic features next to the nuclear craters. The final trip of the series was to Meteor Crater, Arizona: the astronauts' first experience with a detailed study of the rocks and structures of a real impact crater. A tour through the crater introduced the crews to overturned units at the crater rim, surrounding ejecta deposits, and fallback units. Following the tour the astronauts were required to recognize and document these features by mapping them on aerial photographs.

Figure 22. Astronauts and instructor Dave McKay (far right, with glasses) scrambling across the rough surface of a lava flow in Hawaii during a training trip in February 1967. (NASA photo S67-22639)

Series III was designed to further develop an understanding of lunar geology as well as the applications of engineering geology and geophysics. As in the previous two series Series III consisted of three parts: geology lectures, mineralogy and petrology labs, and field trips. The geology lectures were oriented toward the various structural features of the Earth and Moon, at a variety of scales from local to global, and how they can be determined, especially by geophysical techniques. Updating of lunar surface features from the most recent Ranger data was included as well as a lecture on the possible existence of volatiles on the Moon where they might remain as frozen solids in lunar cold traps. The mineralogy and petrology part commenced with lectures on geochemistry, including the samples and techniques that are required for age determinations of rocks and minerals. These were followed by further studies of volcanic rocks.

The field trips of Series III were referred to as "individual field exercises." They concentrated on specific problems of geological mapping, sampling procedures, and geophysical techniques. The astronauts carried out individual mapping and sampling exercises, and geophysical techniques were used to produce additional data. At the end of each exercise all of the information was to be integrated into maps and interpretations that were then reviewed with the geologists.

This series of field exercises continued to emphasize volcanic features. First was a trip to the Valley of Ten Thousand Smokes on the Katmai Peninsula of Alaska where explosive eruptions in 1912 deposited silica-rich pumice and ash over a large area (Figures 24 and 25). Subsequent stream erosion has cut deep gorges through the deposits allowing study and interpretation of details in vertical sections. The summit of Katmai had collapsed by 1500 feet during the eruption. The astronauts studied evidence of the fumaroles and vents formed in the hot ash flows; these volcanic features are quite fresh and offer an excellent opportunity to view volcanic materials and landforms in nearly pristine condition. This was the first of several exercises that were meant to be the start of simulations of lunar missions. This was known as "playing the Moon game," in which astronauts were divided into pairs, placed in a field location with very little prior information about the area, and pretended that they were on the Moon. They had to plan traverses and collect important and representative samples from the areas. The astronauts used radios to communicate with their geologist instructors. These communications were recorded and later discussed with the astronauts for comparison with the interpretations of the field trip leader and to improve the procedures for good communications between astronauts and scientists.

Figure 23. Instructor Al Chidester (left) and astronaut Ron Evans discussing the nature of one of the volcanic rocks on a field trip to Hawaii in February 1967. (NASA photo S67-22457)

Next was a trip to the Askja caldera of Iceland where there was beautiful volcanic geology with practically no vegetation cover (Figures 26 and 27). The features include calderas, ash cones, steaming volcanic vents, cinders, pumice, and various types of lava flows. Iceland was probably the most Moon-like of all the field areas that were visited. Snow and melt water from glaciers presented some logistical problems for the vehicles used for transporting the astronauts (Figures 28 and 29). The Moon game was used for some of the exercises. The following trip was to

Figure 24. Helicopters used for transportation to the Valley of Ten Thousand Smokes on the Katmai Peninsula, Alaska. The terrain in this area was covered with volcanic eruptions of pumice and ash over a large area. It was a good representation of the lunar surface. (NASA photo S66-50404)

the Medicine Lake Highland in California which includes a 5-mile diameter caldera in a large volcanic area with volcanic flows and obsidian domes. The Moon game and some independent mapping were included in the training. A trip to Zuni-Salt Lake, New Mexico in an area with a large volcanic crater and structurally complex rim material was used mainly for geophysical exercises in which the astronauts helped lay out the traverses and gained hands-on experience with geophysical instruments. The final trip was to the Pinacates of Mexico, a volcanic area with explosive craters and subsidence along ring fractures. The astronauts participated in geophysical exercises to help them lay out the traverses and gained hands-on experience with geophysical instruments (Figure 30).

This ended the training for the first three groups of astronauts until some of them were assigned to specific Apollo missions and their further training was directed more toward their individual missions. That training is the subject of a later Section.

When new groups of astronauts arrived the science training programs were to be repeated as necessary. The fourth group, containing six scientist-astronauts, arrived in the last half of 1965. One resigned before the training commenced and three of the remaining five were sent off to pilot training for slightly more than a full year. Therefore, the training for the fourth group was delayed and combined with that for the fifth group of 19 which arrived in April 1966. The training for the combined group of 24 began in May 1966 and continued through September 1967. For the first three months of this program three of the scientist-astronauts were still completing pilot training and it was unusual to have more than 20 students available for classes or field trips. The schedule for the coursework and field trips for groups four and five is given in Appendix A in somewhat abbreviated fashion. Because the content of the lectures was very similar to that given during the 1964 program a relatively complete listing of the topics for this training may be found in the 1964 portion of Appendix A. Series II of the geology training for groups four and five combined nearly all of what had been in Series II and III of the previous training and there was no separate Series III presented to this group (see Appendix A for details).

Training for the sixth group of astronauts that arrived in August 1967 was changed drastically from that of the previous groups. The sixth group consisted of 11 scientist-astronauts, one of whom resigned before completing much of the training. One of the reasons for the change in the training was that there were now several scientists among the astronauts and they could evaluate better the nature of any science training. A second reason involved the cancellation of several Apollo missions as well as all of the follow-on programs for lunar exploration after Apollo. Clearly, this group was not going to be trained for any lunar missions and the role of any particular science in whatever they were to accomplish was undetermined. In fact, shortly after they arrived this group was welcomed by Alan Shepard with a discouraging but politely worded greeting that boiled down to, "We can't use you, and if you had any brains, you'd leave" (Chaikin, p. 388).

Among the earlier group of scientist-astronauts was Jack Schmitt, a geologist who had worked with the USGS on projects related to lunar exploration before he became an astronaut in 1965. Schmitt was highly dedicated to lunar exploration and by 1967, when the sixth group of new astronauts arrived, he was involved in many facets of the Apollo program, especially if it related to the science objectives of the program. He had a significant influence on the nature of the geological training for the remainder of the Apollo missions. As Schmitt attended the lectures and field trips after returning from pilot school in August 1966 he noted that the lecture part of the courses was not going over very well. "The guys were bored. And even the field trips were out of context. It was hard for them to see how what they were doing was relevant to what all of them were aiming for, that is, to be the first person on the

Moon or at least soon after." Such details as measuring dips and strikes of layers, joints, etc. did not seem reasonable to many of them. He was also upset with an apparent atmosphere among both the USGS and NASA geologists at the time that they were going to try to give the astronauts the equivalent geologic training of a Masters degree. "I guess if I heard that once I heard it a thousand times" (Schmitt interview, 1995). (Unfortunately, the idea of the equivalent of a Masters degree in geology had originated in 1964 at rather high levels, according to a New York Times article, "Astronauts Get Geology Courses" [May 11, 1964]. The article states "Members of the Space Advisory Board of the National Academy of Sciences who have interviewed the astronauts have been greatly impressed with the thoroughness and depth of the program and are reported to have concluded that, upon completion of the four courses the astronauts will have the equivalent of at least a Masters degree in geology.")

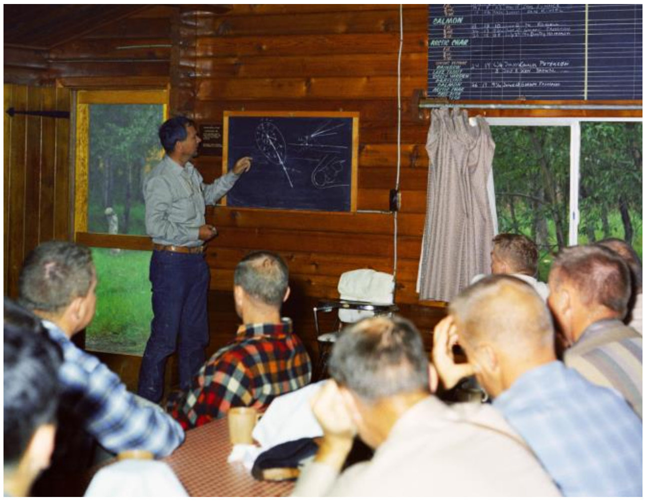


Figure 25. During evenings on the Katmai, Alaska trip there were lectures and discussions. Here, Gene Shoemaker presents some results from studies of meteorite impacts. (NASA photo S66-50356)

According to Schmitt "that wasn't the point. The point was to get the maximum of good information, good samples and good documentation as you could in a very short amount of time and to get them interested to learn the things that would be helpful in that whole process. And so I went to Al Shepard and suggested that the astronauts ought to take more control of the training program in science with the primary purpose to make it mission-relevant." Among the things he had in mind was to reduce some of the detailed terminology, such as mineral names, that was being introduced. "One thing I wanted to get away from was having these guys memorize mineral names. They all knew chemistry so I wanted them to have just a few basic mineral names and use the chemical names that they were already familiar with to modify them when necessary such as Ca or Na plagioclase rather than anorthite and things like that." Clanton counters that "Almost from day one only group mineral names were used by the instructors: K-feldspar, plagioclase, amphibole, pyroxene, olivine, quartz, and mica." Clanton indicates that the astronauts were told that there were more detailed breakdowns of these group names and some of these names were mentioned in case one was interested in using the more detailed names, but the group names were perfectly adequate. Clanton further adds that "the biggest problem was on field trips. The local experts and other geologists brought in to help with the trips, but had not been present in the classroom studies, used specific mineral names and sometimes exotic rock names."

Figure 26. In Iceland instructor Ted Foss (with glasses) discusses the volcanic geology with astronauts Vance Brand (left) and Stuart Roosa. (NASA photo S67-37760)

Usage of general rock and mineral names was usually discussed in the pre-trip discussions with the local geologists, but many of these geologists chose to ignore the suggestions, according to Clanton. Clanton recalls one trip, in particular, to Medicine Lake, California in which the local

Figure 27. Field camp and accompanying vehicles on the geology field trip to Iceland in July 1967. The terrain there was thought to be very Moon-like because of the scarcity of vegetation. (NASA photo S67-38059)

experts used a variety of exotic petrographic names that had been determined during detailed studies of the rocks. Some of the astronauts confronted Clanton about the usage of such exotic terms and Clanton explained that such terms could only be determined by detailed petrographic and chemical studies. For the purpose of their descriptions he suggested that the general term “vitrophyre” (or glassy rock), which they had studied in the classroom would be adequate. Schmitt also wanted to put the field trips on a traverse basis and to start bringing in the Mission Control people as soon as possible. From this point on the training was oriented toward the preparation of individual Apollo crews and is the subject of a following Section.

Other astronauts besides Schmitt became involved in planning the next series of courses. Astronomer-astronauts Karl Henize and Bob Parker organized the astronomy part of the program, physicist-astronauts Curt Michel and Owen Garriott organized the space science part of the program, and Schmitt organized a revamped and reoriented geology program which was now to be called planetology. These astronauts actually presented some of the classes themselves and sought out well-known lecturers for others. For the planetology lectures Schmitt sought out lecturers who were well-respected as scientists and had excellent reputations as teachers, "the kind of lecturers who were very good at relating to students, that is smart people without a lot of geology in their background" (Schmitt interview, 1995). To induce these lecturers to give their lectures in a much more simplified but useful manner, Schmitt "sat with all of them before they talked and tried to make them realize that we're not trying to turn these guys into geologists. We're trying to give them information that will be helpful to them as they move into the business of selecting and documenting samples." In addition, he would prepare each astronaut class by trying to establish the relevance of whatever the lecturer was to talk about. "My memory is that

Figure 28. Melting water from the glaciers in Iceland made travel conditions rather interesting on the geology field trip to Iceland in July 1967. (NASA photo S67-38045)

the astronauts started not only to enjoy the sessions more but also began to see some relevance to them." It seemed clear at that time that none of these new astronauts of the sixth group would be selected for any Apollo crews who needed field training for lunar exploration. Thus, there were no field trips in the program that was set up for this group of astronauts. Schmitt's influence on the field trips is more related to the training for Apollo missions and will be discussed in a later Section.

The courses in the training program for the sixth group of astronauts were revamped starting in October 1967 and ending in March 1968 (see Appendix A). This was the last of the group training efforts before the program changed completely to the mode that treated each Apollo crew individually which is the subject of Section III: MISSION-ORIENTED TRAINING.

Figure 29. In addition to melt water from the glaciers, there were snow fields to cross on the geology field trip to Iceland in July 1967. Astronauts and instructors sometimes had to give a helping hand to get the vehicles through. (NASA photo S67-37670)

There are numerous anecdotes associated with astronaut training, many of them related to the field trips. Swann recalls "the infamous Hawaii trip with the goat hunt" in February:

> *"We contracted with a local helicopter outfit to do some flyovers with two to three astronauts at a whack. And these helicopter guys had two other kinds of contracts. They were helping set some power poles, and they took hunters out goat and pig hunting. They were so tickled to get to know astronauts they were after everybody to go goat hunting and pig hunting. They said they'd take them in the helicopter. It was perfectly legal, and you don't need a license. I think all of that's true. For goats you didn't anyway. They had the guns and all. I was very tempted and I finally said no but I'm trying to remember who went. I think Ted Foss did, I know Joe Engle did, there was a guy from the Survey. Bill Rust was on that. Bill wouldn't miss a chance to shoot something. There were several others. And these guys set them down on some private property, and they didn't know that. They started shooting goats. The land owner complained. I would too, I think, if some helicopter came in and some guys jumped out on my property and started shooting everything. Howard Powers was the scientist in charge of the Volcano Observatory, and the complaint came to him. And man he was pissed. He wouldn't have anything more to do with astronaut training. It made quite an impact on things. They swore up and down they did not shoot from the helicopter, the rancher swore up and down that they did. I don't know, but one of them is lying. That didn't make old Howard Powers very happy either. So anyway, it made kind of a big stink for a while."*

Figure 30. Astronauts Ed Mitchell and Stuart Roosa learn to use a gravity meter on a geology trip to the Pinacates volcanic region of Sonora, Mexico, in November 1966. (NASA photo S66-65992

In fact, Powers was so upset that he wrote a formal letter of complaint to Al Chidester with copies to several offices at the USGS and NASA asking Chidester if he would "find a good way of canceling the future astronaut trips to Hawaii." He complained about the goat hunting escapade and stated "the men involved in that episode are definitely not welcome here again." Further, he commented that "every trip so far has contributed at least one incident that has had to be overlooked by someone." He stated that "the students are not gaining enough to justify a fraction of the time spent and the dollar cost. It is surely obvious that you are not getting any worthwhile help from any of the NASA contingent and most of the other men from Flagstaff seem to take it less seriously than you do." Powers concluded by saying "If you do have to bring more of them down on another trip I'll help out with a sort of opening speech but none of the rest of the staff here can afford to put any more time in on it" (letter from Powers to Chidester, Feb. 27, 1967).

Bill Muehlberger remembered the first class that he took to west Texas in 1964. It was just after Mercury was finished. Gordon Cooper, the pilot on the last of the Mercury flights, and Alan Shepard, the pilot on the first one, were assigned to go on this trip. This was Muehlberger's first experience with training astronauts and he was not familiar with all of the publicity and crowds that often accompanied the trips.

> *"They were the token heroes of the world. It was really fantastic. A friend of mine that I knew out there in Alpine told me about these events afterward. We were due to arrive there in Alpine at 3:00 p.m. according to the NASA PAO announcement that went out. So apparently everyone in west Texas was out there at that airport. At 3:00 p.m., a DC-3 landed. They had two planes come out of NASA, one was a DC-3 that was going straight out there. The other, a Gulfstream, dropped by Austin to pick me up, and then we went on. It was well after 3:00 p.m. when they picked me up, so it was clear that we weren't going to be there at 3. Well at 3:00 p.m. when the DC-3 landed the Van Horn High School band strikes up with patriotic songs. The plane opens up and out comes a load of wet-backs. When we finally got there I thought there were lots of people there but apparently most of them had already left. But Shepard and Cooper would not get out of the plane until all of the bags were in the cars and everything was ready. They'd had enough of this hero stuff where people pull buttons and hair off you and stuff like that. So they finally got out, and there was a certain amount of autographing and we leaped into the cars and went on to the motel."*

Uel Clanton had some reservations about the role of local experts in field trips.

> *"The extent of participation by the local experts is a point that is somewhat moot. I would highly recommend it fairly early in the training but with some reservations. The individual, the local expert, has to realize the limited knowledge of the astronauts and also recognize the way the training is being presented to the individual such that a great deal of stress is not laid on particular fossils or formational names or much of the detailed information that is appreciated only by a geologist." Clanton recalls some instances where the local experts were more than put to the test by the very perceptive astronauts. In one particular case "The local expert was informed on what the astronauts had learned up to that time, their background, and the fact that we ran the courses very informally and, in fact, had instructed the astronauts that, if during class time in the field they did not understand what we were presenting or did not, shall we say, believe, the information that was being presented or had reason to question it, to do so. This, by the way, is a facet that we found that was very well developed in most of the astronauts. Most of them seemed to have a very good, very sensitive, snow-detector, and there came a time when they wanted to hear 'I don't know.' When you said that, they realized that you, too, were human, that you didn't know, and they got off your back. However, the longer you put off saying 'I don't know,' the greater the number that jumped on your back and the more difficult it became for you to finally say 'I don't know.' In the particular instance I am referring to the gentleman had been informed that the course was presented very informally and that chances were good that something would come up during the presentation where perhaps his best answer if he truly didn't know was 'I don't know.' The individual in question, though, chose to ignore his instructions and presented the class accordingly. It was kind of evident from the regular instructor's point of view that the guest speaker's presentation was not being accepted wholeheartedly. In fact, he could see the group beginning to bristle after about 5 minutes, and about 15 minutes into the lecture the position became untenable, at which time, as I recall, Walt Cunningham proceeded to inform the individual that he could think of at least three other ways that would explain the lava deposition sequence that were equal to, or better than, what the instructor had presented already. The first 5 minutes or so after that was one of shock and amazement because here was one of the grand old men of geology who, perhaps for the first time in at least 5, maybe 10 years, had someone there to question something that he said. The blood and guts that followed were a little gruesome, but finally the words of wisdom that we had tried to lay on him before class began to come through, and after about 15 minutes he finally said 'I don't know. Perhaps what you interpret as the possible origin and depositional sequence is equally applicable.' This was a difficult lesson to learn for this individual. Most of us had had a similar, but not quite as bloody, experience. In retrospect it was an excellent*

> *way to do it because the astronauts valued then your capabilities and liabilities, and they recognized that there were some things that they could see in the outcrop, or see in the hand specimen, or see in the photographs, and others they could not."*

11. Reactions of astronauts to training

The reactions of the astronauts to the early training are quite varied, as one might expect. It must be kept in mind that the initial geology training in 1963 and 1964 was for "students" who for the next two and one-half years would be flying the Gemini missions. Field geology, rocks, and introductory geology courses would be of interest only to those who might be selected as Apollo crews several years down the line. A few exhibited some interest in the geology training. Aldrin (Return to Earth, 1973, p. 193-196) became a willing convert to the training especially to the many geology field trips. He admitted to geology opening his eyes to the immensity of time and found himself "paying rapt attention as the instructor talked about things that took place eons before man existed on this Earth." He also found the field trips to be "a unifying force" among the astronauts because they provided an opportunity for large groups of astronauts to be together in rather informal settings. In his opinion camaraderie, if it existed among the astronauts, came from these trips. Bill Anders indicated his perception of the astronauts' opinion of geology training during the early years "We were trained in spacecraft systems, rendezvous, and geology, which I particularly liked. I volunteered to go on all the geology field trips which probably didn't go over too well because you weren't supposed to be interested in that kind of stuff (NASA oral history interview, 1997)."

Others were not happy with the amount of time spent studying geology. In particular, there were complaints about the extent of detail in some of the courses. Collins (Carrying the Fire, 1974, p. 70-73) listed the divisions of the 240-hour course that greeted his group of new astronauts within a month after their arrival: Astronomy-5hrs, Aerodynamics-8, Rocket propulsion-12, Communications-8, Medical-12, Meteorology-5, Upper atmosphere physics-12, Guidance and navigation-34, Flight mechanics-40, Digital computers-36, Geology-58. Collins used this list to point out the lopsidedness of the geology hours compared with the rest of the topics. He further pointed out that these 58 hours were designated as Training series I and would be followed by Training series II, III, IV, V, and VI, all in geology. He further pointed out that these series were to be taken not only by his group of 14 but by all astronauts, including the original 7 (1959) and the second group of 9 (1962). This was way out of line, in his mind.

Collins went on to chastise the geological training as too detailed with totally unnecessary terms and details---detailed petrographic descriptions (hypidiomorphic granular, porphyritic with medium-grained gray phenocrysts), chemical compositions of minerals, application of Mohs hardness scale to minerals, and petrographic studies of thin sections under the microscope. He sarcastically asked if the best identifier of rocks would be selected, in spelling bee fashion, as the first man to be selected to go to the Moon. He correctly pointed out that the astronauts on the Moon would simply pick up a variety of rocks to bring back for the scientists on Earth to analyze in this fashion. They were not to use microscopes or scratch tests to determine what rocks they were collecting. They would simply grab them and bring them back. The later missions did require a bit more study of the materials in-situ but not to the extent taught in the early courses. Perhaps later, when there were lunar bases, it would be necessary to have that kind of training but there would be some scientists along to do those tasks. Collins also criticized some of the other courses. He wondered whether the computer course "was designed for someone to either build a better computer or repair and replace components of the existing computer." He wanted a course that would teach them "to operate a computer and detect malfunctions." "Give us the pilot's viewpoint, not that of the repairman or the circuit designer." He did indicate that they all worked hard at trying to master the courses because there would be a day of reckoning when the good students would be rewarded with flights. He further admitted his own short-sightedness that stopped at the first lunar landing. He visualized more preparatory flights than actually occurred and that the first landing would be a signal of success and would end the program. He did not consider that the additional lunar landings with long-duration traverses on a roving vehicle and deployment of scientific instrument packages would be part of Apollo. Borman (Count Down, 1988, p. 102) had more the attitude of Collins than that of Aldrin and Anders.

Irwin (To Rule the Night, 1973, p. 210) also indicated an adverse reaction to some of the details in the geology training. With respect to mineralogy he said "studying individual crystals and trying to identify them left me cold." He did, however, admit that once assigned to an Apollo crew "geology becomes very important." In addition to the need for learning geology he found the field trips provided a respite for him. "I liked the break and I enjoyed getting out into the wilds. There was always time to relax." Irwin described how the training took place. In the field exercises "we trained just as we would operate on the Moon. Dave and I would work as a team and we'd have a capsule Communicator." They selected rocks to sample, placed a gnomon near the rock to indicate vertical and displayed a color chart, then took five pictures for each rock. "We worked our routine out very carefully and practiced it over and over." He explained that once a landing site was selected for a mission the geologists made detailed maps of the area including topographic relief versions that could be used in the landing simulator. The relief models were placed on the ceiling in the simulator building and a TV camera would move along the direction of the simulator's flight path projecting images of the lunar surface on the windows of the simulator. "It looked just like we were landing on the Moon" (p. 214).

In a review (Liftoff, p. 159), Scott Carpenter spent many paragraphs criticizing the science community for their criticism of pilot-astronauts. He was particularly critical of much of the science community for espousing the concept that scientists trained to be pilots could do a better job on the Moon than pilots trained to do the necessary procedures for science. He continued in this vein by chiding the so-called "hyphenated astronauts" (scientist-astronauts) as being rather unnecessary and superfluous for the objectives of the Apollo program. On page 242 he related that geologist-astronaut Jack Schmitt, when he came across orange rocks on the Moon, thought he "had found the Moon's youngest rocks" and "proudly proclaimed their age as 'less than 25 million years'." These samples were later analyzed and found to be 3.5 billion years old, although their exposure by meteorite impact was about 19 million years, making Schmitt's assessment partially correct. Cunningham stated that "A dumb fighter jock would not have ventured such an ad hoc assessment." On the other hand, Collins, in reference to Schmitt's tenure on the Moon, stated "I'm sure that the sharp eye of the experienced geologist increased the selectivity, and hence the scientific value, of the specimens collected" (Liftoff, p. 159).

John Young felt that the extensive detail in some of the training wasn't too much out of line because no one knew at that time exactly where all of the exploration was headed. He felt that it's always better to know a lot more than you need to know rather than to get there and discover you haven't learned as much as you should have (interview, 1995). Young remembers the geology field trips rather fondly.

> *"Those field trips enabled you to get away from everything. And the USGS and everybody else who was supporting those things really did a lot of work laying out all those traverses. And the homework to do all that stuff, I thought, was really incredible. And all the work that went into one of those. People have no idea how much work had to go into preplanning those damn field trips. And laying it all out, knowing what the rocks were, figuring out what the puzzle was going to be (the geological puzzle), and how it was going to work. It's a lot of work. I think it was a lot of fun, actually" (Young interview, 1995).*

When Schmitt was asked to assess the range of reactions exhibited among the astronauts to these various types of training, he responded:

> *"Total, I mean from total disinterest—honest total disinterest like Al Shepard. He just wasn't interested. He was there to fly the spacecraft, and he would do whatever else he could on the rest of the mission, to people like Dave Scott who threw themselves wholeheartedly in the whole thing. I would say those probably represent the two extremes. Of the people who went to the Moon, I think there were more on the Dave Scott side. And 14, they were straightforward about it, but they really did the minimum that they thought they could get away with. They had a training program. They went through it. They took the field trips. They went through the procedures and did a credible job on the Moon. You could only wonder particularly at Fra Mauro what else might have been done with more interest."*

As Wilhelms reviewed his experiences in astronaut training he pointed out, as did Aldrin and Irwin, that the field trips provided one of the few opportunities for astronauts to be together in informal circumstances. Rather than training in small groups here they had a chance to join in large groups. Interest in the subject matter varied greatly. Some were deeply interested, others looked upon it as a necessary and boring chore and considered that a much smaller amount of geologic training would have sufficed (see Borman's and Collins' books). Some such as Shepard exhibited open disdain for much of the geologic training. Wilhelms states that "most of the astronauts in the first three groups were pilots first, second, and third, and scientists only by necessity. However, because they would do anything to get a lunar-landing assignment most of them did their very best in geology and concealed their lack of interest just in case it counted." Those who showed special interest in geology, according to Wilhelms, were Armstrong, Aldrin, Bassett, Chaffee, Cunningham, Schweikart, Scott, and See (p. 122). King pointed out (p. 46-47) that the Moon Game developed a competitive spirit between pairs of astronauts and some were convinced that they would have a better chance of being selected for a lunar surface mission if they performed well in this part of the geology training. Wilhelm's and King's comments about the importance of geology training to selection for a lunar landing assignment were further amplified in the May 1964 New York Times article ("Astronauts Get Geology

Courses"), which credited a rather startling statement about the geology course to Deke Slayton, Head of the Astronaut Office, as follows: "Maj. Donald K. Slayton, who has emerged as the 'squadron commander' of the astronauts believes that with time it may become necessary to limit the course to the brighter students in geology. It is out of this select group that the first astronaut to set foot on the Moon will be drawn." However, there was never any evidence that this was the case. In fact, Walt Cunningham had quite a different observation. "In the end it didn't make a nickel's worth of difference how we performed in the classes...We [the third group of astronauts] were slowly waking up to the fact that politics and favoritism were very important" (Cunningham, p. 32-33).

Section III: MISSION-ORIENTED TRAINING

1. Introduction

Earlier explorations of new territory by the Vikings, Magellan, or Lewis and Clark simply required that they went off into the unknown where they might encounter new mountain ranges, deserts, rivers, oceans, lakes, and whatever else might materialize. Their efforts might require many months or even many years, and they would have to “live off the land.” But for human exploration of the Moon there were critical factors such as time and safety to consider. The Moon would not provide a breathable atmosphere or any supplies of water and food. The need to bring along the necessary consumables, therefore, would limit the time for exploration to a few hours or, at most, a few days. In addition, the explorers would need to land in locations that were topographically friendly, i.e. free of boulders, gullies, chasms, or other obstacles that would endanger their lives, or at least limit their ability to explore.

Fortunately, from the days of the early explorers to the time of Apollo technology had provided new methods of approaching unknown areas on Earth. The arrival of aircraft and photography had combined to produce aerial photography which for the few decades before Apollo had allowed preliminary studies of terrestrial features, which, in turn, allowed for planning of tasks and traverses before beginning exploration of new areas. With the advent of orbiting spacecraft there was an even newer way to provide images of areas to be explored. But, for the Moon, in 1961 there were only telescopic images that provided resolutions adequate for mapping large-scale features but not adequate to see the boulders, gullies, small craters, etc. that would endanger safe landings on the lunar surface. For humans to explore the Moon there was a need to select landing sites that would provide enough reasonable terrain for safe landings and a few hours or days of exploration. This would also require rather detailed knowledge of the nature of the lunar surface: is it rocky or covered with dirt, is the material soft or hard, will it support heavy loads or will they sink. Such knowledge would require not only prior imaging that would provide the necessary resolution to allow planning for traverses but also would require prior deployment of unmanned spacecraft and instruments to the lunar surface to provide information on the nature of the surface materials. And finally, selecting landing sites that would be of scientific value, i.e. what sites could provide the best information about the origin and evolution of the Moon.

Clearly, several preliminary unmanned missions to the Moon would be required to obtain the necessary data for sending humans to explore our nearest neighbor in space. The stories of these prior missions—Ranger, Orbiter, and Surveyor—are well covered in other documents and will not be further discussed in this study. Once the data from these prior missions became available the real undertaking of Apollo planning commenced. There were many organizations, committees, personalities, and agencies involved in this undertaking. As might be expected there were many viewpoints, conflicts, and details that required resolution. All of these factors impinged on the planning of individual lunar missions and the associated training of the crews who were to accomplish these missions. This Section attempts to address the many factors that were involved in the planning of the missions and the effects of these factors on the training of the Apollo astronauts. There were many steps in the evolution of the planning and training. By the time of Apollo 17 most of the difficulties had been overcome and a smoothly working system had evolved that had required several years of trial and error to find a winning combination.

2. Groups involved in science training

Although there was a need to train the Apollo crews in the procedures and scientific background for their tasks on the lunar surface, there was also a need for training the scientists in how to train the crews. After all, the astronauts were going to perform tasks under drastically different conditions and constraints than are encountered during similar studies here on Earth. Not only did the scientists have to recognize how to use new types of tools and equipment but also they had to learn entirely new means of communication and operations that were necessary for conducting missions on the lunar surface. This Section addresses the many aspects of the science training that, in fact, involved not only the training of the crews but also the integrated training of scientists, engineers, and operations personnel.

To understand the developments that preceded the science activities and consequent training for the specific Apollo missions it is appropriate that we review the involvements of the myriad organizations, committees, and study groups that provided some form of input for these missions. Science training for the Apollo crews was oriented toward both the orbital and surface experiments that were conducted on each Apollo mission. The complex nature of the science (geology, geophysics, biology in the early missions, astronomy, solar physics, soil mechanics, magnetospheric physics, etc.) associated with the Apollo missions required the inputs of many science groups and organizations. (It could be argued that some of this input was politically necessary to ensure that all pertinent groups could be said to have had an opportunity to provide their arguments.) In addition, the mission planners, the engineers associated with tool and instrument development, and the flight directors all had to be involved in the science training in order to familiarize all relevant personnel with the nature of the constraints, objectives, and development of timelines and their associated contingencies. For the field exercises there were also support groups for cameras, tools, vehicles, radios, recording devices, etc., all of which had to be transported to the training locations and maintained in good operating condition during the training. Because scientists were included in both the orbital and surface science-support rooms of Mission Control during the actual missions there were numerous pre-mission simulations of the planned lunar traverses that integrated the science efforts with all of the other Mission Control operations and communications.

At least 43 science experiments were eventually selected and conducted on the Apollo missions (Wilhelms, p. 364-365 or Compton, p. 364) (see Appendix G). Some of these took place on all missions, others on only one or more missions. The experiments ranged from setting up static instruments that would send data back to Earth by telemetry, to collecting documented samples of rocks and soils for return to Earth for analysis, to turning on and off the remote sensing instruments or cameras in the orbiter. There were also handheld photos to be taken on the lunar surface and from orbit with Hasselblad cameras. Many of these handheld photos, both on the surface and from orbit, were taken at the discretion of the astronauts and were of use to more than one investigator, but were especially useful for the geological interpretations of lunar history and documentation of samples. In addition to the experiments 193 PIs were selected to study the returned samples from Apollos 11 and 12. In March 1970 a new RFP was issued to study samples from Apollo 14 through the end of the Apollo program, resulting in about 350 PIs in total. The needs of the sample PIs ranged from information on the orientation of the samples on the lunar surface, to high degrees of purity (i.e. lack of contamination), to knowledge about depths of burial. Therefore, documentation regarding the manner in which the samples were collected was extremely important. The astronauts required detailed training in the execution of all of these activities as well as at least a brief introduction to the scientific background for each one, and it was the responsibility of the PIs, or their representatives, to provide such information. And the science trainers also required detailed knowledge, which can also be read as “training,” in all the operational and scientific constraints in order to conduct the science training in a realistic and beneficial manner.

Both the mission planners and flight directors required detailed knowledge of the time, effort, placement, and priorities required for each science experiment that took place during the missions. These details were tested in training situations that included simulated lunar gravity conditions, test beds for various instruments, and field exercises that simulated lunar traverses. And, of course, the engineers who designed the instruments and tools for each experiment had to work with both the PIs and the astronauts to be sure that all of the products satisfied the science requirements and could be operated properly in a spacesuit at lunar gravity as well as meet the weight and space restrictions for the spacecraft. Nearly all the experiments had been selected years ahead of the missions in order to develop hardware and conduct the necessary tests and training. Any proposals for new add-on experiments that were indicated from the results of previous Apollo missions would require special appraisals and could not significantly impact weight and space limits or time lines on the later missions for which they were proposed. The Experiments Review Board was set up in 1970 for this very purpose. For example, both the neutron and cosmic ray experiments were introduced during the last year of Apollo for inclusion on Apollo 16 and/or 17. They were evaluated and approved by the Science Working Panel (SWP), the Experiments Review Board, the Apollo Spacecraft Project Office (ASPO), and the Configuration Control Board as well as the appropriate Headquarters offices. The neutron experiment involved sticking a rod down a previously drilled hole from which a core was retrieved and recovering the rod at the end of the EVA. The cosmic ray experiment involved sliding open a small plate with sheets of mica, foil, and glass in it; hanging it on the LM; and then closing and retrieving the plate at the end of the EVA. Neither experiment required much training or traverse time, and the stowage was accomplished rather easily.

All these activities, such as the selection of the best science experiments, the best scientists for each experiment, the best contractors to build the equipment, the sequence of events on the lunar surface, and the landing sites on the Moon, had to be accomplished within an organizational framework. This framework included organizations within the NASA structure, other government agencies, outside advisory committees, and the U.S. Congress. An evolutionary process began in the early 1960s that eventually involved numerous organizational elements within NASA, many of which had an impact on the science activities of the Apollo missions and the resulting training of the Apollo crews. Some of the early stages of this process were covered in Section II, but a brief summary of the evolution of NASA Headquarters organizations that had some degree of responsibilities for the science activities on the Apollo missions will refresh the reader's recollection of the growing pains that accompanied the birth and development of science throughout the Apollo Program. The conflicts between various offices should be kept in mind as the Apollo science program and associated science training evolved.

NASA Headquarters

In 1960 through late 1961 the only organization dealing with the early vestiges of lunar science was a Lunar and Planetary Programs Division in NASA's Office of Space Flight Programs. Brainerd Holmes was its administrator. Following President Kennedy's challenge on May 25, 1961 to land a man on the Moon by the end of the decade the necessary organizational changes began to evolve. Brainerd Holmes continued as administrator of what had now become a manned flight program, and, in late 1961 his office was assigned a new, more appropriate name, the Office of Manned Space Flight (OMSF). Also in late 1961 the Lunar and Planetary Programs Division was placed in a newly formed Office of Space Science (OSS), with Homer Newell as director. At this point a conflict began ,and was to continue for several years, over which of these offices was to be in charge of the various science activities for Apollo.

As discussed in Section II Gene Shoemaker of the USGS spent a year at NASA Headquarters (November 1962 to September 1963) with the goal of developing a better working relationship between OMSF and OSS. In September 1962 Newell established a Joint Working Group, which was meant to recommend a detailed program of scientific exploration of the Moon to OMSF and suggest to OSS a program of data acquisition to meet Apollo's needs. The group's chairman would be assigned to OSS but would be a member of both OMSF and OSS reporting to units in both offices. When Shoemaker arrived he was appointed as chairman for the Joint Working Group. This meant that Shoemaker essentially was reporting to two bosses, but, considering the struggle between OMSF and OSS for control over the science for Apollo, no better alternative seemed possible. By July 30, 1963 OMSF and OSS had agreed on a division of responsibilities for the Apollo missions. OSS would select the experiments and PIs and undertake preliminary development of the instruments in consultation with OMSF, and OMSF would develop and integrate the hardware and work the scientific objectives into the mission plans. OSS would formulate plans for the science training of the astronauts and OMSF would conduct the training. OSS would establish the qualifications for selecting scientists for the astronaut program and participate in their selection, but OMSF would make the final selections. With these guidelines in place the Joint Working Group was reorganized in July 1963 as the Manned Space Science Division which again would report to both OSSA and OMSF.

Following Shoemaker's return to the USGS, Verne Fryklund, another detailee from the USGS, was made Acting Director of the Manned Space Science Division. The term "Division" was rather short-lived. After only a few months, on November 1, 1963, it became the Office of Manned Space Science with Willis Foster as its Director; Fryklund returned to the USGS. This Office reported directly to both Newell and Mueller and grew rapidly in 1964 to work on the problems for Apollo science from a broad-based view including engineering, scientific instruments, and sample collection (Beattie, p. 11). The study of these problems gradually expanded from simply landing on the Moon and returning to Earth to a series of about 10 landings in the Apollo Project, and after that to a follow-on program, the Apollo Applications Program that visualized, among other types of lunar exploration, extended stay times of weeks in mobile laboratories that would roam the lunar surface. In Beattie's book, *Taking Science to the Moon*, he provides an entire chapter, "What Do We Do After Apollo," on the details of these long-range plans including the contracts that were let for studies of lunar bases, drilling operations, mobile laboratories, etc. Although NASA Headquarters, MSFC, and USGS put a significant amount of effort put into these programs the newly organized MSC in Houston was not a party to these activities. In fact, when some of these projected activities were presented to an audience at MSC in mid-1964 Max Faget, Director of Engineering, is reported to have asked, "Who thought up these ideas, some high-school student?" (Beattie, p. 35). On another occasion the concept of the Command, Data Reception, and Analysis (CDRA) facility (discussed in Section II), which was essentially a type of Mission Control center that was set up by the USGS in Flagstaff where geologists at consoles could follow the activities of field crews, was presented to MSC officials. According to Beattie (p. 64-65) "this stirred up a hornet's nest. We were told to cease work along these lines.” MSC indicated that this activity would never meet with their approval. Despite these warnings the development of the CDRA continued.

The rapid pace of organizational changes at Headquarters is described by Don Beattie (p. 10) who joined NASA in September 1963 and became a member of the Manned Lunar Mission Studies Office in OMSF but also did some work for the Office of Manned Space Science: "New organizations were being created almost weekly, and the staff was expanding rapidly. During 1963 NASA Headquarters almost doubled in size....the Headquarters phone directory was always out of date, and addenda were published every month." He describes how in 1964 he was transferred from the Manned Lunar Missions Studies Office to a new Special Studies Office. But then in 1965 he was transferred back to the Manned Lunar Missions Studies Office which had been combined with the Manned Planetary Missions Office just a few months earlier, then split off to become a separate office once again.

After Holmes resigned as Administrator of OMSF in September 1963, following his loss of an argument to obtain more funds for manned space flight, there was another NASA Headquarters reorganization, effective November 1, 1963. George Mueller became the new administrator for OMSF and Homer Newell became the administrator for a merger of the Office of Space Science and the Office of Applications, which now became OSSA. Both Mueller and Newell were elevated to positions of Associate Administrators, just a tier below NASA Administrator and Deputy Administrator. Mueller believed that OMSF should have total control over all parts of the manned space program, including the science experiments. To accomplish this he set up within OMSF: (1) a Science and Technology Advisory Committee comprising outside scientists who met quarterly to review all aspects of the program; (2) a MSFEB that was to evaluate any proposed experiments; and (3) an Apollo Program Office which oversaw both the developing Apollo Program and the newly formed MSC in Houston. Closely connected with OMSF was a contract organization, Bellcomm, which served as an advisory agency for NASA Headquarters on matters such as systems engineering and evaluations for both landing site selection and scientific instruments that were proposed for Apollo. Not surprisingly, some space science officials protested that Mueller was usurping their authority to select and evaluate experiments (NASA SP-4214, p. 24-25). As part of the November 1, 1963 reorganization, OSSA had a director of Science Programs and several other units, including: the Lunar and Planetary Programs Division under Oran Nicks, and the previously organized Manned Space Science Division that was also a part of OMSF. In addition, OSSA had a high-level advisory group, the Space Science Board, whose members were appointed by the National Academy of Sciences.

OMSF continued to evolve. In January 1965 OMSF issued the “Apollo Development Plan,” a 220-page document with detailed guidance for all aspects of the Apollo program. This plan included no indication of how the science tasks would be managed or who would oversee the experiment development. According to Beattie (p. 88) “Reading between the lines, you could assume that MSC had this assignment.” There was no mention of any role for Foster’s Office of Manned Space Science that had been set up in late 1963 to coordinate science activities between OMSF and OSSA. In mid-1965 Mueller established the ASSB to approach the topic of appropriate landing sites for Apollo missions. In December 1967 the OMSF’s Apollo Program Office, headed by Sam Phillips, established an Apollo Lunar Exploration Office, under Lee Scherer, within which there was a Lunar Science Division and a Flight Systems Development Division to oversee the science plans and spacecraft modifications, respectively, for Apollo (NASA SP-4214, p. 103). In fact, by late 1967 Willis Foster’s Office of Manned Space Science had been dissolved and its functions distributed between the Apollo Lunar Exploration Office in OMSF and the Apollo Applications Program Office in OSSA. Several of the staff from the old Office of Manned Space Science were assigned to Scherer’s Apollo Lunar Exploration Office. Beattie (p. 100-101) felt that this office and Lee Scherer’s appointment constituted a major step forward because “Lee would have much greater influence on the decision makers than Will Foster [former head of the now dissolved Office of Manned Space Science] did. Being on Phillips’ staff put him [Scherer] directly in the chain of command—no more half OSSA and half OMSF, with both offices never sure whose side you were on” (Beattie, p. 100-101). Beattie’s observation is well taken. As we shall soon see, many of the suggestions from Foster’s office were not followed by Phillips and Mueller or MSC. The Lunar Science Division was to coordinate with OSSA for all science planning. By 1969, within OMSF’s Apollo Program Office, there was even a Lunar Science Branch which later became the Lunar Exploration Branch. After the Apollo 11 mission, in July 1969, Sam Phillips resigned as director of the Apollo Program Office and Rocco Petrone, who had been director of launch operations at KSC, took over the position. A few months later, at the end of 1969, George Mueller resigned as Associate Administrator of OMSF and Dale Myers, who had managed the Apollo spacecraft contract at Rockwell Corporation took over. In November 1971, Scherer was transferred out of Headquarters and William O’Bryant, a retired naval officer who had managed the ALSEP program, replaced Scherer. All of these OMSF organizations were involved in planning for Apollo missions including discussions and guidelines for the science and associated training that was to be accomplished within all of the operational constraints that were envisioned at the time. These changes in organization and personnel required time to adjust to new bosses and a trip up the learning curve as well as new aspects of coordination with other organizations.

The Space Science Steering Committee (SSSC) had been set up in 1961 as an advisory panel for OSSA and had a Planetology Subcommittee that was concerned primarily with unmanned exploration. Beginning in 1964 it began to provide some oversight for OSSA regarding science activities on Apollo. Although the chairman was a strong proponent of unmanned space science and was skeptical about the value of having man in the loop, the committee finally did provide some guidance in 1965 for experiments proposed for Apollo (Beattie, p. 89-90). At about the same time, in mid-1965, OMSF issued the first "Apollo Experiments Guide" which was rather ambiguous about the nature of stowage space and payload weight on the LM (Beattie, p. 91-92). The guide stated that the MSFEB, chaired by George Mueller of OMSF, would approve the experiments and the procedures to be followed for acceptance of such experiments. It also made clear that the MSFEB would decide how the experiments would be integrated with the spacecraft, and also that there would be inputs from the astronauts on their role in carrying out the requirements for deployment. This was a new experience for the scientists who were used to a significant degree of independence in designing and implementing their experiments, and, as stated by Beattie, "Principal Investigators soon learned that if they wanted to participate they needed patience and perseverance" (Beattie, p. 93). Although OSSA was partially involved in the suggestions for science experiments and science PIs on Apollo, it was clearly OMSF that took the lead in most aspects related to science experiments.

Manned Spacecraft Center

Meanwhile, in 1962 the newly formed MSC in Houston was designated as the focal point for development of the various spacecraft as well as the training of the astronauts that would be required for the rapidly developing manned space program. At that time MSC had the prime responsibility for the nuts-and-bolts type of development of the hardware, software, and training for all three manned programs: Mercury, Gemini, and Apollo. Given such a huge responsibility it is not unexpected that MSC began to develop several of its own organizations, some of which duplicated the Headquarters organizations. Included in these developments was substantial involvement with the science experiments and associated science training for the Apollo missions.

When MSC first got under way in Houston in 1962 most of the personnel were scattered amongst several buildings to the south of downtown Houston while the permanent facilities were being constructed about 20 miles to the south, near Clear Lake City. A few personnel were housed in some vacated buildings at Ellington AFB just a few miles from the new facilities being built at Clear Lake City. At the end of 1962 the astronaut training was under the supervision of Ray Zedekar in the FCO unit of the Operations Division which oversaw all the flight activities throughout the Mercury and Gemini programs. This training was primarily for the nuts-and-bolts type operation of the spacecraft. During the following two years numerous changes occurred in organization, location, and size of MSC. The book by Gene Kranz, *Failure is not an Option*, provides details of the growth. When the original team from Langley arrived in early 1962 there were 750 people. Within three months there were 1,800; by 1964 there were 6,000; and by the end of 1966 the total at MSC was 14,000. Kranz also provides some of the detailed changes in personnel as the people from the Mercury project were put in charge of newly forming divisions and branches (Kranz, p. 80-82). To briefly illustrate the changes in one area, in 1962 the Engineering and Development Directorate had three divisions, with a total of ten branches. By October 1963 it had four divisions with 22 branches and by October 1964 it had eight divisions with about 50 branches. By 1963 Operations had split into a Flight Operations Division and a FCO Division. Ray Zedekar's astronaut training unit remained in FCO.

As the need for both science information about the Moon and science training for the lunar missions became more apparent the Engineering and Development Directorate, in early 1963, added a new division, the SED, with a Lunar Surface Technology Branch that had the responsibility, among other duties, for developing a science training program for the astronauts. Not only had this new branch for science training been added but in July 1963 there was also a group of geologists from the USGS brought in under the contract discussed in Section II to aid in the science training. By late 1964 Zedekar's training unit was part of a Flight Crew Support Division in the FCO Directorate which was now the organizational home of the astronauts. Following the previously discussed disagreements between the USGS and MSC personnel involved in the science training, the USGS unit departed from MSC in mid-1964 but was to continue on as part of the training program, from offices at the USGS Astrogeology center in Flagstaff, Arizona, rather than at MSC. Throughout the period from 1962 to 1964 most MSC personnel were gradually moved to the new facilities at Clear Lake City. However, the science training units remained at Ellington AFB until early 1966 even though the astronauts and Zedekar's training unit were at the new facilities by 1964.

This clearly indicated that the science training related to Apollo was of a lower priority than the immediate training needs of the Gemini missions that were to be flown during from 1964 to 1966.

The addition of science-related organizations at MSC accelerated over the next few years. Within the SED of the Engineering Directorate there was a Lunar Surface Technology Branch that was investigating surface conditions on the Moon and had started plans for science training of the astronauts. In 1964 the Lunar Surface Technology Branch became part of the Advanced Spacecraft Technology Division and had three sections: Geology, Geophysics, and Geochemistry, and there was also a Meteoroid Technology and Optics Branch as well as a Radiation and Fields Branch. In 1965 the Geology and Geochemistry sections were combined and a Geodesy and Cartography Section was added. In April 1966 all of these branches and sections were split off from the Advanced Spacecraft Technology Division to become the Space Sciences Division, still within the Engineering Directorate. By January 1967 the science activities were split off from the Engineering Directorate to form the S&AD which included a Space Physics Division, a Lunar and Earth Sciences Division, a Lunar Surface Project Office, and an Applications Project Office. In addition, there was a Lunar Receiving Laboratory Project Office within the Center Director's office to plan a facility for the examination of the returned lunar samples. In 1969 the S&AD took over the Lunar Receiving Laboratory and added an Earth Resources Division and a Mapping Sciences Lab. Within the Lunar Receiving Laboratory was a Lunar Sample Office that made inputs for the requirements of the sample PIs.

Up to mid-1963, at MSC, an Experiments Coordination Office in the Flight Operations Division was concerned with how the science experiments would fit into both the Apollo spacecraft and the flight plan (Compton, p32). From this point on, however, several other organizations became involved in the development of the hardware for the spacecraft, the training and schedules for the astronauts, the medical status of the astronauts, the development of the instruments and equipment for use on the lunar surface, and the planning of the time lines and traverses on the lunar surface. These organizations included the ASPO, the FCO Directorate with its Crew Training and Simulation Division, the Engineering and Development Directorate, the Lunar Surface Operations Panel, the Medical Research and Operations Directorate, the Astronaut Office with a support crew for each flight crew, the Public Affairs Office, and a few others. Coordination of the various types of training activities including flight simulators, field trips, hand tools, cameras, lectures, traverse simulations, etc., required the development of a communication system between all of the relevant organizations at MSC. As the MSC activities developed and expanded not only the science responsibilities but also other requirements and capabilities that were required for the Apollo missions began to overlap more and more with the organizations within OMSF and OSSA at Headquarters. Such overlap was bound to develop disagreements and outright conflicts, and it did.

As an illustration of the difficulties that were associated with both NASA Headquarters and MSC undertaking the same tasks, the conflict in setting up geology training groups by both Headquarters and MSC independently has already been discussed. In addition, the guidelines for Apollo Science were also set up independently. In October 1963 Fryklund sent a memo from Headquarters to MSC containing the scientific guidelines for Apollo. But one month before this MSC already had hired Texas Instruments to do a similar study based on MSC's own guidelines. This clashing of interests continued for some time between the two organizations. To further illustrate the problem, in 1962 Headquarters had authorized the formation of Bellcomm (an AT&T subsidiary) to study potential Apollo scientific operations. According to Beattie (p. 9) Bellcomm had grown to a staff of over 150 by September 1963. Beattie further indicates that "Bellcomm had run afoul of MSC engineers who accused the company of being a meddling tool of Headquarters—some at MSC went so far as to call the Bellcomm staff 'Headquarters spies.' MSC tried to exclude them from meetings by keeping the schedules quiet so that when the meetings were announced it would be too late for the Bellcommers to make the trip from Washington to Houston." Christopher Kraft's book, *Flight*, includes excellent descriptions of many of the conflicts associated with the various organizational overlaps and their impacts on the programs.

Many reasons can be advanced as causes for these continuing conflicts between MSC and Headquarters. Both MSC and Headquarters were expanding rapidly both organizationally and staff-wise. Such expansion can lead to lack of communication as well as confusion about who is in charge of what in the chain of command. Furthermore, the folks at MSC were in the midst of detailed day-to-day planning, building, and testing of hardware in conjunction with contractors, as well as setting up training facilities for the astronauts for Mercury, Gemini and, eventually, Apollo. And all of this had to be accomplished by the end of the decade in order to meet President Kennedy's goal of landing a man on the Moon by the end of 1969. At MSC they did not have the time, or patience, to wait for committees and studies and beaurocratic approvals for the many activities that required immediate attention and decisions. Furthermore, as discussed earlier, the original personnel at MSC had come from an atmosphere of independent research at the former NACA research center at Langley and were not about to have others, who were unfamiliar with such research, telling them how to conduct their research and development.

Not only were there conflicts between NASA Headquarters and MSC but also between units within MSC. Early on, during the first manned flight of the Gemini Project, there was a conflict between the Astronaut Office and Flight Operations over who was to be in control of the remote sites that would be in communication with the Gemini spacecraft at various stages of their orbits when they were not in direct contact with Mission Control. Because this conflict arose just two days before the scheduled flight it required some rather quick and difficult decisions. The outcome was a clear-cut definition of who was in control of what part of a mission. In addition, one of the contributors to the conflict was transferred to another location. (Kranz, p. 127-131) There were also several conflicts between personnel in the Science Directorate who were trying to develop the science instruments and those in flight crew operations who were trying to develop procedures for the instruments. Following the early Apollo landings there was an exodus of some of the science management from MSC in 1969. There was a general feeling among many scientists of "dissatisfaction with the status of science in manned space flight programs." (NASA SP-4214, p. 168) The resignation of Bill Hess as Director of S&AD at MSC was perhaps the most serious "because he had been brought to MSC specifically to give the Houston center some scientific respectability. He had, however, found little support from center management and no understanding of the proper role of science" (NASA SP-4214, p. 168). By early 1970 these problems were being dealt with and by mid-1970 many of the problems were well on the way to being solved. The arrival of new personnel and new organizational arrangements are presented in the later unit, "Evolution of organizations, procedures, and tools." Although there continued to be some disagreements between the scientists and the operations personnel, the interactions and discussions provided by the new organizations and committees usually solved the disagreements and greatly outweighed any differences.

Other Agencies

Other government organizations in addition to NASA were involved with the operations of manned missions. Because the initial United States space activities had been supervised by the military for several years there were already safety procedures in place for launches; and any such activities by NASA required coordination with the Air Force. Recovery operations for the spacecraft and astronauts required coordination with the Navy. Medical plans for emergency landing sites at various locations around the world required coordination with the Air Force and the State Department. And, of course, the U.S. Congress, which controlled the purse strings, had to be informed of all of the planned space activities in order to provide the funding for NASA's programs. The last of these had a major influence on not only the Apollo Program but the entire future of lunar exploration.

Other events influenced the Apollo Program. The impact of the Vietnam War on budgets and the concern about safety as well as waning public interest in the space program caused Congress and NASA Headquarters to contract the number of Apollo missions in 1970. This, in turn, produced a change in the types of missions and the resultant training. In June 1969 it was expected that there would be at least 10 Apollo landing missions. After Apollo 11 there would be four "H" missions each of which would carry an ALSEP package and support two EVAs as foot traverses. After the "H" missions there would be six "J" missions each of which could carry an ALSEP package and support up to four EVAs as well as carry scientific instruments in the service module for orbital experiments. Furthermore, starting with the second or third "J" mission there would be a powered surface vehicle with a working radius of 5 km. When, by September 1970, missions 18, 19, and 20 had been cut and, in April 1970, Apollo 13 had been forced to return without landing, the total number of landing missions was effectively lowered to six and only four of those remained. In the new schedule, there was to be only one more "H" mission, Apollo 14, meaning that there were to be only 3 "H" missions rather than the originally planned five. In August 1970 the Apollo 15 mission was named as the first of the three "J" missions instead of an "H" mission as originally planned, and the use of the powered surface vehicle was pushed ahead to be on this first "J" mission. Clearly, the site selections, science activities, and associated science training required substantial revisions.

As an illustration of the effect of such revisions on the crews Dave Scott provides his reaction to the revised schedule:

> *"The significant shuffling of missions following the Apollo 13 failure in the spring of 1970 had enormous implications for Jim, Al, and me on Apollo 15, which was due to launch in July 1971. When I was assigned as commander of this mission at the end of 1969, the flight had been scheduled as an H mission—essentially the same as the previous lunar landings. Eight months later it was upgraded to the first J mission. That meant we would have to accomplish a great deal more during our twelve-day mission. Instead of spending one and a half* days *on the Moon, during which two walking EVAs would*

> *be performed—as on an H mission—our stay was extended to three days. During that time Jim and I would conduct three much longer EVAs—totaling about 20 hours—with the use, for the first time, of the Lunar Roving Vehicle.*
>
> *"In addition to developing new procedures and testing new equipment, Apollo 15 was to be a highly scientific mission. Most of the time we spent outside the Lunar Module would be dedicated to carrying out a detailed geological investigation of the lunar surface. Because of the length of our EVAs we would have to carry more sophisticated equipment, our backpacks would be of longer duration, and our spacesuits better. So much new equipment was to be put into use for the first time on our mission—not least the lightweight, collapsible, but still cumbersome Lunar Rover—that the Lunar Module had to be upgraded and its performance enhanced to accommodate everything. We would be the first crew who would truly have to adapt to living on the Moon."* (Scott, p. 265)

3. Interfacing with advisory committees

Advisory committees for the purpose of recommending science activities and objectives were a common part of the NASA structure for Apollo. The many experiments that were eventually selected for the Apollo missions involved inputs from several committees, some of which were more influential than others. Also, the individual PIs for each of the experiments required some avenue for input of their requirements and procedures to the astronauts, the trainers, and the mission planners. In addition, several summer studies tackled not only the problems of science to be accomplished on the Apollo missions but also the training of the astronauts. Some of the organizations and studies were discussed in Section II. The nature of the interfaces between these committees, PIs, the various NASA organizations, and the training of the astronauts evolved substantially over the course of the Apollo Program.

Before any actual science training for the specific Apollo missions could begin the detailed nature of the science experiments to be conducted and the tools and instruments to be used required adequate definition. The following paragraphs provide a brief introduction to the growing pains that were involved with this definition.

Experiments and Instruments

Through early 1962 space science investigations were quite independently planned and carried out by individuals under the accepted procedures of basic research. Namely, individual scientists submitted proposals which, once accepted, allowed the investigators to conduct their own experiments without instructions or advice from NASA, or any other agencies, about the manner in which they should proceed. The Office of Space Science under Newell received its advice on overall science policy from The Space Science Board of the National Academy of Sciences. The main tenet of such advice was the concept that "the content of space science projects was determined by the interests of individual investigators and conducted under the direction of the investigator who proposed it" (NASA SP-4214, p. 19). Because of this there was a feeling on the manned spaceflight side of NASA that, under Newell, "space sciences was rather unbending in not getting scientific data which would assist the manned program" (NASA SP-4214, p. 18). Even as late as June 1962 an OSS official made the statement that "pure lunar science experiments will provide the engineering answers for Apollo" (NASA SP-4214, p. 19). This type of independent scientific research was not what OMSF had in mind. Considering the new and unusual operational and engineering constraints under which the Apollo missions would operate there was a need to balance these constraints with the science expectations. In March 1962 OMSF and OSSA set up the Ad Hoc Working Group on Apollo Scientific Experiments and Training. This was known as the Sonett Committee which was to recommend scientific tasks and the associated science training for the Apollo astronauts. The recommendations of this committee for science training of the astronauts were discussed in Section II.

The scientific instruments and disciplines that were recommended for Apollo by the Sonett report, as well as the contemporaneous OSSA-sponsored Ames Summer Study of 1962, were discussed at NASA Headquarters for several of the ensuing months. These discussions resulted in the selection, through the collaborative efforts of OSSA and OMSF, of a few science experts from each of the recommended disciplines to meet at NASA Headquarters on 30 January 1964 (Compton, p. 33). From the recommendations of the Sonett report and the Ames Summer Study these experts were to identify the most important experiments and suggest the instruments that were required for the Apollo missions. The resulting top priorities, not unexpectedly, were geology, geochemistry, and geophysics. Based on these recommendations Foster sent a memo on February 13, 1964 to the SSSC suggesting names that would comprise teams of experts to plan for the nature of the geological studies, returned samples, and the geophysics experiments (memo: Foster to SSSC, Preliminary Definition of Apollo Experiments, Feb. 13, 1964). The SSSC approved Foster's suggestions and in April 1964 the teams of experts in each of these subdisciplines met to define more specifically the instruments and activities that should be involved. Later there were added groups of experts in biosciences and lunar atmosphere studies. A June 1964 symposium at MSC brought together the science inputs and the operational and engineering constraints in an attempt to integrate the science experiments and the operations. Five months later the science groups submitted their report to OSSA. Headquarters distributed the report for comments with the understanding that these recommendations would form the basis for a science definition document on which final instruments and experiments would be selected for Apollo. However, OSSA decided that, first, another summer study was needed in 1965 to further discuss the report's recommendations (Compton, p. 34).

The need for developing the plan for selecting instruments, experiments, and PIs was becoming critical if the goal of landing a man on the Moon and returning him safely was to be accomplished by the end of 1969. The planning groups had stressed field work, sampling, and emplacement of instruments as the main ingredients of the science program for Apollo. The geology and geophysics teams had listed the specific tools and instruments for the investigations that they recommended. The geochemistry and bioscience teams had listed the types of samples that they needed. The geology team also recommended photography and visual observations. With these recommendations in hand, MSC and NASA Headquarters, in late 1964 and early 1965, began making plans for developing and managing the experiments (Compton, p. 34). During this same period OSSA had progressed on two actions: (1) they had let contracts to the potential PIs who were to develop plans for the experiments to be carried out on the lunar surface, and (2) they developed an RFP from scientists who were interested in studying the returned lunar samples.

The relations between MSC and NASA Headquarters, particularly Foster's Office of Manned Space Science, for implementation of the recommendations regarding scientific instruments, however, displayed the same difficulties that were discussed previously. In early 1965, once the contracts were completed with the PIs who were planning the surface experiments, attention was turned to the development of the hardware for these experiments. Foster's office had been working with the engineers at MSFC for more than a year on the design of a geophysical station for the post-Apollo missions. In the light of this work, on May 10, 1965, Foster sent a request to MSFC to submit a work statement for the design of an Apollo scientific station. He also asked MSC to submit a similar work statement. At this point George Mueller of OMSF had already indicated that he thought that MSC should take the lead in managing the work for this station. In fact, on January 15, 1965 MSC had already appointed several interim coordinators for various surface experiments with the comment "It is expected that within the next few months the responsibility of this division [SED] for the development of scientific equipment will be established (memo: Eggleston to Staff, Establishment of interim staff for scientific equipment, Jan. 14, 1965)." Meanwhile, Foster and his office at Headquarters were trying to maintain control over the same tasks. In a memo dated April 1, 1965 to Newell, Foster stated "Experiment coordination responsibility should be established within the Apollo Project Office. … This group should be engineering- and management-oriented" … and "be independent of the projects office and should be responsible for the experiment monitoring." He further stated in parentheses "(It is recognized that this arrangement would be not quite acceptable to Mr. Faget [Director of Engineering at MSC] …)." In another part of this memo dealing with selection of contractors for the Apollo instruments: "I have been to a degree thwarted by Eggleston in that he insists on maintaining a detailed degree of control of the operation in his organization [SED at MSC] and has in fact prepared an RFP for an integration of contractors…" (Memo: Foster to Assoc. Adm. of OSSA, April 1, 1965).

According to Beattie this finally came to a head at a meeting with Mueller and several others on May 24, 1965 where for 2 hours the pros and cons of the proposed work statements from MSFC and MSC were discussed: "The MSFC work statement was judged superior to MSC's and likely to elicit the best proposals." However, Sam Phillips was of the opinion that "in spite of its deficiencies MSC should become NASA's lunar expert." Mueller agreed and MSC became the lead center for the Apollo station. In Beattie's words: "The annointing of MSC as our lunar expert was a devastating blow to many of us in attendance and presaged the, at times, bitter disagreements we and the PIs would have with the MSC managers in the years ahead" (Beattie, p. 128-129).

As a further indication of the difficulties between MSC and Headquarters Faget, in another memo, targeted Headquarters' inept management of the contractual arrangements with PIs for the various experiments. MSC, which was to have the responsibility for the day-to-day management of the contracts, had put a number of the submitted contracts on hold because of Headquarters' lack of action on several issues. Faget complains: "We requested [on March 24, 1965] that you arrange prior written approval for such contracts with the Office of Grants and Research Contracts (SC). To date [May 11, 1965] no such authorization has been received at MSC." He continued: "the proposals are in different formats with numerous errors and omissions (improper or no authorizing signatures by university officials, insufficient information, no cost breakdown, etc.). This situation has occurred apparently due to lack of uniform written instructions to the potential principal experimenters…" There are a number of enclosures with Faget's memo documenting the nature of the problems (Memo: Faget to Foster, May 11, 1965). MSC, OMSF, and OSSA finally worked out a two-stage procurement plan for instrument fabrication, and in June 1965 MSC implemented the first stage by sending out RFPs. The second stage, to be completed in August, would entail the selection of companies for the initial definition stage of the instruments. It will be recalled that this is about the time that OSSA had proposed convening another summer study to develop a science definition document on which the final recommendation for instruments and experiments would be based.

A new Experiments Program Office was set up within the MSC Engineering Directorate to manage the implementation of the newly devised procurement plan. Three of the nine companies that responded to the RFP were selected to compete in the definition stage. Following that stage the contract for actual fabrication was awarded in March 1966 with a hoped-for delivery by July 1967. By late 1966 it was clear that the schedule for delivery was probably not realistic. Furthermore, as discussed later, in one of the design reviews of late 1966 or early 1967 it was discovered that the design of the ALSEP instruments had several problems that would require unacceptable lengths of times for deployment on the lunar surface. Because of the astronauts' need for training with exact replicas of these instruments for several months before the mission, as well as the testing of the instruments and their integration into the spacecraft, the delivery of the training replicas and the flight instruments was required several months before a mission.

Once the experiments packages for the flight were fabricated they were sent to KSC to be extensively tested before being placed aboard the Apollo spacecraft. But there were additional packages that were to be used for training at MSC and KSC. At MSC, these packages were used during training on the "rock pile" or in the "sand box." At KSC, they were kept in Hangar S which was formerly a hangar at the Cape Canaveral Air Station. Inside hangar S were mock-ups of the LM and command and service module (CSM) that were used for stowing and unloading the various pieces of equipment during simulations. There was also the "sand pile" at KSC where simulations were undertaken for deploying the ALSEP. In the final weeks before a mission the crews would spend most of their time at KSC, and it was important to have a place where they could maintain their efficiency in the deployment procedures and stay up-to-date on any changes that might involve the experiment packages or their deployment. In addition, the crews were allowed to participate in the final checkout of the actual flight hardware at KSC before it was stowed on the spacecraft. This made certain that the crews would not meet up with any surprises when they unloaded the equipment on the lunar surface (Beattie, p. 205-207).

Before the Apollo 1 fire on January 27, 1967 it was questionable whether the ALSEP instruments would be ready for the first lunar landing, and Headquarters was already considering contingency plans for deployment of this package on later missions (Compton, p. 95). The fire delayed the Apollo program for more than a year and gave the fabrication of instruments a bit of a reprieve. However, even in 1968, there were still problems as the astronauts encountered difficulties during simulations when they tried to deploy the instruments in pressure suits. This problem provided one of the difficulties that impacted ALSEP deployment on Apollo 11. For a good thumbnail review of all of the ALSEP and other surface experiments that were developed for the Apollo missions see Beattie's Chapter 7, titled "The Apollo Lunar Surface Experiments Package and Associated Experiments."

Tools

While the ALSEP and other surface instruments were being designed and fabricated, hand tools, cameras, and other implements that would be used for the many activities that were planned during the lunar traverses also had to be developed. Beattie lists those that were under consideration at a critical design review (CDR) in February 1967: tool carrier, sample bags, maps, tongs, hammer, scoop, drive tubes, gnomon, color chart, sample bag dispenser, aseptic sampler, spring scale, surveying staff, and a combination brush/scriber/hand lens. In addition there were cameras and associated film magazines. The aseptic sampler was eventually dropped because of difficulties in the design and fabrication of a practical device. The surveying staff was dropped because of the time required for its use as well as the awkward problem of carrying it along with other tools. All of these implements required designs that were not necessarily like those used on Earth. An astronaut's ability to use each one was tested by astronauts, geologists, and engineers in pressure suits and under low, or zero, gravity conditions as described in Section II. As one might expect there were numerous redesigns of many of these implements. For the later missions a few additional implements were developed based on knowledge gained during the first few missions. These included a rake, a sampling device to be used while sitting in the Lunar Rover, and a recording penetrometer. Beattie describes these implements, their uses, and some of the problems associated with their development (Beattie, p. 113-124).

Clanton describes a problem with the scoop and how it was overcome:

> *"With the open scoop, it was impossible to collect sand from the sand box and place it into a sample bag at 1/6th g on the KC-135. The sand pile created some drag on the scoop as the sample was collected. When the scoop cleared the surface of the sand, the sudden loss of friction caused the scoop to pop free and the sample shot out of the scoop and across the aircraft. I redesigned the scoop to get a partial cover over the top. Even then the scoop had to be rotated a few degrees to pry free the sample before lifting it up to be put into the sample bag."*

During an informal debriefing with the Apollo 12 crew after their mission, Clanton recalls asking the question: "Did the lunar soil fly out of the scoop the way it did on the KC-135?" Both Conrad and Bean doubled up with laughter before Conrad responded "On the first soil sample I forgot my training. I did not do the pry-out rotation. I covered Bean from head to toe with soil. But from then on I remembered to do it the way we were trained and had no further problem" (Clanton note, 2005).

Once all the problems with tool and instrument development were solved, or at least well under way, there was still the problem of how the astronauts were to transport the tools during the traverses and still have easy access to them. On Apollo 11 the crews had a very limited number of hand tools (hammer, gnomon, tongs, extension handle, and core tubes) and did not traverse more than 200 feet from the LM. Thus the problem of transporting the tools was not of major importance. On Apollo 12 a Tool Carrier was added to which the various tools could be attached and detached with relative ease. It was a box-shaped device with four legs and could be carried by the astronauts between stations. For Apollos 13 and 14 the traverses were designed for much longer distances. To accommodate the greater need for mobility on these two missions the tool carrier, called the Mobile Equipment Transporter (MET), was further modified to carry more tools and two wheels were added. The final three missions included a Lunar Rover with an MET mounted on the back of the Rover.

Once the problems of transporting the tools and instruments on the traverses were solved there was still the problem of how to integrate the use of tools and instruments with the tasks during the traverses. The traverse planning teams required inputs on locations for deploying instruments, collecting rock samples, taking cores, digging trenches, and performing other tasks, as well as the detailed instructions regarding deployment and procedures from all PIs as well as from operations and engineers. But before the traverse planning could begin there was a need to select landing sites. Only after the selection of a landing site could the objectives and priorities be recognized and organized into traverses and time lines for each landing site. Then the detailed training could be undertaken for specific sites and traverses.

Site Selection

A brief review of the site selection procedure is necessary to understand the importance of this factor and its impact on traverse planning and training. Committees were formed both at NASA Headquarters and MSC for the selection of lunar landing sites. In mid-1962 the OMSF had asked all organizations conducting any investigations of the Moon to provide information on the radiation environment, properties of lunar soil, topography of the Moon, and photos or maps that could permit selection of a landing site. According to the document issued by OMSF these tasks were now to be given top priority in all studies involving the Moon. Several units within NASA, JPL, the USGS, and other organizations became involved in gathering and providing such data. As early as mid-1963 MSC's SED had selected four sites that tried to balance scientific return and mission operational constraints. They came up with five more such sites over the next few months (NASA SP-4205, p. 253). Through 1964 no single organization was responsible for collecting the needed data to evaluate landing site selection. In the spring of 1965 OSSA's Newell organized a Surveyor/Orbiter Utilization Committee to try and use the expected data and photos of the lunar surface in scientifically acceptable fashion. Shortly thereafter (mid-1965) to centralize the inputs for landing sites, George Mueller formed the ASSB whose mission was to evaluate and recommend landing sites to Mueller. The ASSB was chaired by the Apollo Program manager in OMSF, and its members were from OMSF, OSSA, MSC, KSC, and MSFC (NASA SP-4214, p. 39-40, 78).

Photography of the lunar surface by Earth-based telescopes did not have good enough resolution for safe determination of Apollo landing sites. It was adequate for determining scientifically interesting locations in a general way, but the several-hundred-meter resolution did not show potential hazards such as boulders, small craters, and crevasses. Therefore, in 1963 the Lunar Orbiter program was conceived to provide photos with high enough resolution for selection of safe landing sites. This was a joint effort involving OSSA for management, OMSF for design requirements, and Langley Research Center for the day-to-day management of the operations. Lunar Orbiter

1 flew in August 1966 and did not perform as well as expected, but Orbiters 2 and 3 (November 1966 and February 1967) were very effective and provided adequate coverage to commence the detailed job of site selection. Orbiters 4 and 5 were devoted to scientific purposes (lunar geologic maps and interpreting lunar geologic history) more than site selection although their potential use for site selection might become important later on as some of the scientifically interesting sites became candidates for landing sites. An added benefit of the Orbiter program was the ability to track the orbits of the spacecraft closely and map the Moon's gravity field in a manner that would be useful for the detailed planning for orbital tracks during the Apollo missions (Beattie, p. 190).

Although there were many interesting landing sites that were of scientific interest it was rather obvious that the site for Apollo 11 would be determined primarily on the basis of safety and operational constraints with only minor input from the science community. In March 1967 MSC's Lunar and Earth Sciences Division had presented a list of eight candidate landing sites to the ASSB all of which were within the previously defined operational constraints. MSC operations personnel asked that the sites for the first landing be selected from the list by 1 August 1967. The topographic maps necessary for a final selection were slow in coming and the 1 August deadline was extended. The ASSB met on December 15, 1967 and MSC recommended five of those eight sites as the best for the first landing and six for the second landing. The ASSB approved (NASA SP 4214, p. 128). It was also suggested that if the first landing was in the eastern mare then the second should be in the western mare. At this meeting ASSB was urged to focus its attention on evaluating the sites for the remaining missions after the second landing.

A significant step already had been taken to gather more of the science community's input for the later missions. In early 1967 Bill Hess, the director of the newly formed Science Directorate at MSC, began to organize the science planning for future lunar exploration, including not only the Apollo missions but also the follow-on programs that had been in the planning stages for a few years. There appeared to be some lack of confidence in the MSC science staff's ability to carry out such planning. Jack Schmitt criticized a study by MSC geologists to develop a Lunar Exploration Plan: "The study appears to me to indicate a major lack of understanding of lunar geology and geophysics, of the scientific capability of Apollo, and of the scientific requirements for future missions" (Schmitt to Slayton, May 25, 1967). In a March 22, 1967 memo to eminent scientists from several different disciplines Hess asked them to attend the first meeting of what he called the Lunar Exploration Planning group. (Hess to distribution, March 22, 1967). In the letter he pointed out that the newly formed S&AD at MSC had been given the responsibility for scientific planning for the lunar exploration program and he was convening this group to get the preliminary planning under way. Among the things to be discussed were plans for a summer study, mission planning, instrument development, and major hardware items. A summer conference at Santa Cruz in the summer of 1967 was organized at this meeting to "prepare detailed science plans, establish an order of priority for lunar investigations, and recommend major programs to develop instrumental and technological support for the advancement of lunar exploration" (NASA SP-4214, p. 97-98). During this conference Hess established the Group for Lunar Exploration Planning (GLEP) which would be chaired by Hess and work with the mission planners to incorporate as many of the science recommendations as possible into the Apollo program.

During the first several GLEP meetings through mid-1968 the discussions were concerned mainly with a variety of exploration plans that involved not only the early Apollo flights but a continually evolving set of more and more complex missions that would follow Apollo throughout most of the 1970s. These plans were based largely on the recommendations from the Santa Cruz Summer Study and included a combination of lunar orbiters and landing vehicles, both manned and unmanned, with a variety of instruments for remote sensing from orbit, analyses of surface materials, and an extensive geophysical network. There were designs for roving surface vehicles, flying vehicles to extend the range of surface exploration, and dual launch and landing missions that would allow traverses from one location to another on the lunar surface. A rather thorough summary of the topics from the Summer Study are provided in NASA SP-4214, p. 337-344. At the end of September Elbert King summarized the results of the Santa Cruz Conference for MSC's Lunar Missions Planning Board. The lunar flying unit was considered so essential by the conferees that they had recommended lunar exploration be deferred until the flying unit was developed. The Lunar Missions Planning Board was not enthusiastic about this suggestion. Faget, while agreeing that the unit would be desirable, was not optimistic about the cost and schedule and warned that the whole program could be held up if it could not meet budgets and schedules (NASA-SP 4214, p. 100). This was especially pertinent at this time when lunar exploration budgets were being targeted for substantial cuts. Furthermore, MSFC was currently working on a roving vehicle that could carry two astronauts and some scientific equipment, and this seemed to be the best first step.

By early 1968 NASA Headquarters, with its newly formed Apollo Lunar Exploration Office in OMSF, began to develop exploration plans both for Apollo and beyond Apollo that, according to Compton (NASA-SP4214, p. 130), were even more extensive than those being developed at MSC, and Bellcomm also became heavily involved in similar efforts. The estimated budget for such programs was in the order of one billion dollars per year. When the Headquarters program was presented to MSC management the reaction was positive in terms of the plan, but there were reservations that the funds available for the next year were inadequate to get started on such a program (NASA-SP 4214, p. 130-131). Starting with the June 1968 meeting, the growing uncertainties of the federal budget began to cause serious concerns and GLEP was asked to help Headquarters review and prioritize the scientific objectives. Over the next few meetings the various options and priorities were major topics for discussion. Meanwhile, starting in late 1967 GLEP formed a Site Selection Subgroup to provide science recommendations for selecting landing sites to GLEP which would then pass their recommendations to the ASSB. By late 1968, as the future for the more extensive programs for lunar exploration became rather dim, the discussions about these topics became less important and site selection for Apollo missions became the more significant topic, and throughout the remainder of GLEP's life, through early 1970, site selection was often the major topic for discussion.

Although GLEP was composed of representatives from the various lunar science disciplines, there was an influential core referred to as the "rump GLEP," that put together the presentations to the group as a whole. This core group became particularly interested in setting priorities for scientifically important landing sites. As one might expect, the broad range of scientists that comprised GLEP made agreement on priorities for landing sites rather contentious, and agreement was rarely attained as will be seen under the landing site discussion later in this Section. Also, the GLEP scientists wanted an increase in the interval between flights in order to have time to analyze data from the previous mission before selecting the next site. Their requirements would have meant at least a one-year interval between flights which would have stretched out the Apollo program until about 1977 and been nearly impossible insofar as the budget was concerned. This could have produced a significant impact on the training procedures and schedules. A compromise of six months was agreed upon which allowed the training to continue pretty much as it had been. GLEP continued meeting until early 1970 when it was superceded by the SWP which will be discussed in more detail later.

Jack Sevier outlines the four criteria for landing site selection as: (1) geographical accessibility dictated by trajectory constraints and propellant limitations, (2) safety considerations such as nature of approach and landing terrain, tracking coverage during descent and ascent, and propellant margins, (3) availability of adequate quality photo coverage in a wide area around the site for at least a year before the flight, and (4) scientific objectives that had to be balanced over a wide range of disciplines. The relative importance of these criteria evolved with the missions. For example, the science objectives were hardly considered for the Apollo 11 mission but became a major consideration for the last few missions. The constraints for an Apollo 11 site were quite strict: within a latitude of +/- 5 degrees of the equator, between 45E and 45W longitude, and free of any hazardous terrain for tens of kilometers approaching the landing site. The last of these constraints required high-resolution photos which were available only from the Lunar Orbiter missions. Because the lead time for all of the planning and preparation of photos for simulators was 12-14 months all the photos to be used had to be available and analyzed by the beginning of 1968. By early 1968 the photos from the first three missions allowed selection of five candidate sites for Apollo 11. Because the launch window for any site depended on two things—the narrow band of sun elevation angles suitable for landing being available for only one day per month at each site and a three-day minimum for recycling the vehicles in case of any scrubbed launches—there were only three sites that were accessible in any given month. The preferred site, for a number of reasons, was the eastern one in the Sea of Tranquility. This was also chosen as the target site for Apollo 10 which was not planned as a landing mission but could provide valuable information for both ground and flight crews about the operations and the landing site. The other less desirable sites were in the western and central areas of the accepted landing zone. Nevertheless, the Apollo 11 crew required training for all of these landing sites in case there were delays that pushed back the planned time of launch for the first site and one of the other sites had to be used (Sevier interview, 1995).

It should be emphasized that all of this planning for site selection was being accomplished during late 1967 and early 1968 before Apollos 8, 9, and 10 flew during late December 1968 through early April 1969, and even before the crews for Apollos 11 and 12 were assigned on January 9, 1969 and April 10, 1969, respectively. Because of the long lead time required for simulator training for any given site Apollo 12 site selection was required long before Apollo 11 was launched. Recall that Apollo 12 was to follow Apollo 11 within two to four months. And all of this was to be accomplished within the decade, i.e. by the end of 1969, as proposed by President Kennedy in 1961. Therefore, if 11 were unsuccessful 12 would be targeted to the same site two months later. If 11 landed successfully at Tranquility Base then 12 would be targeted to one of the other two or three sites four months later. Therefore, both 11 and 12 crews would be training for the same three landing sites before the Apollo 11 mission. Given that the Apollo 11 crew required operational training for three landing sites and they were in competition with the Apollo 9 and 10 crews for simulator time for a few months, there was not much time for science training before the Apollo 11 launch on July 16, 1969.

After the success of Apollo 11 the landing site for Apollo 12 was narrowed to the two previously selected central and western sites. But new considerations were introduced. Following an almost offhand suggestion made by Headquarters' Lunar Exploration Office in early 1969, MSC engineers suggested landing at another western site where the Surveyor III spacecraft had landed two years earlier. Some parts left from the Surveyor spacecraft could be sampled thereby allowing the engineers to determine how its components had reacted to the lunar environment over the two and one-half years that it had been on the lunar surface. This location seemed to match all the required criteria for a landing site including the fact that it was in the western mare which the scientists wanted to visit. Although the scientists on GLEP and the ASSB unanimously objected Sam Phillips, ASSB's chairman, overruled them all and, on July 25, 1969, selected the Surveyor site for Apollo 12. It was pointed out that, very importantly, this demonstration of pinpoint landing was necessary if future missions were planned to land at precisely the points that the scientists desired. Howard (Bill) Tindall, the Deputy Chief of Mission Planning and Analysis, stated: "It is clear that lunar point landing capability is absolutely necessary if we are to support the exploration program that scientists want" (NASA SP-4214, p. 165).

Jack Schmitt provided a somewhat expanded account of the selection of the Apollo 12 landing site:

> *"There had been a lot of controversy about the Apollo 12 landing site. Originally it was supposed to be Sinus Medii, the central site. But some people, especially the Surveyor people, were particularly interested in going back and landing next to Surveyor, but there was a lot of consideration at Headquarters that 'Gee, we missed the 3-sigma ellipse altogether at 11 and if we announce that we're going to land next to a Surveyor on 12 and we miss it by a mile, we're going to look bad. Why isn't it just as good to say we're going to land next to this crater and if we don't land next to that crater what's the big deal.' So they thought a lot about that. I thought that it was important for the people who were reworking the guidance strategy, Bill Tindall and those guys, that it would be more of an inducement if they had to land next to something. So we managed to get that changed so that we would land at that Surveyor site. There was a lot of consternation about that among the science folks. They thought the crew will get infatuated with fooling around at the Surveyor with the bolt cutters and all that and that will take time away from the geology objectives. .... Anyway, the Surveyor became the target. Of course it worked. .... But to me it was probably the most important decision along about that time because it allowed the subsequent missions to really have specific objectives starting from a known point" (Schmitt interview, 1995).*

To further emphasize the importance of this point Schmitt mentions a situation that he encountered just after the Apollo 12 mission.

> *"I visited Flagstaff about that time. .... I found those guys planning a Fra Mauro traverse which was the site for 13. ... I said 'where's your landing point here?' Well they didn't have a landing point. They were just doing Fra Mauro. But at that time we had already shown that we could do that (land at a specific point on 12). So I was surprised to find that rather than plan their traverses from a particular point they were still assuming that we would land on Fra Mauro* ***somewhere*** *(emphasis added). Then they began to think in terms of a landing point, rather than an ellipse, and plan the traverse accordingly."*

The landing of Apollo 12 within 100 feet of its designated landing point at a very specific landing site was a major step forward in the planning of future Apollo landing sites and traverses on the lunar surface. Soon after Apollo 12 the decision was made to greatly improve lunar exploration capabilities. Starting with Apollo 16 (recall that just after Apollo 12, there were still plans for eight more Apollo missions) there would be a Scientific Instrument Module Bay (SIM Bay) added to the CSM, additional propellant would increase payload capacity, increased consumables would increase the lunar surface stay-time to three days, a roving vehicle would add to the range for exploration, and modifications to the space suit would increase the EVA time. These new capabilities for the last four missions revised the site selection strategy to allow the last four missions to be reserved for the sites having the greatest scientific needs for time and mobility. Science considerations could now be considered as a much more important criterion for site selection.

From the previous discussion of landing site selection it should be clear that the sites selected for lunar landings had a significant influence on the science training for specific Apollo crews. There were several committees, PIs, and NASA organizations concerned with site selection, all with different objectives. The science community wanted to visit the greatest variety of sites possible, each PI wanted to have the best site or sites for his objectives, the operations personnel wanted to be sure that there was adequate information about each site, the engineers wanted to be sure that the hardware and consumables would be adequate, and the administrators wanted to be sure that the sites would meet all safety requirements. Jack Sevier was highly involved in the site selection process and his opinion regarding the effectiveness of the science community's input to site selection was one of skepticism. He felt that it was rather a futile exercise, other than initially picking a variety of sites for further consideration.

> *"That whole period of landing site selection was kind of a farce, I thought, from the standpoint of the scientists. Calio was here (at MSC) by that time. He had his GLEP Committee and it was kind of a voting society. The laser ranging reflector folks had just as strong a vote as the field geology team. Or someone who was taking orbital observations had just as strong a vote as someone who had a surface experiment. With a group like that you're going to get so many votes for this site and so many votes for that site and not have any unanimity, which simply then allows the program office (MSC Apollo Spacecraft Program Office) to pick whichever one they want to because they're bound to make some people happy and other people mad. The official process took place through the ASSB which was chaired by General Philips and then by Rocco Petrone of Headquarters. There was a representative from MSC, one from KSC, one from MSFC, and others. The science voice at those was pretty much from Bellcomm as far as I could tell, Noel Hinners and people like that.*
>
> *"But the site selection thing became an opportunity for Headquarters to hear the various recommendations and they [the ASSB] were charged with the responsibility of making a recommendation to Mueller who would then meet the selecting commission. But in reality the recommendation was pretty much what MSC ended up recommending. MSC would try as best they could to take into account all of the operational considerations, the safety business, as well as the scientist's preferences, and then present that to the Site Selection Board (ASSB). And sometimes there were other alternates. I don't think that the ASSB ever went against their recommendation. Tycho was an example. (The Tycho site was outside the landing zone that was considered to be within safety limits and Jim McDivitt had stated that they would go to Tycho only over his dead body) If they would have said we are going to Tycho but something ever happened, they didn't want it to look like they went against the recommendations of the operations people"* (Sevier interview, 1995).

Shortly before the Apollo 11 mission, in planning for future missions, the ASSB had selected ten prime landing sites for the ten planned missions in a priority sequence that, at that time, was believed to produce the best scientific return. In addition there were five other alternate sites that represented lunar features that were not covered by the other ten sites. A few other sites of interest were outside the range that was considered reasonable for operational constraints. Many of the selected sites did not have adequate photo coverage. Depending upon the scientific returns and the nature of photo coverage (or lack of it) from upcoming missions it was possible that the list of selected sites might be changed. After the Apollo 12 landing the Apollo 13 and 14 landing sites needed to be chosen. Of the nearly 20 sites that had been selected earlier as potential landing sites several could be eliminated because they did not fit the operational requirements or did not have adequate photo coverage. Others were set aside because they would fit better into the later missions when greater mobility and stay-times were available. GLEP recommended Fra Mauro as the site for Apollo 13's April 1970 launch and Littrow for Apollo 14's October 1970 launch. Following the recommendations of GLEP and the MSC representatives, in October 1969 the ASSB placed Fra Mauro at the top of its list for Apollo 13 and Littrow for Apollo 14, even before Apollo 12 had flown. These soon became the approved landing sites for Apollos 13 and 14 by NASA Headquarters on December 10, 1969. The former would be the first sampling of material outside the volcanic maria, and the latter would sample material on the rim of a large mare basin as well as expand the seismic network. Because of an explosion in one of the cryo tanks aboard Apollo 13, that mission was aborted without landing on the Moon; and the same rationale that made Fra Mauro the top candidate for Apollo 13 still held for Apollo 14. Also the ground track for the Fra Mauro mission was over some areas that required photography for future missions. So the Apollo 14 landing site remained the same as for Apollo 13. This change in the summer of 1970 required a significant change in the orientation of the Apollo 14 training, the details of which will be discussed in a later Section.

Another significant aspect in the astronauts' science training was the plan for a long-term lunar exploration program that was expected to follow the initial ten Apollo landings. Before 1967 there had been significant planning for manned lunar missions beyond the initial Apollo flights. This included studies by Bellcomm, the Lunar and Planetary Missions Division of OSSA, USGS, MSFC, and several contractors. All these activities had been factored into the astronauts' early science training as well as the inclusion of scientists in the later selections of astronauts. Within the OMSF there was an Advance Manned Missions program within which was the Manned Lunar Mission Studies project which was charged with designing a lunar base that was to follow the Apollo Program. In Beattie's book (*Taking Science to the Moon*) he devotes an entire chapter to this work titled "What do we do after Apollo." Beattie was assigned to this project and describes the work that was undertaken in some detail. In short, they were studying how to modify the Apollo systems for longer stay times and lunar base missions under the title Apollo Logistics Support System. By late 1963 there were several studies under way, one of them at MSFC, which produced a 10-volume report titled "Lunar Logistic System." By 1964 NASA began providing funding for the USGS to study the details of geological and geophysical field programs on lunar missions with long stay times. These USGS studies included development of a semi-truck-sized mobile laboratory that simulated a roving vehicle on the lunar surface with facilities that could conduct laboratory tests on lunar samples and run geophysical surveys. In June 1964 the Apollo Logistics Support System was renamed Apollo Extension System to more clearly reflect the nature of its studies.

Much of the science for these later programs was based on the Sonett report, and it should be noted that the early science training programs for the astronauts were undertaken while these future plans were being considered. In particular, the USGS role in the early science training involved some of the same personnel who were working on these future plans. In April 1967 the Apollo Extension System was given a new name, the Apollo Applications Program, and NASA requested that proposals be submitted for manned lunar missions starting in 1971, with surface stay times of 14 days. Clearly, by early 1967 NASA was preparing for extensive exploration of the Moon throughout the 1970s. This led to a summer conference at the University of California, Santa Cruz in the summer of 1967. The Santa Cruz Conference made many suggestions for the types of scientific studies and instruments that should be included not only in the plans for the Apollo program but also in the plans for future lunar exploration after Apollo. Also, with the expected extension of scientific activities on the Moon NASA had issued a second call for scientist-astronauts. Many of the recommendations from the Santa Cruz study were hardly set forth before they were essentially vetoed by events over which the scientists had no control.

Throughout 1967 several events significantly impacted the progress of Apollo as well as the ensuing exploration of the Moon and, as a result, the training of the astronauts. The most serious event occurred on January 27 when three astronauts (Gus Grissom, Roger Chaffee and Ed White) died in a fire that destroyed the Command Module spacecraft atop a Saturn launch vehicle during a simulation at KSC's launch complex 34. This required an investigation and changes in the spacecraft design, which caused a delay of nearly 21l months in the Apollo Program. In addition, progress in the manufacture of the lunar surface instruments whose delivery had been scheduled for July 1967 was delayed for a number of reasons (Compton, p. 95). This delay was causing the Apollo Program Office to consider delaying the deployment of these instruments until a later lunar landing mission rather than the first one. Further concerns about the length of time required for deployment of these instruments by astronauts on the lunar surface began to develop. Astronaut Jack Schmitt had already expressed concern about this: "In the early days, the crews ...were worried about having enough to do on the Moon...In the early design stages, they [the ALSEP designers] took to heart the crew input to 'give us something to do' and it was a monster...The way they had that thing put together it was going to take forever to deploy" (Compton, p. 96). Add to this the full blown war in Vietnam and its increasing demands on the federal budget which caused Congress to reconsider funding for the continuing exploration of the Moon after the first few Apollo missions. In November 1967 OSSA's Lunar and Planetary Missions Board, which advised NASA on the balance between lunar and other planetary programs, met to review the future of lunar exploration. They were uneasy with the current lunar exploration plans that MSC had in mind and requested that "in light of the severe fiscal constraints currently in effect" (Congress had cut NASA's overall budget request by 10%) GLEP should rethink some of their current plans in a manner that could reduce the cost of lunar exploration. Although the Apollo Program was cut by only 2% in the fiscal 1968 budget the space science programs that included exploration of the Moon were cut by 22%. During the budget negotiations in Congress the post-Apollo programs including the Apollo Applications Program and other planetary missions had been either heavily slashed or eliminated (Compton, p. 101-102). By the time the Santa Cruz Conference ended in late summer 1967 it was clear that NASA's budget for the coming year would not include any further exploration of the Moon beyond the already planned Apollo flights.

Despite this gloomy picture NASA Headquarters and MSC forged on with plans for lunar exploration throughout the remaining Apollo missions and extending beyond Apollo. Even before the Santa Cruz Conference, in April

1967, MSC's Science Directorate had developed a plan for lunar exploration that identified the scientific observations that were essential to a basic understanding of the Moon. These plans even included a one-man flying vehicle that would allow for greater range of mobility on the lunar surface. For the remainder of 1967, a joint study team from OMSF and OSSA at Headquarters and GLEP at MSC collaborated on a plan for future exploration of the Moon. In February 1968 Headquarters presented, through the newly formed Lunar Exploration Office, a plan that was even more comprehensive than that of MSC ten months earlier. It included several orbital and surface missions, an extensive network of geophysical instruments, and long-range traverses. The estimates for funding such a program were in the $4.20 to $5.54 billion range (NASA SP-4214, p. 129-131). With NASA's budget already being cut there were many folks who exhibited considerable skepticism about the future for such a plan, and rightly so.

Although funding for extending lunar exploration beyond Apollo was just about dead plans had already commenced to enlist the astronauts needed for these extended missions (Compton, p. 126-134 and 193-196). The announcement of applications for a second group of scientist-astronauts had gotten under way in September 1966 and they were selected in August 1967. The plans for this new crop were based on the expectation of an extended exploration of the Moon. Deke Slayton had a system of promoting the backup crew for one mission to the prime crew three missions later. Before 1967 when there were to be ten or eleven Apollo landing missions and the follow-on Apollo Applications Program, the need for additional scientist-astronauts seemed real. But, as the funding for such programs began to disappear in late 1967 the new crop of scientist-astronauts was about to find that they were not needed. As it became clear that there would be an excess of astronauts for the remaining Apollo missions the eleven new scientist-astronauts dubbed themselves "The Excess Eleven" (Compton, p. 136). In contrast to the training of the earlier groups the initial six months of classroom studies for the new group, totaling approximately 225 hours, included only about 35 hours of geology-related studies. As an indication of the change in training resulting from the change in future mission plans, after they finished flight training in late 1968 they took no further training in geology and never had any field trips. From this point on only the specific Apollo crews would be trained in geology and only for the activities that were related to their individual missions. Apollo 20 was axed in January 1970 because of no funding for additional Saturn launch vehicles, and the remaining missions, Apollo 13 through 19 would be spread out from April 1970 through 1974. But as the war in Vietnam continued and the Apollo 13 mission suffered a near fatal disaster, the budget was getting tighter and there was more of a worry that luck might run out and a crew might be lost. These concerns resulted in the cutting of two more Apollo missions, essentially 18 and 19, on September 2, 1970.

When it became clear by mid-1970 that the future of lunar exploration was in danger of being totally scrapped Jack Schmitt tried to find a way to build more excitement into the program and rekindle the program. He felt that the remaining missions were not going to be daring enough to excite the public and the media. So he developed a series of bold new exciting missions that would challenge the engineers, flight controllers, and the scientists as well as develop some suspense for the media and public. His rationale was: "Americans are historically interested in doing new and exciting things and only secondarily committed to systematic studies and long-range programs…However, it is becoming increasingly clear that if manned spaceflight is to continue as a long-term research and development effort on the frontiers of space and technology, we must continually appeal to the short-term interests and emotions of the American public and the agency" (Schmitt to Record, July 30, 1970). His suggestions included missions to the far-side of the Moon as well as the North Polar Regions. Gene Kranz recalls Jack's efforts which he first learned about through a couple of encounters in mid-1970. Kranz received a call from computer services asking if he had authorized some runs to study a lunar trajectory to land on the back side of the Moon. When he called John Llewellyn, the person requesting this study, to his office Kranz discovered that there was a group trying to revive the space program, and Llewellyn, a very volatile person, stormed out of Kranz's office when Kranz tried to delve into what and who was involved in these efforts. Shortly after this encounter Schmitt appeared at Kranz's door and explained: "I've got a small study group going on alternate lunar missions. We meet after work in my apartment. I provide the refreshments." Kranz went to Schmitt's next study session. He found that "the team believed that if we could pull off something spectacular, something that had never been done before, we might recapture the interest of the American public and get the cancelled missions back in the program. After all, the space hardware was already bought and paid for, and the team did not want to let the Saturn boosters and capsules end up as displays in museums." Kranz believed that "The plan never had a chance…but Llewellyn, Schmitt, and their team members believed it was better to go down fighting than to meekly accept defeat" (Kranz, p. 341-343).

By the end of September 1970 it was clear that the number of remaining missions had shrunk to four and the photo coverage would not be available for all of the originally suggested landing sites. Thus, the combined effects of all the committees, organizations, and outside influences, as well as the lack of a landing on Apollo 13, required not only the reordering of the missions but especially the selection of sites all of which impacted the training. Although the landing site for Apollo 14 was clearly to be the same site that had been planned for Apollo 13, the strategy for the remaining three missions evolved significantly to meet more complex scientific objectives. Each of the previous missions had been designed primarily for one specific objective: samples and general geology of a specific mare region on 11 and 12 or samples and general geology of a hummocky area thought to be ejecta from the Imbrium basin on Apollo 14 (originally 13). If there had been several more missions this strategy of single objectives might have been reasonable; but with only three missions remaining the need to satisfy multiple scientific objectives became paramount. Jim Head, who was involved with site selection for these final three missions, commented "The only push was to get to better, more complex sites; obviously that's what everyone wanted; we were always pushing the operational constraints all the time (Head interview, 2004)."

Shortly after the Apollo 13 mission was aborted in April 1970 GLEP had met and recommended the Davy Crater chain as their first priority for a landing site for Apollo 15. This selection assumed that the Apollo 14 mission would return the necessary photography, but, as it turned out, Apollo 14 would fly too late for its photography to be used for Apollo 15 planning. As a result, the site selection subcommittee of GLEP met again in June 1970 and suggested Marius Hills for 15, Descartes for 16, leaving only Littrow and Hadley-Apennine on the list of candidates. At this point GLEP and the science community disagreed about the subcommittee's suggested site for Apollo 15, and for the next three months MSC tried without success to obtain a consensus among the various scientists for an Apollo 15 landing site. Finally in September, Anthony Calio, Director of MSC's S&AD, summarized the features of the site that he felt met the most broad-based science requirements. It was Hadley-Apennine which provided a sinuous rille, a mare surface, a mountainous highland, and a high-latitude point that satisfied requirements for a dispersed array for both the seismic and laser retroreflector experiments. Also important in this decision was the fact that Apollo 15 commander David Scott preferred the Hadley-Apennine site. On September 24, 1970 the ASSB approved Hadley-Apennine for Apollo 15 to fly between July and September 1971, and Descartes for Apollo 16 to fly between January and March 1972 (NASA SP-4214, p. 218-219). Head pointed out how critical the pinpoint landing at the Surveyor site on Apollo 12 had been for selecting Hadley-Apennine for Apollo 15: "I think I would have absolutely targeted that site [Apollo 12] on that basis alone, in retrospect. The confidence that one got from that landing paved the way for increasing inclination and getting to Apollo 15: when you think about Apollo 15; a 300-meter hole in the ground [Hadley Rille], like a barrier, and next to a mountain [the Apennine Range]" (Head interview, 2004). Although the crew for Apollo 15 had started training together in late 1969 and was officially announced in March 1970, the selection of a landing site in late September 1970 finally allowed the training to be oriented toward the topography and geology that they would encounter on the actual mission.

Descartes had been one of the potential landing sites since early 1969; but, at that time, it was expected that Descartes would most likely be the site for a later mission such as Apollo 18, 19, or 20. It was hypothesized from the orbital photos that Descartes was a highland site with a different type of volcanic material than was found in the mare areas. In addition, it was hypothesized that there was yet another type of volcanic material filling some of the depressions. Some people further suggested that there might also be large patches of ejecta from the Imbrium basin. By late 1970, when the number of remaining missions had been cut to four and one of those was already destined for Fra Mauro and another to Hadley-Apennine, the selection of the remaining two sites became critically important and was placed in the hands of the Ad Hoc Apollo Site Evaluation Committee which had superseded the GLEP subcommittee for site selection. Because of the limited number of missions remaining it was felt that at least one of those missions should be targeted to land in a highland area with a variety of geological units such as those displayed at Descartes. In order to provide adequate photography for the Descartes site Apollo 14 had a special camera, the Hycon camera, mounted on the CSM to take high-resolution photography of the site from orbit. However, a few minutes before passing over Descartes this camera failed to operate; and, despite prolonged attempts to correct the problem, no photos of Descartes were obtained with it. Nevertheless, after the failure of the Hycon camera Stu Roosa, the CMP, managed to shoot some handheld, high-resolution photos of the Descartes site with the Hasselblad camera thereby providing good operational photography for the site. Although there were additional arguments made for other sites after the ASSB had approved Descartes for Apollo 16 in September 1970, the ASSB gave final approval for Descartes on June 3, 1971 (Wilhelms, p. 288). Again, although the Apollo 16 crew had been training together since mid-1970 and was named officially in March 1971, this final approval of Descartes on June 3, 1971 finally allowed the training to be oriented toward that site.

For Apollo 17 the previously recommended sites of Marius Hills and Copernicus were among the ASSB's leading candidates in late September 1970 when Hadley and Descartes were selected for Apollo 15 and 16. But there were others still in the running and orbital photography from 14, 15, and 16 might provide even other possibilities.

Because this was to be the last mission to the Moon Rocco Petrone started the site selection process on October 28, 1971 by circulating a site evaluation document among selected scientists. The scientists were to respond before an ad hoc site evaluation committee was to meet by December 30 and make recommendations to the ASSB in early 1972 (Compton, p. 247). The ASSB met on February 11, 1972 and listened to all the responses that had been received from both the science side and the operations side. The scientists had agreed that the multiple objectives for the selected site should be to investigate and collect highlands material, sample young volcanics, provide good terrain for the new traverse geophysics experiments that were to be used for the first time, and provide coverage of areas not previously investigated by the remote sensing instruments from orbit. Marius Hills and Copernicus were eliminated on either operational or scientific grounds. The only two sites that met both the operational and science requirements were Gassendi and Taurus-Littrow, and the ASSB selected Taurus-Littrow. Among the main reasons for this selection were the facts that Al Worden, the Apollo 15 CMP, when flying over the Littrow site had spotted dark mantle deposits that looked as though they might be young volcanic material, and also the Apollo 15 orbital panoramic photography had photographed the area with a 2-meter resolution thereby providing excellent terrain detail. Although the crew for Apollo 17 had been in training for six months since being selected on August 12, 1971 the training for a specific landing site finally could begin.

Once the nature of the science experiments, the instruments, the hand tools, and the landing sites had been selected, the traverse planning could commence. Because there were so many people and groups involved in traverse planning this topic requires a subsection of its own. Only then can the reader have a complete understanding of how it was accomplished and integrated with the training of individual Apollo crews.

4. Integration of groups and disciplines in traverse planning

Because of the many groups, disciplines, and organizations that required inputs to the science training the nature of the training became more complex as the missions evolved. The traverses became longer in both time and distance, the items of equipment became more numerous and complicated, the use of a Lunar Rover introduced many new experiments along with constant TV coverage by a camera on the Rover, and the orbiter carried additional remote sensing devices for longer periods in orbit. Furthermore, multiple Apollo crews were in training simultaneously. Because of these complexities several iterations for the organization and integration of the mission-oriented training activities occurred over the years from 1968 through 1972.

Jim Head recalls the evolution of his role at Bellcomm, the organization that was meant to keep abreast of all of the science activities and brief the folks at NASA Headquarters on what was happening:

> *"One of the things that we were tasked to do was to think about the major scientific objectives in terms of integrated strategy. The idea was to try to integrate all of this together. The USGS was looking at the geological aspects: lunar geology and landing sites. JSC was thinking more from the sample collection point of view. Some other experimenters were coming in with things that might be on the ALSEP. At the same time we also were helping Headquarters to assess the possible instrument complement that would be on ALSEP. The proposals for that were coming in and being reviewed. We were supposed to be thinking about how all this integrated together. And to be able to present this to the director of the Apollo program: keep that person, who was Sam Phillips when I first started, and then Rocco Petrone, informed on a day-to-day basis. Not just this landing site is good, but this is good both from the geology, the orbital science point of view, the kind of experiments you're going to do on ALSEP, and if so what are the implications of that for future landing sites. If you are going to do one here does that bias you to something in the northwest quadrant to do a seismic net? It was more an integrated science package, not just somebody has a certain view about why we ought to go to a site to get a certain kind of sample but also how does that fit in with, for example, the solar wind experiment. Is that the appropriate place to be? Is this the first leg on a seismic network? What might we learn on this site that's going to influence our selection of the next site? Kind of a rolling, integrated strategy.*
>
> *"Around Apollo 11 it became clear that things were going to get much more complex in terms of the time on the surface and the mobility and so on. At the same time we were doing studies on what do you do with a Rover, what do you do with a lunar flying unit, what do you do with a duel-mode Rover, would you use it on the surface and then send it off to rendezvous with another Saturn V somewhere else? So all those kinds of things we were doing from time to time and being kept aware of other arenas of the program here at JSC and so on. I think a major change somewhere around Apollo 11 was the realization that there's going to be an even more complex systems engineering job here,*

> *which is beyond site selection and it's into the traverse planning. And the people from the Apollo Spacecraft Program Office, Jim McDivitt and others, were really concerned with that. So…the idea developed that some sort of group had to be put together to help make sure that that was a reality and that all sides of the discussion were represented in the traverse planning. From Headquarters, at least, I played a role in that"* (Head interview, 1995).

While integration of the variety of science objectives was under way there were other groups working on the development of the hand tools and cameras that were needed for surface exploration and on the design of the instruments that were to be deployed on the lunar surface. One of the early attempts to integrate science into the development of tools and other equipment was the formation in late 1967 of a Lunar Surface Operations Planning Committee that was chaired by Ray Zedekar of the Crew Systems Division at MSC. This group—included scientists who had experiments on the Apollo missions, personnel who were involved with development and testing of equipment, and people developing procedures to be incorporated into the training—They met monthly through 1968 and covered such topics as the latest results from spacesuit simulations, tool designs, sampling procedures, and life support system capabilities. This group was replaced after 1968 by another planning process (Beattie, p. 99-100). Zedekar then formed the Lunar Surface Operations Panel which continued to work with the same kinds of details. The resulting data could then be used to develop procedures that eventually became important details in traverse planning. Procedures in detailed written form could be condensed into short-hand notes and transferred to the cuff checklists (for an example of a cuff checklist see Appendix R) that were used on the actual traverses starting with Apollo 12.

A major science objective was the collection of samples for the hundreds of PIs who were to be involved in the analyses of the returned rocks and soils. The samples were to be collected on traverses that would use the hand tools, cameras, and procedures that were developed initially by the joint efforts of the geology team and Zedekar's surface operations personnel. The need for specific information about the environment, potential contaminants, and orientation for each sample was important for the wide variety of studies to be undertaken on the returned samples. As a result geologists and operations personnel needed to coordinate their procedures and types of collecting tools with the sample PIs. The initial effort for such coordination was a letter from Homer Newell to Jim Arnold on Oct. 24, 1966 advising Arnold that Shoemaker as PI for the Field Geology Experiment must plan for sample collection to be a joint effort to represent all science fields. Arnold was asked to represent the requirements of the sample PIs in the fields of geochemistry and petrology. This effort eventually evolved into a substantial input from a committee, the Lunar Sample Analysis Planning Team, which represented the entire range of sample PIs. The composition of any tools, collection bags, and sample containers in the LM and the Command Module that came in contact with the samples required careful control dictated by the sample PIs' experiments. The resulting training for procedures and documentation for sample collections on the lunar traverses and storage during the return to Earth was then incorporated into all of the pertinent simulations.

Although the initial planning of traverses was not organized into a detailed plan it eventually became a very well-organized effort that involved many organizations. On Apollo 11 there was very little planning of actual traverses. Because the landing site was designated as a rather large elliptical area no specific landing point from which to run traverses was designated. There were some instruments to be placed, some outlines of procedures associated with the types of samples to be taken; and it was left up to the crew to determine where to accomplish these tasks. For Apollo 12, shortly before the mission, some of the geology team were at the Cape, and Pete Conrad suggested that they sit down together and lay out some traverses. They picked four possible landing sites in the vicinity of the area where they hoped to land and designed traverses from each of those landing sites. Those were the first planned traverses that included time and activities at specific stations.

After the completion of the Apollo 12 mission and its pinpoint landing it was clear that it was now possible to design specific traverses starting from a specific point with designated tasks, time lines, and objectives at several specific stations. Once the planning of such traverses got started it was only natural that there would be increasing demands for time, location, and tasks by the numerous groups who were involved with the scientific investigations. However, there were numerous groups involved with the program, and their coordination was rather informal. On the science side there were GLEP (which was involved in defining the objectives for each site), GLEP's Site Selection Subgroup, the ASSB for site selection, a Lunar Traverse Planning Team to develop the traverses, Lunar Sample Analysis Planning Team for the detailed requirements of the sample PIs, numerous PIs with lunar surface experiments, several PIs with orbital science experiments, the USGS team and some NASA geologists who were training the crews in the field for a few days each month, petrologists involved in training the crews through study of lunar samples and briefings on what was learned from them, and a few others. On the operations side, there also were the flight directors, the astronaut crews, the various engineers (for the Rover, life support, suits, surface tools, etc.), ASPO, and others. Although there was some coordination between these various groups there was no overall committee or panel where all of these folks could be represented in a forum in which all groups could participate.

Following the first Lunar Science Conference in January 1970 there was a meeting on February 5 at which several of the top officials at MSC plus Homer Newell of NASA Headquarters met with nine prominent lunar scientists to discuss some of the issues that had caused a schism between the scientists and the combination of astronauts and operations planners. A major issue was the minimal amount of contact between the various groups. It was felt that the geologists involved in the training had a distinct advantage over the other lunar scientists who had difficulties making their voices heard. Also there was a feeling that there should be a better way for the scientists on the ground to communicate with the astronauts when they were on the Moon. The meeting led to some solutions that eventually worked quite well. The scientists agreed to a greater role in simulations which allowed a better understanding of the constraints under which the operations must be conducted on the lunar surface. And most importantly, the SWP was formed in early 1970 as the single forum to integrate all of the inputs from the science community and coordinate them with engineering, traverse planning, and flight operations. It included PIs, astronaut trainers, traverse planners, site selection representatives, equipment personal, an astronaut crew representative, the Apollo Spacecraft Program Office, and other groups who had a need for input to the missions. The SWP met once a month, generally at MSC where most of the detailed planning activities were concentrated, and information bearing on operations and equipment could be obtained from various MSC sources within a matter of minutes or hours. Appendix O contains the charter for the SWP.

Jack Sevier was the representative to SWP from the Apollo Spacecraft Program Office and his recollection of SWP is as follows.

> *"SWP was a creation of, I don't know whether it was Calio (Director of S&AD at MSC) or the Program Office, but that was who the Program Office listened to in terms of recommendations. I think it was originally Calio's thing. I went to those meetings. It was less than effective when John Zarcaro chaired those things. John's just not that type. He was just a representative of Calio. Then they put Jim Lovell in charge of it and that changed everything. McDivitt (head of the Apollo Spacecraft Program Office) listened to Jim. Jim did a marvelous job of listening to everyone's opinion and getting a consensus about things rather than getting a half a dozen different alternatives and having someone else make the decision. So that became quite effective. SWP became the first place where the science input's operational constraints really got a fair shake in this. The operations folks began to have a much better appreciation for what the science folks were trying to do and at the same time the science folks began to get a real appreciation for what the real constraints were: the safety things and the like. The first time that happened, it seems to me, was when Hadley Rille had been picked as the Apollo 15 site, and Glynn Lunney asked Jim Head and I to come over and brief his mission operations team on Hadley Rille and what the objectives were. I talked about the traverse planning and Jim talked about the regional geology and that sort of thing. Glynn had about 100 guys in the Building 30 auditorium and things really went better after that. There began to be a mutual sort of thing. We're all in this together. The operations guys wanted to get the most science that they can out of it. Also the flight directors began to come along on the field training trips. Gene Kranz, Milt Windler, Gerry Griffin, Pete Frank, and Glynn Lunney began to accompany the geologists and the crews during pre-trip briefings, during the field traverses, and on the walk-throughs after the traverses"* (Sevier interview, 1995).

Sevier recalls that "the first one they went on was out to the Rio Grande gorge at Taos, the Hadley Rille analog. The flight directors really began to get a feel for it being more than just an engineering thing" (Sevier interview, 1995). Actually the first trip that the flight directors went on was to Buell Park, Colorado (see Appendix I) in September 1970, nearly six months before the Taos trip mentioned by Sevier.

The importance of selecting the right individuals to fill the roles of the critical personnel on SWP cannot be overemphasized. Of prime importance was the chairman. For the first few meetings it was John Zarcaro, the manager of the Lunar Missions Office in . John was prone to delaying decisions until the problem could be studied in more detail and he was apt to assign a few people to look into the matter and report back at some time in the future. But a few meetings with such delays prompted the appointment, in May 1971, of a new chairman, astronaut Jim Lovell, who had recently become the Deputy Director of S&AD. Under Lovell decisions were made at the meetings and instructions for actions were given immediately. His attitude was “okay we’re gonna decide right here and now." As Farouk El-Baz describes Lovell's approach: "We're here to do it, so, let's do it. Lovell was good at that" (El-Baz interview, 2004).

The second important individual was the liaison person who maintained contact with traverse planners, scientists, ASPO, and other operations personnel. This person's job involved recognizing problems ahead of time and contacting the relevant personnel to understand all of the ramifications of each problem. This allowed many, if not most, of the problems to be solved before the SWP meetings, and presentations at the meetings could provide enough background material to reach a consensus. This person was Jack Sevier of ASPO. Head describes Sevier and how they worked together: "He was very effective, as you remember, in taking the geological observations and implementing them into the time line and knowing who to talk to and the overall mission development, etc. And he and I would work together, I was sort of independent, he relied on me to help take the things [science activities] that were being developed and help him understand how they might be converted into information for the appropriate people like Ray Zedekar [head of the Lunar Surface Operations Panel] and others. Jack, in developing the traverse planning was very, very heavily involved then, and sort of in Apollo 13, 14, and definitely on 15 through 17, and so we would help to design the traverses, work out the operations in terms of detailed strategies for where you go and what you do and then what the operations were at individual sites. We would work with you guys [MSC science personnel] a lot and with the Survey. Then we'd be the traveling road show for, you know, here's the latest version to NASA Headquarters, to other people and groups at MSC, like the operations people, etc." And Sevier had the perfect personality for the liaison role: "He was an engineer, and he was also incredibly easygoing but intense; he had a laser-like vision of what needed to be done and how you do it but with a completely comfortable and easygoing manner about him" (Head interview, 2004). Don Beattie also singles out Sevier as "a key science ally at MSC. Jack's personality was perfect for the difficult job he was assigned, acting as a mediator between the scientists and the MSC engineers. Easygoing, with a ready smile and a quiet sense of humor, Jack became an important contributor to the rump GLEP meetings starting in 1967 providing MSC's constraints that could affect site selection. He was the Branch Chief of the Operations Analysis Branch and was the focal point for all the competing factors that could influence the outcome of our scientific activities" (Beattie, p. 219).

Throughout 1970 and 1971, as SWP began to develop its structure and its management came under the proper people, the integration of efforts began to show great promise. By the time of Apollo 15 the traverse planning had changed substantially. Head described the sequence for planning the traverses after the selection of the site in September 1970. As a member of Bellcomm he was very involved in the site selection process and was familiar with all the discussions in GLEP and ASSB that had led to the selection of Hadley-Apennine as the landing site for Apollo 15. The objectives of the various investigations in geophysics, geology, sample studies, etc. were well known to him. Again, as a member of Bellcomm and relatively independent of the biases expected of the various investigators, he was asked to put together a traverse that would optimize all the objectives of the various investigators. "When the site was narrowed down to the Hadley-Apennines for a variety of very good reasons: Imbrium basin ejecta, the Maria, etc., then the question became 'where do you land in there'?" Jim commenced to answer this question by developing traverses from five different points within the Hadley-Apennine landing site. "We would put together preliminary traverses to illustrate what you could do at each of those five sites. That was the basis for then doing analyses and deciding where to land, ranging from the source region of the Rille all the way up to the actual Apollo 15 site. So I really had to focus my mind-set on a geoscience objective point of view: how close you could get to the mountains, the importance of the rille, the source region, and this, that, and the other thing. I remember I wrote a memo that had five different points in the Hadley-Apennine region as candidate sites" (Head interview, 2004).

Head's memo (Bellcomm memo from Jim Head dated Oct. 13, 1970) was distributed for comments to SWP members, various MSC organizations, the USGS team, PIs, crew members, and others. At this point Sevier became very important for the next step which was to interface with all of the groups at MSC who would overlay all the operational constraints on the traverses. "Immediately after you developed those candidate sites there'd be operational discussions, there'd be presentations about these, and people would be doing analyses; some at Bellcomm, but primarily at MSC. And this is where Jack was really critical, making sure that we were talking to the right people, etc. At some point a decision would be made on narrowing that down. And then, part of the selection had to do with how good they [each of the five possible landing points] were operationally. And working with Jack, we worked on the 7-km (4.4 mi.) radius for the life support system, the buddy system constraint, along with their metabolic rates and so on. That was great because then we could take a landing site with the 7 kms (4.4 mi.) and do a lot that way. Then talking with the crews and working with Jack Sevier, because he was an engineer, we would develop these kinds of candidate traverses and then we'd say 'Gee with all the operational constraints, if everything else is equal, it looks like the one on the north is the one to go to because you can do it all. We can get to the mountains, to the Rille, you can do the Maria, and here's a few crater clusters and you can get some secondaries.' You know there were a lot of people involved. And then we'd also talk to all the science working groups who were involved with that all the way along: Here's what we think; here's the ideas." When asked if they requested input from the ALSEP PIs while developing the traverses Jim responded that from his participation on GLEP "we pretty much knew what they wanted, from our interactions with them, like optimize the triangles for the seismic data, and most of the others were fairly straightforward. Our job was not to just do geology. Our job was to optimize the whole thing" (Head interview, 2004).

A similar procedure was followed for the remaining two missions. At some point in the development of each planned traverse for each mission the traverse was further massaged by a Lunar Traverse Planning Team. The traverses were then presented to the monthly meetings of SWP where there were representatives of the Traverse Planning Team, the Surface Operations Panel, the USGS geology team, the ALSEP PIs, the orbital science PIs, the sample PIs, ASPO, the crews, the science trainers, flight operations, NASA Headquarters, etc. At these meetings all the relevant personnel could make their inputs. If any of the inputs required any potential changes to the traverses the Panel would then discuss how such changes impacted the timelines, other science experiments, and operational constraints. After a full discussion decisions would be made on what, if anything, would be modified.

As an example of the evolution of traverse planning we can look at the manner in which the final plans for the Apollo 17 traverses were documented. On June 19, 1972 the first edition of Apollo 17 Traverse Planning Data was published. It was compiled by a broadly based team representing the geology team, Bellcomm (Jim Head), ASPO, FCO, and engineers. It included the potential traverses for all three EVAs with times, stops, tasks, constraints, instruments to be deployed, procedures, etc. Following many discussions with various scientists, mission planners, ASPO, and reviews at SWP meetings, a second edition was published dated September 1, 1972. This edition contained various modifications to the first edition, such as revised times and changes in locations of stops. After further reviews and discussions a third edition was published on November 1, 1972. This edition contained several changes to the traverses, tasks for the newly approved 500-mm camera lens, a better definition of station tasks, a change in location for the heat flow experiment, moving the SEP deployment to the end of EVA 1, and moving station 10 to 10b. Even up to the last few days as the crew was at KSC, and the geologists were meeting with them regularly in the evenings, a few last minute changes might still be possible.

Jim Head was responsible for regularly briefing Rocco Petrone, head of the Apollo Program Office at NASA Headquarters, on the progress of traverse planning and other aspects of the upcoming missions. When asked of his impressions of Petrone's reactions to the science activities Head responded: "I think he was somewhat of a detailed kind of guy. He'd kind of want to know in depth about a lot of things. I had a very strong sense that he—for example when I'd give my briefings to him as part of the larger briefings on the mission status, which was fairly often, and I'd tell what field trips we'd been on, the science we've been thinking about, here's the traverse status, etc. he was always very interested in that. I would say interested in the fact that the crew was getting out there and really participating in the field trips and training. I always felt very positive about that. Never did I get a sense that he felt that it was interfering with their real job. Quite the contrary. He had a very strong view of exploration and science and doing things right. In fact, my sense is that he, in fact, was pleased that they were getting as much science as they were. We would have these briefings that used to drive a lot of the people who worked for him nuts but I'd always start my briefing with a full Moon viewgraph. It would invariably set off a 'Oh yeah, that reminds me. I've been thinking about a problem here.' He'd put his big meat hook up on the table and you could just see all his engineering colleagues roll their eyes in the background. It was going to cut into their time. He just loved it. He really understood the science and had thought about what had happened since our last talk and was interested in the details about how it was going to be done. He was very positive that way. A lot of people couldn't care less: 'Just get the suckers there and get them back.' From a crew training point of view that meant that I participated in a lot of the training trips to various places, particularly when we started doing traverse simulations where you hear the backroom kind of thing. That was also very important because he wanted to know what did the simulation look like? How did it go? What's working and what's not?" (Head interview, 2004).

5. Rationale for content and types of training

The scientists and astronauts understood that not only did the science experiments need to be easily accomplished through well-understood procedures that the astronauts practiced, but also the nature and importance of the data to the basic scientific understanding of the Moon should be provided to the astronauts. The training, therefore, involved field exercises to develop experience with the use of each of the hand tools and practice in verbal descriptions of geologic features, lectures on the basic science of the missions, recognition of rocks and minerals, flyovers of terrestrial features for developing acuity in orbital observations, practice in setting up instruments, PIs' lectures on specific experiments, and a few other activities. Although all of these aspects of training were well developed by the end of the Apollo program they all evolved with time as the missions became more science-oriented and the scientists developed better insights into what data they needed and into what the astronauts were capable of accomplishing both on the lunar surface and from orbit.

Before Apollo 11, the planning for the classroom activities through Apollo 13 included:

1. Eight hours of review of mineralogy and petrology
2. Four hours of rock descriptions with emphasis on volcanic and fragmental materials
3. Two hours of meteorite identification and descriptions
4. Two hours of terminology and principles for particulate matter
5. Four hours of Orbiter, Surveyor, and Ranger photography
6. Six hours of Orbiter photography for specific Apollo sites

It was a general rule of thumb that a minimum of 4 hours of preparation was required for each hour of class time. It was recognized that there would be differences in the degrees of training among the flight crews and some accommodations to the above plans might be necessary (Geology Training for Apollo Crews, undated [early 1969], unsigned document from Uel Clanton).

The field training was necessary to develop the techniques required for proper procedures during photography and sampling as well as keeping track of location and time. These techniques had to be so ingrained that very little thought would be required for the routine procedures, thereby leaving plenty of time for the astronauts to observe and describe the terrain and devise approaches to studying each station on their traverses. It was felt that this would require the astronauts to perform simulated traverses in locations that were similar to their respective landing sites on the Moon. Such traverses would be of similar duration to their lunar traverses and, by the end of the Apollo missions, would be carried out for at least two days per month during the year before the actual mission.

The early plans for field training (Geology Training for Apollo Crews, undated [early 1969], unsigned document from Uel Clanton) required that the geologists assigned to each flight crew determine what simulation sites have topography, morphology, and lithologies that are applicable to the particular crew. In order to select the appropriate areas a rather detailed planning procedure was followed. Two to six geologists would visit a potential field site. Although prior information might suggest that an area was appropriate it should be emphasized that only walking through the entire area will permit final approval of a site. After a 12- to 14-hour day of close examination a site might be found unsuitable because of poor exposures, inaccessibility, difficult topography, etc. As a general rule between two and four man-days were required for each hour of acceptable field exercises for the astronauts. During these investigations of potential sites notes were taped and photos were taken for features of interest. These notes were used to determine times, mileage, morphology, tasks, etc. for the possible areas for field exercises. Comparisons of the various areas led to the determination of exactly which sites would be used for astronaut training. The last day of the reconnaissance was usually devoted to shooting aerial photos of the potential areas. One of the geologists was a pilot and, using a rented plane, photos could be taken for use during further planning and also during the actual field trips.

Back in Houston the tapes were transcribed and the photos developed and the best aerial photos were selected for enlargement to prepare photo maps at 1:5000, the same scale as the lunar maps to be used on the actual missions. Many man days were required for proofreading the transcripts, reviewing photos, and verifying scales on the final photo maps. At this stage a field trip plan was assembled and included time to be spent at each site, driving time between sites, geologic features of interest along the way, arrival and departure times, motel facilities, eating provisions, and equipment required. A date for the trip was then arranged to fit the astronauts' schedules. One to two days before the actual field trip the geologists and equipment personnel packed up their gear and traveled to the field location to set up equipment, make final checks of the exercise areas, and make sure transportation, lodging, and meals were all set.

Beginning with some of the Apollo 12 exercises the crew would be in voice communication with the CapCom in a simulated backroom and all conversations were taped. On completion of each exercise a 20-minute to one-hour debriefing was carried out while still in the field location to determine how well the crews did on the exercise, how well the tools and other equipment performed, and how well the procedures worked. Upon return to Houston the collected samples were laid out, the tapes were transcribed, and the photos developed in preparation for a detailed critique with the astronauts. The photos and transcripts were correlated with the samples and further related to the geologic features that were studied. It is estimated that each critique required about 8 hours of preparation by the geologists for each exercise. This would include notes on evaluation of photography, adequacy of samples, and completeness of descriptive information. The resulting critique with the crews would last for 2 to 4 hours.

Bill Muehlberger describes the nature of the field training by the time of Apollos 16 and 17. "It was operated as if we were on the Moon." There would be briefings by the people who made the traverse maps, usually on the evening before the field exercise, and the crews, the CapCom, the backroom personnel, and the support group would be introduced to the next day's traverse. "First of all there's an aerial photograph which had been interpreted as 'Here are the things that are here, and here's the route that you ought to go to check and make certain these are the correct interpretations.' And that's all I knew about the area, [as well as] most of my group."

On the day of the exercise the crew would start off on a predetermined traverse with several stops and a time line with designated tasks and observations to be accomplished at each stop. In a tent somewhere out of sight of the astronauts was the backroom group. "We would be sitting there playing Mission Control with the astronaut who was going to be on the radio at Mission Control, the CapCom, he was there working with us, and he talked to the crew. So we talked to him and he talked to the crew, sort of a short-circuiting of the Mission Control approach to life. The backup crew for the mission went through exactly the same training that the prime crew did. The only difference was they left about a half hour later on the field trip loop than did the prime crew, and, therefore, we had two Mission Controls, one for the prime crew and geologists working with them, and one for the backup, two different sets of two-way radios on different communication systems, so that we could talk to our crew rather than interfere with the other one by doing that."

Muehlberger also explains how the crews used cuff checklists during the training.

> *"They'd have cuff checklists just like they had on the real thing, which is at that stop [demonstrating on one page of an actual cuff checklist], and then the other side of the page would be the instructions on what you're to do(see example in Appendix R). Then you can flip the page. It also would tell you how far was the next one [stop]. These were designed by the astronauts for their own use, so one of my guys, seems to me he spent half his life, between flying to the Cape [Canaveral, Florida] and flying to Flagstaff doing these modifications until, finally, everybody, the crew had what they wanted. Those [the completed cuff checklists] are the things that went with them.*
>
> *"So these exercises would last between 3 and 4 hours each. Then when they were done doing it, we'd have a radio talk back and forth, in which we'd ask questions and they would explain things or they would try to amplify what they'd learned, so we figured we had the answer now. Then we'd go have lunch, and then that afternoon we'd go walk through the same trip. One of my guys had been out with the crew, so he had a radio and he could hear both sides of the conversation. He could see what they were doing, which we couldn't. We didn't have a TV on the fake Rover that we used. It ran on a battery and ran sort of like the Rover, but it was still mimicking. You didn't have all the good gadgetry. So then he took over [on the walk-through after lunch] and said, 'Okay, backroom. They told you this and this and this. Now, look. If you had asked this question, look what you would have learned.' And they thought, 'Oh, we blew it.' Or 'Crew, you told them this and this and this and led them off on this wild goose chase, when you should have phrased it this way,' or whatever.*
>
> *"So we were each learning how each of us sees these things, as well as what we're going to say about them, so when they finally get to the Moon, they know those rocks perfectly well. So these exercises were the major training game to get them designed. Then, of course, the real exercises or the real things on the Moon, we talked those over with them so many evenings there at the Cape, they knew it all by memory.*
>
> *"These exercises got more and more complex through time and they were trying to be similar in length and in the kinds of things they would be doing when they went to the Moon, because we had to interpret the landing site. Once the landing site was picked we had the job of designing the traverses that they would do, and training the astronauts on how to do them. So we would set up these field trips to similar kinds of things so they would get familiar with that feel. Then the last exercise was a full-up thing, we're in Mission Control and they're out there in the field somewhere radioing back and*

> *everybody playing that this is the real thing around the Moon bit"* (Muehlberger interview, JSC oral history, 1995).

The field exercises were meant to develop the techniques of not only the crews doing the surface procedures but also the group working in the backroom. Muehlberger describes the technique for collecting samples: "We had a little tripod [called a gnomon] with a rod sticking in it that was free-floating, so it was always perpendicular to the ground, and it was painted with one-inch stripes so it was a rod in which you knew the dimensions. On one of the legs was a panel with colors on it, and you knew the real colors, so, therefore, when the pictures came back the photo lab was supposed to match the real colors rather than invent colors like they seem to do so often. That was set down in front of the rock that was going to be sampled with the color thing pointing at the rock and into the sun. Then they would take two pictures. This gave a stereobase to look at it. Then they took [another] one, sort of a regional one, so just looking at that rock you were seeing enough of the setting that you could figure out where that rock was sitting on the Moon before they picked it up. Then they picked it up, told us the bag number. These bags had little aluminum strips to them and they could pull those things like a baggie and give the Teflon bag a flip and then bend these aluminum tags over and the thing was sealed in that bag. We knew the number of the bag, if they remembered to tell us. One of my guys [in the backroom] kept track of all the bags and what rocks were in each one" (Muehlberger interview, JSC oral history, 1995).

Muehlberger also notes the important role played by the previously returned lunar samples. "The other part of it was run basically by the Johnson Space Center (MSC at that time) geologists who had all the lunar samples. The astronauts were taught about all the different kinds of rocks and they saw all the lunar samples, [so] they had a knowledge of what we'd collected already, so that when they went to their area they could see something different or, 'They're all like the ones we've gotten back there, so we'd better get a bunch of representative ones,' or whatever the case may be. So there's two different groups that were teaching them. We always had one of the Johnson Space Center people working with us [in the field], so that there was some cross-reaction in this whole thing."

Field training not only provided experience in the procedures for the crews but also provided information for the logistics required for the flight. It was standard procedure to keep logs during field training of the number of photos taken, the number of samples collected, and the weight and size of the samples. From these data it was possible to predict the number of film magazines and sample bags needed, the volume of storage space, and the returning weight load to be planned for the missions. For example: the Apollo 15 crew averaged about 150 photo frames per hour during their geologic traverses suggesting that 14 film magazines would be necessary on the actual mission.

The field exercises also provided an opportunity to fine-tune any problems with the hand tools, cameras and other equipment. During the field exercises there were personnel to provide and maintain the hand tools and cameras. Problems with these instruments were always documented and either corrected on the spot or slated for further study on return to Houston. For example, on one of the Apollo 15 trips both the prime and backup crews had trouble with the release mechanism on a new design for the tongs used to pick up samples. On the same trip it was noticed that the scoop for digging trenches had a rounded shape that did not allow digging a trench with sharply defined walls. Also an extension handle failed to attach. These problems would be reported to the engineers and modified for the next trip.

To develop a sense of the scientific importance of their exploration and their ability to make contributions to lunar science, the astronauts were introduced to the problems of lunar science via lectures and sample studies. Before samples were returned the principal source of lunar data came from telescopic observations or the photos and remotely sensed data from Ranger, Orbiter, and Surveyor. From these sources maps had been made of the different albedos, colors, and textures to produce map-units of the many varieties of surficial features, but the exact nature of the materials was unknown. There were also the basic astronomical data of size, density, albedo, and surface temperatures for the Moon. All of these sources had been combined to provide hypotheses about the nature of the lunar rocks, volcanism vs. impact origin of craters, age of the Moon, and origin of the Moon. Although these topics were covered in lectures for the early Apollo crews the importance of safely landing on the Moon and returning were paramount, and the lectures were met with rather indifferent attitudes.

After Apollo 11, however, the research on returned samples began to provide information on rock types and their ages. More specific models for the internal structure of the Moon as well as theories of its origin began to emerge. This provided some fodder for lectures to the crews to develop an interest in the scientific knowledge to which they were contributing. Several hours of lectures were included in the training for the later Apollo crews to cover the results of the ongoing research and to present different sides of the hypotheses that were beginning to develop about the origin and evolution of the Moon. The lectures were designed to cover a wide range of lunar observations, including geology, geochemistry, geophysics, lunar atmospheres, and cratering processes. Once the astronauts had some indication of what they could do to help solve lunar problems in each of these fields it was felt that they would be more enthusiastic and even compete with each other in what they could contribute. This concept became quite evident with the crews of Apollos 13 and 15 through 17, even to the point of proving that some of the hypotheses were incorrect. For example, in some cases the people doing the mapping were a bit too hasty in hypothesizing about the origin of their mapped units. At the Apollo 16 landing site the rather flat units had been mapped as volcanic and much of the training was geared toward volcanic rocks and features. But when the crew began traversing the surface they found very little evidence of volcanic rocks. Their observations, plus the study of returned samples, made it quite clear that the rocks were mainly impact breccias suggesting that this was a surface formed by the debris from many cycles of excavation by impacts into a very old lunar crust. As John Young commented when asked about his reaction to the breadth of training in addition to that which was geared to his specific landing site at Apollo 16:

> *"The theory was that when we went to the Moon on Apollo 16 it was supposed to be some kind of volcanic rock and it didn't turn out to be that way. You could sort of tell that and I think we tried to say that but they were arguing against us all the way back. I remember that part. So it turned out okay when they got the rocks back. But I'm glad we got to see all that stuff (on the other field trips). We got to see anorthosites at the Duluth gabbro, and we saw them out the San Gabriel Mountains. The ones at the Duluth gabbro had a remarkable resemblance to the ones out there that we found at the 16 place"* (Young interview, 1995).

Clearly, any advance knowledge of the types of rocks and soils on the lunar surface would be of great advantage when the astronauts were making selections on their traverses. The initial study of rocks and minerals before the lunar landings required the use of terrestrial materials based on some intelligent guesses about the nature of the material that might be present on the Moon. But once the samples were returned from the lunar surface the studies could now concentrate on actual lunar samples rather than the terrestrial materials. As more and more samples were returned by each mission the nature of the variety and condition of the rocks and soils as well as the subsurface layers in the cores provided a much better understanding of the material that could be collected on the lunar surface. As the missions progressed a greater variety of samples provided a much better set of materials for training purposes. The problem was now one of selecting a good representation of the wide variety that was available. The trainers gradually developed a good representative set and provided photos and descriptions of these materials for the astronauts to study. Several one- to two-hour laboratory sessions with these lunar samples were provided for the crew members of the last three missions.

Some of the orbital science activities involved remote sensing instruments that required little more action from the astronaut than making sure the spacecraft was in the correct orientation and activating a switch to start it and again to end it. Very little training other than lectures to explain the nature and importance of the data was devoted to these experiments. Most of the orbital science training, however, was directed toward observing, describing, and photographing features that were recognized by the pilots as of interest in solving geologic problems. This activity required both lectures on what could be observed from orbit and experience in making such observations by means of flyovers. The lectures were devoted to features that might be observed along the orbital paths for each mission as well as the importance of these features to understanding the origin and evolution of the Moon. The flyovers were conducted two or three times a month over terrain that provided reasonable analogues for lunar features. To be most effective the flyovers were accomplished in two modes. One was done in T-38 jets at high altitudes that would provide the best simulation for orbital observations around the Moon. After the high-altitude flyovers the same terrain would be overflown in light planes at low altitude to see what the features looked like at close range. During the flyovers the astronauts were taking photos and tape-recording their verbal descriptions, just as would be done from lunar orbit. The developed photos and the tapes allowed for detailed critiques of the astronaut’s performance.

For the ALSEP and other experiments that were deployed on the lunar surface the variety of needs of the many PIs generated a variety of training requirements. Some experiments required very little training in the deployment procedures, and these PIs needed only a lecture to explain the basic scientific reason that their data were needed. Others required setting up instruments that had to be unstowed and opened to an operating configuration as well as laying out cables. These required not only lectures from the PIs about the nature and importance of the science but also detailed procedures that required substantial training. The deployment of the ALSEP instruments required many iterations at the Cape or Houston in a pressure suit. For the later missions access to a roving vehicle and longer EVAs created an opportunity to add experiments that might take advantage of the additional distance or time that would be available. These experiments included a portable magnetometer, a traverse gravimeter, and a device for measuring surface electrical properties, all of which required instrument activation and taking readings at various points along the traverses. A seismic profiling experiment required setting up geophones and/or deploying charges at various points along the traverse to be detonated later as seismic sources. For such experiments to become part of a routine procedure it was required that they be integrated into the field training as part of the scheduled activities of the timelines on the field traverses.

6. Field training for surface-science procedures

Field training was perhaps the most emphasized of all of the science efforts because it involved most of the EVA time on the lunar surface. Activities that were emphasized included: selecting proper locations to stop, collecting representative rock and soil samples, digging trenches and sampling different levels of the trenches, driving core tubes into the soil and extracting them without losing the contained soil, describing the geologic features verbally, documenting the sampling with photography, overlapping panoramic photos of each stop, setting up instruments on the surface, keeping track of locations on maps, adequately labeling the samples for later recognition, etc. All of these activities had to be practiced over and over as well as critiqued in debriefings for more than a year for each crew. This part of Section III will describe these efforts in some detail with specific examples for each mission as illustrations of the wide variety of people and the painstaking methods that were involved. A detailed schedule of the field exercises and participants is provided in Appendix I.

The science training program for the lunar landing missions became very hectic. The original schedule for landings every three months would have stretched the system beyond its limits. For every mission there were at least two crews, both a prime and backup crew, in training at any given time, and the training consisted of both orbital and surface components. For the surface component alone, there was one field trip of two or more days per month for each crew after Apollo 11. During the final six or seven weeks before a mission, there would be several dry-run simulations of the traverses carried out through Mission Control with all of the operations personnel and the science teams in place at their consoles. In addition, there were many hours of study with orbital photos and simulated terrestrial flyovers of appropriate landforms by the CMPs. Add to this the lectures by PIs, studies of lunar samples after they were returned, practice in setting up instruments, and debriefings for the field procedures after the field trips, and it adds up to several days of science training per month. All of this had to be integrated with the even more intense operational training for the astronauts in the simulators as well as inspection trips to the factories where the equipment was being fabricated for their missions. Scheduling these activities for two or more crews simultaneously was a grueling task. The scientists involved in the training had the additional problem that they were also involved with the opening, documentation, descriptions, and early studies of the returned lunar samples as well as putting together reports on the geology and samples from previous missions. For each mission the time required for preliminary examination of the samples and preparation of reports grew to several months in length as the missions grew longer and returned greater amounts of samples from each landing. Even further, after the return from each mission the astronauts met many times with the scientists who had been involved with both the opening of samples and the training. The sample sessions involved viewing the samples over the several weeks that they were being opened to discuss what could be recalled about the collection of the samples. There were other sessions with the geology team in which they reviewed photos and TV from the missions, again to recall what they saw as well as their interpretations of the geologic environment. Clearly, there was a growing need for the missions to be spaced over nine months to a year apart unless more personnel and equipment were added for both the training and the sample facilities. The following paragraphs describe the field training efforts that were undertaken with each of the Apollo crews.

Apollo 8

Although Apollo 8 was an orbital mission with no lunar landing the crew did have a field trip into the Big Bend area of west Texas, at which time they went through what was, in effect, a landing mission: the crew collected rocks and made comments on the geologic setting of the samples that were picked up to be brought back (Clanton tapes, 1975). Preparations for this trip were made on January 15-17, 1968 when Clanton, Dietrich, McKay, and Hait visited the area to plan the details of the exercises. The trip with the crew was made in February 1968 before the reversal of the Apollo 8 and 9 missions in August 1968. Therefore, the participants were actually considered as the Apollo 9 crew at the time of the field trip. But at the time of the field trip both Apollo 8 and Apollo 9 were to be Earth orbital missions, so there was no real reason for either of these crews to undergo any extensive surface science training. In addition, according to an unsigned memo, the eventual Apollo 8 crew, during early 1968, had also undergone 7 hours of review on mineral and rock identification, a one-hour review of general geologic principles, 4 hours of lunar photo interpretations, 2 hours of lunar Surveyor results, a 1-hour briefing on the lunar geology field equipment, and a 2-hour lecture on meteorites. The memo that includes this information is dated June 3, 1968 and states that it is an outline of the geology training program for lunar landing missions. In addition, Ray Zedekar's calendar shows a total of four ALSEP deployments, two in shirtsleeves and two suited, in April and June at MSC. It is not clear why the Apollo 8 (originally Apollo 9) crew received this training when they were not expected to take part in a lunar landing. The training for the more suitable orbital science is discussed in a later Section.

Apollo 10

Because Apollo 10 did not include a landing on the lunar surface, no surface science exercises were conducted. In some of his notes being collected for a history of astronaut training, Jackson lists Pisgah Crater as a field trip for the Apollo 10 crew on March 26-28, 1968,; but this was only a scouting trip to determine whether it would be a good location for a future trip. It was never used as an actual training site. There was an extensive amount of orbital science training that is discussed in a later Section.

Apollo 11

The first real planning for surface science training for a specific mission began with Apollo 11. Although all of the Apollo astronauts had undergone field geology training in their general training in the mid-1960s, there had not been any training for setting up instruments and collecting samples for a specific mission to a specific lunar location. Therefore, setting up such training became a learning experience for all concerned and required the participation of many personnel. Before the science activities for Apollo 11 were finally put in place there were a number of events that determined the scope of these activities. While the Apollo 8 crew was being trained for their lunar orbital mission in late 1968, the President's Science Advisory Committee asked for their first briefing on the Apollo 11 mission. Buzz Aldrin and Jack Schmitt were assigned the lunar science part of that briefing. Aldrin did the orbital science portion of the briefing and Schmitt did the surface science portion. According to Schmitt, "That was the first time that we were forced to put together a time line for a two-EVA Apollo 11 mission. That's when Ray (Zedekar) and I really started to work together a lot on that time line. The impact on training was that....we finally had something that we could focus our attention on, even though it was not the time line that was ultimately used. It was more like an Apollo 12 mission. But it started to focus the training a great deal because we now had a time line. The President's Science Advisory Committee deserves a lot of credit for insisting that they get briefed even though we were working our butts off at the time trying to get ready for Apollo 8" (Schmitt interview, 1995).

Eventually the second EVA for Apollo 11 was eliminated and a single-EVA mission was adopted. In addition, there were changes in the nature of the instruments that were to be deployed on Apollo 11. The initial plan was for Apollos 11 and 12 to deploy an ALSEP package that consisted of a magnetometer, seismometer, suprathermal ion detector, solar wind spectrometer, and heat flow instrument (Compton, p. 85). In addition, there was to be a laser corner reflector and a solar wind panel. There had been a few problems with the ALSEP package, as mentioned earlier. In addition, according to Schmitt, he and Bill Anders attended a preliminary design review (Schmitt believes it was sometime in 1967) at the Bendix factory that was building the ALSEP instruments. "We got up there and there were like 59 of these so-called calfex fasteners holding things together and everyone took a full turn of the hand to let it go. We both said you can't do that. They said 'Walt Cunningham told us to do it that way' and we both said 'What?' They said 'When Walt first came up (Walt had the job in the astronaut office to look over the science stuff) Walt had said well, give us something to do.' So they immediately felt like they could use whatever fasteners that they wanted. Bill said 'what you need is a big red button. We'll kick it and if the thing is deployed we'll go on and do something else.' Well, we made some progress. We ended up with 19 of those fasteners and it just took a quarter turn to release them. Thinking about training for the ALSEP began in those days" (Schmitt interview, 1995).

In early 1968 the Apollo 11 mission was being considered for two EVAs. The question of science priorities was debated, especially for the purpose of ALSEP deployment. It seemed clear that the ALSEP would be deployed during the second EVA on the first mission but during the first EVA on the second landing mission. Apparently, some confusion about this is indicated in a letter to Hess from Gene Simmons in which he implies that the draft of a letter to Headquarters from Hess must not have made clear the ALSEP deployment question. Simmons requests that Hess amend the letter "to indicate that on the second mission, the ALSEP be deployed on the very first EVA" (Simmons to Hess, March 11, 1968).

The ALSEP deployment question was soon settled by other circumstances. By mid-1968, simulations with the ALSEP showed that suited astronauts encountered difficulties in deploying the package. A letter from Gilruth, replying to a request from George Mueller, scheduled a simulation of the ALSEP deployment for August 15, 1968, in which astronauts Schmitt and Lind would perform ALSEP deployment as well as other tasks including parts of the geology experiment. In addition, there was to be a presentation and a movie for Mueller of these activities in lunar gravity on the KC-135 aircraft and in the POGO simulator. Also in this letter Gilruth confirms that in a recent simulation there were “several problems with experiment alinement [sic] methods which we had previously suspected from other tests” (June 27, 1968 letter, Gilruth to Mueller). Further concerns with weight in the LM and the energy source for the ALSEP instruments led to discussions about a smaller, less complex instrument package. Added to this was a growing concern for crew safety and mission success on this first attempt to land men on the Moon. All these concerns led to a proposal by Sam Phillips in August 1968 to limit the mission to only one two-hour EVA that was to involve only one astronaut. Furthermore, the recommendation at that time was to carry no scientific instruments to the lunar surface and to limit the geology investigation to collection of the contingency and preliminary samples on this first landing mission. These suggestions were based on simulations that indicated that at least 1½ hours were required for ALSEP deployment and 3 hours for the geology investigation. Also, the amount of weight assigned to the ALSEP central station seemed too large if its deployment was limited to only one instrument in an effort to save time (Memo with attachment of Aug. 30, 1968, Phillips to Gilruth). A memo from George Low on September 13, 1968 indicates that the OMSF Management Council reviewed Phillips’ recommendations and had generally accepted them with some additional comments, including the following: “we would run detailed studies of the value of single-man versus two-man EVAs. In connection with the alternate scientific experiments…work with Bill Hess’ people in order to get the simplest possible mechanization of the new experiments.”

When the decision to shorten the Apollo surface activities to only one EVA of about 2½ hours duration without deploying any of the ALSEP instruments was announced, there was a backlash from some of the science community and the priorities of the planned surface activities were reconsidered. The difficulties with ALSEP and the fact that it was nominally planned to be deployed on the second EVA led to the need to somehow lessen the time for instrument deployment in order to have time for the geological sampling and photography. In an ensuing meeting at MSC Schmitt suggested that "if there's a possibility that you're not going to fly the ALSEP we need to work on what experiments should fly that are fundamental. If you never got back to the Moon what would you want to have there? I had talked with a lot of people and suggested the seismometer and the corner reflector. Bill Hess came absolutely unglued. .... He's probably never wanted to speak to me again, since I would even suggest that ALSEP wouldn't fly on the mission. George Low was going to look for every pound that they could in order to maximize hover time for that first landing. And ultimately that's what happened. ..... Gilruth authorized that EASEP [Early Apollo Scientific Experiments Package] alternative." EASEP included only three experiments: the seismometer, the corner reflector, and a solar wind panel, and NASA Headquarters accepted that as the new package on November 5, 1968. On December 2, 1968, George Low sent a memo to Sam Phillips indicating that MSC and the Apollo Program manager had agreed on the contents of the EVA. Among other things this provided for a two-man EVA with the second man egress about one hour after the first man, various photography and sampling procedures, and deployment of EASEP (memo Dec. 2, 1968, Low to several recipients). "Those things also began to focus our attention more on the ALSEP and training for the ALSEP" (Schmitt interview, 1995).

When the Apollo 11 crew was announced in January 1969 with a planned launch on July 16, 1969, only six months was available for all of the training. Regarding the science training for the surface activities, according to Clanton, "the constraint that everyone was working under was that the Apollo 11 crew had a very limited range and capability. The mission was designed such that a landing...and a successful recovery of crew was considered a successful mission. Anything beyond that was extra. Consequently, the Apollo 11 surface-science training was quite limited both in the classroom and in field geology. There was one field trip to the Quitman Mountains [in February 1969]. The exercise consisted actually of two different areas, one of them was the so-called ‘broken gate’ area; the other one was the ‘sand dune’ area. A third area that was worked during the Apollo 11 [training] mission was the so-called '50-foot circle.' There was some indication, even at a month or so before landing, that the people would only perhaps move in a 50-foot, or maybe 100-foot, radius from the LM. So the third area was distinct from the first two in that the crew was put into a very limited area to collect samples, to photograph, to document. The training...was accomplished using tape recorders, and then the tape recordings were transcribed back here (MSC) and the samples that were collected laid out on the tables here and evaluated and discussed with the crew. The tools were very limited and the total procedure was very cursory” (Clanton tapes, 1975). The radios and tape recorders which had been in use on the earlier geology training trips were supplied by the geology trainers from MSC, while the cameras, gnomons, hammers, scoops, and other hand tools were supplied on the Apollo 11, and on later field trips, by Ray Zedekar’s personnel in the Lunar Surface Procedures Section of FCO.

The main purpose of the Apollo 11 field trip was to practice sampling the variety of rocks that were present and obtain a representative collection of all of the types that were present. Collecting a variety of rocks, however, was made difficult by their altered surfaces. Dietrich recalls that "we took them into one place with rocks that all looked alike but were different when you cracked them open. And we had another site over yonder where they looked all different, but when you cracked them open they were all alike. They had different kinds of weathering on the surface" (Dietrich interview, 1995).

According to some later recollections by the USGS' Bob Sutton, this training trip included a second day at Kilbourne Hole, New Mexico. He indicates that this was "a show-and-tell exercise to acquaint the crews with maar deposits, tuff breccia, and xenoliths as well as stratigraphy and structures of volcanic and non-volcanic rocks." Sutton was "really amazed at how little the crews had been trained in photographic procedures from Batson and our group [USGS]" (Sutton, personal notes, 1975). Others involved with this Apollo 11 trip indicate that there was no second day associated with this trip and Sutton was not on the trip. Sutton may have been thinking of a later trip to these locations with another crew: there was a two-day trip to these two locations for Apollo 14 in which Sutton participated. Further simulations for the geology part of the Apollo 11 mission were carried out at the "rock pile," or other simulation areas, in Houston on March 27 and 28, June 18, and June 25-28 to further acquaint the crew with photo and sampling procedures. The June 18 simulation was to practice an EVA with radio communications to Mission Control. The Geology team participated in this by staffing the SSR, or backroom, in Mission Control. Another field training exercise was scheduled at Flagstaff for mid-May 1969 but was canceled at the last moment. Some of the field training for instrument deployment and tool use was accomplished on the so-called "sand pile" at the KSC or, as mentioned by Armstrong, in the "sandbox," which was a test and practice area of about 100 square feet at MSC. And Aldrin added "but not pressurized" (Apollo Lunar Surface Journal, Apollo 11, comments at 110:15:47). Armstrong also mentions that much of the training was done to determine time lines for specific tasks and only a couple of times did they try to complete the entire EVA from start to finish.

A major problem developed with the media during the Quitman Mountains field trip. The first exercise was nearly a total disaster because of the excessive number of newsman, TV cameras, and even a helicopter. John Dietrich recalls that there was a parade of about 30 cars in the media procession that left El Paso for the field area. According to Schmitt,

> *"It was a media circus. Every network was out there with helicopters [in fact, there was only one helicopter] and cameras. I can barely remember it other than my arguments with some of the media people to get the hell out of the way. I mean the guys just couldn't hear themselves. Helicopters were hovering everywhere and that triggered all the VOX mikes. It was a mess" (Schmitt interview, 1995).*

Uel Clanton recalls that the helicopter was flying so low that dust was being stirred up and obscuring much of the activity. Clanton recalls that as the geologists and astronauts were eating lunch Armstrong left to have a conversation with Paul Haney, who was in charge of MSC's PAO, about the problem with the press. During this conversation Armstrong told Haney that if he was not able to control the press the geologists would do it. Before the second exercise Clanton was able to bring the media activities under a bit better control by using an axe handle (with attached blade) to draw a line on the ground just outside the training area and warning the newsmen that there would be serious consequences if they tried to cross the line (Clanton interview 1995). Clanton also recalls that a couple of weeks later during the debriefing for the field trip with the Apollo 11 crew there was a phone call for Neil Armstrong from Gilruth, the Center Director. Armstrong and Gilruth discovered that Haney had indicated to Gilruth that Armstrong had approved the media activities in order to get Gilruth's approval, and had indicated to Armstrong that Gilruth had approved the media activities. In fact, in both cases the other person had not been consulted ahead of time and it was felt that Haney was using one to gain approval by the other. In view of this problem, within about one week, Haney was no longer in charge of PAO at MSC (in fact he resigned from NASA shortly thereafter) and future field training was often undertaken with no advance publicity, and if there were any news media present they were more highly controlled by NASA's PAO. Only very limited numbers of media personnel were allowed, and they had only very limited access to the perimeters of the training areas.

Another problem that developed over the course of Apollo 11 training was PIs attempting to access the crew directly, especially the commander. Schmitt recalls,

> *"Deke asked me to be the scientist for the Apollo11 mission about a month before the launch, but I had already been acting in that capacity because Neil had asked me to sort of shield him from the science experimenters as much as I could. At least bring some order out of the chaos of people*

> *pounding on the door trying to get in to see him. They [the PIs] seemed to think if they could tell him just one thing it would make everything go well"* (Schmitt interview, 1995).

The amount of time spent in geology training, especially field training for geologic activities on the Moon, increased drastically during the course of the Apollo missions. There was one field trip for the Apollo 11 crew in contrast to 14 for the Apollo 17 crew. In addition, the later crews had a wealth of lunar samples to study from previous missions. When asked about the amount of geology training for the Apollo 11 mission Armstrong indicates that "we spent a lot of time in geology training, predominantly before we had a flight assignment, not exclusively before, but predominantly before." One must consider the very limited time that was available for such training. Not only were there only six months from the time the crew was named until flight, but there was a very limited amount of time for geologic activities on the lunar surface. In Armstrong's words:

> *"I enjoyed geology, and it was certainly appropriate to understanding what we were seeing on the surface of the Moon, but our time was quite limited there. We had a lot of things to do. Had I been a better geologist, I might have seen some things that were important that I missed…But in the time that we had available, I think everyone did a credible job of being able to see things that were important and know which samples to pick up and be able to describe to people back on Earth what they were seeing"* (Armstrong interview, 2002 JSC oral history project).

There were several difficulties in the surface activities on the actual mission because of unforeseen problems that added time to the activities. An understanding of these unforeseen problems allowed for corrections to be made and was useful for the traverse planning of later missions. For example: Armstrong required much more time to collect the bulk sample than in the simulations because the area planned for the collection was in the deep shadow of the LM, making it very difficult to distinguish between sample types. He also felt that there would be less contamination from the rocket exhaust if he went further from the LM. Therefore, he made a number of trips back and forth from the sunlit area well away from the LM to the sample bag at the LM to collect the expected amount of bulk sample. As Armstrong puts it, "I probably made 20 trips…I took a lot longer, but by doing it that way I was able to pick up a hard rock and [soil] in almost every scoopful. I tried to choose various types of hard rocks out there so that if we never got to the documented sample at least we would have a variety of hard rocks in the bulk sample" (Apollo Lunar Surface Journal, Apollo 11, comments at 110:27:20). His thinking was quite appropriate because the time that was eventually available for the documented sample was much shorter than planned, but he still got an excellent variety of rock and soil samples.

The Apollo 11 mission, being the first to actually attempt to use the tools and procedures on the lunar surface in the reduced gravity state, allowed for revisions of some of the tools and procedures based on what was learned on the mission. The core tubes were the prime example of a necessary revision. As Schmitt describes it: "Gene (Shoemaker) had been working with—who was the old guy at Texas who designed the original core tubes that failed miserably? Oh, Hoover Mackin was the name. Those core tubes were designed just like the core tubes that he was used to using here on Earth…the core tube fiasco originated with his insistence, with nobody arguing with him, that we ought to have core tubes designed like we did (here on Earth) with the core tube that was smaller than the bit. Of course nobody had really figured out that lunar soil was essentially incompressible. You couldn't drive those things through it" (Schmitt interview, 1995). The tubes were redesigned and worked well on future missions.

Apollo 11 was the first crew to take photos on the lunar surface. For the Apollo 11 mission the procedures were quite basic. There were to be panoramic photos taken through the LM windows soon after landing to show the general nature of the terrain. Then after egress from the LM there were to be more panoramas of the area taken from the vicinity of the LM. Photos of the various EASEP instruments, astronaut footprints, and the foot pads of the LM were to be taken for the PIs and soil mechanics experiments. For sample documentation there were to be photos taken of the general area of the contingency sample, of the other sample areas as they were approached, and of the individual samples with a gnomon present for scale, orientation, and color. Photos also were to be taken to document the sample areas of two core tubes that were to be driven with a hammer into the surface for cores of the subsurface layers. There were also photos taken with a specially developed stereo close-up camera to determine the nature of the lunar soil. Clanton points out that for the Apollo 11 crew the very limited amount of time for geology field training provided only cursory experience in these photo procedures. The experience of the 11 crew allowed the procedures for these photo activities to evolve significantly over the course of the next few missions. Clanton also discusses one significant development in the camera operation that came about during training for the Apollo 11 EVA. In the early training the astronauts hand-carried the cameras used for documentation. But "Neil Armstrong...came up with the idea of hanging the camera on the chest pack. His comments, along with Zedekar and a few other people, were what developed into the camera mount on the chest to allow both hands to be free. In retrospect, this was a super move considering the limited mobility of the astronaut in the pressure suit. If he had been forced to hang on to the camera with one hand we would probably have seen only about half the samples and half the photographs that we presently have" (Clanton tapes, 1975).

Apollo 12

Shortly after the Apollo 12 crew had been selected, but not officially announced, Pete Conrad, the Mission Commander, met with Uel Clanton and Bob Laughon to plan the Apollo 12 training schedule. Conrad stated that they would follow the same basic plan as for Apollo 11, but there was to be no coverage by the PAO. The trainers were not to give the PAO any of the locations or dates of any of the field trips. He wanted to restrict the participants in the trips to only Clanton and Laughon, who would bring along all of the equipment, and the CapCom. There would be no equipment personnel, no PAO personnel, no photographers, etc. He did agree eventually that one other geologist could come along to man the simulated SSR along with astronaut Gibson who was to be the CapCom for the mission. Conrad also explained that there would be very little participation by the backup crew because they were scrambling for the few odd hours that might become available in the simulators when the Apollo 11 crews or the Apollo 12 prime crew were not using them. Conrad felt that he had been abused by the press coverage during his Gemini flight and was adamant that it would not be repeated on Apollo 12. Therefore, at Conrad's direction, the Apollo 12 training trips were accomplished almost in secret. Several times it was suggested that Jack Riley, the new Head of NASA PAO, be included in the field trips, but Conrad insisted that there be no press of any kind on the trips. Only after the successful completion of Apollo 11 was the training program allowed to expand and include a couple more field trips and classroom activities, but still no press coverage.

At the initiation of Apollo 12 field training, Clanton recalls,

> *"The philosophy of the field trip planners had been, because of our limited detailed knowledge of the lunar surface, only the broadest outline would be given and the crew themselves would more or less develop the traverse once they landed. To my knowledge Conrad has to be tapped with the concept of the pre-landing traverse planning. His request to Schmitt, and the folks at Flagstaff specifically, was, 'assuming that we land at the appropriate place and hop out and start the traverse, what are the areas that we should see?' It was Conrad that pushed for and got the mission photographs documented to show localities where samples should be collected and photographs should be made: things like this. .... At this time the amount of contact time for geology with the crew was still very limited. The people had a lot of training to complete. The 11 crews had taken preference on the simulator time, and then the 12 crew made some attempt to make up for lost time on the simulator with the completion of the 11 crew. The 12 backup crew had been pushed out of the simulators so much for so long that they too were in the busy process of trying to catch up to learn how to fly the mission. So, much of the science had to be worked in around their other activities."*

In addition there was also extensive training for dismantling several parts from the Surveyor III spacecraft, which was one of the reasons for selecting the Apollo 12 landing site, as discussed earlier.

Clanton also points out that

> *"Apollo 12 was designed to go within a couple of months behind Apollo 11 should Apollo 11 not make the landing successfully and return. Consequently, much of the early Apollo 12 training followed the same, very cursory and hectic pace of Apollo 11. Until a successful landing could be demonstrated all other activities were secondary. ... The primary purpose of 11, and if 11 failed, 12, and if 12 failed, 13, was to land a man on the Moon and bring him back before the end of the decade. It was only after Apollo 11 made the successful landing and return that we changed gears in the Apollo 12 training" (*Clanton tapes, 1975).

As for the actual training for the surface activities there were a number of developments that were incorporated into the training for future missions, i.e., more training with actual tools, photo documentation, time lines with specific objectives on planned traverses, and more realistic simulations with CapCom and a backroom. In a debriefing following the mission Bean and Conrad were promoting more use of hand tools and other instruments in the field training and simulating the traverses in much the same way they would do them on the Moon. They complained that they had never had a chance to train with the drive tubes. When they got to the Moon they threw away one of the parts that they needed and then had to go looking for it. They felt that if they had trained with it they would have known better. They suggested training with these items regularly until it became second nature.

The photo documentation procedures were constantly being revised as more experience with the traverse planning took place. Such changes, however, led to frustration among the crew. Clanton recalls that Pete Conrad complained about the photo procedures.

> *"He just barely figured out what they wanted and then they decided they wanted something else...If I recall correctly, there were five major changes in the dancing diagram, the positions that the astronauts took to photograph samples and collect samples on the Moon...it seemed like every time we had a class meeting or made another field trip a new epistle had descended....stating that the photography would be accomplished in a different way. I think it is on tape from one of the geology field trips in Hawaii where Pete Conrad just about lost his cool. And if you've ever been around Pete Conrad, whenever he loses his temper it is something that one would not forget too readily. Anyway after about the fourth or fifth change in photography procedure Conrad more or less laid down the law. What was given then was it, and there would be no more changes. In fact, his words went along somewhat like: 'before we can learn what you want to do this time, a change is made and we're doing something else. Okay, this is it. There will be no more changes. You have had "x" months or years to figure this out. This is what we're going to train with. We're going to stop the Mickey Mouse changes that are occurring on a regular basis' "* (Clanton tapes, 1975).

The photo procedures eventually were worked out and for the final four missions were essentially as shown in detail in Appendix P.

It was on Apollo 12 that the field training began to develop more along the lines of the missions. According to Clanton:

> *"Pete Conrad recommended that they start taking along a CapCom and flight director on every field trip. .... Beginning with Apollo 12 we began to work directly with the crew and the CapCom and developed the interface from a geological point of view a little more completely. It was also during this time that the backroom, so to speak, began to tag along and the people involved in the training began to appreciate the rapport that could be developed between the people in the backroom and CapCom, which would aid in getting questions through during the actual mission. The early backrooms consisted primarily of one geologist. With Apollo 12 it was either myself or Bob Laughon or Ed Wolfe. Later on with 13, 14, and 15, more and more people got involved. These were the first efforts really, when time was available and the critique was available, where we went through the exercise with the people in the field and had the backroom working using the radios and made some effort to begin to totally integrate what the astronaut did on the lunar surface with CapCom and the backroom."*

The participation of flight directors in the field trips as suggested by Conrad did not start until Apollo 15. Clanton also indicates,

> *"Through the efforts of Pete Conrad the cuff checklist developed. His concept of this, developed more fully by Roger Koppa, eventually developed into the cuff checklist. So that the astronauts had a handy dandy rapid check on what activity was supposed to be done and what the current dancing diagram was or sample photography and collection"* (Clanton tapes, 1975).

For Apollo 12 the first field trip, of six that they took, was into the Quitman Mountains area on March 13, 1969. This trip actually occurred a month before the crew was officially named for Apollo 12, but it was expected from their backup position on Apollo 9 that they were in line to be the Apollo 12 crew. Clanton's description of the field trips indicates that the geologists walked through the area with the astronauts as they exercised the EVA and noticed not only what the astronauts saw, described, and sampled, but also what they missed. The astronauts were in radio contact with the CapCom and backroom who were situated some distance from the astronauts. After completion of the exercise the geologists and others involved in the exercise would walk back through the field area with the crew and point out to them not only what they did well but also what they missed and how they could improve on their procedures. These walk-throughs allowed all participants to enter the discussions. When each field trip was completed the tapes were returned to Houston and transcribed. The photographs that were taken during each field trip were developed and the mosaics and the 360-degree panoramas were put together. These pan photos and the sample photos along with the transcribed astronaut descriptions were then critiqued with the crew during a debriefing in Houston.

Clanton felt that this critique was "quite important," and should be done on a "regular and fairly detailed basis."

> *“We did this for 12 and 13, the two crews that I was most involved with. After the crew performs in the field and does a 360-degree panorama, for instance, when this is brought back, developed, and then taped together and shown to the astronaut, he has the appreciation finally for what he is doing or not doing. You can indicate that 'Yes, this is good,' 'No, you are standing too far away,' 'photographs and everything is out of focus'; it is only by complete debriefing like this that he begins to appreciate the level of his performance. I can recall John Young, for instance, on one panorama in Hawaii, 24 photographs for the 360 panorama, and it still doesn't close in about two places. He was shocked, thoroughly shocked, to find out that he had goofed. Once the training and the rationale is explained to the astronauts, and what he is to do and how he is to do it, then when you come back and show him what he has done on the field trip and how he has either done what you wanted or how he has goofed, your level of training goes up. He understands perhaps a little better what he was doing wrong, whether he is standing too far back or too close, that he is at the wrong sun angle, that he did not complete the 360 pan properly. I don't think I could too heavily stress the need for the complete debriefing. I should also point out that it is a very time-consuming and painful process to go back through, to develop all the photographs, to paste them together, to arrange for a debriefing time, and to spend 2, or 3, or 4 hours with the crew, as necessary, to pull it through and show them where they did well and where they did not do so well. But it is a very productive time, productive probably second only to the field trips, because here the astronaut sees for the first time how well or how poorly he does"* (Clanton tapes, 1975).

Clanton's recommendation after Apollo 12 was:

> *"There needs to be a more complete integration of the people that understand the suit capability, the PLSS capability, the capability of the astronaut in the environment, and the PI. ...The local people that have the expertise at what can be done, and the equipment and how it works need to have an equal input to the PI for running it. It's only after you participate in the training and in the debriefing and you know intimately the crew, do you fully understand what they are doing in the field, or what they are not doing in the field. This information comes across even on the Moon. Along this line, I would suggest that: (1) Either the people involved in the training have seats in the backroom and be part of the total package as far as field geology and whatever group that is going to be, or (2) The people that sit in the backroom be more completely developed and more particularly utilized in the training. This means a sacrifice on various people's part either way. Many of the people that sat in the backroom for Apollo 12 had very limited, if any, knowledge on what was actually going on, had never seen, or had seen only cursorily, any activity by the crew in the field." Clanton feels that, "In this particular instance we lost a lot from Apollo 12 because of the failure to utilize the people that understood what was going on with the crew. This was mainly Clanton, Bob Laughon, and Ed Wolfe”* (Clanton tapes, 1975).

Another significant part of the training was done at the Cape. It was on a small area near the crew quarters where an area of sand was laid out to practice simulations for setting up ALSEP. Jack Schmitt recalls that "Don Lind and I had already done the preliminary work on ALSEP deployment. We did some of the early stuff for the CDR at Bendix. Working procedures and stuff like that. At that time we had it down to something manageable. We had a mock-up and deployed it a lot over here (MSC) in one of the big high bay areas (Schmitt interview, 1995)." This had allowed the procedures to be initiated and the 12 crew did a number of simulations in setting up the instruments.

Also, during the last few weeks before the mission the crews spent much of their time in simulators at the Cape. At that time Swann, Chidester, and Karlstrom of the USGS conducted week-end briefings at the Cape on the geology of the landing site. Also, the traverse maps were reviewed by both prime and backup crews along with CapCom Gibson, Flight Director Gerry Griffin, and the geologists. In addition, during that time some of the geologists from Flagstaff spent time, especially in the evenings, with the crew going over the planned traverses and the tasks on each of the traverses. Gordie Swann recalls that "on 12 we started getting involved with them down at the Cape with crew briefings shortly before the missions. It was before the premission quarantine. They were going down there and doing sims” (Swann interview, 1995).

As mentioned above, planning for the Apollo 12 lunar surface activities included, for the first time, some actual traverses. According to Swann,

> *"There had been very little interaction between the USGS team for the Lunar Geology Experiment and the crew during the field training exercises. Only Ed Wolfe from the USGS had participated. But*

> *shortly before the mission when some of the USGS team was at the Cape for some briefings, Pete Conrad said, 'Let's sit down and have the data packs and the photos.' We hadn't put in the final maps yet; we had a very short time to do that. He said, 'Let's sit down and let's pick—here's Surveyor—Let's pick four landing sites in the vicinity, and let's design traverses from each of those landing sites.' That was the first planned traverses. So we did four. We called them nominal traverses. So we wrote out what to do at each station and all that. We had a first EVA, which had very little time, to do ALSEP. Then a second geology EVA and it was short, 4 hours, I think. We did it for four landing sites"* (Swann interview, 1995).

When they landed and their actual landing point had been determined, it was the first time that the planned traverses were used to redesign the actual traverses during real time. Again, as Swann describes it:

> *"When they landed we knew they were somewhere in the ballpark because they had seen the snowman [a landmark at the landing site]. It was when they got out on the first EVA and Bean said 'there's our old friend Surveyor.' It was right behind them. But they had landed half way between two of these so-called nominal landing points. So what we did in the backroom was sit down and combine parts of the two closest traverses into a new traverse. So that was a significant amount of interaction, but that was about it. So we replanned the traverse, or kind of, during the first EVA and then between EVAs. But it was a simple matter. We just took the stations, and I think they had a cuff checklist for each one of these nominal traverses, so we just said use stations dah di dah dah dah in this sequence"* (Swann interview, 1995).

One advantage that the 12 and later crews had was the ability to see actual lunar samples that were returned by the 11, and later, missions. John Dietrich's [Dietrich was highly involved in the early training of the Apollo crews] comment, when asked if he thought it was a significant benefit to have the astronauts study the returned lunar rocks, was:

> *"Yes, particularly before they went up. I'm not talking about the astronauts who collected them. I'm talking about the next crew to see what the stuff was that was coming off the Moon. I think that was a big help. I think they got a fairly good feel, even in the early missions where everything was still locked up behind the barrier. They were able to see enough of what was there to understand more of the problems that they were going to face when they brought back samples. Just to see what they looked like. ..... They had been cleaned to the point they could see crystal faces, vugs, and other textural features that we could see and talk about. And we could talk about words to use when you were describing these things: made more sense using them. Of course we had somebody in gloved hands in the boxes so we could turn them over so that they could see them. That was a valuable part of the training, to be able to actually see samples that had come back"* (Dietrich interview, 1995).

Dietrich's comment about using words to describe the features is an important concept that should be discussed a bit. While collecting samples during the Apollo 11 mission, Buzz Aldrin made a comment involving mica that was criticized by some folks. While describing a rock he said that it was "sparkly" "like some sort of biotite" [a type of mica] but he would "leave that to the lunar analysts" (Armstrong et al., p. 329). This comment was criticized by some scientists because mica contains water which was not to be expected on the Moon. Although the sparkles turned out to be glass, that criticism was not justified because Aldrin really didn't say it was mica. He said it was sparkly like biotite. That criticism, however, led Pete Conrad to tell Alan Bean on Apollo 12 that "we're not going to describe these things using any geologic terms. We'll just say it looks like a green beer bottle, or something." We may have lost some real-time information because of that type of unjustified criticism. In fact, during the EVA Conrad described a crystal as "ginger-ale-bottle green" (Compton, p. 183), but after Apollo 12, Bean made a comment to the effect that, "Yeah, we knew that was olivine but we didn't want to get nailed like Buzz did."

There were eight days of simulations at MSC in October and November with the ALSEP and partial EVAs, using hand tools and cameras to practice procedures, which were observed and critiqued by the geology team. There was a final field simulation at Flagstaff involving Mission Control in Houston on October 10, 1969 to prepare for the mission. On October 9 there was a dry-run of the simulation by astronauts Gibson and Lind to iron out any problems with the traverse. On Octobe, 10 the prime crew was to meet at 8:00 a.m. for an overview of the simulation. According to Clanton, Commander Pete Conrad exhibited impatience when USGS personnel began arriving late, and they explained that they were having difficulty rounding up the equipment and vehicles for the exercise. (Conrad had a tendency to get rather upset when plans did not follow time lines closely.) Conrad asked Clanton, who had a vehicle and knew the field area, to take the crew out to the simulation area for the run-through.

Clanton complied and the crew and Clanton had the opportunity to study the traverse for nearly 45 minutes before the other vehicles and equipment arrived. After lunch the astronauts participated in a two-hour traverse of the geology portion of EVA 1 on a man-made crater field near Flagstaff, Arizona, with the geology team assembled in the SSR at Mission Control in Houston to carry out their respective roles that would be undertaken during the actual mission. This was followed by a radio debriefing between the crew in Flagstaff and the team in Mission Control. A run-through of the geology portion of EVA 2 was scheduled after the debriefing. Radio communications between Flagstaff and Houston allowed the astronauts, CapCom, flight operations personnel, and the geology team to better understand how they were to interface during the actual mission.

In the Technical Debriefing that followed the mission there were many comments about detailed items that could be corrected for future missions. These dealt with such things as unpacking some of the ALSEP equipment, leveling certain instruments, difficulty reading labels, flexibility of the material in the solar wind collector, lengths of handles, and size of tongs and sample bags. They also complained that the tool carrier was too heavy once it was loaded with rock and soil samples. While trying to hold it away from the body with one arm it continually bumped into their legs. They felt that there must be a better way for them to transport the tools and collected samples. Most of these were hardware problems that could be dealt with by the engineers. Bean, when commenting on traverse planning, commented that "It looks like we can land now on one spot; thus you want to practice the exact traverse on Earth that you are going to be doing on the lunar surface. This allows you to save a lot of time by going to the proper side of the crater and trenching and core-tubing at the right place. Then, on the Moon you can follow the same preplanned traverse and get a lot more done much faster" (Apollo 12 Tech Debrief, p. 10-41).

As will be echoed in the debriefings of later crews both Bean and Conrad felt that the 1/6 g flights provided excellent simulations for most procedures, while they did not think the neutral buoyancy tests in the water tank were very useful. As with future crews they could not praise enough the 1-g, suited walk-throughs of their EVAs. They felt that the field exercises went very well and "complimented Uel Clanton and his troops on well-organized field trips. I think they learned, and I think we learned, because we insisted on using our normal lunar surface tools and not make them just straight geology trips. I think there was a little bit of education on both parts" (Apollo 12 Tech Debrief p. 24-7, 24-8).

The geology trainers who had been involved with planning and executing the field trips were not included in the debriefings. In fact, some questions had been prepared by them but were not included in the debriefings. As a result of this omission, in early 1970 after the Apollo 12 crew had completed their other chores, Clanton arranged for a separate debriefing with the crew to discuss the geology training. This debriefing has never been published in any form and, in fact, has not been seen by any people other than a couple of the geology trainers who were involved in the next couple of missions. In consideration of the interesting information provided in this debriefing it is included here as Appendix S. In it the crew stresses the importance of using all the tools and cameras with associated procedures on all the field exercises. They also emphasize that flight controllers and directors should be present on the field exercises. And further, they discuss the difficulties of deciding what samples to collect, what geologic features to emphasize during training, and the difficulty of following a time line versus doing what they consider necessary to complete the basic geology at a given station.

Apollo 13

While the training for 12 was under way the training for 13 and 14 had commenced. The first official trip for the 13 crew was on September 28, 1969, but shortly before that Schmitt had arranged for a change in the nature of the field training. He had observed that the enthusiasm for field exercises was not as great as he thought it could be and the need for more experienced and charismatic instructors could help develop more enthusiasm and competence among the crews. As Chaiken puts it (p. 391-392), Schmitt "knew what was needed more than anything else was a professional teacher, someone who could relate to the pilots and inspire them." Schmitt contacted his former professor at Caltech, Lee Silver. Silver had spent many years doing field work and was known as a great teacher who had a great deal of energy and enthusiasm that he seemed to impart to his students. According to Chaiken (p. 393-394), Schmitt arranged for a meeting between Silver and the Apollo 13 crew of Lovell and Haise at a coffee shop in Cocoa Beach. Silver convinced them to try one field trip with him. If they liked it they would continue with other trips with him. Apparently the astronauts were looking for a change in the training that would develop more enthusiasm and competence for their geologic objectives because Chaiken indicates that this was not an official trip. "The astronauts paid their expenses out of their own pockets and took the trip out of their vacation time" (Chaiken p, 393). In mid-September 1968 Lovell and Haise and their backup crew of Young and Duke set out with Silver and one of his field assistants, along with Schmitt, for the Orocopia Mountains of southern California for a week of field work. For most of the week they worked from dawn till dusk in the field and discussed geology in the evenings until they went to bed.

Silver's version of the trip is worth recounting.

> *"When I came down to Houston for other reasons, Jack [Schmitt] was going to introduce me to Jim Lovell and Fred Haise, and they were going to look at me.... But a talk for thirty minutes or so doesn't prove very much. But I persuaded them to make a deal, and that deal was that they would give me a week. They'd come out into the desert with me in southeastern California, and we would see whether or not I could make a case that their working with me would be worthwhile to their mission...*
>
> *"This was not a deal with NASA; this was with Jim Lovell and Fred Haise. It wasn't even a deal with the full team, because Mike Collins, who was the Command Module Pilot, didn't come out. We went to a place about 60 miles southeast of Palm Springs [California], 40 miles southeast of Indio, in remote desert. It was hot. I had a very good postdoc working with me, who's now just retired as the Chairman of the Department of Geology at the University of Pittsburgh, but he was my postdoc at the time. He and I drove two vehicles. One of them was my own personal carry-all, and the other was a [Caltech] division carry-all.*
>
> *"We put in what amounted to six field days, a week. They had one day off to go into Palm Springs and clean up; we had no showers. All the water we had was in G.I. cans and things like that. I did two important things: I created some exercises for them, and I cooked. They did several important things: they worked their butts off, and they washed the dishes. It was a successful exercise, and I made some good friends.*
>
> *"Fairly important in that was the fact that Jack [Schmitt] was with us for the first three days, to make sure they got to know me. And another very important thing was that there was a backup crew. The Apollo 13 backup crew was led by Captain John [W.] Young and by Charlie [Charles M.] Duke, and their interest was just as high. And so I had a set of exercises which in part was show-and-tell, but more importantly than show-and-tell was literally exercises: they had to do things. And I just had to innovate. I mean, my classes aren't taught that way, you see, so I had to innovate. And I had some moments of inspiration, and I had the feeling that the whole project, the whole Apollo project, was blessed.*
>
> *"For example, on that first week I needed to make them get a sense of what they could do practically. Now, this chunk of desert is very barren. Trees are sparse. Only along the rims of bigger dry washes can trees get their roots down deep enough to get some water. There's a particular kind of tree called an ironwood tree, which has thorns like everything else on the desert, very, very dense, very tough wood. And we camped in one wash called Canyon Springs Wash, because it had some water in it, not potable, but water in it. And I gave them exercises to do in that wash. It was a place I had used for training students at Caltech, in the past, so I knew it quite well.*
>
> *"But there was a little canyon tributary which rose about seventy-five feet above the bed of the wash. In that little canyon was a stunted ironwood tree, and I said to them, 'Help me and use your imagination. This stunted ironwood tree is a landing module. Now, you're in the landing module…and I want you to tell me what you see, because you've got 360-degree vision, and now we want to practice articulating the hard stuff you see. Now you're going to do documentation. You've got first-rate cameras. You've got all kinds of other things. But I'm in the science backroom, and I'm trying to see how well your landing site suits the needs that had been projected as the targets of the mission.' And we started off with that.*
>
> *"One by one, all four of those guys went through that exercise, and in the end it was interesting. They were different in style and different in capability. But having been a military pilot, or having been a test pilot, the business of calling what they see was as natural as it could be to them, you understand, and so they took to it. So I think that little tree was one of my blessings. There was no obvious source of water for it. That tree's still there. It ought to have a monument on it, as far as I'm concerned. That's another example of how the breaks fall for you.*
>
> *"I'll give you another. On the third day I had them walking down the edge of the main wash and I would take turns with each of the crew members, and I'd walk behind them, and they were to [observe and] articulate. They're not talking to me, but they're articulating and I'm listening. Okay. Now we're coming down the wash, and the wash was about three times as wide as this room, and there's banks going up five, six, seven, eight feet. The wash itself is filled with dry sand but the banks are*

> *exposures of rocks, and that's what I wanted them focusing on: what are you seeing? And some of it was very straightforward: color, shape, texture, and all the other things that have to go into a description.*
>
> *"Maybe I was as far away as the camera was when I saw a place where there was a ledge; it was straight, just standing up, almost on the edge. And there was something interesting on top of it. I looked at it, and I recognized it for what it was. It was an ancient clay pot, and this turned out to be a Paiute pot. But the business of seeing everything and articulating it and with a little nudging here and there about describing things and all, Jim Lovell came on that pot. He said, 'I've got this…' He came on this thing, and he said, 'There's something here that doesn't look natural.'*
>
> *"Paiute pottery is not very beautiful, but it was nearly a whole pot with one thing wrong with it: the bottom was out. This was a pot in which they had placed a potful of seeds and beans and things like that. One of their chiefs had died and this pot had been placed where he had been known to frequent, and it was for him. But Jim picked it up and handled it. I said, 'Jim, that's yours.' He liked that, and in later years I was at his study, and that pot's still there. But the feeling of satisfaction with the experience was enhanced by that little incident. So as in all complex enterprises, you need the breaks to keep the human interest up. I'm sure that that contributed"* (Silver, NASA Oral History Project).

Silver's enthusiasm and ability to excite the astronauts about geology worked well. Lovell was so favorably impressed with Silver and his method of approach that he and the crew agreed to continue with Silver as their mentor. The backup crew, Young and Duke, who would go on to be the prime crew for Apollo 16, were also hooked on this type of procedure, and asked Silver to do the same for them on Apollo 16.

Schmitt recalls the Orocopia trip as a major milestone in the field training:

> *"The real breakthrough and the place where the guys really started to learn was when the Apollo 13 crew agreed to take one field trip with Lee Silver to the Orocopias. And that's when we really started to get down and dirty on mission-related training. And Lee did such a good job with those guys that they spread the word that this is the thing we ought to be doing. ..... In order to get that training going I called Lee, I called Dick Jahns, and I called Bob Sharp, and Lee agreed to do the 13 job, or at least he agreed to do that one trip, which turned out to be a volunteer affair. They agreed to go out there on their own hook. We used the T-38s. We could always do that. And he put together the whole trip. Tom Anderson was his graduate assistant at the time. Tom and Lee put the whole thing together for us. That convinced Lovell and Haise and Young and Duke that this was an important way to go. And Lee was involved on all of the trips with them, at least most of them"* (Schmitt interview, 1995).

Clanton also recalls the importance of Silver's introduction to the training as being very timely because after a few futile attempts by the MSC geologists to get the USGS group at Flagstaff to assign someone to help plan the field trips for Apollo 13, they had given up the hope of getting this type of support. He then indicates that "it may be significant to point out at this time that Lee Silver became involved fairly well with the training beginning with Apollo 13 and this was a move in the right direction. Here was an individual who would be operating in the backroom, who was participating extensively in the field trip planning, and in the (research) activities that were going on the Moon" (Clanton tapes, 1975).

The photo procedures were still a problem on the Apollo 13 trips. Clanton recalls:

> *"If my memory serves correctly, there were six major changes in the dancing diagram (photo procedures) for Apollo 13. Only after the Hawaii trip with Apollo 13 did the photography procedures gel. And only after the photography from Hawaii had been shipped and evaluated at Flagstaff, and the failures again to document or to identify the samples that were photographed, collected, and returned were documented…did we get the photography squared away...*
>
> *"By Apollo 13, well even with Apollo 12, we were running hot mikes and radios to communicate between CapCom and the crews in the field. This was also true of Apollo 13 and later missions. Again, the field trips were designed primarily to duplicate one or more portions of one or more of the EVAs, and the time the people spent in the field on a particular field trip, or portion of a field trip, was designed to duplicate some facet of what was expected of them on the lunar surface. The major accomplishment I feel of Apollo 13, other than getting the people back, was causing, for the first time, the field geology team and the ALSEP teams to finally stop and think through a bunch of the*

> *procedures that were being generated really without much thought; and forcing the various experimenters to totally evaluate what they were proposing and what the crew could do. The turning point in the lunar missions for much of this had to be with Apollo 13. The level of frustration, not only with the crew but with the trainers, to see almost a daily change in activities has to be lived to be appreciated. The thing that is probably not totally appreciated by the PIs and Co-Is, who were making these daily changes, was the effect it had on the crew as mentioned previously for Apollo 12 and exemplified beautifully for Apollo 13. If the presenter can go to the crew one time and say 'This is how it is done and this is what you are going to do and this is the information we are going to get from it,' then the chances of getting this, or of the astronaut appreciating what the problem is, and actually the scientific community getting the maximum return; that's the way it needs to be. But the thing that needs to be stressed...is that the position of the PI, the role of the PI, and how he is viewed in the crew's eyes, changes as the changes continue to come in his particular experiment. The crews typically were quite willing to listen to the various PIs explain their experiments, why they wanted what to be done, and the explanation of what this information would provide to the scientific community...and in all instances that I can think of, the crews indicated a very direct willingness to participate. But as an observer, and one of the people participating in the training, one could also see the falling of the PIs stature in the eyes of the crew as these daily changes came in. The PI, in a sense then, needs to present to the crew a complete story the first time, hopefully. This complete story needs to be one that is developed with the best talent available, be it NASA, USGS, JPL, AMES, wherever the information comes from, it should be totally evaluated and the best information possible put out"* (Clanton tapes, 1975).

Dietrich recalls the use of CapCom and backrooms on Apollo 13 training trips.

> *"We had radios on the 13 trips. We were using radios and talking back to CapCom, or to somebody acting as CapCom. In fact, I think we had one of the astronauts that was going to be on CapCom along on one or more of the trips."*

When asked if they did walk-throughs after the field exercises, Dietrich responded:

> *"Not always. Our field work was done to a clock and we usually had them doing new things all the time we were in the field, at least on the trips that I was on. Then we did the recapping later on."*

He pointed out that the recaps included critiques of the photos and the rocks that were sampled:

> *"We would get those photos made and go through those photos one at a time. Some people took 72 pictures and never got a panorama because they would go 1 degree on this and then 5 and then 25 degrees on the next one, up and down. Every trip we made, we had the rocks back here that they had picked up."*

Dietrich relates a humorous incident that illustrates the difficulty involved in transcribing the tapes from the field trips.

> *“We brought these things back and a secretary in our area transcribed what the astronauts had said on the tape. We had this cute little brunette lady who was doing our work, really a shapely little person. We were talking about sinuous rilles when they were getting ready to go to, I guess it must have been in the early 15 trips. When she typed it all up it came out sensuous rilles. Everybody got a big bang out of that. That's the trouble with transcribing tapes, incidentally. You put the words in that you know.”*

Dietrich also emphasized the importance of making dry runs through the training sites within a week or two before the actual training trip. On at least one trip where the people in charge of the trip had not visited the area for several years there were locked gates that hindered the access of the crews on the actual training trips. Dietrich remembers:

> *"In Hawaii we went up to a site and we never got there because we couldn't get through a gate."*

Clearly, this was not appreciated by the crews or others on the trips. As Dietrich puts it:

> *"Every one of the trips that was conducted by the people here at JSC was run the week before, or at most two weeks before, by the crew that was going to be out there with the astronauts. We were convinced that their (the astronauts’) time was more valuable than our time."*

Dietrich explained some of the features observed on the field trip to Kilbourne Hole, an explosive volcanic crater.

> *"That was a pretty good one because there again you could see in cross section what happens when a block flies out. And there were several blocks that were blown out of the explosion there that went into soft sediments and deformed the sediments…you can see the dimple that they made, a foot or more depression into what was essentially a solid layer of stuff. It just hit hard enough to press it down. And of course everybody got to see that you can get mantle rocks at the surface"* (Dietrich interview, 1995).

Dietrich also recalls, with some amusement, a field trip for Apollo 13 in the Kapoho area cinder field in Hawaii.

> *"That was probably the best field exercise that we had that I went on that were laid out by the USGS. The one that was actually in charge of it was someone who was with the Volcano Observatory there...They had laid out a place on the Kapoho area where there had been some blocks regurgitated by the little vent down there that created craters. I mean you could see what was blown from over yonder to over here. And there was this crater with the push-up on that side and not so much on this side; low-velocity impacts. We'd been talking about drainage craters. We were talking about the possibility that you could step into one but you couldn't get out of it. They had kind of pooh-poohed this. One of the two prime crewmen was standing there on the cinder field where there was about a foot of cinders over a crack and he turned on his heel, turned his foot, and he went in right up to his waist. I think it was Lovell that half disappeared but I'm not sure. Then the other thing that happened on that one that was quite memorable was the backup crew, which was Young and Duke. They went up a fairly steep slope and I was behind them. I could see the heat rising. They couldn't feel it through their boots and hadn't put their hands to feel that it was hot. But there was a little bit of heat still coming up there, and we were using simulated lunar sample bags. Instead of Teflon we were using polyethylene. So one of the guys reaches down and scoops up a batch of it [volcanic ash] and pours it into the bag and it just goes right on through. Then we backed off and let them see that they could see heat rising. We took them in to the active vent which was coming up and rising, then going back down another hole. We took the prime crew in and we then went off somewhere else and then the other crew went in later. They were doing something else during the first part; didn't want to get both crews in there at the same time. We got on over to another site and looked back and the thing was fountaining about 80 feet into the air. Here were these little ants running across the thing getting away from there. And the flow came down between us. So to get together we had to go all the way around to the parking lot and come back in."*

John Young recalls the same incident:

> *"I remember we were fooling with the Apollo 13 guys and they were in the middle of the floor looking at Kilauea, and the thing went off and started shooting stuff up in the air. They ran one way and we ran the other way. I was afraid we were going to lose or burn up the prime crew and the backup crew would have to take over, but it didn't happen" (*Young interview, 1995).

The crew deployed ALSEP with the PIs present to make any modifications on September 15 and 19, 1969. They also studied the returned samples from Apollo 11 on September 17 and practiced driving the core tubes on October 8, 1969. Sutton recalls six days of simulations at MSC in February and March 1970 with the ALSEP and partial EVAs using tools and cameras to practice procedures which were observed and critiqued by the geology team. (Sutton personal notes, 1975) At the request of the crew, while they were at the Cape during the last couple of weeks before the mission, a simulated traverse was held on the sand pile. The traverse was run without aerial photos or maps but used flags to outline the course. There were several rocks that had been scattered over the course of the traverse by Clanton and Dietrich who brought the rocks with them from Houston. The crew used the lunar surface equipment to describe, photograph, and sample using the standard procedures for a lunar traverse and was in radio communications with a simulated backroom and CapCom at the Cape. Following the exercise there was a debriefing with the backroom personnel and CapCom in the crew quarters.

Apollo 14

After the failure of Apollo 13 to land on the Moon in April 1970 Apollo 14 was rescheduled to land at the same site as originally planned for Apollo 13. Because the field training for the Apollo missions was directed toward features that simulated the features expected at the planned lunar landing sites, it was necessary to rethink the field training for Apollo 14. The landing site for Apollo 14 had previously been Littrow which was expected to contain mostly volcanic material. Therefore, the Apollo 14 field training had emphasized volcanic terrains before Apollo 13. The new landing site for 14 was not a volcanic terrain but had a significant impact structure, Cone Crater, as one of its main features. Therefore, a redirection of the training toward crater studies was called for during the remainder of their field exercises. The Ries Crater in Germany, the craters of the NTS, and a man-made Black Mesa Crater field (a special USGS project for astronaut training) in Verde Valley near Cottonwood, Arizona were scheduled as the final three field exercises for the 14 crew. Gerry Schaber recalls an incident involving the 14 crew after an exercise in the Verde Valley Crater field:

> *"After we did an EVA in the crater field they (the press) came up to interview the crew, and it happened to be Shepard's 47th birthday. And the very first question that some guy asked him, 'What does it feel like to be an old man of 47 and about to go to the Moon?' You know Shepard, he just completely came apart. He came up to George, or whoever was running the test, and then he came up to the NASA guys and Lee Silver and he said 'I'm not going to answer any more press questions. I want all these guys out of here for the rest of the test'* (Schaber interview, 1995).

While there is essentially unanimous agreement on high accolades for all of the other Apollo crews that went to the Moon, the 14 crew does not enjoy that type of praise, especially from the scientists. This judgment seems to result from a lack of interest or enthusiasm by the crew, especially the commander. Jack Schmitt, who was again instrumental in selecting a lead person for the field training on Apollo 14 comments that:

> *"Dick Jahns agreed to do the 14 field training. That didn't go nearly as well (as on 13). Again, it's an attitudinal problem. The 14 crew just wasn't interested and never became interested. I think Mitchell would have been but Shepard wasn't. That pretty well controlled the way things went. I feel that I may have done Dick a disservice because I had hoped if anyone could have inspired that crew it should have been Dick. It didn't work out that way. But Bob Sharp sort of came in and gave each crew, if I remember correctly, a field session in what he called 'belly geology.' They'd go out in the desert and he got them on their hands and knees and we'd spend the better part of a couple of days looking at what you could see on your hands and knees. They loved it. Bob is a hell of a teacher. So that went over well too with most of the crews"* (Schmitt interview, 1995).

Bob Sutton, who went on some Apollo 14 trips, also observed the lack of interest by the 14 crew and noted that "it was obvious that Cernan and Engle (the back-up crew) were more observant and better describers than the prime crew" (Sutton personal notes, 1975).

Gordie Swann's comment when comparing Apollo 14 to 15 was: "If Dave (Scott) had been on 14 and Al Shepard had been on 15, 14 might have been a little better and 15 wouldn't have been nearly as good" Swann interview, 1995). Lee Silver did not have a good impression of Shepard: "I didn't think that Alan Shepard set a very good example as the prime commander for Gene (Cernan), the backup one, although Gene did not walk in and out (from lectures) casually the way Alan Shepard had. And that wasn't only from my briefings; there were other briefings as well" (Silver interview 2002). Chaiken reports that "One NASA geologist who was assigned to train Big Al was warned by his colleagues 'Don't be alarmed when he acts like this isn't very serious.' During briefings Shepard would tell jokes to whoever was sitting next to him, including his Lunar Module Pilot" (Chaiken, p. 396). Silver adds: "I would never want to say negative things about any astronaut who went to the Moon. I wouldn't want to say anything negative about Al Shepard. But I have to call the quality of the performance as something less, and it wasn't happy for me to learn that Ed [Mitchell] was trying to conduct psychotelepathy experiments instead of working on what he was supposed to be working on…Some crews prepared themselves better, and some crews, I think, saw the mission as their triumph, rather than their mission as an Apollo triumph, and that was not what I was most interested in. The Apollo 14 crews did not have the right attitude, did not learn enough about their mission, had the burden of not having the best possible preflight photography, and they weren't ready." Silver further points out that: "In the backroom while Apollo 14 was going on, in the science backroom, were two guys: myself and Dave Scott, the commander of the upcoming mission. When we got through, Dave said, 'Lee, that's not going to happen on our mission' " (Silver interview, 2002).

Silver does admit that perhaps there were some unusual circumstances surrounding the Apollo 14 mission: "The Apollo 14 mission was conducted with photographs that weren't very good, preflight photography taken by the previous missions, and the crews weren't properly prepared. On Apollo 14 they didn't have a Rover. They had the oldest man in the astronaut corps pulling a little rickshaw, which carried all the equipment and the sample bags and the other stuff up slopes that were steeper and over distances that were longer, so it was physically challenging. So if l said they got lost, it wasn't as if they weren't working hard, but they had not acquired that little bit extra" (Silver interview, 2002). Schmitt, according to Chaiken, would allow that "Shepard had other things on his mind, like getting up to speed after a ten-year absence from spaceflight, and the fact that he was about to fly the first flight after a near disaster." In any case, the geologists learned a lesson with Apollo 14: The commander sets the tone (Chaiken, p. 396).

The first two field exercises for the Apollo 14 crew were mainly show-and-tell exercises to familiarize them with geologic field activities such as terminology, descriptions, rock-type recognition, and sampling. Neither Shepard nor Mitchell had been involved in any of these activities for several years and a sort of "crash course in geology" was undertaken. They visited Meteor Crater and observed the structural and ejecta features produced by a large impact crater. This was followed by a trip to Craters of the Moon where volcanic craters and their features were observed as a contrast to an impact crater. On the third trip, a field excursion of five days to the Pinacates volcanic area in northern Mexico, the crew started with some more descriptive and instructional exercises but gradually began to undertake more exacting exercises that included not only descriptions, discussions, and sampling but also the first of the simulated lunar traverses with full lunar equipment. On this trip the crew had their first opportunity to use the MET, a small two-wheeled cart that was designed to carry all of the lunar surface tools, cameras, film magazines, sample containers, and a magnetometer. Dick Jahns, one of the principal trainers of the 14 crew, led the third trip. He observes that on this trip "they made a quasi-successful test of the MET. The really important thing in that exercise, however, was the abandonment of the 'crash course in geology' approach and the embracing of a new emphasis on complete and accurate observation followed by careful and well-organized description. I thought that the response of the astronauts to this change in emphasis was tremendous" (Jahn's letter, June 21, 1974).

For some of the field exercises, the 14 crew actually did some mapping of units on aerial photos and planned some traverses themselves. When Mike McEwen, the MSC person involved with the Apollo 14 training, was asked if the crew had any preplanned traverses for their field exercises in Hawaii he responded,

> *"Well, yes and no, we did that in two ways: one was to give them an aerial photograph and put an overlay on it and ask them to identify different units based on texture, color, or patterns, or any other things like that they could see; pretty much the way the lunar maps were built. So we asked them to do that and then asked them to figure out a traverse; to try to sample and identify what the various units were that they had identified on their maps. We didn't have them do that on all trips but on some trips. On other trips we just turned them loose. On some trips we actually had predefined traverses."*

McEwen also indicated that a backroom simulation was also used on some of the Apollo 14 trips:

> *"Some of the geologists would actually sit on the other side of the hill with a walkie-talkie and serve as the backroom. They'd sit where they couldn't see the crew. And the crew would describe what they were doing and the backroom guys, when appropriate, would ask questions." Also when asked if a CapCom was along on the trips he stated: "On most of them, yeah. I'm sure on some we did not."*

He indicated, however, that the flight directors were not along on the 14 trips (McEwen interview, 1995).

A schedule for all of the science training for Apollo 14 is shown in Appendix J. It is worth noting that during one of the final briefings on photo procedures on December 7, 1970 the crew was shown examples of various panoramas, close-ups, and other documentation photos from Apollos 11 and 12. These photos provided many good examples of what was done correctly and incorrectly in carrying out the photo procedures on the previous missions. The 14 crew quickly grasped what was done right or wrong simply by studying these photos, and they requested that sets of these photos be reproduced and sent to their offices at KSC for study during evenings and other slack periods.

There were a few new procedures to be learned for the Apollo 14 mission. Between Apollo 13 and 14 it had been recognized that a collection of several walnut-sized rocks from a few localities would provide an important suite of samples that might include a larger variety of rock types than a few larger rocks from the same vicinity. It was suggested that a raking device might be the way to collect such a suite of rocks. The rake could not be developed, tested, and used in training before the Apollo 14 mission. So the suggested method for collecting such a suite of rocks on 14 was to select an area in which several walnut-sized rocks were observed to be present and outline a circle within which all "walnuts" and some associated soil would be collected. This was termed a "comprehensive sample" and required a bit of additional training. In addition, the training for deployment of ALSEP on Apollo 14 included a couple of new experiments, the Active Seismic Experiment and the Portable Magnetometer, both of which required a bit more training. For the former three geophones were strung out on cables from the central ALSEP station. After setting out the geophones the LM Pilot (LMP) was to set off 21 small charges along the geophone line. A second part of the experiment involved setting up a mortar to fire four explosive charges that would detonate at different distances from the mortar. The mortar firings were to be activated several months after the mission. The astronauts had to set up the mortar in the correct location with the correct alignment. For the magnetometer the instrument was to be set up and readings were to be made at various stops along the traverses.

Sutton recalls eight days of simulations at MSC in November and December 1970 and January 1971 with the ALSEP and/or partial EVAs with tools and cameras to practice procedures which were observed and critiqued by the geology team (Sutton personal notes, 1975). One of these, on November 9, was a computer-generated sim of EVA 2 in which a simulated fan malfunction in the PLSS near the end of the EVA was introduced to test real-time decision capability of the Control Center teams.

For Apollo 14 the briefings for the ALSEP and other PIs were scheduled by the Mission Scientist from the Astronaut Office in conjunction with the science trainer. . They would contact the PIs to arrange for times of the briefings: about 2 hours per PI was the estimate for the average briefing. These briefings started in October 1969 and continued for several weeks. In addition, all PIs were invited to EVA run-throughs that involved their instruments either at the Cape or MSC. Many of these were to be fully suited simulations in order that the PIs understand exactly what the crews would be doing and verify that the procedures were consistent with the PIs' requirements. The geology team was on duty in the SSR of Mission Control for some of the run-throughs (Monthly report of USGS, Nov. 1970).

In the Technical Debriefing for Apollo 14 Mitchell made an important point regarding the time taken for procedures during simulations with training equipment at 1-g versus the time doing the real thing on the lunar surface. He suggests adding a time cushion because "there's one factor you can't take into consideration. This is the fact that you're just a bit more careful with the actual flight equipment in the actual case, you want to be sure you do it exactly right, so this just takes a little extra time" (p. 10-19, 10-20). Mitchell pointed out that they were generally well ahead of the time line during training, whereas on the Moon they were generally a bit behind. Shepard added "if you're not ahead in training, then you're going to have problems. Shepard also pointed out that the difficulties of carrying the ALSEP equipment to the deployment area during training was not very realistic. After unstowing all of the ALSEP and other equipment in the building and loading up the MET, they "would walk to the door, get in the truck, and ride out [to the deployment location]. Somebody else would drag the MET out for us. At least once we ought to go ahead and carry the thing out there to give a feel for it" (p. 10-25). As with Apollo 12 the crew mentioned a few hardware problems that were not foreseen during training and should be dealt with by the engineers. In hindsight, they felt that during training more attention to identification of specific landmarks along their traverse might have avoided the frustration they faced in trying to find Cone Crater.

Mitchell had a suggestion about the classroom training.

> *"As long as we are working under time constraints, like we work under on lunar exploration, we ought to emphasize the things that are most useful: sampling techniques and recognition of features that cameras don't show or that the geologists need in real time to help real-time planning in the traverse. I think we were fairly effective in working with the field geologists to develop the descriptive techniques and the thinking processes that allowed us to be flexible in real time. This doesn't include much mineralogy and rock identification, etc. It was fundamentally the operational problem of how you describe the terrain that you're seeing and bring back samples that will allow them to work for the next two years"* (Apollo 14 Technical Debrief, p. 25-18, 25-19).

There were many lighter moments involved in the field trips. When Mike McEwen was asked to recall some of them, he came up with the following stories:

> *"In Idaho the 14 prime crew was down in a crater. They were off on some sort of a traverse. So Shepard and Mitchell were down in the crater, and I was standing up on the rim with Cernan and Engle [the backup crew]. Engle picked up a little pebble and reared back and threw the thing in a great high arc out toward where Shepard and Mitchell were way down, far away in the crater. A few seconds later we saw Mitchell sort of jump and his knees buckle a little bit. That pebble had hit him right in the head. Fortunately, it was small and didn't cause any serious damage. But when he came back he was joking about the length the backup crew would go to get on the flight.*
>
> *"At Kilbourne Hole Bruce McCandless had brought along a plaster rattlesnake. It was coiled and it was so real looking that, even though I knew it was plaster, I was careful about even touching the thing. He had placed the thing in the back of one of the vehicles thinking he would scare someone*

> *with this coiled up snake. Well, nobody saw it so he moved it somewhere else. Again nobody saw it. So, he brought me in on it and he said 'where are we taking them next?' I told him we had a perfect place. We were going to go down a little notch in the rim of the crater to look at some of the strata down there. So he slipped over and put it on a little ledge right at shoulder level in this very narrow passageway into the crater. The whole contingent: astronauts, geologists, prime crew, backup crew, tool people, everybody walked by it going down and walked by it coming back out. Nobody saw it. Bruce and I were there giggling in the background. Finally, we decided that no one was ever going to see it. So he put it out in the middle of the area near the parked vehicles and then said 'Oh my God, look there's a rattlesnake.' So we started picking up stones to throw at it. And every one in the group was throwing stones at the thing. Finally, somebody hit it and it shattered into 25 pieces of plaster. And everybody then knew they'd been had. Bruce said he was going to mount those pieces on a plaque and present them at the post-mission dinner.*
>
> *"This was in Hawaii with the 14 crew and there was some active volcanism going on then. There was one place on the east rift. I don't remember the name of the particular pit, but you could stand on the edge of this thing and look down into the boiling turbulent lava. It was really an awesome thing to see. Shepard and Mitchell went over and stood on the edge looking down into there. When Shepard came back he said, 'My God, if Deke knew we were doing this he'd cancel all the rest of astronaut training for all time' "* (McEwen interview, 1995).

Apollo 15

Starting with Apollo 15, for a number of reasons, there were several major changes in the nature of the missions. New engineering developments had resulted in three EVAs, a powered vehicle to extend the range of exploration, and some new tools for science investigations. The science payload to be taken to the lunar surface was about 1200 pounds, six times that of Apollo 11 and nearly three times that of Apollo 14. These developments brought about a significant increase in the amount of science training, the intensity of the crews' interest, and the extent of scientific investigations at each landing site. All of these additions led to substantial changes in the science training, not only in the field exercises but also in the coordination with other operations associated with the missions. It became standard procedure to have a simulated backroom with CapCom and scientists on nearly every field trip. For the first time all of the CapComs were scientists and that would also be the case for the actual mission. Flight directors and Headquarters personnel began to accompany the scientists and astronauts during the field traverses. Traverse planning now included contingency plans for all conceivable problems, and paper simulations and math model simulations (described later) were run several times before the actual missions. The extent of classroom, laboratory, and field training is summarized in Appendix K.

The attitude of the crew is reflected in the comments of Commander Dave Scott:

> *"Another vital focus of our training was the intensive preparation for the geological investigations we would be carrying out. This meant field trips. I loved them. I loved to be outdoors. It was a chance to get away from the simulators and other hardware for three days at a time, a chance to have a few beers in the evening after a hard day in the field."*

He adds that it also provided a chance to think a bit about some of the details of the mission:

> *"In the evenings after many of these trips we discussed the names we wanted to give to some of the craters and mountains of the Moon that we spent so much time studying. Technically only the International Astronomical Union can approve names for landmarks on the Moon, and, as it turned out, they didn't like some of the names we chose. They wrote us a long, very serious letter stating their objections to, for instance, 'No-name Crater': 'You can't call a crater that. It's just not logical.' But the names we chose stuck and were used by all the geologists and scientists working with us at NASA. In the end they were recorded in all the official documents and that essentially carried more weight than the objections of the IAU"* (Scott, p. 270).

See Appendix L for the interesting names that were used for the craters and other features by the Apollo 15 crew, as well as the reasoning behind each name.

When the 15 crew first started training in late 1969 they were expecting to carry out walking traverses with the MET. It was not until September 1970 that some of the later missions were canceled and it was announced that the 15 mission would be the first to use the Lunar Rover. The USGS had been developing a simulated Lunar Rover (Grover) and had it ready for testing in late August 1970. At that test it was driven by astronauts, engineers from

MSC and MSFC, and others from NASA Headquarters, and found to be quite satisfactory (Beattie, p. 185). By November 2, 1970 the USGS had Grover available for training and the Apollo 15 crew had their first experience in using Grover on traverses at the Cinder Lake Crater Field and Merriam Crater (See Appendix I). Nearly all training in the field from that point on used vehicle traverses many of them with Grover. Grover had nearly all of the features that would be present on the Lunar Rover. There was a tool carrier, a navigation system, and mock-ups of the relay antennas, TV, and other equipment that would be on the real Rover. Sutton recalls that Scott and Irwin during the walking exercise at Buell Park in September 1970 expressed concern about how much geology they would be able to accomplish from the Rover. He tried to reassure them that once they had used the Rover in enough training it would become second nature to them and they would see a lot more than on the first couple of times using the Rover (Sutton, personal notes, 1975). This was borne out on the real mission where they described the geology extremely well while riding in the Rover and actually stopped the Rover once to collect what they felt was a unique sample that they spotted while driving.

One of the major considerations for the success of the field training was the interest of the crew in the geologic tasks combined with the rapport that developed between the crew and the trainers. Dave Scott had heard of the great respect developed for Lee Silver, who had been the prime mover for the geology field training of the Apollo 13 crew, and wanted Silver to perform the same role for the Apollo 15 crew. When asked about Lee Silver working with the Apollo 15 crew Jack Schmitt responded that Scott "very much wanted Lee, and I think he probably persuaded Lee to do it because of what Lovell and Young had said about it. 'Cause I was having trouble getting Lee to take on another crew." Schmitt indicated that training schedules were very tight at that time because several crews were involved with field exercises over the same period of time and to be involved with 15 and 16 (Silver had already been asked and agreed to train the 16 crew) would have required at least two weeks per month of one's time. Schmitt felt that Silver's reluctance was related to such a time crunch (Schmitt interview, 1995). But Silver agreed to work with the 15 crew and on May 18-23, 1970 he led the first field trip for the Apollo 15 crew to the Orocopia Mountains in southern California and accompanied them on nearly every one of their later trips. Silver also was a member of the SSR in Mission Control during simulations as well as the actual mission. Schmitt recalls one of the more humorous events on the Orocopias trip. "I remember that on the first trip to the Orocopias Lee was standing up on a little ridge and I was down in an arroyo that bounded the ridge and he had all the astronauts lined up on the ridge. They had missed a fault. He was standing up there silhouetted against the sun with his arms outstretched and I said in sort of a stage whisper, 'Hell of a way to spend Easter, Lee' and we just wiped out" (Schmitt interview, 1995).

Silver developed a wonderful rapport with the crew and one cannot overemphasize the necessity for this type of interaction. He recognized the immense responsibilities that rested on the shoulders of the mission commander:

> *"Now, you have to know what they had to do in terms of continuous flight training, continuous work. You had to know about the discussions about contingencies, alternate options, all the other things. The key man on all of this was the mission commander. Among the many things that I got to learn was, the mission commander has immense clout. But at the same time, he knew that in order for his crew to make the accomplishments that were required and, most importantly, to come back, he needed a successful super operation"* (Silver, NASA Oral History Project).

This interaction with the commander was very successful, as indicated by the comments of Dave Scott:

> *"There had long been resistance among senior managers and engineers at NASA to including more science on the Apollo missions. Their position was, I think, 'Seen one rock, you've seen 'em all. Just get the geology out of the way. Get the rocks and come home.' But there was a gradual shift in opinion once the major hurdle of landing men on the Moon and safely returning them to Earth had been overcome. That was due in large part, I firmly believe, to the brilliance and enthusiasm of Professor Lee Silver, our main guide and mentor in the study of geology.*
>
> *"Lee Silver was an inspiring teacher and a really nice guy. He made learning entertaining. He knew how to get across the complexities of what he was talking about. He knew how to fill us with enthusiasm for all that could be achieved in the geological study of the Moon. Lee worked closely with our geology team leader, Gordon Swann. They had been close friends for many years and were both great to work with. But it was Lee who usually led the geologists who took us out in the field, preparing trips to areas resembling some of the geology we might expect to find on the Moon. At least once a month throughout most of our twenty months of training, Lee and his team took us out to ever more complex and demanding locations. We went to Hawaii, the Rio Grande, the Mohave Desert, and*

> *the Orocopia Mountains, the Coso Hills and the San Gabriel Mountains in California. We were taught to observe carefully and analyze what we saw. We were shown how to pick out key rock samples, which explained how that particular piece of the Earth's crust had been formed. On the Moon, our mission was to find rocks which would explain the mysterious genesis of our nearest neighbor in space.*
>
> *"In the beginning, we had little idea of what was expected of us. When asked to describe what I saw on one of the first trips to Orocopia, for instance, I got not much further than saying, 'Boy, there's a lot of stuff on the other side of the hill.' Lee Silver helped us tune in to the language of geology, and soon we were describing the composition of that 'stuff' as granite, basalt, sandstone, or conglomerate, and its shape as angular, sub-angular, or rounded. On the long drive out to a site, he would suddenly have us pull over by the side of a road cutting through the mountains and get us to describe the rock formations we saw. One of Lee's favorite tasks was to get us to collect a "suite" of rocks, a selection which represented the geological setting and diversity of the area. There was always a fair amount of friendly competition between the prime and backup crews, so Jim and I would compete against Dick Gordon and Jack Schmitt to present the most impressive suite to the professor. Jack was the first trained geologist recruited to the astronaut corps and his expertise spurred us to learn. It also meant he and Dick were a tough team to beat. On a trip to Hawaii, Jim and I got caught in a thunderstorm on a pretty remote mountainside and approached our geology task with a little less enthusiasm than usual; consequently we missed something important. Jack and Dick hadn't missed it, of course, and said mockingly that we 'needn't think we could get out of a task because of a little freezing rain.' It was all good-natured but kept us on our toes none the less"* (Scott, p. 272-273).

Silver also realized,

> *"The mission commanders were training me. More than once, David Scott barked at me. He said, 'Do we really have to know this? Do we really have to do this?' He wasn't being contrary. He was continuously weighing the importance of what was being done, continuously weighing the time. Their mission wasn't just to go up and pick up samples. They had to deploy very sophisticated instrumentation. They had, if necessary, to make connections or repairs if they were necessary. They had to make judgments in real time whether or not they could perform the experiment as originally planned, because no one could anticipate the details of the landing site."*

Silver likes to point out one of the results of his input to the crew's approach to obtaining the best information:

> *"One of the things that I had used in the training approach which the crews all seemed to appreciate was, first, stop and look. Don't jump in and start doing the things. Look around. Because Dave knew the capabilities of the landing craft, Dave said, 'Lee, 'what do you think if, before we get out and do the first EVA, if we open the hatch at the top of the landing module, look out, take a good long view, and take a camera and shoot the big picture before we start focusing in the details?' This was a splendid, splendid suggestion and, as far as I'm concerned, indirectly, one of my achievements, because that had come out of all the things we'd been doing in there. But I'll take nothing away; it was Dave's suggestion" (Silver, NASA Oral History Project).*

This was to become known as the "Stand-Up EVA."

Although the Stand-Up EVA was eventually accepted for the mission, the procedure to acquire the necessary lens for the camera [a 250-mm telephoto lens] was not so easy to accomplish. Again, Silver's recollection of the process:

> *"We [Scott and Silver] talked about the camera. We wanted a lens with a longer focal length, because we're now taking pictures way off in the distance. We wanted to make a picture of the higher parts of the Hadley-Apennines, which go up, just so that you can understand, 25,000 feet on the lunar surface. So we decided we'd ask for one of those, and it went in on a routine request from the troops. But on a mission where weight was absolutely critical, the weight of another lens was considered critical, and remember, weight could lead to the violation of the number one requirement: get them back. So he was turned down.*
>
> *"Well, by that part of the Apollo mission, I had a pretty good standing, so it was agreed that I'd go in and see General McDivitt. I went in to see General McDivitt, who'd had a distinguished career as an astronaut. He said to me, in sum—this is not a direct quote—'Lee, you have your mission and I have mine. Mine is to get the crews back.' And I said, 'This is a marginal request. If the total*

> *planning depends on the weight of one lens, something hasn't been done right.' Of course, that's already been said by the commander, who knew as much or more about the flight requirements, about the anticipated performance of the landing module, of all these other things. But the general had to do it by his likes. I said to him, 'Okay, Jim, you're running the safest and best lunar trucking operation, but you're not contributing to the accomplishment of it.' Well, he wasn't very happy with that, and I wasn't very happy with what I said. But in the end we got to talk to Rocco Petrone [at NASA Headquarters]; we got the lens. And Dave got up and did a superb thing, and his pictures of the Apennines, it was the one place you could get grand vistas. It was great, and he did just exactly what he had to do; he knew what he had to do and what he had to say, and it was just super" (Silver, NASA Oral History Project).*

Scott had some additional input to the problem associated with getting another new item for his mission:

> *"There was little appreciation at first of how complex our geology missions were. I'd had an interest in geology for some time; the art of interpreting millions of years of history in rock samples and structures seemed a natural progression from the interest I had long harbored in history and archaeology. But it proved pretty hard to get some of the NASA guys interested in observing our performance during this aspect of the program. I never could get Deke Slayton to go on geology trips, for instance, or even in the simulators for the mission. It was really difficult to communicate with him at that time. He seemed rather detached. I remember one meeting, in particular, with Deke late one evening in his office. I had to argue my corner very hard to get him to agree to us taking just one extra piece of geological equipment, a light aluminum rake. Deke just didn't get it. He chewed his cigar and slumped back in his chair digging his heels in as I explained it would enable us to pick up small fragments of rock. He was equally resistant to my idea of taking a telephoto lens for high-resolution distant shots of geological features we would not have time to study at close quarters.*
>
> *"I understood his concerns about the extra weight the items would add to the LM, which was already heavier than that of any previous mission because of the Rover and additional equipment we needed for our longer stay on the lunar surface. Weight was a crucial issue on every spacecraft and was closely monitored by NASA's Configuration Control Board. Early on in the Apollo program, technicians had been asked to review every single item carried aboard, and, in an effort to rid the spacecraft of even the smallest unnecessary weight, they reduced the number of Band-Aids in the first-aid kit. But I was confident that the two extra items I wanted to take could be accommodated. For certain aspects of the mission, we required less propellant in the LM than previous missions, for instance, because we would be making a direct rendezvous with the Command Module after our lunar stay, rather than orbiting the Moon once before the rendezvous. Deke eventually came around to my way of thinking, but I still had to spend time arguing my case at higher levels"* (Scott, p. 271-272).

Scott describes the progress of the field exercises and provides an excellent description of the difference between field geology on the Earth and the Moon:

> *"Once our knowledge was sufficiently advanced, we started conducting geological traverses as if we were on the surface of the Moon. We carried backpacks of a similar shape, with radios attached so that we could communicate with a mock-up Mission Control—another member of the geological team sitting in a tent on the other side of the mountain we were exploring. These exercises were valuable in getting us to describe the landscape in detail to people who could not see it. During the months with our geology mentors, a new concept of field geology emerged, which might be called 'planetary field geology.' In some ways it was more of an art than a science, since it had to be conducted under very different and much more demanding conditions than terrestrial field geology: in a hostile and unforgiving environment and under extreme time limitations offering no opportunity to return to the same location—at least not in our lifetime. A terrestrial field geologist can often spend weeks or months in one location and return later to complete and reevaluate findings. We had to make instant analyses and decisions on the scientific value of the objects we found, without time to relish their meaning. In effect, we would have to rely on instinct and training in picking a sample and would have only about five seconds to look at it, and maybe ten seconds to describe it, before bagging it and moving on" (Scott, p. 273-274).*

Silver was very proud of the way the Apollo 15 crew had responded to his training and had become geologically savvy enough to recognize geologic problems and, on their own initiative, devise means of approaching the problems. He points to some of these situations on the actual Apollo 15 mission where this training paid off.

> *"There was an experiment for a group of people who were interested in what the solar wind and cosmic rays were doing to the surface of materials on the unshielded Moon. On Earth we're shielded by atmosphere, by magnetic fields, and other things. So what is the nature of this stuff? We described a potential experiment for them. We got two rocks that were shielded on two sides; collect [samples], see if you can get a photo down below, see if we could get some of the walls of the rocks that are partially shielding them. They did better than that. They found a rock about that high [Silver gestures]. They rolled it over and brought up the shielded side. They sampled the unshielded side. They sampled the shielded side. They sampled the soil underneath it. You understand, they revised the experiment and did it better. Remember, this is the first mission in the lunar world with a vehicle [Lunar Rover]. Nobody knew exactly how well that vehicle would perform. We'd asked them to pick up lots of big angular fragment samples. On the way, all of a sudden, there was an uncalled-for stop, Dave worried, said something, muttered something about 'I'm fixing the seatbelt.' Bald-faced lie. They'd seen a big rock, thereafter known as the 'seatbelt rock,' which they stopped to pick up [even though] it was interfering with the time lines in their mission" (Silver, NASA Oral History Project).*

Scott recounts the same story from his perspective:

> *"Once when Houston prompted us to get moving and head home, I was so determined to pick up a very interesting black rock, which I could see not far away sitting all alone on the gray surface without a speck of dust, that I had to resort to subterfuge. I stopped the Rover and pretended to readjust Jim's seatbelt so that I could stoop to pick it up. This beautiful rounded piece of scoriaceous basalt was later dubbed the 'seatbelt basalt' "* (Scott, p. 302).

Another of Silver's examples of the extra insight by the crew involved the visit to the rim of Hadley Rille:

> *"The Apollo 15 crew got to the edge of the rille. You've got to watch yourself. Do not get on slopes which might slide or give away on you. They'd already run into that problem when they'd gone up on the flank of Hadley Delta, and their vehicle was sliding down. Suppose they'd lost their vehicle. Suppose it had slid. They didn't take the vehicle over the crown. But they started to walk over because they could see rocks. To the time that we were into Apollo 15 and probably throughout the entire string of Apollo missions, we had never directly sampled a rock that was still in place, what we would call bedrock. And these guys knew that one possibility was that they would find that in the rille. And they went over, and they sampled, and they took their pictures [telephoto pictures of the opposite side of the rille]. But the pictures we took of the opposite side of the rille with that camera and lens; in fact, there were a series of flows exposed there [as bedrock], just as they were in the canyon of the Rio Grande, the gorge on the Rio Grande. And we think there's a very good chance that—they took several samples—that some of the samples they got were probably, that's all we can say, probably, akin to what we could see in the opposite side of the canyon"* (Silver, NASA Oral History Project).

One of the most memorable samples was the anorthosite, dubbed 'Genesis Rock' by the media, that was collected at Spur Crater. Silver recalled it as follows:

> *"Dave reached out with this device we had created where he could grab onto a rock and bring it up, and he brought it up. And Dave said, 'Gee, look what I've got.' And Jim said, 'That's it.' What they had found was a rock made up mostly of the mineral called feldspar, and geologists have a special name for that, and it's called anorthosite. Now, if you look at the Moon, either in high-quality photography or when you've got a full Moon, you'll see darker parts and lighter parts. Well, they've already identified that the darker parts, which are called mare, are made up of lunar basaltic lavas. Fifteen was one of the beginnings of our beginning to understand the uplands [lighter parts]. In Apollo 11, people sorting through the finer fragments [in the soil samples], fragments that were one millimeter to one centimeter in size, like that, in that area right there, they began to see little bits and pieces of what looked like rocks which were called anorthosite [a light colored rock], and here it was, a piece that was that big [Silver gestures]. It wasn't a little teeny piece; it was a big hand specimen. And because we'd learned from 11 and had built it into the experiments—I had taken them to a place in the San Gabriel Mountains behind Pasadena where we have anorthosite, and they'd looked at it, and we had discussed the fact that the anorthosite might have been the most primitive, or primordial, rocks on the lunar surface. But when they picked this up, they said, 'That's it,' and they described it a*

> *little bit, and in the backroom we knew that they had picked up a piece of what looked like anorthosite"* (Silver, NASA Oral History Project).

Scott had his own rather graphic version that illustrates the excitement that they experienced with this discovery:

> *"Just then some bright crystals caught the sunlight. 'Oh, man!' cried Jim, startled. 'Oh, boy!' I said, turning to look at a small white rock perched on top of a gray pinnacle, almost as if it had been placed on a pedestal to be admired. I picked it up with my tongs to look more closely and saw a sliver of white crystal to the side of it catch the Sun again. 'Look at that glint,' Jim exclaimed, and in that moment I felt a bright flash of recognition. 'Aaaah…Guess what we just found,' I radioed Mission Control, barely able to contain my excitement. 'I think we found what we came for,' I said, my heart pounding a little faster with a mixture of excitement and pride. 'Crystalline rock, huh?' Jim remarked, in what was less a question than a slow whistle of amazement. 'Yes sir. You better believe it,' I said, laughing out loud now and then for the benefit of the backroom boys. 'Oh, boy, I think we might have ourselves something close to anorthosite....What a beaut.' 'Bag it up,' radioed Joe Allen enthusiastically"* (Scott, p. 307-308).

Clearly, the enthusiasm and excitement of exploration of the Moon had been developed to a much greater extent for Apollo 15 than for previous missions. In addition, on Apollo 15 the flight directors began to find that it was important for them to attend the field exercises. In fact, as their participation evolved so did their interest in the geology that was being taught to the crews. An SWP was set up in early 1970 to bring together the PIs, the traverse planners, and the operations personnel to help plan the science activities for the missions. At the SWP meetings, the PIs held briefings on the procedures and locations for use of their instruments or accomplishing their tasks. The operations personnel presented the constraints and capabilities of the various tools, life support equipment, and vehicles. The Mission Controllers outlined the communications, time restrictions, and chain of command that was involved, and the traverse planners tried to put all of this together. According to Sevier who chaired the subcommittee for traverse planning,

> *"SWP became the first place where the science input's operational constraints really got a fair shake. The operations folks began to have a much better appreciation for what the science folks were trying to do and at the same time the science folks began to get a real appreciation for what the real constraints were: the safety things and the like. The first time that happened, it seems to me, was when Apollo 15 had been picked, Hadley Rille had been picked as the Apollo 15 site, and Glynn Lunney asked Jim Head and I to come over and brief his mission operations team on Hadley Rille and what the objectives were. I talked about the traverse planning and Jim talked about the regional geology and that sort of thing. Glynn had about 100 guys in the Building 30 auditorium and things really went better after that. There began to be a mutual sort of thing. We're all in this together. The operations guys want to get the most science that they can out of it." [At that time] the flight directors really began to get a feel for it being more than just an engineering thing"* (Sevier interview, 1995).

In fact, Gerry Griffin, one of the flight directors on the first field trip for flight directors, wrote a memo to Scott after the field exercise indicating that he felt this was an excellent operation that would be "very worthwhile for operations types" and for "senior management types." He also felt that the observers should have an extra day learning about the field exercise, or at least an evening briefing the night before. He suggested that the observers should stay near the field trip leader during the exercise to ask questions and hear his comments. He summed up the experience by stating "I learned more about field geology in two days than I did in all of my preparation for Apollo 12 lunar surface operations. I would like to hit it once or twice more before Apollo 15" (Memo: Griffin to Scott, Sept. 24, 1970). Flight director Pete Frank "thoroughly enjoyed the field trips. It was necessary to stay out of the way and not interfere with the training, but it was easy to monitor the discussions between the trainers and the trainees. I was impressed with the difficulty of training someone to act as an onsite explorer for a remotely located PI. The importance of the crew's use of standard nomenclature and specific key phrases to describe actual rocks collected at the training site was a detail I learned to appreciate. I understood that it would be important to leave the CapCom, the crew, and the PI undisturbed in their discussions during the mission. It was too bad we could not have trained geologists on each of the landing missions, although I thought the astronauts did a remarkable job under the circumstances. There was a lot of effort required to adequately train them" (personal communication, 2004).

Lee Silver recalls two training trips in particular, Buell Park and the NTS, where the flight directors were present:

> *"On both of those, several key members in the Flight Controllers Directorate, like Gene, like Gerry Griffin, like Glynn Lunney, came along, wanted to know what I was doing with these guys and whether or not they could understand how it would relate to the mission. And that was extremely important. They had to know what the science teams were trying to do, and they listened and they commented. They never commented to me; they commented to the crew commander, because that's where the power and the action was. But we hit it off in both those cases, and so when things came out of the science backroom, he would know I wasn't top-dog [in] the science backroom. They knew that I was there, and they got to meet the members of the little backrooms we were operating. I even ran a mission, an exercise, in the California desert. What's the naval station up there by Ridgecrest? China Lake. And for that one, Rocco Petrone came from Washington [D.C.]. Chet Lee came from Washington, you understand, and they all wanted to see what the hell we were doing. And we had a full-out communication system with the CapCom working, and we worked it as if we were going to be in the science backroom. And by doing it this way, by the time we got to the actual operations, we got closer and closer to reality. But maybe the thing you have to take out of this is, we were training each other and sharpening our ability to do the job"* (Silver, NASA-JSC Oral History Project).

Gene Kranz had some very interesting comments about the field trips.

> *"One morning in the spring of 1971 Gerry Griffin walked into my office. He said 'The Apollo 15 crew thinks it would be good for you to take a break and get out of this stuffy cell. How would you like to go on the next field trip with the crew and myself?' [NTS trip of 19-21 May]…This was something new, something different, something pure fun. I knew nothing of field geology, but since we had won the race to the Moon, the shift to lunar science dominated most of our effort. The trip might provide an opportunity to get smart on a new aspect of the business…I jumped at the chance…The Apollo 15 crew, Scott and Irwin, attacked their role as surface geologists with the intensity and enthusiasm they demonstrated in learning to fly a new spacecraft. They were exploring a new world full of riches for the scientists and were in competition with their predecessors and themselves"* (Kranz, p. 353-354).

Kranz also had high praise for Lee Silver. In his discussion of the scientists involved in the surface geology training he stated:

> *"No one among them impressed me more than Lee Silver. He stood out as we were setting up the surface science rooms, and again during the skull sessions at the apartment of Jack Schmitt…Silver's academic credentials were formidable, but the man was even more impressive. You can tell great teachers by their demeanor, how they talk, how they always seem effortlessly in control…The bond between teacher and student astronaut was clearly evident on the way to the site as Silver and his students engaged in a lively Q and A session. There was not a wasted moment…"*

Kranz soon discovered that Silver did not expect the flight directors to just come along on a field trip for the ride. Lee was determined that the controllers should experience the same types of problems as the astronauts. "Griffin and I were really just along for the ride, but we found out quickly that Silver had other ideas. After a brief summary of the training objectives, Lee gave me a quick course in geology 101, then sent me off to find as many different materials as possible within walking distance of our landing site. I had no idea where to start, but I felt obligated to give it my best shot" (Kranz, p. 354).

Gordie Swann's recollection of the participation of the flight directors is also worth noting:

> *"But starting on 15 is also when some of the honchos like flight directors and those guys started going on the missions and that helped. It gave them a better picture of the things we were trying to do. Gerry Griffin was a strong supporter. Gene Kranz was a hell of a supporter. I think Lee probably had more to do with getting some of those guys interested in going than any one person. During those simulations when we were down there in the Control Center he would really talk his head off to those guys. You know Lee could sell ice cubes to Eskimos. Dave Scott of course was a big key factor. And so was Jack (Schmitt), and Jack was backup. And that's when that kind of thing started coming together. And Gerry Griffin was Dave Scott's choice for the flight director. And Joe Allen was Dave's choice for CapCom. And he went to Deke about both of those things. I guess he went to Chris about Gerry Griffin. Then he and Jack were pretty instrumental in trying to get the flight controllers out in the field. Of course Little Joe was really active as the mission scientist and he was a real scientist in spite of being a physicist from Yale, an Eli (spoken with a sly grin). Joe was really an eager guy to get*

> *in and do all that was good for science. Things just kind of started falling together then. It was happenstance. If Dave had been on 14 and Al Shepard had been on 15, 14 might have been a little better and 15 wouldn't have been nearly as good. That's what it amounts to. It was about that time that the three prime crews started getting some kind of competition. Well there's no question, 16 set out to do a better job than 15. They knew they had a hell of a tough act to follow. And they did a damn good job. I don't think it was near as good a landing site as 15. It wasn't fun all the time. Then 17 of course shifted gears a little bit with Schmitt in there. He was damn well going to do a better job than any one else. He was a geologist. And they did a very good job"* (Swann interview, 1995).

Having geologist Jack Schmitt as a member of the backup crew on Apollo 15 allowed better input for the simulated traverses that were run during the field trips. He had been a test subject for many of the suited and lunar gravity tests to develop hand tools and other instruments as well as the procedures for their use. Schmitt helped plan some of the field trips that were to be used in the training. For the Apollo 15 training trip to Buell Park, Schmitt and Gordie Swann went to the area a few weeks ahead of the scheduled time for the crews' training trip and planned the traverses and tasks. Because they had actually mapped this area several years earlier as part of a USGS project, they were familiar with the geology and the terrain and were able to design a very useful exercise. Schmitt recalls an amusing incident that occurred during the planning for the trip.

> *"Gene Simmons went out there with us. And Gene and I stopped off in Gallup to buy some steaks to cook. We were going to camp out. We got some beautiful steaks. They really looked good. And we finished our day's activities planning the traverses etc. We went up into the pines and put up a big fire and got some coals. Gordon had bought a rot gut whiskey, Mattingly and Moore. 'Have you ever heard of it?' Oh God, talk about bad whiskey. Gordon has a propensity for buying bad whiskey. Somehow I ended up in charge of cooking the steaks, so I marinated the steaks in this Mattingly and Moore. They were absolutely the best steaks that anyone had ever had then or since. And after I came back here not too long after that I decided I would try it again with some Mattingly and Moore in my apartment. They were terrible, absolutely terrible. I don't know whether the steaks were good or we just had had enough to drink that anything would have tasted good."*

Many of the training exercises for the ALSEP instruments and other tools that were used in the missions were accomplished on the area known as the "sand pile" at the Cape. Earlier, it was mentioned that some trainloads and truckloads of large rocks were brought in to spice up this training area and make it a bit more realistic. According to Swann these were brought in shortly after the Apollo 14 mission. Therefore, the Apollo 15 crew was the first to use this new feature. He recalls,

> *"We threw in some ringers too. I had a big chunk of kimberlite from Buell Park. That's almost unheard of because the stuff is so crumbly. I found it in a wash. Jack (Schmitt) and I did a fair amount of work out there. And that chunk had rolled down since we had been there. So I just brought it home. I threw it up on top of the load of cinders. We were out there [on the sand pile with the Apollo 15 crew] and it was kind of funny. Jules Bergman [a journalist] was there and I said 'We've got this traverse arranged where Jack's gonna go find this piece of rock from an area that he spent quite a bit of time in. Let's just see if he recognizes it.' Well Bergman was just lying in wait to see what Jack would do. Old Jack just went through this long elaborate description of the colors of it and the clasts in it and on and on. And finally 'It's the kind of thing you might see at Buell Park'. He knew exactly what it was when he walked out there. Bergman's face kind of fell. Then he started grinning"* (Swann interview, 1995).

When Swann was asked if there were any changes made when he came in as PI on 14 and 15, he responded:

> *"I don't think so, really. First of all, any changes I really wanted to make would have to go through about 17 committees. I couldn't make a change. I think we did get it [field training] a little more problem-oriented. The photo procedures stayed pretty much the same. On 15 was the first time we really had control of the [TV] camera from the ground. That was something that we had done a lot of work with in the field with a remote-controlled video camera and it was a very useful tool. We knew that from hours of experience. I think we were able to help get that on when Fendell (the TV operator in Mission Control) came on some field trips with us. Fendell did a good job. He was very responsive. But that really didn't have much to do with the training. Fendell did accompany us on many of the field trips so he had a good idea of how we worked in the field"* (Swann interview, 1995).

Another feature that intensified with Apollo 15 was contact with the crews during the two to three weeks before the missions. For those final few weeks before the mission, the crew was almost continuously at the Cape working in the simulators and reviewing procedures. During that time, Jim Head, Farouk El-Baz, Jack Sevier, and a few people from the USGS spent nearly full time at the Cape and squeezed in whatever time was possible to discuss the geologic procedures and objectives for the planned traverses. Head recalls,

> *"Starting with Apollo 15 when Jack Sevier and SWP were involved we spent a lot of time with them at the Cape and did crew training sessions in the evenings. The primary focus was the traverses. What I would also try to do was select a theme. Like EVA 2 on Apollo 15 is going to the edge of the Rille. So let's step back and look at sinuous rilles on the Moon. Try to pull all that together. You guys and the Survey have covered that to some degree, but at the same time let's distill this and talk about the major objectives, what the issues are, and how you might test them. Then we'd go into the traverse step by step and talk about the scientific goals and objectives in an integrated way. That was almost always after dinner in crew quarters."*

Head felt that the crew was not doing this just to be sure of procedures but because they were truly interested in doing an outstanding job.

> *"But my sense is that they carved the time out of their own private time; 'cause it was in the evenings. We did some stuff during the day but mostly they were tied up in the simulators all the time, then we'd have dinner with them in crew quarters and after that we'd do these briefings"* (Head interview, 1995).

Jack Sevier points out that they did these evening briefings at the Cape for Apollos 15, 16, and 17.

> *"That's when I became more involved in the traverse training. Schmitt had a great deal to do with that. Most of the training that they got outside the field trips they got at night down there at the Cape. Otherwise they'd be in there watching TV or relaxing. We would go down there and have dinner with the crew. They'd probably put in a 12-hour day by that time. Then, after dinner we'd go in the conference room and spend a couple or 3 hours briefing them about the traverses. Farouk would take the CMP off in another room. We; Jim Head, Gordon Swann, and others like Tim Hait, and later on Bill Muehlberger, and those would discuss the traverses. And the crew made inputs into the traverse planning, particularly the station locations, or the orbit they were going in. I remember in 16 on that first traverse, I think we had three stations and we went to the nearest one, then the next one, and then the next one. They thought that was kind of stupid that we didn't go out to the furthest station and work your way back. So that's what we did: many little things like that, and things to do with contingency planning. If you were an hour behind in getting out of the LEM on the second EVA and you had to cut an hour out of the traverse, which stations would you cut out, that type of thing"* (Sevier interview, 1995).

A new addition for the science training was what came to be referred to as "math model sims." These were simulations that did not involve the crews but did use most of the other participants in the missions. The sims used the facilities of Mission Control. Generally these sims followed the planned traverses for each mission but would introduce numerous problems that would require modifications of the original traverses and procedures. The problems might range from rather simple such as the loss of a film magazine to very serious such as failure of the Rover. In each case the science team had to work with the appropriate equipment personnel to reach a satisfactory solution that would preserve as much of the scientific data as possible without compromising the safety of the crew. Ersatz astronauts huddled together with a few other personnel in a separate room to dream up diabolical but realistic schemes that would challenge the geologists and engineers in Mission Control. The role of the astronauts was usually played by people who were familiar with the traverses as well as the science activities. Jim Head commonly played the role of commander. Jack Sevier recalls playing the role of Jim Erwin on one of the Apollo 15 sims. Sevier also indicates that 15 was the first mission on which this type of sim was introduced. (Sevier interview, 1995) They commonly had preplanned some ideas for problems to be introduced during the sim but in some cases would introduce problems that they dreamed up while actually conducting the sims. There were two math model sims in July in which Head and Sevier played astronauts in traverses that were deliberately designed with several surprises and problems to test the geologists and engineers in the backroom. The math model simulations were sometimes accompanied by "paper sims," which led to pre-mission development of contingency plans and priorities for the science activities that could be used during the actual missions. The paper sims consisted of presenting a set of anomalies that might occur during EVAs and asking combined teams of scientists, flight controllers and engineers to re-plan the traverses to overcome the anomalies and still meet the main objectives of the traverses. There were four such paper sims for Apollo 15 at MSC on May 27, June 8 and 21, and July 7, 1971.

Another type of sim was carried out by both prime and backup crews on the sand pile at KSC while the backroom personnel practiced their skills in Mission Control at Houston. During the final six weeks before the mission there were several such exercises on the sand pile at KSC. In May there was a simulation of EVA I from KSC to carry out science and engineering tasks using pressure suits, science equipment, the Rover, and the TV camera. The geology team used this simulation to make mosaics of the panoramas and other photos taken from the TV camera during the traverse to search for areas that might suggest redirecting the TV camera to zoom in on specific areas of interest.

Starting with Apollo 15, there were three support teams in Mission Control for the geology traverses: (1) the SSR team that kept track of location, samples, photos, and descriptions during real time and made suggestions for CapComs to evaluate as possible information to pass on to the crew; (2) a summarizing team that summarized all of the data and traverse locations with photo and sample locations at the end of each EVA for use in succeeding EVAs; and (3) a planning team that evaluated results from prior EVA(s) and planned any potential changes in upcoming EVAs imposed by results of previous EVAs or changes in operational timelines. This last team was well-versed in the contingency plans and would work between EVAs to replan the upcoming EVAs to take into account any problems that had developed during previous EVAs. This team was used extensively on the final three missions for both minor and major revisions of EVAs. Difficulties with the deep drill on Apollo 15 required major revisions of the last two EVAs. Breaking of a cable on Apollo 16 again caused some significant revisions on later EVAs.

The final field traverse for Apollo 15 near Flagstaff, Arizona was run as a full-up simulation through Mission Control in Houston (see Appendix I for June 25, 1971). It should be noted that there were well over 50 people involved in this exercise, including the people in Mission Control and the field. In preparation for this final field traverse as well as for the actual mission, one of the previous field trips to the Coso Hills had been run as close to an actual mission as possible without going through Mission Control. For the Coso field exercise Swann (memo Apr. 23, 1971) requested that the personnel for all three of the support teams that would be in the backrooms during the actual mission would also be present for the field exercise and perform in the same roles as during a mission. This was to include PIs, sketchers, position plotters, categorizers, sample collators, and CapComs. These groups were to remain together for the two days of exercises, prepare questions and recommendations for the radio debriefings at the end of each traverse, and meet between traverses to consider updates for the next day's traverses depending on information gained during the first day.

The Technical Debrief following the mission provides some useful inputs for future training. Both Scott and Irwin felt that the Rover simulator at the Cape was very useful. It allowed them to simulate driving the Rover with images of the Apollo 15 landing site projected onto the screen in front of them. They felt that a couple of times around each traverse was just about what they needed. In Irwin's words "It made us feel right at home once we got to the Moon." And Scott felt that "It made us familiar with the sequence of craters we'd encounter and their names and relative positions." (p. 17-3, 17-4)

Both Scott and Irwin felt that the 1-g suited simulations on the rock pile at MSC were very important. In Scott's words:

> *"I don't think we would have traded any one minute of that, particularly the suited operations. That really prepared us for the surface work. There were some suggestions toward the end that we run shirtsleeve. We both decided to run suited up to the end, and I'm glad we did. I think every exercise we had out there in suits was well worthwhile"* (p. 17-11).

Also, the addition of the rocks to the sand pile simulation area at the Cape for Apollo 15 was considered to be a step forward. Scott felt,

> *"The addition of the geology stops there at the Cape is good. We didn't have the opportunity to exercise all those rocks they'd put out there for us, but I think the following crews will find it very useful to drive the Rover and go through the procedures of getting off the Rover and doing the geology…It was very good training"* (Apollo 15 Technical Debrief, p. 17-12).

Similar to comments from earlier missions it was hoped that all of the training equipment would be the same as the flight equipment. In Scott's words: "We saw a few new things on the lunar surface. I hope that's rectified in the next go-around for the next flight" (p. 17-14).

Apollo 16

Field training for the Apollo 16 crew started in early September 1970. This commenced with observations and discussions of geologic features interspersed with some walking traverses that were outlined on aerial photos. There were always walk-through debriefings after any traverses. All these exercises were designed to bring the crew up to speed on basic geology and traverse procedures. In January 1971 the first exercise with CapCom, a backroom, and full-up equipment was completed. By March 1971 the exercises were getting into full swing with a full complement of support personnel in addition to the crews, CapCom, backroom, and geology trainers. However, the early field training for the Apollo 16 crew was limited mainly to John Young and Charlie Duke of the prime crew and Fred Haise of the backup crew because the other backup member, Ed Mitchell, was busy either with training for Apollo 14 or with post-Apollo 14 chores. This led Tony England, who would be the CapCom for the actual mission, to act as the second member of the backup crew with Fred Haise while makeshift arrangements for CapComs from the geology personnel were decided at the last minute during the field exercises. In a couple of instances one of the geologists would play the role of a backup crew member allowing England to be the CapCom. Because of the need for good communication between the actual personnel who would be in the backroom, the CapCom, and the crew, there was an exchange of memos in June 1971 between the geology PI, MSC science organizations, and the Flight Crew Director, requesting that the situation be remedied with a more permanent arrangement for a backup crew member and CapComs (Memo: Muehlberger to Lovell, June 16, 1971; Memo: Lovell to Director of FCO, June 16, 1971). The situation was finally resolved during the September 1971 field exercise at the Rio Grande River gorge near Taos, New Mexico when Mitchell began participating in the training and a second astronaut was assigned to act as CapCom. The final four field trips were done with a complete complement of astronauts and CapComs for both the prime and backup crews.

As the training progressed the logistics for field trips became much more complicated from the standpoint of both equipment and personnel. The first few exercises through the fall of 1970 consisted of four astronauts with cameras, film, and sample bags for equipment and three or four geologists. By early 1971 there were still only four astronauts but the additional personnel had increased to eight to ten geologists and 15 or more support personnel for all the required equipment that included cameras, film magazines, radios, tents for backroom people, antennas, tape recorders, geology hammers, trenching tools, tongs, sample bags, simulated backpacks (life support packs), core tubes, vehicles as simulated Lunar Rovers, TV cameras on vehicles, a tool carrier for each vehicle, and a few other small items. The amount of equipment required for each trip had grown to the list presented in Appendix H. By September 1971 the flight directors had been participating in both the Apollo 15 and 16 field exercises for several months and Gene Kranz, Chief of the Flight Control Division, found that such participation "has been very valuable in helping us plan and execute the Mission Control functions for the Apollo missions" (Memo: Kranz to Phinney, Sept. 9, 1971). Furthermore, Kranz’s memo requested that some of their personnel be included in all future field trips. The description in Appendix I of the Apollo 16 training trip at the Rio Grande River gorge near Taos, New Mexico gives a good outline of the extensive amount of planning, personnel, and activities that were involved in the training of all crews from this point on.

By the end of the Apollo 16 field exercises there were up to eight astronauts, 12 to 14 geologists, up to 30 additional operational personnel, including flight directors, headquarters personnel, advisory panel personnel, equipment or other support personnel, and 20 to 30 media people on each trip. Arrangements for room and board, transport and maintenance of equipment, as well as vehicle assignments for personnel and equipment to and from the field became a major task. The media also required controlled access which was handled by NASA's PAO. Some trips required several rooms at each of three motels. For the trip to the NTS, the logistics were even more complex because of the additional security involved and military helicopter transportation between Las Vegas and the Test Site. All people on that trip had to be listed with next of kin and have security clearance., All equipment taken on the site had to be listed in detail along with any personal cameras, and clearance for an overflight by the Command Module pilot had to be arranged. There were additional personnel from the Atomic Energy Commission for radiation safety, public affairs, and security purposes. In some cases during the Apollo 16 training the field trips were not publicized to keep the media from descending on the locations and causing additional logistical problems. In any case, the media was not allowed to follow the crews during the training traverses but were usually allowed access to the crews for a limited time after completion of the traverses. At other times the PAO personnel would brief the media on the nature of the traverses and how they progressed. A few overzealous news people would try to get around the rules and observe the traverses; but they were essentially curbed from this procedure by various means. One rather bizarre case occurred at a training exercise at the China Lake Naval Ordinance Center when newsman Jules Bergman tried to convince a naval helicopter pilot that he had permission of the base commander to be flown over the simulation area and observe the training exercise, but the astute pilot called the commander's office to verify this permission. Obviously, the permission had never been granted; and the reporter was escorted off the base by security personnel.

Most of the field training for the 16 crew was designed around the photo-interpretation of the landing site as volcanic terrain. Therefore, the main areas chosen for their simulations were in terrestrial volcanic areas. The occurrence of several craters in the designated landing site also dictated the need to train in terrestrial areas where there were craters present, ideally in volcanic terrain. Thus, when looking through the Apollo 16 training sites in Appendix I one finds mostly volcanic sites with a sprinkling of a few cratered terrains such as Meteor Crater, the NTS, Sudbury, and the USGS man-made crater field. Because of the widespread occurrence of anorthosite that was now apparent on the Moon there were two trips to areas of anorthositic rocks (Minnesota and San Gabriel, California). Within the first hour of the actual lunar EVA it became apparent that there were no volcanic units at the landing site and discussions of alternative tasks and stops were undertaken, but no serious revisions were accomplished. According to Bill Muehlberger, the geology PI,

> *"On 16 I, at least, certainly didn't take into account the other alternative interpretation of the geology of that landing site. It got pretty obvious fairly quickly that we're not going to be running into any basalts or andesites or rhyolites or any other type of volcanic rock. Now how can we change the traverses to take advantage of this new information? We really never got to do that. Luckily they'd seen all the lunar rocks from before, so they were at least familiar with the different kinds of beat-up rocks that happen in a meteorite impact area. John [Young] and Charlie [Charles M. Duke, Jr.] were a very complementary pair in the way they worked. Charlie was talking all the time, jabbering away and describing things, and John, whenever he did say something, you'd better listen. It was important. We caught on to that pretty quickly, early in the game. John would correct things that he saw that made him interpret it differently than Charlie. They worked together, as I see it, quite well. Did a heck of a good job, especially with the handicap that we gave them by telling them the wrong kind of stuff that they're going to be finding"* (Muehlberger interview, JSC oral history).

Muehlberger also recalls an interesting sample that required a bit of ingenuity for its collection and return to Earth.

> *"They ended up going to this one crater. They parked on the near side, the side closest to the Lunar Module. They walked around, they were sampling on the far side. Meanwhile, we spotted this rock with the TV and had Ed Fendel, who we used to call Captain Video, to please look at this rock for us, and he did. He zoomed in on it, saw a big rectangular white crystal flashing at us, and figured [that] the only crystal that does that is anorthite, the feldspar, and that's lunar crust, and that's not what we were supposed to be finding here. We suspected it might have been a possible source of lunar crustal stuff thrown into our region. So here we are. First stop and we've got a hunk of lunar crust. We're in this volcanic country. What a stroke of luck. So we asked them to pick it up. Of course, we had no idea how big it was, because there's no trees, no fences, no nothing on the Moon to tell you size. They were clear over on the other side of this big crater. So as they got close to it and saw what it was that the backroom wanted, they started complaining mightily because it was so big. When finally Charlie Duke gets into the crater and reaches over and sort of rolls the rock up the side of his pants, we could see that, yes, this was a big rock. I don't remember the exact phrase Charlie and John started saying, but, Muehlberger if this thing makes us fall into the crater, or something. You can read that. So it ended up being nicknamed 'Big Muehly.' It's the biggest rock that ever came back from the Moon. But we'd trained the guys, and everybody had told them, 'You don't need big rocks. Something no bigger than your fist is all that's necessary for the laboratory types. So don't pick them up.' And right off the bat we did this. So they left it at the foot of the Lunar Module until the very end when they knew they had the weight and the capacity to bring it home. So now we've got it here, and it turned out to be typical of all the rocks brought back from that sample place, that landing site."*

John Young recalls the benefit of all the training in the different terrains and how the variety of experiences came in handy on the actual mission:

> *"We saw a lot of rhyolites too and that kind of rock. The theory was that when we went to the Moon on Apollo 16 it was supposed to be some kind of volcanic rock; and it didn't turn out to be that way. You could sort of tell that and I think we tried to say that, but they were arguing against us all the way back. I remember that part. So it turned out okay when they got the rocks back. But I'm glad*

> *we got to see all that stuff. We got to see anorthosites at the Duluth gabbro, and we saw them out at the San Gabriel Mountains. The ones at the Duluth gabbro had a remarkable resemblance to the ones out there that we found at the 16 place. Well, in our case, the fact we'd seen so much anorthosite that we got where we could recognize it when we ran across it on the Moon. I think that (the field training) was really very helpful. Well, all the stuff that we learned like the overturned flaps stuff. At North Ray Crater, we were able to use some of that cause here were those big blocks sitting right on the rim. So we took some samples of it. I guess we got pieces of rock that came from down in that crater 250 meters deep which we couldn't get down to. There was other stuff on that rim too that might have come from down there. It was white rock, pure white, pretty well crunched up, a lot of it, really friable. It's easy to look back and say you didn't need this or you didn't need that but I think the purpose of most training is to help you take what you learned and go on from there. It's not just to keep you riveted to know what you're doing but more to take what you got and go on from there with it. It's almost certain that the training we had was mighty detailed but on the other hand, on our mission, we had more than a hundred problems that I counted, counting a lot of them on the surface that nobody pays any attention to, and we solved them in real time with us and the lunar geology people in Mission Control. I can't fault the training. I know you always do way too much. But it's not the amount of training you do. It's just how it prepares you. I think we were all well prepared"* (Young interview, 1995).

The importance of repeating the lunar surface tasks over and over cannot be overemphasized. Not only does the repetition of these tasks become ingrained to the point of being second nature, but it also helps to overcome difficulties that were not foreseen until they are practiced in an actual traverse with time restrictions and other tasks that must be interleaved. For example, the photo procedures for documented samples and panoramas were rather detailed and would be rather awkward to perform if they had not been done so many times that each step became automatic.

There were also other types of training for the crews in the classrooms and laboratories. Over 20 hours of lectures were presented to provide information on what had been learned about the Moon. These included lectures on lunar chemistry, magnetic properties, cratering, shock effects caused by impacts on rocks and minerals, lunar soil contents, radiation on the Moon, and the implications of ubiquitous anorthosites. There were also lectures by the various PIs to explain the purpose of their instruments and the data that would be obtained. Because so many actual lunar samples were available by the time of Apollo 16 training the astronauts spent many hours studying the previously returned lunar samples even though it was known from previous experience that many of the loose rocks on the lunar surface would be covered with lunar dust. John Young felt this was a valuable experience: "I think it helped. We knew we weren't gonna go up there and find rocks with big clasts in them that were going to be recognizable and all that stuff. That's for sure. Except for maybe some of the breccias." In fact, the study of the returned lunar basalt samples had prepared them for the expected volcanic samples that were not there; and the crew realized this: "We kept looking for ilmenite and all those little crystals in the basalts, but we didn't see any basalts and no ilmenites and everyone got mad at us" (Young interview, 1995). Clearly, the crew's study of lunar samples allowed them to recognize that the rocks at the 16 site were not volcanic despite the initial disbelief of some of the geologists, but this allowed the geologists in Mission Control to better appreciate the true geologic nature of the site and adapt to the remainder of the EVAs.

Another aspect of the training for Apollo 16 was the addition of several special samples whose collection required special training. As a result of studies on the samples from previous missions there were a number of specific questions that had arisen about several aspects of the lunar environment; and many of the sample PIs had been making suggestions for collecting special samples for their particular interests. To accommodate these requests, a meeting was held to develop a list of the special samples that would satisfy the requests (Hörz to Meeting Participants, July 19, 1971). The resulting list included about 11 special samples that required specific techniques for collection (Hörz, Minutes of the Meeting on Special Samples, Sept. 2-3, 1971). One of these required a special tool to sample only the uppermost film of soil, and another required some padded bags to protect minute details on collected rock surfaces. There were also special sampling procedures for split rocks, fillets, permanently shadowed soil, radial samples, and others. In January there was a meeting in Houston to allow scientists and operations personnel to discuss contingency plans for Apollo 16 and also to meet with the Special Samples Subcommittee to discuss procedures for collection of the special samples. After consultations with the crew, the SWP Sample Subcommittee, and pertinent PIs, a set of procedures was developed for each special sample. According to a memo from Fred Hörz, the science trainer for Apollo 16, to several of the scientists and operations personnel, the crew "insists that these activities be planned at specific stations rather than left as targets of opportunities throughout the three EVAs." Specific amounts of time were to be allocated for each of these special tasks, and the crew had several other tasks already assigned for each station. Therefore, it seemed reasonable that they should not have to be searching for situations that would apply to the special samples. Planning for such tasks in the time line was the best way to accommodate these special requests. They also asked that each of the special tasks be arranged to provide "clear-cut priorities" for these special tasks (Memo: Hörz to distribution, Jan. 24, 1972). All of these procedures were included in the field training exercises.

In addition to the training for the special samples there was also training for ALSEP and some other experiments which had become a bit more complex than on previous missions. ALSEP training included the active seismic experiment that was described above under Apollo 14, but for Apollo 16 there was a change in the firing mechanism for the small charges and the mortar was moved to a different location. The deep drill core now had a new extraction mechanism and the pressure exerted by the astronauts to drill the core was to be better controlled. A new experiment, the far UV camera-spectrograph, was added as the first experiment to use the Moon as a base for astronomical studies. It was a telescope that was placed in the shadow of the LM on the first EVA and moved on each EVA to keep it in shadow. It was pointed at different sectors of the sky, three times during the first EVA, four times during the second EVA, and three times during the third EVA. Then the film had to be removed and stowed for return to Earth; a rather involved procedure that required a bit of training to get it right. The other addition to 16 was the Lunar Surface Cosmic Ray Experiment which involved sliding open a small plate with sheets of mica, foil, and glass in it, hanging it on the LM, and then closing and retrieving the plate at the end of the EVA (A summary of the Apollo 16 training is given in Appendix M).

By Apollo 16 the staffing of the Science Support teams had grown significantly from the three groups on Apollo 15. For the actual Apollo 16 mission, there were now four operating groups: (1) the SSR group for real-time decision-making during the traverse; (2) a planning group to reconfigure upcoming traverses depending on preceding results and observations; (3) a backup group to summarize the results of verbal and TV data received during each EVA and distribute a report and traverse map before each ensuing EVA; and (4) a plotter team to follow the traverse on a stereo model and record observations of the CMP as he passed over the landing area. These teams had a total of 40 people plus a team of court reporters.

When Bill Muehlberger, the PI for the geology team, was asked if there was anything that he might have modified on the Apollo 16 mission in hindsight, he responded:

> *"I think on 16 I, at least, certainly didn't take into account the other alternative interpretation of the geology of that landing site might be. [It] Got pretty obvious fairly quickly that we're not going to be running into any basalts or andesites or rhyolites or any other type of volcanic rock. Now how can we change the traverses to take advantage of this new information? We really never got to do that"* (Muehlberger interview, 1995).

The Technical Debriefs following the missions often provided useful information that could be applied to later training. Charlie Duke felt that "The geology field trips were outstanding. The monthly trips that we did from the time we started on the crew were just right. In two or three days you could come up to speed." John Young chimed in: "Also it helps you to get a team work pattern and I think that's real important. You are not very effective unless you're working as a team up there. Otherwise you're just going to be spinning your wheels on the Moon and that's not where they want you to spin them" (p. 17-29). Duke further points out that the geology on the Moon may not be like what they saw during their field training exercises because "The Moon has its peculiar geology and there really are things to look for. It's mostly in descriptive terms on both a broad and a narrow scale. By broad I mean describing mountains, such as Stone Mountain, in general describing rocks in detail and estimating. Getting your eyes tuned to estimation of slopes, and percentages and sizes and things, and the only way you get that is on field trips" (p. 17-30).

Both Duke and Young were pleased with the photography equipment and training. Young, in particular, was pleased with the instructions they got about malfunctions. "I think Dick Thompson did a lot to help. Before, I never had anyone sit down and go through the malfunctions with the camera and take pictures and critique what you did with them and all those things. He took the time to review each photo that we took and what we could have done better about it, particularly the ones we took in geology training, and then sat down and made sure we talked about all the malfunctions. We went through all the procedures. I thought that was a super thing to do" (p. 17-37). Both Young and Duke were enthusiastic about the 1/6 g airplane training and the training in the pressure suits for ALSEP deployment and practicing lunar surface procedures. Young felt that "you should do a minimum on the unsuited work, as little as you can to get an idea of what you're doing, and then plunge into the suited work for the EVA training." Duke felt that "At most, two ALSEP exercises [unsuited] were enough to learn the procedures, and I think that after that you are wasting your time as far as effectivity goes, because it's that suit that encumbers you." Duke estimates that they had done at least 13 or 14 ALSEP deployments in suits and many EVA 2s and 3s. Young said that his records indicated 350 hours of training in pressure suits and "I think it paid off. I think that learning to work in a pressure suit is the most important thing you do in the lunar surface operation, because you've got to learn the limitations of the equipment" (p. 17-27, 17-28).

Apollo 17

Apollo 17 had a new situation: the first scientist to fly in space was to be part of the crew that landed on the surface. Not only was Jack Schmitt a scientist, but his field was geology, the main part of all surface activities on the Moon. Schmitt had been very active in developing and revising many parts of the science training program over the years as has been discussed at several points previously. Although the scientists were quite happy that one of their brethren was going to land on the Moon there were some concerns about how this situation would develop during the training. One of the concerns that Schmitt had, at first, was that his crew mate, Gene Cernan, might just defer to him on all the geological questions. But this did not happen and Schmitt felt that Cernan really did try to get himself in a mode where he could be his own independent guy as far as geology was concerned. He could do his own descriptions, and he could try to recognize all kinds of things without asking Schmitt to "come over here and tell me what this is." And Schmitt felt that Cernan did a pretty good job of it (Schmitt interview, 1995).

Gordie Swann also had a couple of concerns about how Cernan would react to Schmitt being his crew mate:

> *"Then 17, of course, shifted gears a little bit with Schmitt in there. He was damn well going to do a better job than any one else. He was a geologist. And they did a very good job. I was concerned about Cernan all the way. I always liked Gene but Gene's a grandstander. No question about that. There was a little show we went to where Wayne Newton introduced the astronauts. When it was Cernan's time to stand up he goes like this (clasps his hands together and raises them above his head). That's pretty damn rah-rah. You do that in a boxing ring. I was afraid during all the rehearsals, or field trips, Gene would let Jack take the lead and kind of be Jack's field assistant. And he was good at it. It worked real well. I was afraid that when they got up there in the eyes of the world were on them Gene would start---but it didn't. It didn't at all. He went right through as he did when they were out there collecting rocks. Jack took the lead and Gene was a damn good field assistant. Gene was a good observer but that didn't change one bit. I think if we hadn't had as much training then Gene would have just gone up there and been that kind of guy".*
>
> *"And another thing Gene had to face was he lost his crew member that he'd been brought up with, Joe Engle. And he suddenly had this smart-ass young scientist. And Gene was a dyed-in-the-wool macho jet jockey. And I think he did a very good job of accepting that. I mean, it sure didn't show to us. Whether it did at home or with the other astronauts or something, I don't know. But we sure never saw any kind of animosity or anything over that. They fit right together. I give Gene a lot of credit for that. I assume Joe and Gene got along well and liked each other. I think if I had trained with some guy and worked with him and had gotten ready for the great culmination of my career with this guy I'd been working with, then all at once I have this other guy thrown in—. And Jack probably isn't as good a pilot as Joe Engle. Joe Engle had flown X-15s. So if your butt's on the line, and your buddy may have to save it for you. And apparently, according to one of the books, I think it was Andy's (Chaikin, A Man on The Moon), Gene did have a little bit of skepticism about that. I mean here's this damned geologist going to be my LM pilot, and I've had this very competent guy. But his fears were soon dispelled because, one good thing, Jack just lived in the simulator. He damn well showed that he could do it as well as anybody"* (Swann interview, 1995).

Both Cernan and Schmitt had already gone through extensive training for geologic field activities, Cernan in the backup crew for Apollo 14 and Schmitt in the backup crew of Apollo 15. So they were aware of most of the procedures, and the main thing they needed to do was learn to work together as a team. Bill Muehlberger was the geology PI for Apollo 17, and he took Cernan and Schmitt on their first field trip together. This was an introductory session to establish geological proficiency and determine the ability of the crew to work together. Muehlberger describes a bit of this trip and his first impression of Cernan's ability as a geologist:

> *"We all flew to El Paso [Texas], rented a station wagon, and I took them all through the Big Bend country. We'd stop at some place and I'd turn my back to the things we were looking at, and said,*

> *'Describe it to me.' And Cernan turned out to be remarkably good, [he had a] nice capability of descriptive things and what's there. So we figured, well, Gene could pick up this aspect, you know. How are you going to have two people whose trainings are so different working as a team? You've got to teach them to do that. Well, they ended up, I think, a remarkably good team"* (Muehlberger, 1999, JSC Oral History Project).

They not only worked together well in the training activities but also got along well as buddies as illustrated by a story that Gordon Swann tells about a field trip in Nevada. Cernan and Schmitt were riding in the Rover across an alluvial fan. Cernan was driving and Schmitt fell off on one of the slopes. Gene commented over the radio that "Schmitt just hit the fan." They all had a good laugh.

Learning the various procedures for the surface activities was very important. The objective was to drill the crews to the point where the procedures could be accomplished as second nature with very little wasted time thinking about what to do. The photo procedures were considered among the most important. Muehlberger describes the procedure for the panoramas that were taken at each station just after the crew dismounted from the Rover:

> *"The first guy off goes out a short distance and takes a 360-degree film panorama while the other guy's getting all the tools out, and this sort of thing, and getting ready to start work. While this guy's doing this panorama, he's sort of looking around and saying 'Well, there's a rock over there we'd better sample, and we'd better do our core over here,' trying to design what's going to happen in these next few minutes that was assigned to that place. The panoramas were important because after they were all done, before they left, then the other guy took one from a different place, and that one showed, of course, all their footprints. You could check to see which rocks were now missing. You could add in some other details that way. If they still didn't know where they were, you could use those two panoramas, because there's now a stereobase, and you could look at the distant mountains and play triangulation games and locate the actual craters they were standing by on the Moon"* (Muehlberger, 1999, JSC Oral History Project).

Muehlberger recalls one of the efforts that was used to critique the photo techniques of the Apollo 17 crew during their field exercises on the volcanic terrain in Hawaii:

> *"We had a photo team that was over there with us, so every night they'd be in the photo lab running all the film through, setting up the panoramas of the day before, so you could see, 'Look, guys. You've got a big gap here, and you didn't do it right.' 'Well, let's do it this way.' Until it became an automatic routine. By the time they got all done, the camera was mounted on a bracket, so they didn't have to hold it. All they had to do was pull the trigger, aim their body. .... Experience, the endless looking at what you did the day before and learning from that, going on and on, getting the routines down. There's a lot of dull, dumb kind of stuff you've got to learn, but it's the same way with all the other equipment that they had to lay out. The first time they did it, it took a lot of time. Practice makes perfect. It might not be perfect, but it's damned good"* (Muehlberger, 1999, JSC Oral History Project).

There were some rather confused arrangements for a backup crew throughout the Apollo 17 training. The prime crew did all of the training for the first few months without a backup crew. In February 1972, the Apollo 15 crew of Scott, Irwin, and Worden were finally assigned as the backup crew in the training activities, and Scott and Irwin went on their first field exercise with the 17 crew on February 22-25. Scott and Irwin continued as the backup crew through May, although on two of the four field trips during that time, only one of them participated. By June a scandal involving the selling of stamps and envelopes that had been taken to the Moon eliminated Scott, Irwin, and Worden from the astronaut corps, and Apollo 17 was again without a backup crew. For the final six months of training the Apollo 16 crew of John Young and Charlie Duke stepped in to fill the function of backup for Apollo 17, and they participated in the final four field trips. The final field exercise was a two-day set of traverses on November 2-3, 1972 at Sunset Crater near Flagstaff, Arizona and is described in Appendix I. In a critique of the exercise Hank Moore awards high praise for both the prime and backup crews but chastises the backroom scientists for not acting properly in response to some of the observations of the crews. When the crew indicated that one of the routes between stations appeared to be impassible the backroom had them "press on" until it became obvious that the route was, in fact, impassible. The backroom finally re-planned the traverse and dispatched the crew to another location. When the crew arrived at the new station the backroom was reluctant to believe that the crew was really there. In yet another case the crew had to work hard to convince Houston they had already sampled a unit that the backroom wanted them to sample. Moore has a few other criticisms for the backroom about sampling and requests for descriptions but essentially no bad things to say about the performance of the crews (memo Nov. 6, 1972: Moore to Muehlberger). It seemed clear that the crew was ready for the real mission.

Muehlberger explains how Schmitt's ability as a geologist was used on Apollo 17 to let Schmitt use his geological knowledge to determine what was to be done in real time. "But we did a sneaky thing on Apollo 17, because there we had the only scientist that was ever flown to the Moon, as well as Gene Cernan, a remarkable, capable pilot." In the science backroom there was a TV camera that was focused on a fairly detailed geologic map of the Apollo 17 site. The image from that camera was projected onto the left-most screen in Mission Control: a screen which was never up on public TV. When the crew reached a specific station on the time line Cernan got out, got the tools off, set the TV antenna so we could start getting TV, and started the gravity meter so it could detect the pull of gravity. Meanwhile Schmitt got off and ran around telling in detail what he was seeing at that site, in effect telling the scientists in the backroom what needed to be done at that site. Although there was a list of tasks that were to be done at the station Jack's input would be used by the scientists in the backroom to revise the tasks, perhaps substantially. The revised tasks would be written on a note that was placed in front of the TV camera in the backroom, thereby allowing it to be projected onto the screen in Mission Control where the CapCom could see it. The CapCom could then read off the tasks to the Apollo 17 crew and they would accomplish the new set of tasks that were developed from Schmitt's real-time input. In Muehlberger's words, "In effect he [Schmitt] was running the mission from the Moon. But we set it up this way. All of those within the geological world certainly knew it, and I had a sneaking hunch that the top brass knew it too, but this is a practical way out, and they didn't object" (Muehlberger, 1999, JSC Oral History Project).

Muehlberger recalls another helpful thing that Schmitt did: "at the end of each place, as they're driving off, he summarized everything that he'd seen and learned, so by the time they landed in the Pacific Ocean, we'd written a report about that landing site that was better than the one we used to write for the previous missions, the 90-day report. We had one that good before they landed, and then it grew from there. My judgment, of course, is send scientists" (Muehlberger, 1999, JSC Oral History Project).

There were several new experiments on the 17 mission. A new sampling tool was introduced for Apollo 17. There had been some concern about the fact that while driving the Lunar Rover the crew might pass by some important samples without being able to afford the time required for the crew to dismount from the vehicle, collect, and bag the sample, and remount the vehicle. The time lines were much too tight for this type of activity. It was suggested that a tool be developed for sampling from the Rover without having to dismount (Lovell to ASPO, Jan. 18, 1972). The result was a sampler designed by Uel Clanton, whereby Schmitt could just reach out with a scoop at the end of a long handle and scoop up a sample. The scoop had a nested set of numbered sample bags, sort of like nested Dixie Cups, at its end. Therefore, the sample was already in a numbered bag when it was scooped from the surface. Schmitt would let Mission Control know each time he did this, and the location of the sample along the traverse could be plotted by knowing the time that Schmitt reported the collection of a sample. This technique allowed a much more thorough sampling of the landing site.

Other new experiments were the Traverse Gravimeter which required stopping several times on each traverse and making a reading of the gravimeter, and the Surface Electrical Properties Experiment which required activating a device while stopped to send out signals that were picked up by a receiving station near the LM. The seismic profiling experiment was modified from the previous active seismic experiment for the 17 mission. The astronauts carried several explosive charges with them on the Rover and dropped them off at various points along the traverses to be detonated at a later time. There was a safety concern because the astronauts were to have these charges with them on the Rover throughout all three traverses while they were accomplishing other tasks and also hand-carry the charges from the Rover to the deployment locations. To overcome any possibility that the charges would be accidentally activated there were several built-in safety features. Beattie describes these features as follows: "Every firing circuit had either double or triple redundancy before the firing command could activate the charge. The arming sequence was as follows: Each explosive package had three pull rings on top. Pulling one ring started the safe/arm timer. Pulling ring two, and rotating it 90 degrees, released the safe/arm slide to start the mechanical timer. Pulling ring three cleared the firing pin and placed a thermal battery timer on standby until a coded signal was received from the ALSEP central station. In case ALSEP commands weren't received the mechanical timers were preset for periods of 89.75 to 92.75 hours after activation, well after the astronauts left the lunar surface."

Another new experiment was the Surface Gravimeter that was part of the ALSEP. Although it appeared that the instrument was working well shortly after it was set up the data that were returned were clearly not in the range that was expected. Despite several attempts by the engineers, including sending commands to the instrument from

Mission Control, there was no change in the spurious data being returned. Astronaut Schmitt, who had deployed the gravimeter, went back several times during later EVAs to try and jiggle it into a more favorable orientation but without any change in the readings. It was later determined that an incorrect calculation to correct for the lower lunar gravity had led to improper weights being installed for the balance beam of the instrument. According to Jack Schmitt,

> *"We deployed the flight hardware for the last time for Apollo 17 over there in the big hangar on the Air Force side [at KSC], I actually asked a question of Weber [the PI] and his people, whoever was there representing the long-period gravimeter—the gravity wave machine, had they tested the caging mechanism on a 1/6-g simulator, inclined plane or something. And the answer was no, they hadn't. So I pursued it a little more and said 'Why not; don't you think you ought to do that?' And they said 'well, it would reveal proprietary data and we agreed not to do it.' And I should have pursued it. We were about a month from launch or something like that. I suspect that in more than one case, the deployments did come up with necessary—either modifications, slight modifications in hardware but almost certainly modifications of procedures or precautionary things"* (Schmitt interview, 1995).

Another new experiment on 17 was the Lunar Neutron Flux Probe, which essentially required sticking a rod down a previously drilled hole and recovering the rod at the end of the EVA. All of these new experiments required the usual detailed practice of procedures under normal terrestrial conditions as well as in pressure suits and low gravity as additions to the training during surface simulations (a summary of Apollo 17 science training is given in Appendix N).

Throughout the many months of field training the crew and the scientists developed an excellent rapport which paid off nicely during the actual missions. A good example of how the crew and the scientists in the backroom worked together is illustrated by the results of an unscheduled stop on EVA 2. As originally planned, the crew was to take a sample from the Rover with the scoop described above and move on without stopping. However, the PI responsible for the gravity readings convinced the manager for the science activities that there should be a full stop here to make a gravity reading. Bill Muehlberger describes the geologists' reaction:

> "There was one spot where we stopped, and I had no idea they were going to stop. We hadn't been told. The guy that had the gravity meter wanted another reading in between [stations], and that caused a bit of shock. Of course, as soon as they stop, Jack says to us, 'What do you want us to do, guys?' We didn't even know they were going to stop. So there was a quick frenzy and dream-up of what's the most logical thing to do in the few minutes that the gravity meter needs to level and get its reading and we can get off again. I don't remember now what we did. It's in the records, of course" (Muehlberger, 1999, JSC Oral History Project).

In fact, there was quite a bit of sampling and photography accomplished at this stop. There were two surface soil samples, another soil sample from a depth of 15 cm in a trench to compare with the surface material, two breccia samples from the surface and two more breccias from the trench, and a friable clod from the wall of a small crater. This allowed a more extensive sampling of the so-called light mantle deposit that was interpreted as an avalanche from the mountains on the south side of the valley.

During the Technical Debriefing following the Apollo 17 mission the crew had several comments about the science training. Cernan felt that the Apollo 17 crew had spent more total time in science training (ALSEP, SIM Bay, orbital geology, and surface geology) than any previous crews. Although he admits that, at the time, it seemed like they were spending too much time in this area, in retrospect, it was time very well spent, and did not compromise the entire training and readiness for the flight. Schmitt compliments the many people in the S&AD, including contractors, who went out of their way to provide access to the returned lunar samples. "I think it paid off handsomely in recognition of rocks on the lunar surface. They also supported very frequently with two- or three-hour discussions on various lunar problems which also was above and beyond the call of duty" (Apollo 17 Technical Debrief: p. 17-12).

Schmitt had praise for the use of the lunar-gravity aircraft simulations in certain types of procedures that could be tested in 20 seconds or so. He felt that "it paid off in evaluating the LRV sampler and convinced us that it was a feasible way to sample" (p. 17-14). Schmitt also had praise for the USGS Grover that was used on field trips: "It had a lot to do with getting us used to the problems and advantages of using a four-wheel drive vehicle for geological explorations. The Grover was good for emphasizing the amount of time you have to spend in driving versus what you…see on the LRV simulator." Cernan echoed these sentiments: "The Grover, I think, was very useful for extending our geology training and putting us in the right environment in terms of distance to cover, getting on and off, and what have you. The dynamics of the vehicle were nowhere near what the real vehicle is, but it was certainly an advantageous device to have for field training and geology, without question. Even on Earth terrain the guy in the left seat [driver] is not going to do much geology. He's going to navigate and pay attention to the driving task. The Grover brought that home very clearly." Cernan felt that the combination of 1-g training in the Rover at the Cape plus the lunar-gravity airplane training in hard suits had also provided much-needed experience for: "the reach capability, the control capability with the hand controller, studying [sic] the low-gain antennas, the surprising reach on LRV sampling, and taking the sample out of the container bag and reaching over to put it in the LMP's bag" (p. 17-17, 17-18).

Cernan also had some comments regarding contacts with PIs for both the surface and SIM Bay experiments:

> *"When we first got introduced to the new experiments packages, we started out by having briefings by the PIs. It gave us a chance to meet personally and know each other's basic objectives. I think it gave the PIs a feeling that we were interested personally and professionally in carrying out, to the greatest extent possible, every objective of their experiment. It was a very, very good relationship and I'm very glad we did it"* (p. 17-20).

Schmitt had an overall comment about the field trips:

> *"The support we received, the cooperation of the US Geological Survey and the Science and Applications Directorate, was outstanding. I think all problems that existed several years ago, and continued to exist to a limited extent, were just about gone, if not completely gone. The groups are working extremely well and I understand continued to work together through the mission in various capacities in supporting our operations on the surface"* (p. 17-15).

Some rather amusing but significant incidents that occurred on the Apollo 17 field trips are worth recounting. Bill Muehlberger recalls one of the traverses in Hawaii: "The exercise that was done there just south of the fire pit on Kilauea. Between the 15 crew and the time that we were there with the 17 crew an eruption had happened. Here we were using the photographs [from 15] not knowing there's a new lava flow right across the middle of the area. That was really a real-time change. I remember Schmitt saying 'we're driving up onto the edge of a beautiful fresh looking lava flow.' He didn't know it had just erupted. And we were saying, 'What are you talking about Schmitt. There's nothing on the photos like that.' Since we had done it before, we were being rather casual about it. And there were the tracks of the [Apollo] 15 jeep going right underneath it" (Muehlberger interview, 1995). On another exercise in Hawaii, the backroom was set up in a tent near an artillery firing range. Throughout the traverse there were several uneasy people in the tent as the military decided to conduct some tests, and we could hear the shells bursting a couple of miles away. On yet another occasion in Hawaii the charging units for the radio batteries did not arrive in the shipment of gear that included the VOX radios. We were fortunate to have along a very ingenious engineer, Earl Quinn, in charge of the radios. Earl scrounged through the local electronics shops and bought wires, resistors, bulbs, etc., which he proceeded to lay out as a make-do charger on the floor of his motel room. Although most who saw this strange arrangement in his room (not including the proprietors) could not believe it would work, Earl charged the batteries overnight and had them available for the radios every day.

On the trip to Lunar Crater, Nevada when John Young was the backup commander, he recalls that the vehicle in which we were riding hit a rock and displaced both the pan and the transmission underneath the vehicle. "Gordon Swann was the driver. We had to run back. It was a long way back to Tonopah. Out in the middle of the desert in the middle of the night, we'd have been very chilly" (John Young interview, 1995). John was being very modest by saying "We had to run back." The vehicle broke down nearly 2 miles from the remainder of the field personnel and they were all in the midst of packing up the gear and beginning to leave in their vehicles for Tonopah, which was about 60 miles away and the nearest town to Lunar Crater. There was no radio for communication with the departing vehicles. So John started running, all by himself, at an incredible pace and got within shouting distance just as the last couple of vehicles were about to leave. The people in the stranded vehicle were rescued and got to Tonopah a bit late but at least with a roof over their heads for the night.

7. Command Module training for orbital science

There were orbital experiments on each Apollo mission. From Apollo 8 through Apollo14 the main orbital activity was photography of various types, but on the last three missions several additional experiment packages (see Appendix G) required much more training for the CMPs. Although there had been suggestions for orbital experiments at some of the summer conferences sponsored by OSSA, it was not until 1968 that this was considered seriously. By the summer of 1968 MSC was requesting contractors to identify how some of these orbital experiments might be incorporated into the Command and Service Module. At about the same time, OSSA was looking over the proposals that had been submitted a few years earlier for potential inclusion in a lunar orbiter program that did not materialize. In June 1969 several of the experiments were recommended by OSSA, and OMSF directed MSC to proceed with modifications to the CSM to accommodate the new experiments starting with Apollo 15. Although many of these new experiments would send their data back to Earth by telemetry some of them involved the CMP retrieving films and other data from the SIM Bay by means of an EVA somewhere on the journey back from the Moon to the Earth.

For the earlier missions the CMP training was directed primarily toward describing geological features on the lunar surface and taking handheld photos of important lunar features. This required lectures on lunar surface features, ability to use aerial or orbital photos, and use of cameras at proper angles. For the later missions, beginning with Apollo 13, terrestrial flyover exercises to observe analogs of lunar features were scheduled regularly in T-38 jets at high altitude and small planes at low altitude. During these flights, they taped descriptions and took photos that were later critiqued with the pilots. For the final three missions the CMPs also required numerous briefings on the scientific nature of the new experiment packages as well as the operation of the associated instruments. As with the field training for the lunar traverses a mentor for the orbital training eventually evolved and became one of the most trusted teachers for the crews. For the CMPs this person was Farouk El-Baz who provided substantial input for this unit of the history. His role increased with time; and his interest and dedication to the observations that could be made from orbit led to substantial inputs for observations that both aided future missions and added to the geological knowledge of the Moon.

El-Baz was an avid enthusiast of lunar exploration but came on board with Bellcomm in March 1967 with essentially no knowledge of the Moon. His background was in the lead-zinc deposits of the Mississippi Valley. In his words: “My real problem was the fact that when I joined the program I knew not a damned thing about the Moon, not word one when I started.” He was a quick learner and soon became accepted as one of the experts on lunar topography. About two weeks after he joined Bellcomm he attended a meeting at Langley Research Center:

> *“All of these big guys were there; Gene Shoemaker, Hal Masursky, Howie Pohn, and Don Wilhelms, and you name it, all of the big names. They would give briefings mostly on large craters like Copernicus, the domes of Marius Hills, and similar things. And I felt lost. ... So I went back to Washington and from that day on I was determined to figure out what the lunar surface features are by myself so that I could communicate with these people.*
>
> *“I went to the Bellcomm library and asked about the lunar photo collection because that library kept the collection of photographs for NASA Headquarters. With the key in hand, I went to open the room. It was a huge room, twice as big as this one here, with piles and piles of Lunar Orbiters I, II, and III images, with the newly acquired Lunar Orbiter images and pictures from telescopes all in a total mess. I requested some tables to fix it and received an okay for nine tables, which were in place on the following morning. I brought some towels and cleaning items from my house and started removing the dust and marks from the pictures and organized them: pictures from telescopes separately, then Lunar Orbiter pictures—whatever it is that we had up till then and organized them in piles and in sequence.*
>
> *“That accomplished in three days, I began to sit and look at each of the pictures. I studied them one by one, to see what is in it to my satisfaction—as a geologist who didn’t know a thing about the Moon. For each one, I started a 3 by 5 index card and would write the number of the Lunar Orbiter and the frame number and this and that in addition to a description of what is there and maybe a drawing or two of something that is especially interesting. It took me about three months to go over all the frames, and I began to figure out what the story was about in terms of lunar surface features, which I didn’t know anything about before. I began to figure out that there are varieties of craters; there are round ones, blocky ones, hollows, and this and that, in addition to rilles and ridges and rifts. These things were organized in groups” (El-Baz interview, 2004).*

All of this effort soon paid off. El-Baz attended the next session on lunar geology at Langley and gave a presentation on potential lunar landing sites that would provide the maximum variety of surface features, and his presentation was received quite favorably.

> *“That made me part of the geology team. Here I was a foreign guy who spoke with an accent who*

> *didn't know anything about the Moon and right after the second meeting, people began to call me up and say: 'When you said such and such, what was that based on?' I had put my collection of 3 by 5 index cards in canisters and kept them on the top of my desk. If somebody would call me…from some other place, I would flip the cards and pick one right out and say: 'this is based on a picture from Lunar Orbiter IV and such and such a frame number.' 'Oh, thank you.' So I became kind of accepted as a geologist within the geological community. I became a source of information on what is there and where"* (El-Baz interview, 2004).

Apollo 7

Apollo 7 was an Earth orbital mission whose main objectives were to check out the detailed capabilities of the launch vehicle and the spacecraft during 11 days in orbit, which would simulate the time for a lunar mission. Most of the objectives were operational in nature and involved no surface-science training. However, the crew attended the Griffith Observatory Planetarium in Los Angeles to practice identifying 37 navigational stars used by the guidance computer in case anything went wrong with the computer. Before the fire in the Apollo Command Module that caused the death of Grissom, White, and Chaffee on January 27, 1967 there had been one science briefing for the Apollo 204 crew in October 1966 by the Terrain Photography team. This was essentially a further elaboration of the objectives and procedures from the Gemini flights, the last of which was yet to occur. Following the fire there was a 21-month delay until the manned flight of Apollo 7 while the spacecraft and operations were modified to implement the recommendations of the extensive report resulting from the investigation of the fire. During this time there was little time for scientific briefings. Only two science experiments were to be conducted on the Apollo 7 mission: Synoptic Terrain Photography and Synoptic Weather photography. There were also some medical experiments to study bone loss and changes in the blood during long-duration space flights (NASA SP-4029). Because of the extremely demanding training schedule there was time for only one two-hour photography briefing in the crew quarters at the Cape while the crew ate their evening meal. The topics were the same as in the Gemini briefings but with some different sites as photo objectives. The importance of several types of phenomena were provided and the astronauts were to take photos of "targets of opportunity" when time was available. Fortunately, Schirra, the commander, had attended some of the Gemini briefings and the now-prime crew had been the backup crew that attended the one earlier briefing for the deceased prime crew in the prior October. Also, the crew made good use of the previously prepared notebooks of the best and worst photos from the previous missions. Despite the limited amount of training the mission returned about 200 pictures of good to excellent quality (Lowman, 1975). Although few of the planned targets were covered this was compensated for by coverage of many unplanned areas.

Apollo 8

The Apollo 8 crew was originally the Apollo 9 crew and both the 8 and 9 missions were meant to test the undocking and docking of the LM and CSM in Earth orbit. The first of these Earth-orbiting missions, Apollo 8, was scheduled for December 1968. However, when it was discovered in the summer of 1968 that there were weight and other problems with the LM, and it would not be ready for the December launch, the possibility of a CSM orbital mission to the Moon was discussed for Apollo 8. During the summer of 1968 the MSC engineers studied the details of flying a manned lunar orbital mission with the Command Module in December 1968, while the final revisions on the landing module were being completed. In early August the plan began to look like a real possibility, and on 10 August Frank Borman was unexpectedly called back to Houston from a trip on which he was testing the development of the Command Module in California. The reason for the return was to tell him that the Apollo 9 mission for him and his crew was being changed from testing the docking procedures in Earth orbit to orbiting the Moon as Apollo 8 during the coming December. This meant that the Apollo 9 mission would be the only mission to test the undocking and docking of the LM and CSM in Earth orbit at a later date. On August, 19 a decision was made to go ahead with plans for a lunar orbital mission in late December 1968; and the crews for the two missions were switched, which explains why the original Apollo 9 crew flew the Apollo 8 mission. To further complicate the training schedule it would not be known until results were available from the Apollo 7 flight in October whether Apollo 8 would be truly lunar orbital, or perhaps circumlunar, or even only Earth orbital. The crew was instructed to start training for a lunar orbital mission which was the most complicated of the three options. Following the successful completion of Apollo 7 in late October the decision was made on November 12, only five weeks before the scheduled launch of Apollo 8, to go ahead with a lunar orbital mission.

In August, with only four months until the actual mission, the training and other preparations for the drastically redesigned mission required intense activity. Whatever science was to be done had to be planned and communicated to the crew in record time. On September 6 the science planning began with a Lunar Apollo 8

Science Advisory Team. This team included a Lunar Science Working Group that was to recommend lunar surface areas that could benefit from photographic studies and a Lunar Operations Working Group that looked at potential photography from an operational aspect and also kept all the recommended activities within a reasonable time frame amid all of the other activities required for the success of the mission. On September 25 an Astronomy Working Group was added to recommend astronomy tasks (NASA SP-201, p. 103). These working groups eventually organized their recommendations into three areas: operational photography related to upcoming Apollo missions, scientific photography, and astronomy. Approximately 20 scientific tasks were proposed and incorporated into a checklist. Given the short time of preparation for the mission and the busy schedule of required activities during the flight it was clearly understood by all that the scientific tasks would be performed only on a "target of opportunity when time was available" basis. Included on the mission were a 16-mm data-acquisition camera with four lenses (from 4 to 200 mm) for operational sequence photos, two 70-mm Hasselblad electric cameras with two lenses (80 and 250 mm), and a TV camera. Both color and black and white film magazines were included (NASA SP-201, p. 104). Oral briefings on all these activities and the use of the cameras were conducted whenever time was available.

In preparation for the Apollo 8 mission, Commander Frank Borman spent nearly all his time working on the operational aspects of the mission. Both Jim Lovell and Bill Anders, however, spent a considerable amount of time studying lunar features. Lovell's main task was to look for lunar features that could be used as landmarks to aid the crew and the ground controllers in tracking the position of the spacecraft. Anders, however, had met with the geologists who discussed numerous lunar phenomena and problems that could be approached with photography, and Bill developed a great interest in observing lunar features from a geological point of view. The lunar geologists suggested about 50 features that were worthy of observations and photography and were accessible from the orbital path of Apollo 8 (30 of these were actually photographed). Mike McEwen, one of the science trainers from JSC, recalls: "I just remember using the (Lunar Orbiter) photos that we had and trying to educate them about volcanic versus impact features, and some things on the Moon that we had questions about." He also recalls that there were sessions dealing with photographic details such as what camera, what lens, what settings, and film to use under different lunar lighting conditions. In fact, as discussed by Wilhelms (p. 183-184), there was a science advisory team chaired by Jim Sasser of MSC's Mapping Sciences Branch and a lunar science working group that included Wilhelms as its chairman and several lunar scientists including Jack Scmitt. Wilhelms indicates that every opportunity to brief the crew about the geologic objectives and their significance was taken including going to the Cape shortly before launch. On one of the visits to the Cape with Hal Masursky to provide a briefing for Bill Anders, Bill "made sure we knew what he was up against by letting us climb inside the Command Module simulator, where instant claustrophobia and the difficulty of getting near the small windows made his point abundantly clear."

According to Chaiken (p. 104) Anders was interested enough to work out his own personal flight plan in conjunction with Schmitt to include observations and photos of geological features during his time in lunar orbit. Schmitt spent many hours with Anders going over features that were of interest to the geologists and suggested which ones might be photographed. According to Schmitt,

> *"Bill Anders wanted to know something about the Moon before he got there and Frank [Borman] had asked me to act as liaison between the crew and Bill Tindall's organization which was doing the mission planning. There were only four months to put this thing together; and exactly how Frank tapped me I don't remember, but I was the only one (astronaut) working on the lunar stuff and had been for some time. I suspect that was the reason that Frank asked, and Bill had already asked me independently, to get him as far up to speed on lunar features as I could. ... We would do this by bootlegging time because Frank didn't really approve. He didn't say no but he really didn't approve. So we were doing this on bootlegged time, and fortunately nobody needed any sleep in those days. But also, after a while, after going through these sessions—and I was gathering photographs from everywhere and trying to organize them in some sort of systematic way—Bill said 'you know on the far side of the Moon we've got to have names. We've got to have code names for these craters because there aren't any names.' All of this stuff had just started to come in. So that's where the naming of craters came in. Not much to do with training but it makes it a lot easier to talk about it. Bill and I were naming craters on the far side of the Moon. I don't know whether many of them stuck. And the first checklist was done as a result of that. Bill said 'Can't I have a checklist of what these features are and the types of things: a geological checklist?' So I prepared the first checklist for Bill. And we would go over that in the sauna down at the Cape before I'd fly back here (MSC) to work on the flight plan. So the checklist concept really started here and eventually that evolved into the cuff checklist of later missions. We had targets; and, if I remember correctly, he took maps on board with some*

> *targets laid out. One thing that we didn't work was getting a good television picture of the Earth. We should have. I guess none of us had any reason to realize that the camera that they had designed for Apollo was so sensitive that you'd never be able to get anything other than a bright light out there. And so during the mission we were over there in one of the optics labs seeing what filters we could put in front of that (the TV camera) in order to get a decent picture of the Earth. And we finally ended up taping together every filter you have and put it in front of the lens and that's where we got sort of a crescent"* (Schmitt interview, 1995).

Also included in the Apollo 8 tasks were some photos that would provide flight planners with additional information about potential landing sites. Further tasks included the ease of sighting landmarks that would help determine the spacecraft's position. The crew's ability to discern landmarks and topographic details with ease from orbit reduced some of the uncertainties about visual observations on future missions (Compton, p. 133-34). They were also to observe the potential landing site for Apollo 11. Jim Lovell observed the potential landing area in the Sea of Tranquility and found that there were no large boulders or other obstacles and the lighting conditions were better than he expected. It looked like a fine place to land (Chaiken, p. 113). Most of the astronomy tasks were either not attempted, or looked for but not observed. Therefore, in short, there were many scientific and operational observations that could be made with ease from lunar orbit and the potential for more formal and specific orbital training for scientific studies appeared to be justified. Suggestions by the astronauts in postflight briefings provided important input for equipment modifications and other aspects for future missions. For example, after Apollo 8, Anders suggested that a sighting device on the TV camera, clearer markings on the film magazines, calibration of the film budget, and elimination of hand-written logs were needed (memo from El-Baz, Jan. 13, 1969).

El-Baz, starting with Apollo 8, became the principal orbital geology mentor of the CMPs throughout the Apollo program. El-Baz, during his first three months with Bellcomm at NASA Headquarters in 1967, had accomplished the incredible feat of sorting and organizing all of the 4,322 pictures from the unmanned Lunar Orbiter missions into every lunar feature that could be identified: domes, craters, ridges, rilles, massifs, rays, etc. As written by Chaiken (p. 394-395), El-Baz formulated a list of 16 candidate landing sites that, when combined, included examples of every feature on the Moon. He was, indeed, a walking lunar database; not bad for a person who had just completed a PhD thesis on the lead-zinc deposits of southeast Missouri. El-Baz recalls his first introduction to the training of the Apollo 8 crew:

> "*There was a meeting at the start of astronaut training at the Mapping Sciences Division of the Manned Spacecraft Center, under Jim Sasser. The intent was to prepare astronauts for lunar photography on the first Apollo lunar orbital mission which would turn out to be Apollo 8. We didn't know the final number designations then. I heard about that at Bellcomm—we would get announcements of all such happenings from the NASA centers. I went down for the meeting with Sasser, Lou Wade, Mike McEwen, and others. We sat down and talked about what could we do and what kind of things we need. We needed to give the astronauts maps to show them the orbits and then to ask them to take photographs of special areas. What photographs we'd ask them to take and the term came up, I don't know who thought of it: 'targets of opportunity.' At that meeting Jim Sasser set up a group that would work on the targets of opportunity for the first mission that would fly around the Moon. We began meeting on this to work on what do these guys see from orbit and what pictures they would take. And without saying it out loud, to help us later in site selection for the Apollo landings on later missions although this really wasn't part of the kind of assignment that we were asked to undertake. The guiding principle was since we see such and such in Lunar Orbiter images, maybe we can add some more details by photographing them.*
>
> *"By then I had studied all of the 1,950 photographs of the five Lunar Orbiter missions; about 300 were foggy or otherwise not very good, and the rest were sharp and clear. There were significant gaps in our knowledge, for example, we were thinking of an Apollo mission landing inside craters such as Copernicus or Tycho. If that were the case, then there were all kinds of things to consider, such as where would the orbit be and what would be its footprint. We'd sit down and work out on the maps of the targets of opportunity. Then came, for the very first time, a briefing of the astronauts on the maps they would carry so we can explain to them what the maps they are going to have would look like before we finalize them. Also, to discuss what these targets of opportunity are and why; that was the very first briefing"* (El-Baz interview, 2004).

When asked about the attendees at these briefings, El-Baz responded,

> "B*oth prime and backup crews. The astronauts would come grudgingly and stand expressionless. Jim Sasser would start the briefing with the fact they would have a map and the map would be folded and with such and such colors; the red color would be the first orbit and would have the targets of opportunity. And Farouk here will tell you in a minute something about the targets of opportunity. We'd start this way, and then I would go on to discuss the targets of opportunity and what they mean and what they are. Then we'd wait for questions. This first briefing lasted only one hour because the guys came to it rather grudgingly. We'd continue this kind of thing until Bill Anders himself on the second or third time would ask questions, after we gave them the real thing with the real colors; the real orbital map. After answering their questions they would become a little bit smarter without getting into a lot of geology. I knew that about these guys beforehand. It was Mike McEwen who first told me that 'these guys really don't like geology. So, just take it easy with them.' I said' fine, we'll just talk to Bill about unnamed targets until he asks a question and then I'll give him a little more.' Because we had different filters for the camera, the astronauts started thinking okay because the regular film does this, but this other filter would do this and that."*

When El-Baz was told about Schmitt's comments about Anders asking for some help from him on lunar geologic features, he commented,

> "*That could very well be because Bill Anders, when he came to these formal sessions, was quite knowledgeable and he asked interesting questions and that's the only time that I stepped in and spoke a little bit about geology and rock types, or maybe this feature or that, or the real geological property, or even feature importance. That went well to a limited extent*" (El-Baz interview, 2004).

Apollo 9

Apollo 9 was in Earth orbit for ten days, primarily to test the docking procedures for the Command Module and the lunar landing module. Therefore, no briefings on lunar science were involved. However, Apollo 9 carried the most elaborate terrain photography experiments yet flown. There was not only the standard Terrain Photography Experiment (S005) carried over from the Gemini missions but also a Multispectral Terrain Photography Experiment (S065). The former (S005) was now beginning to benefit from feedback from investigators who wanted further photos of features seen in earlier photos. The Mercury and Gemini missions provided approximately 500 photos of terrain and oceanic features as well as photos of a hurricane and a typhoon. Some of the photos, especially those of the oceans, provided clearer views of ocean features than any previous manned flights. Apollo 7 had recently added 200 more photos to the growing inventory. The latter (S065), for the first time, had a camera assembly that was mounted on the Command Module window in contrast to the handheld camera of the previous missions. For the first time this required orienting the spacecraft in the proper direction to photograph the desired sites. Although time for science briefings was limited all the crew members had attended Gemini briefings for the S005 experiment, and the sites for the new S065 experiment were predetermined requiring mainly pointing of the spacecraft rather than scientific initiatives by the crew. The MSC project engineers gave the crew some operational briefings for the Multispectral Camera. Most important, however, was the provision, for the first time, of a staff support room for the science teams. The room was equipped with flight path maps, global satellite weather pictures, and other mission-oriented material. This room was manned around the clock and the investigators could meet daily to discuss and coordinate the next day's photography. The astronauts could report on cloud conditions which allowed the investigators to select desired locations for photos. The results were outstanding. Several hundred handheld photos and 90 sets of multispectral arrays were returned including some where the handheld photos complemented the multispectral arrays (Lowman, 1975). Contributing to the success was the fact that after the completion of the operational tests for undocking and docking the LM, there were five days remaining with little to be done but terrain photography. Also there was a more spacious vehicle with windows that provided better viewing than the Gemini vehicle.

Apollo 10

On Apollo 10, there was little time for many scientific observations. The crew was very busy testing the spacecraft and the operational capabilities. In John Young's words,

> *"There were some crews that were really so busy learning about the spaceship they couldn't spend*

> *a lot of time on geology. I mean on Apollo 10 we didn't do a real lot. We did some photo geology but, you know, we were really trying to learn the vehicles and learn the mission which was a very--well you know--- it was a lunar mission with lunar orbit, lunar rendezvous, and all that stuff. Tom and Gene just had their hands full with the Lunar Module. And I pretty much had my hands full with the Command Module even though I'd backed up Apollo 7. We were right at the leading edge of trying to learn how to do stuff"* (Young interview, 1995).

Young recalls that there were a number of photographic objectives that had been outlined for him. One was to photograph the potential landing sites for Apollo 11. The Apollo 10 trajectory was along the same equatorial orbit that Apollo 11 was to fly, and he was to obtain pictures that would help determine the smoothest areas for landing. They also did some tracking that was designed to assess how much influence the mascons would have on the landing trajectories. When Jack Sevier was asked if Apollo 10 data were used for Apollo 11 he stated, "Yeah, 10 was essentially a dry run for 11. It was designed as if they were going to land where 11 landed." He did not recall that the photos John took were as good as the ones from the Lunar Orbiter photography for planning the Apollo 11 landing (Sevier interview, 1995).

For Apollo 10, the same procedures were used to determine science objectives as on Apollo 8, and the same camera equipment was used. Schmitt's role was invoked again by the Apollo 10 crew.

> *John Young came to me and said he wanted—having seen what I had done with Bill on Apollo 8—he wanted the same kind of stuff for Apollo 10. So I began to work that problem....with him. And if I remember correctly, Farouk got involved. I cannot remember—I'm sure I had run into Farouk somewhere (in fact they had worked together in the planning for Apollo 8) but my first real involvement was to bring Farouk in to help me with the briefings because I was just getting saturated then. Too many other things were going on. Anyway my recollection is that he came in on Apollo 10 because I couldn't brief John as much as John wanted to be briefed." When asked if the other crew members were involved in any of the science training, Jack responded, "A little bit. Late in their training cycle, my recollection is that they started to spend some time with us. One of Stafford's big interests was to get the color television camera on board, which I worked for; and we finally got that on board"* (Schmitt interview 1995).

When El-Baz asked if he did the same type of training for Apollo 10 as he had done for Apollo 8, he responded,

> “*Yeah, very much so. Tom Stafford was indeed the guy that took in most of it and gave off most. No question about it. Tom Stafford was really interested in whatever we said and he was a straightforward-like kind of a guy. He was a little bald and there was no joking about him. He was no trouble, but he was, by God, very swift. He picked up like that and he’d come back with questions and was ‘with it.’ Tom Stafford did a fantastic job on his descriptions and in supporting the whole issue of lunar photography”* (El-Baz interview, 2004).

To provide a bit of insight into the type of thinking that was involved in operational discussions and how that impacted the type of photographic and observational targets that were brought into the Apollo 10 crew training, Schmitt offered the following anecdote:

> *"They (the Apollo 8 crew) had taken pictures of the mare site, the first one, but because of sun angle didn't have time to look at any others. It turned out that with a longer stay time on Apollo 10, if we targeted Apollo 10 to what later became Tranquility Base, then we could not only see that one but we were gonna be up there long enough to see two more. So by the time we were through (the Apollo 10 mission) we would be familiar with four sites across the equatorial belt. I argued this all the way through JSC (formerly MSC). What it required was changing the launch date by one day: from May 17 to May 18 I believe it was. And Tom (Stafford) got all excited about it. He said, 'We don't want to go back to the same place.' You know those guys never wanted to do anything the other guys had done. So Tom was an obvious ally. And George Abbey was helpful because he was George Low's executive secretary. I was able, through George, to get audiences with Low and Kraft. They had their package with minor modifications to the data package for Apollo 8. They were ready to go. So I finally got Chris Kraft's attention and I gave him a briefing on all the advantages of this and one advantage happened to be that you end up with a daylight landing in the Pacific. Whereas with the May 17 launch you would have been near sunrise but still pretty dark, and Jerry Hammack, who was responsible for recovery operations, happened to be in the room when I gave that briefing and Jerry*

> *said 'wow all of that and a daylight landing.' Chris's eyes started to brighten up a bit because every one was concerned about the nighttime recovery. So Chris became an ally at that point. Then we moved on up to the CCB late night presentation to George Low, and Sam Phillips happened to be there. George's inclination was very strongly 'let's forget it. We've got too much to do to make changes.' So Tom and I came out of that saying 'well we tried, we used up a lot of time.' Then the next morning they changed the launch date. The only thing I can figure is that Phillips and George talked about it"* (Schmitt interview, 1995).

Apollo 11

El-Baz recalls the orbital geology briefings with the Apollo 11 crew as rather stiff and staid: "Then we began with Apollo 11 and it was even more formal and more off-standish [sic] with the Apollo 11 crew because there would be no smiling and no give and take in a big way. We would get our hour and I would leave not really knowing what in the hell did these guys get…did they get everything we told them or not? Actually, Neil Armstrong would be the one that would ask more of the interesting questions. He just showed a little more interest and a little more appreciation of what is it that we're looking for." El-Baz got the impression that "he (Armstrong) was very interested. The fact that he was easygoing was good for Mike Collins too, because he (Collins) was the guy who was going to do most of it. We knew that it was not Neil who was going to do the photography. But we really wanted to keep Mike Collins interest and he was, very clearly. Mike Collins would respond. After Neil asked me a question I would answer it, and Mike would come up with another question. I would answer him back and we would go back and forth, and it would turn out to be okay but still standoffish. There was not the camaraderie that we needed to generate here." El-Baz further illustrates the attitude with an example of the response he got from Mike Collins when El-Baz tried to discuss the relationships of orbital relations to the types of rocks and the history that could be gleaned therefrom. "In essence the reply was 'I'm not interested' and I said something about the history of where it came from, and he said 'we're not going to have a microscope on the Moon to look at it. We're not going to have a microscope to see what kind of rock this is and what kind of silicate this is or whatever it is you guys say, or call it. So we're going to bring you back this stuff. We'll take a picture of it. We'll get the sample and you can have it.' Just like that. Kind of standoffish" (El-Baz interview, 2004).

At about the time of the Apollo 11 briefings El-Baz recalls a conversation with Mike McEwen in which he expressed his concerns about the difficulties he was feeling about getting things across to the 11 crew. The interest just wasn't there to develop a good exchange with the crew. McEwen mentioned that he had been talking to Ken Mattingly, an astronaut who would probably be flying on a future mission. Mattingly seemed more interested and might be able to arouse more interest among other astronauts. McEwen offered to get in touch with Mattingly and try to arrange for a meeting with El-Baz. Shortly after that McEwen called El-Baz to let him know that Mattingly had agreed to give him an hour before dinner at the Cape to present his case for the importance of orbital observations and photography, although Mattingly had made it clear that there's really nothing pressing that a briefing on the geology of the Moon could help him with.

According to El-Baz,

> "*I arrived over one hour before the time to begin and took with me as much of the photographs of the equatorial region of the Moon as you possibly can from Lunar Orbiter IV pictures mosaicked in strips. I unrolled the strips and arranged them on the wall with lines showing the rough orbit of Apollo 11 because we didn't know what the next missions were going to fly over. And I put it up on the wall of the briefing room.*
>
> *"I had looked into all of the books, the flight plan books, which were prepared for the CMP, the one who remains in lunar orbit. I studied what they looked like and what the CMPs do throughout the mission, and figured out that one of the most important things that they do is sighting landmarks. These are five spots that they mark by using a sextant so they can fix the mission orbits. I thought I would pick out some of these landmarks and concentrate on them and show him that if he actually figures out the geography, not the geology, of the Moon and where these places are before he comes up on the landmarks, there would be a very good possibility that he [could] fix the location of all five landmarks right on the spot rather than the two or three that they usually do. I approached my briefing from that point of view.*
>
> *I started with a view of the full Moon and then the features along the track leading to the approach of the landmarks. For example, before you fly over F1, which is the landmark, you have this very large dark area. I didn't even say Mare Crisium or the Crisium Basin, I just said flat, dark region. So*

> *I just walked him through from one feature to the next and talked about them one by one. He'd say 'this one here, its kind of a crater doublet.' I would say: 'Yes, let's call it the doublet,' and we would write doublet on the twin crater. Then we'd come to something else and do the same thing. While we [El-Baz and Mattingly] were doing that [the discussion of landmarks], Ken became really interested and wanted to continue talking. After the hour passed, he said: 'Would you like to have dinner with us?' I said: 'Sure.' He said: 'Six o'clock we'll eat dinner.' We talked for a few more minutes and I went with him to dinner and he introduced me to the whole bunch of them with Jim Lovell, Fred Haise, Jack Swigert, Tony England, and a whole lot of others and sat down with them at the Cape and had dinner. We talked about this and that and at the end of the dinner he said 'if it's okay with you, you're going to give us a briefing on the Moon's geology. When can you come down again?' I said 'anytime, whether you're here or in Houston, I can come anytime.' So he said 'we're going to be here for a while. Can you come next week at this time?' I said 'sure.' He said 'We'll give you the hour after dinner. Can you come down and have dinner with us first and then go at it?' I said, 'Sure'* (El-Baz interview, 2004).

In the words of El-Baz,

> "*This was music to my ears, because they initiated the request for a briefing, not me. When this occurred I was, in a sense, a little more prepared and did the whole thing again with the orbital tracks and they all came, including Jack Swigert who was known to skip as many briefings or training sessions as he could. There was a whole bunch of them, about ten guys. I started talking about the lunar geography and put in a few little things here and there and Jim Lovell would jump in. It was Ken Mattingly that initiated the interes, but it was Jim Lovell who was really pushing it now. We went through this whole briefing, and it became obvious that these people are beginning to be interested in this whole geology thing. On that same night, the second night I had dinner with them, I said to Ken Mattingly, 'You know when you fly the T-38 from Houston to the Cape we can give you examples of the kinds of things you can see so that we can give you a hint of the kinds of questions that we have for you from orbit.' Ken said 'listen, that's a great idea'. I said: 'Now if we can figure out the velocity of the T-38s and the altitude then we can simulate the velocity of the spacecraft over the Moon,' and he said 'great.' So Ken Mattingly volunteered to do that and he did. He figured out that at 25,000 feet and such and such aircraft speed he would simulate the motion of the spacecraft around the Moon. I said 'the next time you are going to fly, just let me know and I'll come the day before to tell you what you're going to fly over—the path that you select for your flight, and then I'll give you questions to answer' "* (El-Baz interview, 2004).

Just after Apollo 11 was completed the Apollo 13 crews started making the observations during their flights between Houston and the Cape. And this is how the concept of flyovers began and became a routine part of the training for the remainder of the Apollo missions. El-Baz would get the crew's flight plans and develop training exercises as described below.

> "I *made my own clipboard with a hardcover for the flight from Houston to the Cape. In that flyover exercise they were going to fly over New Orleans and this and that starting from Houston, Texas. Thus, I started looking at the geological map of Texas and asked what could be done here and over the Mississippi Delta, and then over the lakes in Florida and so forth. So, I started looking for the kind of interesting geological features. These included a big fault in Texas and several units with different textures. I then organized questions about all of these sites to answer as they fly over them. I would go to Houston and give them copies of the homemade, flyover book; usually it was only two guys who would fly, the CMP and his backup. I would fly myself that night to Florida and then I'd wait for them at the McCoy Air Force Base in the place where they actually land, which is not in the regular airport. They would come down in their flight suits and we would have a little table and we'd sit down and answer questions. All of the questions that they had I knew the answers to. Otherwise, how am I going to help them out? They would come and sit down and I'd ask them: 'All right, at this place did you see the fault scarp?' One would say, 'no, how would I see it?' I'd say: 'there is something that is high up like this, it would appear to be something like a straight line, there could be a dark line, because of the shadow—a sharp line.' 'I missed it. I've been over it a thousand times and I never saw it at all.' I would say: 'Never mind; the next time you will.' 'Okay, did you notice any difference in the texture?' 'Well yeah, there was something there.' 'Okay so that's what we call texture.' This procedure worked. Little things like this added to the discussion of colors and this and*

> *that. For example a question would be asked: 'what do you think made this lake?' 'It's a hole in the ground.' 'Yes, but how was this hole in the ground formed?' We'd talk about sinkholes and solution of limestone by ground water. It was useful at a time like that to ask questions about something I know the answer to beforehand from a geological map, or whatever, and ask them to explain it. We began to make the flyover exercises a little more elaborate by recording their observations during the flights, because they would be recording their observations while in lunar orbit. We became even more ambitious and more involved by adding, 'and take pictures because you will be taking pictures from lunar orbit.'*
>
> "*It turned out that Ken Mattingly began to talk about the knowledge he gained from the briefings a lot. He spoke about what the orbit of Apollo 13 might go over during the mission and what they know about this and that. He started talking among the astronauts in Building 4 of the Johnson Space Center. About the time that Apollo 12 was about to fly, and Apollo 13 crew assignments were announced, I was walking through the door of Building 4. From the other door coming out of the building some guy stopped in the middle. He looked at me and loudly asked: 'Hey, are you Farouk El Bayez?' I said 'yes.' 'Hey, I'm Stu Roosa. I'm gonna be on Apollo 14; I'm gonna be the CMP on Apollo 14. I want you to make me as smart as Ken. Hell, no, I want you to make me smarter than Ken.' That day I could have been flying on a magic carpet. I knew that the guys are going to begin to compete in their knowledge about the Moon. That was really great. I just knew it. As I was walking up the steps in Building 4 to see Ken Mattingly I thought 'My God, now we've got them by the balls, because now they're going to talk about competing with each other about the knowledge of the Moon. Man, this is it; as soon as we get them to do that this is it, because they will ask the questions and they will ask for time for the briefings and they will request more time for science on the missions' "* (El-Baz interview, 2004).

Apollo 12

There was a rather hectic schedule planned for the ensuing missions if Apollo 11 had not been able to land. In fact, such plans would have required training of a single crew for potential landings at more than one site and would have been extremely difficult to impossible. According to Jack Sevier,

> *"Subsequent missions were scheduled to follow on two month centers in the event that Apollo 11 didn't land. Apollo 12 would go to the same place two months later. If it didn't land 13 would go to the same place two months later until you succeeded. That's one of the reasons that we had so many vehicles, or Saturn Vs. Going back and reading some of that early stuff on Ranger and Orbiter you expected a lot of failures. The same way with planning for the first lunar landing. The program was prepared to have a number of missed landings. Certainly not a number of catastrophes but I think everyone was surprised that we landed on the first one. If we had kept to that same multiple launch strategy, as we had before Apollo 11, we would have probably gone to the central site first on 12 and then, if we had to recycle, we would have gone to the western site. So you'd have had at least two changes. Conrad (Apollo 12 commander) spoke up and said, 'There's no way, there never has been any way, that a crew could train for any more than one site per month. They just can't.' And they really hadn't been doing that because even though there were on-board maps for landmarks, etc., for the second backup site and the third backup site etc. I don't think anybody had time to pay any attention to them and really train with them. Conrad was really the first one who spoke up and said the reality is that one landing site is all that one crew can train for. That did a great deal toward changing the strategy. Plus the fact that we felt more confident because all the Saturn V launches had been on time, including the unmanned ones before Apollo 11. That was when the training got site-, or point-, specific. Between Apollo 11 and 12 the guidance folks figured out what they had to do to improve the likelihood of landing at a point, which involved updating in the LEM computer the very latest information that you had after tracking it for several orbits rather than information that was several hours old. So you essentially updated the computer to tell it to work the starting problem and, of course, on Apollo 12 Conrad pitched up and got the first look at the Snowman pattern and said 'there it is. Just like it's supposed to be' " (Sevier interview, 1995).*

El-Baz continued with the lunar "targets of opportunity" training on Apollo 12:

> "*Beginning with 12, we were a little more involved because we had the multispectral camera on 12 and Dick Gordon was really a lively guy and he became an easier character to deal with in the*

> *briefings because he would ask all kinds of questions and cracked jokes. You could easily tell him that if you studied it you will do it right, if not, you are going to mess it up. It was easy to deal with him in that fashion*."

Also the orbital training began to take on more subtle aspects, especially the visual observations of color difference. Much of this was initiated by Alan Bean whose talents as an artist led to a more detailed scrutiny of minor changes in hues.

> "*On Apollo 8 the Moon's maria, or dark regions, were described as gray, cement gray, or gunmetal gray. Frank Borman was the one who said it was all gray; all hues of gray. It is kind of bleak gray. He described the Moon to be of one and the same color with very little variation. He was comparing it in his mind to the colorful Earth. Thus, he gave us the impression that all the lunar maria are all in the same gray; islands of lead gray—all gray. In the meantime the photographs showed all kinds of variations. So, maybe the color film was misleading. We set out to do two things: we went to Kodak to say that we needed to see if these are real colors on the Moon, and we needed to get some film that actually reproduces the real color of the surface. Kodak started working with us on this. Its film experts had worked with the Navy on a color-sensitive film and they began to see whether we could get a version of this SO-33, which was a special color film. However, when Apollo 10 came it was Tom Stafford who started talking about the maria that were grayish browns and then lighter browns and some dark chocolate browns. All kinds of colors like this were very different from what came down from Apollo 8. Thus: 'what have we here, where are we here?' We began then to talk about color and what does color mean and vary with the sun angle even if it is dark gray. How does the sun angle affect the surface color?*" (El-Baz interview, 2004).

At this point Alan Bean began to ask questions that led to a need for a better way to describe the subtle changes in color: "if it is such and such gray, then what word would you give to the brownish tint, because the brown did show up on the color film and on the TV tapes. There were some browns, so what did these browns mean? Is it a real brown color or is it a fake thing that is an imprint from the film color recording properties; its color sensitivity? Thus, there was a great deal of discussion of this at the time that was led by Bean." At this point, Bean suggested to El-Baz that they begin using the Munsell color chart. El-Baz was not familiar with the chart, but "I bought a box of the Munsell colors. I had looked at other color schemes, there are three of them, but I decided on the Munsell color system and what does it mean and the relationships between this hue and that. It became a positive part of this whole training program. I went and studied it…and we began thinking about taking a color wheel into orbit. It got turned down, but we finally did send it up into Earth orbit on the Apollo-Soyuz, the joint U.S./U.S.S.R. mission of July 1975. It was a little simple thing. I began figuring out the color wheel and worked with the Mapping Sciences engineers to make a wheel of some light metal and put colors on the inside and on the outside rim. The astronauts could hold it, like this against the window, and tell us the number of the color that they're looking at" (El-Baz interview, 2004).

Apollo 13

The questions and discussions associated with the flyovers between Houston and the Cape had become practically routine for the 13 crew. The interest that had been generated byLovell and Mattingly at about the time of the Apollo 12 flight had really become a part of their training, although in an unofficial capacity. It was their own personal interest that kept these flyovers going. Not only the flyovers but also the orbital geology briefings were now generating a great deal of personal interest; enough so that the astronauts were spending many of their free evening hours discussing lunar geology with Farouk El-Baz. Just before the Apollo 12 launch El-Baz was at the Cape with the Apollo 13 crew and he was impressed with the fact that they were interested enough to continue the briefings into the evenings for as much as 3 hours after dinner.

> "T*he astronauts became interested and asked all kinds of questions. It became very interesting to them as we started looking at photos. At that time we had just finished the decision that Apollo 13 was going to land at Fra Mauro. I carried that decision from NASA Headquarters to the astronauts. So, I carried a picture of the Fra Mauro site and sat down with them. Apollo 12 was about to launch, and I recited all of the good things about the site and then I said there are all kinds of visual observations that an astronaut can make from lunar orbit that will help us to figure out the context of the site. 'So, let's look at the site from orbit.' We began to look at the details of the Fra Mauro site and it was during that session that the famous Cone Crater was named by Jim Lovell. I said: 'By God, yes, it does look like a cone.' He said: 'Yeah, let's call it Cone Crater.' So it was named right then and*

> *there by Jim Lovell. He was the one that suggested it. We talked about how can observations from orbit give a better context for the collection of rocks on the surface. This became an interesting topic for all of us from that day on; from the time of Apollo 13 on. It became a real issue. Astronauts on the ground are going to sample rocks here and there. But, what is the context of these rocks, and where they have come from; what is the setting of the samples? That became a very important and significant aspect of the orbital training from that day on. It helped a great deal, because people began to emphasize the setting of the site and its area, and what does this mean as to what is there and what is not. Certainly, Jim Lovell's interest added a great deal to Ken Mattingly's interest, and Ken was a great guy and he really wanted to do the best possible job he could do. H*e (Mattingly) wanted to make absolutely certain that we get the absolute maximum return and he was very thoroughly convinced that that's why we're sending man to the Moon; or else we can send machines. So we'd better prove that man is better than a machine, for some reason or another" (El-Baz interview, 2004).

When asked about any photos taken by the Apollo 13 crew, El-Baz commented that Fred Haise was able to take some photos despite the rather perilous situation of their spacecraft.

> "*Absolutely, they were quite good, of the far side; of features that we had not seen before. It was quite an addition by Fred Haise from the Apollo 13 flight when they were on the far side and apparently this was not discussed a great deal with the ground. He did it on his own and he picked up the things, because he was fascinated by the view of the Moon from orbit…and actually some photographs were taken by Jim Lovell. Jim would say: 'give me the camera' and look from another window and shoot it. From the log afterward, actually Fred Haise was talking about something and taking pictures and Lovell would say 'I see something; you need to give me the camera, I'll shoot it from the other window,' one of five windows, one is looking at one side and the other at the other side. So, he would take a picture and give it to him back*" (El-Baz interview, 2004).

An interesting sidelight of the orbital geology training in photo procedures was the manner in which the skills of the photo team were used to aid in the investigation of the cause of the explosion that nearly destroyed the Apollo 13 spacecraft. In order to assess the exact nature of the damage to the spacecraft it would be necessary to photograph the Service Module after it separated from the Command Module. According to Farouk El-Baz,

> *"Rocco Petrone…called me up. He said, 'Hey, now if all things work well and they can turn around, they will separate the Service Module from the CSM. We need to know what happened and how much damage was done, and we need to photograph that well. Start working on it now.' So it took me three days to do nothing but this. I went to the guys from the Flight Planning Group and they looked at this, and they needed the whole thing looked at in detail. They could work out the separation time, angle and the velocity, where the Sun is going to be, and what is such and such, and what cameras do we tell the astronauts to use at what time, etc. We started working and we continued all three days just to make this happen right. This was so much out of the ordinary because nobody had calculated anything like that before. We worked on the system and procedure to photograph the blown off side of the Service Module as soon as they separate, otherwise they were going to separate fast and they would not be able to see a thing and we would never know what part of it exploded. So, we worked on that and it was part of kind of a photographic team effort and we became kind of a persona grata for having done that work, and done it right"* (El-Baz interview, 2004).

Apollo 14

As mentioned above Stu Roosa was very enthusiastic about becoming "smarter than Ken" in his knowledge of orbital geology. As a result, El-Baz set up several flyovers for him between Houston and the Cape as he had done for the 13 crew. In addition El-Baz arranged for specific flyovers of volcanic and crater features in Arizona similar to many of the features that were expected on the Moon. These enabled Roosa to provide substantial descriptions and photos from lunar orbit. However, "we had a real problem on 14 with the Hycon camera. It just didn't work. And that took a great deal of the time from Stuart Roosa to troubleshoot it. It took much of his time from observations. He started to make some observations and he had a keen eye and he was a real observer, but during the mission his observations were limited by the fact that he had to be trouble-shooting that Hycon camera when it died. We really wanted to have the Hycon camera take the good pictures with high resolution of a strip of the central lunar highlands for a later landing site (Apollo 16), better than those of Lunar Orbiter, but the camera wouldn't do it" (El-Baz interview, 2004). Nevertheless, "There were some photographs that were taken on 14 which were useful for the 16 site. But, for 11 and 12, those sites had been photographed up and down during Orbiter.

You couldn't do any better than that. The reason the 14 photos helped with the 16 site was because we didn't have any great photography of the 16 site to begin with" (Jack Sevier interview, 1995). The photos referred to by Sevier were taken by Roosa, the CMP, who managed to shoot some handheld, high-resolution photos of the Descartes site with the Hasselblad camera.

As was the case with nearly all of the CMPs, Roosa had high praise for Farouk El-Baz:

> "*I certainly felt well trained in this area. You do have a single-point failure in the CMP's orbital science training in the form of Farouk El-Baz. He is the only one in the system who is adequate to train the CMP. My lectures that I got, other than his, I didn't think too much of. His were extremely good. He has the talent to train the CMP…If the CMP works with Farouk, he can essentially chuck the orbital map by the time he is ready to fly. I wouldn't waste too much time getting briefed by anybody else. We didn't work with Farouk too much on the landmark identification. The book that we make up on the landmarks is sufficient. My book of landmarks and the photomosaics that they had for them were extremely good. I'd studied them before flight, and during flight I could recognize them" (Apollo 14 Tech. Debrief, p. 25-17).*

Apollo 15

El-Baz indicated that, starting with Apollo 15, the training for the CMPs became much more detailed and intense:

> "*Everything came to a head with Apollo 15, because I was formally assigned the designation of Principal Investigator for Visual Observations and Photography (Visobs). Now we had our times for briefings—long briefings, and we had the plan for the flyovers—detailed flyovers, and if they were not flying, we could assign a flight time for them and assign a routine, which we did not have before. Because of this we could also change flight plan schemes so that we could accommodate this versus other types of instruments; and this became very important actually for me to be part of the Orbital Science team because we would accommodate the other orbital science experiments and when do you turn this on and when you make sure that everything else works: the gamma ray and the X-ray and all of that. And we worked with these other teams very well.*"

There were eight major new experiments to be conducted in orbit on Apollo 15. So the need for a good working arrangement with the other teams became very important.

When asked if he ever had the opportunity to go along in a T-38 jet on the flyovers, El-Baz responded,

> "*Yes, they took me once with Stu Roosa and once with Ron Evans just to show me how that was achieved, how does it look when you are looking upside down, which was a weird thing. I nearly fainted. To see what, when we talk about 35,000 feet at such and such speed, what does that mean. So I could see it for myself and see what are the problems they are encountering. I would be looking at what's there and then Stu Roosa would turn the plane over and so I could see the Earth coming up above me, and the sky below me. So I'm down under and flying this way and you suddenly see how disoriented you are.*
>
> "*We also had the little planes. We flew in those a lot. With the little planes it was good to show them what is it we mean when we talk about a scarp, when we talk about a hill, the crater ejecta around meteor crater for instance, what does that mean, in the little plane. So, we flew the little planes a lot. And in most cases, this was the USGS plane. Remember that one, especially in Arizona. We had a couple of flights with Ron Evans in Florida and in Houston, Texas, but we could see very little. The flights in the little planes were really good over Arizona because there is little vegetation and lots of features and the many volcanic cones; the kinds that were very interesting to study. In addition, specially flying over Meteor Crater was very instructive*" (El-Baz interview, 2004).

The high-altitude flyovers also provided an opportunity to practice looking for the LM from orbit. Locating a small black halo like that produced during the lunar landing or a reflected glint off the metallic coating at the right sun angle could indicate the presence of the LM. In the words of El-Baz,

> *"We have now come to the real beginning of the visual observations of the Moon in a big way. There were several things to consider here:*
>
> 1. *The general impression within NASA that the three J-missions (Apollo 15-17) were science missions, and that gave us a helluva lot of justifications.*
> 2. *Rocco Petrone's total emphasis on the importance of science was, by hook or by crook, our filter*

> *in every aspect of the missions. He was encouraging all of the time, which meant in part that we functioned over the objections of the directors of the NASA centers. Because of Rocco's pushing, they would go along with extensions of time and this and that related to the science on the missions. Therefore, this was filtered down to the planners and the flight directors.*
>
> 3. *The fact that the astronauts were now very clearly competing with each other in their science knowledge; no longer in just flying the machines. They were all very good with the machines and on Apollo 11 they landed safely. And Apollo 12 gave us a pinpoint landing, and 13 was messed up but returned unharmed, and for 14 they could land in the highlands. So every aspect of landing the spacecraft beautifully had already been accomplished. It was a huge thing that competition from here on was about their knowledge in science and their ability to contribute to our knowledge of the Moon. So this was very good work.*
>
> *"The backdrop of that was the fact that the crews themselves became a little more amenable to the training and more interested in geological questions. This might have been championed by David Scott. But he didn't have to try very hard because everybody else went along with it, and they were just as eager. Perhaps he was a little more verbal about it. And the other thing, Al Worden was more interested but not as glib as Dave Scott in saying so. But here was a whole interested crew; there was not a single training session for Apollo 15 in which I didn't have the whole crew in the room. They would all attend. Most of the work would be done by the CMP, so I needed the CMP and his backup, but they were all there. Even at the Cape, all of them would come. It was great. It gives you a feeling that there's camaraderie, number one, and number two is we're all in this thing together. Number three is that they all really wanted to know the crater names and which one is that one, and why is this one lop-sided rather than round, why is this such and such, and which one is old and which one is young, and why do you say that. Thus, this became a real part of their training in geology. It was the orbital view that fascinated them. It was no longer just a little bit of geography. It became geology from orbit that helped the geology on the ground. And they became very heavily involved in all of it.*
>
> *"The training of Apollo 15, particularly with Worden, took on a whole new tack…a whole new vista, because he would devote enormous amounts of time to it. We would begin to make flyover exercises from Houston to L.A., and they would do these flyover books and the briefings beforehand. Then Al Worden and his backup, Vance Brand, would go on the other end at L.A. and sit down with the recorder and turn it on. And 'you missed this, you picked this, we did this, and we did that' and so on"* (El-Baz interview, 2004).

One of the significant results of this training was Worden's orbital observations during the actual mission of what he suggested were cinder fields in the Littrow area. This became a major factor in the selection of Taurus Littrow as the landing site for Apollo 17.

In the Technical Debriefing following the mission Worden indicated that "I thought that the training that I received in orbital geology was better than I had anticipated. I was very well prepared when I got there. The only comment that I'd have is that most of that detailed training we had came late in the game. It had to be sandwiched in with other things at the Cape…It would be helpful if we got into the detailed part of that a little bit earlier in the training cycle" (p. 17-10). Worden also indicated that less training under neutral buoyancy in the water tank would be better. He felt that "the sensation of neutral buoyancy is sufficiently removed from zero-g that with too much training in the WIF, it almost turns out to be negative training. The operation is so much more difficult in the WIF than it is in flight or the zero-g airplane that fewer sessions in the WIF would have been in order" (p. 17-15).

Apollo 16

Ken Mattingly's role in the development of orbital flyovers, both before and during his position as CMP for Apollo 13, was discussed in detail earlier. Over a year before the scheduled flight of Apollo 16, Mattingly, who was to be the CMP for 16, indicated that he wanted a more significant role than that of a "button-pusher" during the Apollo 16 mission. He wanted to be involved in activities that would produce the maximum return possible from a person flying in lunar orbit. It was agreed that, in addition to knowledge of the hardware and procedures, his training should include information on the scientific basis of problems associated with lunar, planetary, and solar processes as well as the type of information required to solve these problems. As a result, the personnel involved with the orbital science training were instructed to provide a clear definition of a specific problem and its background, the nature of the data that might help solve the problem, types of observations (other than instrumental data) that a person could provide from orbit, specific observations to complement specific instrumental data, and references through which a CMP could become more familiar with the problems and associated data.

Dick Laidley, a geologist/jet pilot in the Geology Branch at MSC, conducted several orbital training flights with Mattingly. Mattingly knew about Laidley's reputation as an excellent pilot and wanted him to be involved in the flyovers. The two of them would fly together in a T-38 over numerous geologic features. Laidley took along a camera and a tape recorder for Ken to take pictures and record on tape what he was seeing and what the photos were meant to show. Laidley would get the photos developed and listen to the tapes, even get some of the tapes transcribed. Then the two of them would get together and talk about what Mattingly had seen, how accurate his descriptions were, and the usefulness of his photos. Laidley's combined geology and jet pilot background was an excellent addition to the training and certainly helped a great deal.

Jack Schmitt also recalled Mattingly's enthusiasm for flyovers, "I remember Ken persuading me to fly in a T-38 out to west Texas where he picked the right sun angle and we did some upside down flying using the right angles and right viewpoints. He was terribly meticulous. He had it all figured out. I flew him so he could take pictures and try to observe west Texas at an appropriate altitude" (Schmitt interview, 1995).

Each of the 18 geology overflight training exercises with Laidley was divided into a high-altitude (40,000 ft) and low-altitude (1,000 to 5,000 ft) exercise. The high-altitude portion was a lunar orbital simulation with recorded descriptions and interpretations of the objectives, 35-mm photography with the actual camera to be used in lunar orbit, and evaluation of viewing devices (monocular, binocular, single reflex camera lens). The time on each specific target was approximately equal to the time on target while in lunar orbit (each pass equivalent to one lunar revolution). The resolution unaided from 40,000 ft. is approximately equal to that of 10 power binoculars from a lunar orbit of 60 nautical miles. The high-altitude phase lasted from 1 to 1½ hours. The low altitude exercise was from 3 to 8 hours and is analogous to a flying classroom. It also used recorded and photographic documentation. All of the flight exercises included several hours of pre-briefings, several hours of preparation with photogeology and accompanying study guides, and a few hours of debriefing, which included evaluation of recorded descriptions and interpretations of exercise objectives and simulated orbital photography.

Bill Muehlberger, who became the geology PI for Apollos 16 and 17, recalls very little contact with the CMPs:

> *"Of course, we never really saw the third guy, Command Module Pilot; because they were trained by a totally different group. .... So the orbital guys trained always from an airplane, looking down, the high-flying jet. A geologist pilot [Dick Laidley] would take them and do these trips. Then they'd get done with the jet level and they'd get into a light plane and fly at a low level over the same place, just to see what it was that he was really describing, so he could better understand all these things. I got to go on one of those, went from Mount Lassen to Mount Hood [with Laidley and Mattingly in October 1971]. Wow, what a trip. We also tried having the Command Module Pilot join us on one of these field trips, just to have him get involved in a different perspective. He flew over in his T-38 and then landed and came and joined us. I don't know whether it was useful or not but we did it. I would like to think it would be, just so you see more in detail, so you have a better chance of interpreting when you get up in orbit"* (Muehlberger interview, 1999).

In addition to the flyovers there were numerous lectures and photo study sessions which totaled about 145 hours. These included eight general geology lectures on various aspects of lunar geology and pertinent Earth geology, six sessions of 3 to 5 hours each on regional lunar geology with instruction by the lunar mapping teams from USGS, several sessions on the detailed lunar geology of the Descartes landing site of Apollo 16 by the USGS mappers, several four-hour sessions studying and critiquing the various types of photos taken from orbit on previous missions involving astronauts from previous orbital science activities and Farouk El-Baz, and a series of briefings and seminars with each of the nine orbital science PIs. During the final three weeks of crew quarantine at KSC before the mission, El-Baz met with the CMP for a few hours each week to review the photo and visual targets as well as the overall orbital flight plan.

In the Technical Debriefing following the mission the crew had several comments on their training. For the orbital training Mattingly had some praises and some criticisms. On the positive side he found the flyovers and the geology briefings to be well done:

> *"I can't say enough good things about Dick Laidley. Dick Laidley came in and set up a training plan [for flyovers]. His first task was to convince me that when you carry a map and pan camera, there's some reason why you should spend your time looking out the window, and use the man's time at all. I'm really glad that he did because the proof of the pudding came a couple of hours ago when I went over and looked at the photographs again this morning. The things that I saw and recognized*

> *with my eyes are not on the photographs. I think if I can record those things that it would all have been worth it. The training was set up, again, solely by Dick Laidley. I think it's a unique thing, as we don't have a system that handles this very well. We had one man with the unique capability to take his capability as a pilot, and his ability to fly and recognize what he sees from orbit—that made him especially useful. He gets my vote for being the most organized and most thorough person I worked with in a training capacity anywhere. He'd set up a trip, run through it, make sure that all the kinks were out of it, he'd fly the things, prepare maps and briefings before you went, and he'd provide for critique. He provided for briefings by local geologists on the area and he proofed the whole thing before he ever wasted 1 minute of crew's time on it. And you just can't say enough for his thorough preparation.*
>
> *"At the end El-Baz got back in the loop and Dick didn't know as much about the Moon as he did about genera1 geology. El-Baz, on the other hand, probably knows about all there is to know about the Moon on a human basis. The problem is that it's a single-point failure, if there ever was one, in the Apollo Program. El-Baz can't afford to sneeze, cough, or anything, because he's the only person that has expressed any interest in that. Putting it all together, it's frightening to me that one person is in that position. It's fortunate he's the super kind of guy that you can afford to have in that kind of job. I just don't think we should be running a program as expensive as this with only one person carrying the ball for such a large portion of the activity. In this case he got wrapped around the axle on Apollo 15 until very late in the game. By the time he gets through reducing the data on 16 and gets through with all that stuff, he'll probably be late getting back into the Apollo 17 picture"* (Apollo 16 Technical Debrief, p. 17-23, 17-24).

El-Baz also spent time on the visual recognition of the landmarks that were needed for accurate tracking of the spacecraft. Again, Mattingly had some comments:

> *"We spent a lot of time on that at the end…I think that the time that we spent on it though was really well worthwhile. I was able to operate by looking out the window and knowing where I was without referring to the map. Your time on target is so short that if you waste your time cross checking against a map, and looking back and forth, you're not going to get around to doing anything except verifying that the pictures on the map are in the right place."*

According to Mattingly, the SIM Bay experiments did not require any formal training because he and the crew had been in on the hardware development since it started nearly two years before the mission. Mattingly, however, had some different feelings about the Command Module Experiments:

> *"There is nobody that looks after all the Command Module experiments. There's nobody that lays them out. There's nobody that puts them together in any kind of a reviewed fashion to see what it is we are trying to do, except the flight crew. There is no one to point out who we should talk to. There's no one to set it up, and yet you have to do everything through the backdoor. For instance, take an experiment checklist that's one and a half inch thick of experiments. There's nobody that screens how those things are done, how they should be done, what it is you're trying to do, how you should take them, when they should be done. We've pulled every bit of that stuff out like pulling teeth. I am one of the few people that knows what's in that book. I should be given that book with a set of procedures to learn. Instead, I'm one of the few people that knows what is in there and why it's there. But I don't think the flight crew has the time to do that stuff. I feel like I put so much more in this thing than you should do.*
>
> *"I started on this thing one and a half years ago, and that's the only reason I got there because I sat down and I talked to everyone of those PIs and every one that had an idea. I had to call them in and I had to look them up and find out what they were trying to do, try to put it in the context of where our spacecraft was going to be and what we could do and how we do it. The things we got [from the engineers and procedures personnel] weren't useful. They weren't usable. The requirements would come in and they'd be ding-dong. You look at it and you would say, 'Well, this is not going to do anything because I know what the guy wants to do.' All they're doing is reading from a mission requirements document, which doesn't do a doggone thing for you. The whole area of orbital activities has totally been lost. No one is looking after it except the flight crew. Perhaps the proper approach is to drop it. But I would never recommend that another crew spend the time that I spent on it, and if I were doing it over again, I would not spend the time on it"* (Apollo 16 Technical Debrief, p. 17-39 to 17-41).

As an example, Mattingly referred to the dim light experiment: “Somewhere I’ve got a copy of the original procedures we got. They are humanly impossible to do…They should bring a set of experiments that have been thought out and practiced. There’s no excuse for anyone ever bringing me an experiment that they haven’t sat down and done themselves, and I don’t think we got a single one that was brought to us that way” (p. 17-42). He complained that he spent at least 15 hours by himself in the CSM trying to develop techniques and procedures for the dim light photography. Mattingly recommended that there should be a person who was responsible for all these experiments, set up priorities, put them into a flight plan, and provided the procedures along with a training package, similar to the way it was done for the surface experiments.

Apollo 17

By Apollo 17 the training procedures for the CMP were well established and Ron Evans, on 17, underwent a very similar training as Mattingly on Apollo 16. There were numerous flyovers with Laidley, lectures, briefings at the Cape, and photo study sessions involving similar personnel as listed for Apollo 16.

In the Technical Debriefing following the Apollo 17 mission, Evans cited three people in particular for his orbital science training. Dick Laidley had been a co-pilot and “the CMP’s geologist, so to speak, for Apollo 16 [and 17] and for the field trips: getting ready, knowing where to go, how to follow flight plans, what to expect, what photos to take, and this type of thing. He’s indispensable from that standpoint.” Second was Jeff Warner, who “organized the rest of the scientific briefings, got them squared away and participated in the field trips from the low-altitude standpoint, and also with the site specialists.” Third was Farouk El-Baz, “who came into his own along toward the end of the training cycle when we were involved primarily in the crew familiarization and training for the lunar geology itself.” Evans felt that El-Baz’s role in providing the lunar geology close to the end of the training cycle and continuing right up to launch was the way it should be.

8. Simulations based on lunar traverses

As landing sites were selected for individual missions both the orbital and surface training could become more focused. The CMP who was expected to provide descriptions and take handheld photos from orbit was briefed on the specific features that were to be overflown along the orbital track. These features could then be studied firsthand by a knowledgeable observer familiar with the scientific problems. The field training exercises could also be selected to be more realistic in terms of specific terrains, rock types, and other problems. As the lunar traverses and timelines became better specified, so could the training exercises be made more similar to the lunar traverses. For Apollo 11 there was no specific traverse planning for the landing site; only a rather broad landing area and a given amount of time in which to deploy three instruments, collect a contingency sample, and collect some samples of soil and rocks. The one field training trip for Apollo 11 included sampling and photographing samples in a terrain that included some volcanic rocks but was more of a general nature and did not have time lines for specific stations. For Apollo 12 the actual lunar traverses were planned rather hurriedly at the Cape within the final few weeks before the flight; in fact, they came up with four possible traverses dependent on where in the general target area they landed. The actual traverse, or combination of traverses, would be decided after the landing when a specific landing location had been confirmed. Most of the five field training trips for Apollo 12 used traverses in volcanic terrain which was the expected environment for the landing site. The fifth and final field exercise for Apollo 12 was a simulation in an artificial crater field and included voice communication with the CapCom and other operations personnel in Mission Control in Houston. The SSR in Mission Control was also in the communications loop and was staffed by the same team that would be on duty during the mission.

In contrast, by Apollo 17 there were three planned traverses on the lunar surface with specific times for stops at preplanned locations for sampling, coring, deploying instruments, and other activities. Even contingency traverses were planned in case there were any perturbations to the original traverses. As the more detailed plans evolved, the monthly field trips and the deployment of instruments were tailored to the expected terrain and geologic units at the landing sites. In addition, the personnel and operational techniques associated with the traverses evolved to become as much like an actual mission as possible. The field exercises were conducted using aerial photomaps produced at the same scale as the photomaps to be used on the Moon. Traverses with station locations were shown on the training photomaps which displayed geologic units had been delineated based on the various textures and shades that a photomapper would use to suggest different units, just as the photomaps for the actual missions were made. Any topographic features that could be identified by the photomappers were also shown in both maps. Thus, the training for each individual Apollo mission became more and more like the real mission during the last few months before each flight, and the final field exercise was conducted in a terrain similar to that of the actual landing site, with communications being funneled to the personnel manning the consoles at Mission Control in Houston.

For the final three Apollo missions the last few field exercises were held in field areas that mimicked the lunar landing sites, and the times and stops on the traverses, including the specific tasks, were as close as possible to those planned for the actual EVAs. For example, the first of the last four field trips for the Apollo 15 crew was to the Rio Grande gorge north of Taos, New Mexico where the volcanic terrain was cut by a deep canyon and the surrounding area was covered by a moderately thick regolith. This was very similar to the Hadley Rille location at the 15 landing site. A USGS press release on the training of the Apollo 15 crew at the Rio Grande Gorge provides a good illustration of the reasoning behind the selection of this location as one of the training sites:

> *"As part of their preparation for lunar exploration, the Apollo 15 crew carried out detailed practice missions earlier this year in the Rio Grande Gorge, near Taos, in north-central New Mexico, a site that offers a number of striking similarities to the lunar landing target. The general features of the Taos area, long known to geologists, led it to be considered as a training area for the Apollo team. Following a close examination by scientists of the USGS Center of Astrogeology, aided by geologists from the New Mexico Bureau of Mines and Mineral Resources, the area was chosen as an ideal outdoor real-scale classroom, where USGS teams organized a series of traverses and exercises that are scheduled to be closely duplicated on the Moon. Survey geologists said that few places on Earth provide such a resemblance to features that exist at the lunar landing site.*
>
> *Near the Apollo 15 landing point, the Hadley Rille is about 1 mile wide and about 1,000 feet deep. Near Taos, different segments of the Rio Grande Gorge are from 1,000 feet to over 4,000 feet wide, with a depth of about 650 feet. The longest planned motorized traverse on the Moon's surface is about 5 miles, and an unobstructed stretch along the west side of the Rio Grande Gorge permitted a traverse there of the same length. Other similarities noted by the geologists: the land surface adjacent to the Rio Grande Gorge is gently rolling, and covered with gravels of several distinct characteristics corresponding to the rolling cratered lunar mare ("sea") surface and its veneer of rubble. Both the gorge and the lunar rille are entrenched in basalt lava flows and, although the walls of the gorge are probably steeper than the walls of the rille, areas of talus (a heap of broken rock) and slumping are present in both features.*
>
> *During their "warm-up" exercises at the Gorge, the Apollo 15 astronauts and backup crew worked exactly as though they were on the Moon, navigating a training "rover" vehicle along a prescribed route marked on maps, photographing features and landscapes, taking cores, digging trenches, and testing a variety of communications and support equipment. Care was taken that even the angle of the Sun was correct, at their backs, as it will be at Hadley Rille. Hadley is the only rille that will be visited during the present lunar exploration program; thus, it looms as a particularly significant target. Samples taken from it should yield information unlike that gathered in previous landing missions, and provide a better framework of knowledge for theories about the origin and evolution of the Moon"* (Dept. of Interior news release, July 20, 1971).

The second of the last four trips for 15 was at the Coso Hills where there was a relatively flat area of volcanic rocks next to a steeply sloped front. This was very similar to the Apennine Front next to the plains units at the landing site. The third was at the NTS where there were numerous craters in volcanic rocks which allowed radial traverses across the ejecta blankets to sample the units ejected from the craters as well as the regolith. This would simulate the potential radial sampling that might be performed around some of the craters at the landing site. The final field trip was a full-up simulation through Mission Control, run at Coconino Point, Arizona. The exercise was to simulate EVAs II and III in an area with similar morphology to the Apollo 15 landing site. Coconino Point on Gray Mountain simulated the Apennine Front and the Little Colorado River Gorge simulated Hadley Rille.

9. Evolution of organizations, procedures, and tools

Organizations

At MSC essentially all of the science training from mid-1963 onward through most of 1967 had been directed at group training of the astronauts. Although some of the training had included aspects of flight mechanics, biology, solar physics, and astronomy, most of it was concentrated on geology and geophysics, including lectures on the geology and geophysics of the Earth and Moon, geology and geophysical field trips, use of hand tools in the field, and the use of instruments to measure planetary properties. The geology training was carried out by a combination of geologists, some from the USGS and others at MSC. The MSC and USGS personnel who did the training were also involved in many of the suited and lunar gravity simulations to develop the best configuration of the tools and instruments. The MSC training personnel underwent several changes both organizationally and physically during this period. Initially they were in the Lunar Surface Technology Branch which in 1963 was part of the SED of the Engineering Directorate and located in some converted barracks-style buildings at Ellington AFB. In 1964 the Lunar Surface Technology Branch was placed in the Advanced Spacecraft Technology Branch of the Engineering Directorate. By 1966 the geologists involved with the training at MSC were still in the Engineering Directorate but they had their own Lunar and Earth Sciences Branch within a new Space Science Division located at the newly built MSC in Building 31, a building designed for science research. At the beginning of 1967 a significant reorganization at MSC created a S&AD in which there was a Lunar and Earth Sciences Division in Building 31 with its own Geology and Geochemistry Branch that included the geologists involved with astronaut training. It was within this structure that the mission-oriented training started.

In 1968 the nature of the training shifted from lectures and field trips for large groups to the training of individual Apollo crews. For the early Apollo missions, before the Apollo 11 landing, the flights were entirely orbital, either lunar or terrestrial. There was very little need for much surface science training for these missions. Although there was one field exercise for the Apollo 8 crew most of the science training for Apollos 7 through 10 was confined to orbital science observations and photography, as described earlier. By 1969, as the training for Apollos 11 and 12 got under way, there was a significant amount of preparation required for use of the instruments and tools that were to be deployed or used on the lunar surface, and simulations for lunar surface activities became a regular part of the training. For the first few lunar missions, however, the need for operational training was paramount as the first attempts at lunar landings were about to be undertaken. As John Young explained it, “There were some crews that were really so busy learning about the spaceship they couldn't spend a lot of time on geology. I mean, on Apollo 10 we didn't do a real lot. We did a lot of photo geology but, you know, we were really trying to learn the vehicles and learn the mission which was a very—well you know—it was a lunar mission with lunar orbit, lunar rendezvous, and all that stuff. Tom and Gene just had their hands full with the Lunar Module. And I pretty much had my hands full with the Command Module even though I'd backed up Apollo 7. We were right at the leading edge of trying to learn how to do stuff. But later, on Apollo 16 we devoted more than half our training to the scientific objectives of the mission” (Young interview, 1995).

For Apollos 11 and 12 the surface science training was done primarily by the geologists at MSC and consisted mainly of organizing and participating in field trips plus some refresher courses in geology and rock study. For Apollo 12, after several requests for USGS participation in the field trip, Ed Wolfe was assigned from the USGS with the stipulation that he would help only on the trips when the crews were present. He attended the final five of six Apollo 12 trips. Any science briefings by ALSEP PIs were organized by the Astronaut Office scientists or the Lunar Surface Project Office. For Apollo 12 there was also particular emphasis on the samples returned by Apollo 11. Clanton especially recalls one instance when they studied the Apollo 11 samples. Clanton had asked Dan Anderson, the Acting Lunar Sample Curator, for a session in which the Apollo 12 crew could view the lunar samples. One afternoon, at about 5:45 p.m., after most people had left for the day, Clanton, Laughon, Conrad, and Bean assembled in the lobby of Building 37 where they were to meet Dan Anderson. He came in and told them to wait while he got the samples. A few minutes later Anderson returned with a tray of samples consisting of lunar soil and several walnut–sized rocks. The soil and rocks were passed around and the crew was able to actually dig their fingers into the soil. This was quite a surprise in that they had all expected to “suit up” and view the samples in glove boxes. Dan explained that these samples had been used in some earlier tests that “compromised” them, thereby allowing the astronauts to handle the samples with bare hands. They all sat around for an hour talking about the comparison of these samples with what they had seen previously in lab studies of terrestrial samples and on field trips.

The extensive training for the operational aspects of these first few missions, 7 through 12, was of prime importance, and the time available for science training was quite minimal. On Apollo 12 some of the field trips used a simulated backroom staffed by the CapCom and a geologist. The final field trip for 12 actually was a simulation that included radio communications with Houston’s Mission Control. Once it was shown that the LM could land successfully on Apollo 11 and that the landings could be made almost on a pinpoint on Apollo 12, the role of science in the missions increased and, as a result, the need for science training increased. Starting with Apollo 13, therefore, the science training began to change significantly. For Apollos 13, 15, and 16, the field trips were largely planned and conducted by Lee Silver with help from USGS and MSC as discussed earlier.

Once Apollos 11 and 12 had successfully landed the mission-oriented training began in earnest and many modifications were made to the organization of the training, the hand tools, and the methods of training as well as to the personnel and organization of the SSRs in Mission Control. These were made as a result of several factors. Astronaut reactions to the training continued to be important considerations and led particularly to many changes that were initiated by Jack Schmitt. Most of the long-standing conflicts between USGS, MSC, and the PIs were resolved. Most importantly, the experience gained from mission training and the actual missions was used in ways that had not been possible before 1969. This part of Section III will set forth the changes that occurred and attempt to analyze the reasons behind the changes.

Starting in September 1969 Jack Schmitt had brought about a significant change in the field training for the Apollo crews. For Apollos 8, 11, and 12 MSC geologists had organized and led essentially all of the field trips with little help from the USGS, which housed the PI and his team who were responsible for the geology to be done on the lunar surface. Schmitt felt that the enthusiasm for field exercises was not as great as he thought it should or could be. His solution was to seek out more experienced and charismatic instructors who could help develop more enthusiasm and competence among the crews. He found the ideal person to plan and conduct the field trips for the Apollo 13 crew. Lee Silver, a professor at Caltech, was known as a great teacher who had a great deal of energy and enthusiasm that he was able to impart to his students. Lee became the revered mentor for the crews of Apollos 13, 15, and 16. Also, in the midst of the training of the 13 crew, the USGS became more active in the training and by late 1970, the collaboration between the USGS and Silver became very effective. Starting with Apollo 15 the USGS became a major contributor to the field training.

During late 1969 and early 1970 there was a significant change in the science management and objectives at MSC; and this provided one of the major reasons for the change in the science training of the astronauts. There were departures in each of the following positions: Director of S&AD, Chief of the Lunar and Earth Sciences Division, Chief of the Geophysics Branch, Chief of the Geology Branch, and the Office of Curator. In addition to the departure of the personnel from these positions there were transfers in mid-March of Ted Foss, the Chief of the Geology Branch, and three other people from the Geology Branch: Uel Clanton, John Dietrich, and Mike McEwen, who had been involved in astronaut training for several years and were in lead positions for training the current Apollo crews. Clanton, Dietrich, and McEwen were transferred to the Lunar Missions Office; and Foss was transferred to the Mapping Sciences Lab from which he resigned after a few weeks. In conjunction with these mid-March transfers in 1970 the responsibility for astronaut training in geology at MSC was shifted from the Lunar and Earth Sciences Division in Building 31 to the Lunar Missions Office (to become the Science Missions Support Division in 1971). The Lunar Missions Office was in Building 4, the same building that housed the astronauts, and the three people transferred there were expected to continue their activities in astronaut training. The radios, tape recorders, camping gear, some of the rock and mineral collections, and other items used in the field training were also transferred to Building 4.

This reorganization at MSC in the early 1970s was short-lived. An even more drastic change took place in August 1970 when the responsibility for geologic training was shifted back to the Geology Branch of the Division of Earth and Planetary Science in which several new staff members were put in place to coordinate the science training and collaborate in the field exercises with the new geology PI from the USGS. Even Clanton and McEwen, who had been heavily involved for many years, were no longer involved with much of the training. By this time the science training responsibilities had evolved significantly. The three people who had been transferred to the Lunar Missions Office to continue training activities were eventually transferred elsewhere: Dietrich to Mapping Sciences, McEwen to the Directorate Office, and Clanton back to Building 31 to commence SEM work on the returned lunar samples. The evolution of the organizations involved in astronaut training from 1963 through 1970 is shown in the charts of Appendix F.

According to Clanton, Tony Calio, the new Director of S&AD, had carried out conversations with Foss for several months in an effort to have Foss recruit some respected outside scientists for involvement in the training of the Apollo astronauts and, at the same time, recruit new research personnel while developing and upgrading the research facilities. For some reason Foss did not comply with these requests, and Calio finally transferred the four Geology Branch personnel to other offices. Clanton indicates that he, McEwen, and Dietrich were totally unaware of the nature of the discussions between Foss and Calio over the previous few months and were completely surprised by the transfer actions. Several days after the transfers, when Calio asked Clanton and McEwen to meet with him separately, Calio asked each of them why they had not complied with his requests and they indicated that this was the first that they had heard of it, that Foss had never discussed it with them. The people who had been transferred to the Lunar Missions Office would complete their activities with the Apollo 13 and 14 crews and have much less involvement with future training. After 1970 only two of the astronaut trainers from the 1963-1970 era were involved with astronaut training. Clanton attended four of the sixteen Apollo 15 field trips and three of the eighteen Apollo 16 trips. Clanton also did some briefings on Apollos 14 and 15 surface photography for the Apollos 16 and 17 crews. Dietrich went on a couple of the Apollo 15 field trips. The rock and mineral collections, radios, tape recorders, camping gear, and other items used in the field training were transferred back to the Geology Branch in Building 31.

In addition to the above-mentioned personnel changes the Lunar and Earth Sciences Division was being transformed into a top-notch research facility. State-of-the-art laboratories were being developed in several fields of research and several new personnel were being added to conduct research on lunar samples. Post-doctoral fellows were coming to the facility to conduct research. A Lunar Science Institute immediately next door to MSC had been set up to attract leading scientists for short-term appointments as visiting scientists who would have access to the new facilities at MSC. The goal of Homer Newell, Associate Administrator of OSSA at NASA Headquarters, to develop a respected research capability at MSC was now being achieved, following several years of his efforts to accomplish this.

By September 1970 the science training had been reorganized into a new system. Because there was more than one crew in training at any given time, the organization of the science training required that one person be the overall coordinator of the science training while other people were assigned as the Science Trainers for each individual crew. The science training continued to be coordinated by the Geology Branch Chief in the Lunar and Earth Sciences Division. Starting with Apollo 15 the Geology Branch Chief was to assign a lead Science Trainer for each Apollo crew. The Science Trainers, the Mission Scientists from the Astronaut Office, and the Crew Training Coordinators from the Flight Crew Support Division were responsible for setting up schedules for all of the science activities. Time slots for PI briefings, lectures, field trip briefings, rock-study labs, flyovers, and field trips would be arranged between the Science Trainers and the Crew Training Coordinators, after which the Science Trainers would then arrange with the PIs or other pertinent personnel to use these slots. Once the dates were established for the field trips, which were the most complex of the activities, the USGS, in conjunction with the local geology expert(s), would arrange for the geologic aspects of the trip and the Science Trainers, Mission Scientists, and the Crew Training Coordinators would make arrangements for the NASA personnel and equipment required for the exercises. Also, for the field exercises, the USGS would produce photogeologic maps with traverses on aerial photos that included stops, distances between stops, time lines, and compass headings. They also produced cuff checklists that detailed all the tasks to be performed at each stop along with a total time that should be allotted to each stop. The maps included the geologic units with descriptions based only on what could be interpreted from the photos using standard photogeology mapping techniques, and the cuff checklists included brief indications of the importance of each stop to the overall geologic problems. Tasks on the cuff checklist referred to the individual map units for sampling, trenching, coring, photographing, raking, etc.

There were several reasons behind all the changes in 1969-70:

1. Although the rock and mineral samples that were transferred from Building 31 to Building 4 made it more convenient for the astronauts to study these samples, there would be little need for such study now that lunar materials were being returned. Nearly all the future studies of rocks would concentrate on the returned lunar samples that were housed in the Lunar Receiving Laboratory, immediately adjacent to Building 31.
2. The field training was to be conducted under an entirely new procedure. Through Apollo 12 the MSC geologists had organized and conducted most of the field trips. For parts of Apollos 13 and 14 the MSC geologists continued to maintain a role in the trips. Starting in early 1970, however, the USGS began to play a much larger role. With Apollo 13, but particularly for Apollos 15 through 17, the trips were conducted in large part under a “mentor” with extensive collaboration from the USGS. Lee Silver’s role in Apollos 13, 15, and 16 has been discussed extensively in prior units. Although one or two MSC geologists continued to participate in each field exercise the USGS role began to expand as they produced the photos, traverse maps, vehicles, and cuff checklists, and furnished personnel to man the backrooms, for most of the field exercises.
3. There were new PIs for the geology team starting with Apollo 14 and they played a much more active role in all aspects of the training than did the PIs for Apollos 11, 12, and the early stages of 13.
4. Starting in November 1970, the USGS provided a mock Lunar Rover that would be used on nearly all the remaining field exercises.
5. The lectures for the crews now included many more “outsiders” since Jack Schmitt had called for a revision in the nature of the lecturers, as discussed in Section II in the segment on “Continuation of the training after USGS departure.”
6. There were many developments to accommodate in the training such as longer stay times, new instruments to deploy, more PIs to oblige, new techniques for special samples, and new hand tools.
7. The meeting between scientists and MSC administrators in February 1970 resulted in a greatly expanded role for scientists in the backroom during missions. This, in turn, was going to require a much larger participation of

the geology team and other experiment PIs in simulations both in the field and through Mission Control.

8. There was also a substantial change in the objectives of the Earth and Planetary Science Division. Homer Newell, Associate Administrator for Space Science at NASA Headquarters, had long been highlighting the need for a research emphasis in lunar and planetary science at MSC. Several new staff members were added to the Earth and Planetary Science Division to accomplish this goal. Rather than have people assigned as full-time trainers over the duration of the Apollo program, the new system was to assign a different science trainer for each individual mission thereby allowing these individuals to spend a limited amount of time, a year or so, as a trainer and conduct research both before and after the training period. Generally, the periods for training assignments coincided with slack periods of research, such as when labs were being set up or moved for the assigned individuals.

Obviously there were some awkward, and even bitter, feelings felt by the MSC people who had been involved nearly full time with the science training for several years and were now either being forced to leave NASA or removed from essentially all training activities. There were adverse attitudes toward the new heads of the Division and Directorate where the personnel decisions had been made. John Dietrich, one of those who was transferred, recalled: “We were moved to Building 4 with the training function because the word was that Gast and his crowd didn't want to have anything to do with training. Four of us that got fired from 31 got sent to 4 because that's where the astronauts were. And we were to continue the training, and that lasted for about 6 weeks.” Mike McEwen’s comment was “I don't want to get too much into the politics of what was happening. It was moving one group out in order to get rid of certain individuals and establish a new group.” Rumors were rife about the reasons for the changes and who was behind them. But, overall, the many new developments in the Apollo program, as outlined above, were clearly going to require significant revisions to the science training, and the new administration felt that a complete change in personnel would overcome some of the past problems and create better collaboration between all the participants in the program.

Bill Phinney, who was hired to coordinate the new training procedures, recalled his perception of the situation:

> *“When Paul [Gast] called me about the job he pointed out that there had been some of these problems between the USGS and MSC as well as within MSC; but he essentially said, I think if we bring in new people, a lot of new blood, and remove the people who have been involved with the animosities, we can probably work this out. He mentioned that Lee Silver was going to take over a lot of the training activities for the field trips; and I had known Lee for several years and got along well with him. So I accepted and got here in the midst of all the changes and my reaction was we should all be working together here. As the months progressed I didn't feel that the old animosities were there anymore with all these new folks like Gary Lofgren for 15 and Fred Hörz for 16. I didn't feel that that kind of animosity existed anymore as we were planning lectures and field trips, etc. So I think that the idea of putting a lot of new blood in there and avoiding a lot of these old conflicts of people having to work with each other when they disliked them really overcame a lot of that. But I was appalled one day a couple of years later when I went to a meeting that involved the Chief Geologist of the Survey. When something was brought up about what NASA should do and what the USGS should do, he made a comment to the effect, ‘Well if you people think you should do that or you're going to cut back our budget so you can do that, I think it's necessary for the USGS to go to Congress and tell them that we're the agency that's supposed to be doing that.’ Apparently some of the old resentments were still present.”*

All these developments involved not only new individuals but also many new activities. The nature of the field exercises was to involve many more people associated with the geology experiment team from the USGS. Also, the briefings and procedures associated with the PIs involved in the increasing number of surface and orbital science experiments (there were 43 over the entire Apollo program, see Appendix G) were about to increase significantly. There was also the laboratory study of the rocks returned by previous missions, lectures on the overall results of the lunar research provided by data from the previous missions, and lectures on lunar science problems to which the Apollo crews might contribute by their activities on the lunar surface or in orbit. Many of the people involved with these activities were involved in both full-scale simulations that were run through Mission Control and planning sessions for contingency plans, all of which were carried out several times during the last few weeks before each of the last three missions.

With all these evolving and expanding science requirements a revised organization for the science training was devised. Some people exhibited a bit of impatience as all these new people and organizations were being developed.

For example, Jack Schmitt, in early 1970, was concerned that the Apollo 15 training regarding the samples and photos from Apollos 11 and 12 was not being scheduled in any organized fashion by the appropriate units at MSC and suggested that the Mission Scientist from the Astronaut Office would have to organize this aspect of training (memo Apr. 28, 1970: Schmitt to Allen). As the new system of training got under way, these problems were solved and the samples and photos were well covered in the training schedules. As evidence that the new system was working, Schmitt, by August 1970, had changed his view. "The S&AD geologists have been very cooperative and effective in providing basic tutorial training in the fundamentals of recognizing and describing rocks and differences between rocks. In contrast to our past experiences, the Principal Investigators for field geology have made themselves and their coinvestigators readily available to provide training guidance and basic proficiency instruction in field geology…There has been a very strong rapport between these men, the crews, and the mission scientists so that a strong thread of continuity extends from the field training to the classroom briefings related directly to lunar science" (Schmitt to Slayton, August 8, 1970).

To provide a basis for the details of the training an internal MSC document titled Lunar Missions Science Training Program was developed. This effort had started in the fall of 1969 with a meeting of people from the geology branch at MSC, USGS, the Astronaut Office, the Flight Crew Support Division, and the Experiments Branch of Flight Control. The objective as indicated by Slayton was to have the document in place for the training of the Apollo 15 crew (memo Oct. 17, 1969, Slayton to numerous addressees). Because of all the changes that took place over the next few months in the science organizations, combined with the Apollo 13 incident, this document was not completed until mid-1970 but still in time for nearly all of the Apollo 15 science training. The bulk of the input to this document came from a combined effort of the Geology Branch of the Lunar and Planetary Science Division, the Astronaut Office, and the Mission Operations Branch of the Flight Crew Support Division. The document would be modified as the Apollo Program progressed and more detailed information became available regarding new mission capabilities and scientific research from previous missions.

The previously described friction between the USGS and MSC geologists had abated somewhat over the years. Some of it continued through the first few Apollo missions, but by Apollo 14 there had been several changes in personnel and organizations that helped to overcome the problems. McEwen recalls his experience with the USGS on Apollo 14 as very cooperative. "In fact, on Apollo 14, the one that I was responsible for, the support that I got from the Survey was just excellent. All the people that I worked with I had a good working relationship with. I was certainly aware of the fact that there had been friction and differences about who should be in charge of what. Particularly, by the time we got to Apollo 14 the old training group had been removed and I was left in another organization [the Lunar Surface Project Office which became the Science Missions Support Division] in Building 4. I think Uel Clanton was the other person who was left in that office. Of course, I needed a lot of support for the field trips that we were making. And I got most of it from the Survey: just by calling and asking for help in conducting field trips" (McEwen interview, 1995). By this time essentially all the MSC personnel who had been involved with the early science training were no longer involved with the training. They had either left NASA or were now in different buildings and units that did not have any direct responsibility for the training. Only Clanton and McEwen, both of whom had been temporarily transferred to another organization, the Lunar Surface Project Office, continued to be involved in the training, but McEwen's involvement ended with Apollo 14. Clanton attended a few of the later field trips and gave a few briefings on the lunar surface photos but his involvement was significantly less than it was through Apollo 12. In addition, Gene Shoemaker, the previous PI of the lunar geology team from the USGS was no longer involved with the astronauts' science training after Apollo 13 and was replaced by Gordie Swann for Apollos 14 and 15 and Bill Muehlberger for Apollos 16 and 17, both of whom were much more actively involved with the day-to-day training and worked with the MSC geologists and engineers in a much more collaborative manner. From mid-1970 until the completion of the Apollo program in December 1972 there were no further significant changes in organization and the training went along quite smoothly.

Adding to the successful science planning for the missions was the introduction in April 1971 of regular Lunar Science Review meetings within S&AD. These were initiated by A. J. Calio, Director of S&AD, "to address the science mission planning required to ensure effective implementation of Apollo 15" (memo Apr. 7, 1971: Calio to numerous people). The minutes of these meetings provide details of such topics as the best location for the deep drill core, photographic documentation of the Solar Wind Experiment, the objectives and interrelations of the orbital geochemical instruments, and objectives of the various stops along the Apollo 15 traverses. These meetings eventually considered similar information for Apollos 16 and 17. Calio also convened two Apollo 15 Traverse Planning Meetings in May 1971. The first of these meetings was "to review in significant detail the background and current status of the planned surface traverses for the Apollo 15 Mission" (memo May 13, 1971: Calio to

Distribution). The second was to review a detailed seven-page letter from Dr. Gerry Wasserburg, which resulted from Wasserburg's impressions of the earlier meeting. Although Wasserburg addressed several problems the major point of the letter was to point out that simply collecting a variety of documented samples for return to Earth did not allow many important lunar processes to be addressed. He suggested 19 specific types of sampling procedures that could provide data for some of these processes (letter May 13, 1971: Wasserburg to Calio). The timing of this letter was too late for the development of new procedures for the Apollo 15 mission, but the letter provided impetus for a series of meetings commencing in early September 1971 to consider not only the special sampling techniques mentioned by Dr. Wasserburg but also any others that were felt important. Following these meetings several procedures were selected for incorporation into the remaining missions. Some of these were discussed under the section on Apollo 16 surface training.

Science Support Room

- The evolution of the science support activities in Mission Control was substantial. Although there had been some interaction between PIs and operations personnel during the Gemini missions, the nature of the science activities on the lunar surface promised to be much more complex and would require much more interaction than had been anticipated by the operations personnel. Fortunately, the USGS had been conducting simulated field activities as part of their input for the planned lunar geology tasks. This had been an outgrowth of their expected role in the lunar geology experiment. As part of this role they had developed a SSR (the CDRA [Command Data Reception and Analysis] facility) in Flagstaff, Arizona, that maintained radio and TV communications with their field geology teams that were conducting tasks similar to what would be accomplished by astronauts on the lunar surface. According to Don Beattie some of the flight directors from Houston were invited to come to Flagstaff and witness a training exercise that was being conducted for a post-Apollo mission simulation. The demonstration of the use of the CDRA facility, which was essentially a smoothly functioning SSR, convinced the flight directors that an experiments room in Mission Control in Houston would he a valuable asset. This demonstration had produced firsthand knowledge of the value of having experienced scientists to back up the crews on the lunar surface. "After much give and take on how experimenters and the science community would interact with Mission Controllers and the astronauts in real time during an Apollo mission, MSC agreed in 1967 to build an experiments room in the Mission Control building. Christopher Kraft and his flight controllers in the Flight Operations Directorate deserve the credit for recognizing the wisdom of having such a facility, but the intervention of Jack Schmitt, Flight Operations Directorate Donald Lind, and other astronauts who had worked with the training and simulation teams assembled by USGS was critical to getting this agreement" (Beattie, p. 94).

The nature of this SSR evolved rather quickly during the following months. In April 1967 the Flight Operations Directorate at MSC issued the "Flight Operations Handbook for Experimenters," which formally provided for a SSR. Initially it was proposed that the experiments room be located with other support teams in Building 226, a few blocks away [from Mission Control Building], and for Apollo 8 that was its location (Beattie, p. 95). Bill Hess, Director of S&AD, had requested that S&AD be provided a position in the Mission Operations Control Room for a Science Requirements Officer and outlined the various voice and monitoring capabilities that would be needed. Hess admitted that the time until Apollo 8 was rather short and the request might not be implemented in time for the mission but hoped that it would be available for later missions (memo Nov. 19, 1968, Hess to Kraft). Meanwhile, Jim Sasser, Chief of the Mapping Sciences Laboratory, had established a large working area in Building 226 to provide support for the Apollo 8 mission. This area contained lunar photos, maps, and other lunar data. Sasser proposed to have Lab personnel and scientific investigators from universities, NASA Headquarters, and other agencies present to answer requests for information by the Mission Control Center. To accomplish this it was requested that phone lines, speakers, and head sets be provided to monitor various communications loops during real time on the Apollo 8 mission (memo Nov. 27, 1968, Sasser to Kraft). Kraft responded to Hess by indicating that there was not enough time to satisfy the request for a position in the Mission Operations Control Room but agreed to allow S&AD personnel to monitor real-time activities at a console in the flight director's Staff Support Room. This console was to be shared with at least two other activities and, therefore, only one person could be assigned to the task by S&AD. In addition Kraft indicated that arrangements were being completed to provide the voice loops requested by Sasser in Building 226. Upon completion of Apollo 8, it was suggested that it would be appropriate to discuss the real-time support role for S&AD (memo Dec 17, 1968, Kraft to Hess).

Following the Apollo 8 mission Farouk El-Baz summarized the questions that were referred to the Science Support Center in Building 226 and pointed out that logs pertaining to the location of photography were kept to correlate with the voice tapes. They also kept logs of incoming telephone logs from outside amateur and professional astronomers. El-Baz recommended that the support center be continued for future missions and provided suggestions for improvements (Bellcomm memo Jan. 7, 1969, El-Baz to File). Kraft was eventually convinced that for the landing missions this room had to be nearer the action, like other critical staff support rooms, so that the displays and other information could be coordinated with other operations and be accessible to those who might have to make quick decisions (Beattie, p. 95). The scientists were assigned Room 314 in the Mission Control Building which contained TV monitors, tables, phones, other equipment, and eventually closed-circuit TV, all of which allowed quick exchange of vital information.

The Handbook for Experimenters also developed procedures for simulations that would involve both the operations personnel and the scientists. For the first time this placed experiment simulations involving scientists in the mainstream with all the other simulations carried out for the missions. Simulations would cover normal and abnormal situations that might require consultation with the SSR, and the flight controllers were given particularly wicked problems as they gained experience. The schedule [for Apollo 11] called for the experiment simulations to start four weeks before launch. Don Beattie recalled that the Apollo 14 schedule “called for two simulations of the planned first EVA and three simulations of the second, spread over two months rather than the one month originally planned. It was getting hard to assemble the large cast of characters that was required and, more important, to fit the simulation into the astronauts’ tight schedules. …. There were also two ‘canned’ simulations at Houston when the astronauts were not part of the exercise and the flight controllers and the SSR staff were tested with contrived problems. Later missions, because of their complexity, added additional simulations. Each simulation would last 4 hours or more and would be followed by a candid critique, usually leading to new guidelines on how to respond to emergencies during the real mission” (Beattie, p. 96-97).

During Apollo 11 it became clear that more space was needed to accommodate all the people and equipment required to follow the action. “Raymond Batson from USGS recalls that during Apollo 11 this auxiliary SSR got so crowded you could hardly move around. In addition to Ray’s crew, who were monitoring the TV pictures coming back from the Moon and the air-to-ground conversations with the astronauts, Bendix engineers were at their consoles keeping track of the data transmitted from the deployed experiments. Court reporters were also taking down the voice transcriptions so this historic record wouldn’t be lost if the tape recorders malfunctioned. After Apollo 11 the auxiliary SSR was moved to a larger room where a plotter allowed Ray’s crew to create a real-time map of each landing site, showing where the astronauts were and had been. They would supplement the map with Polaroid panoramas captured from the TV pictures sent back to Earth. Based on all this information the staff and PIs in the SSRs would formulate questions and send them to the CapCom, who would then decide whether to pass them on to the astronauts. Later in the program, for the final landings, three SSRs were staffed, two for surface science and one for orbital science” (Beattie, p. 95-96).

As Mike McEwen recalls the evolution of the SSRs, "On Apollo 8 we [personnel involved with science activities] had one console position; we had one chair at a console in the flight director's staff support room. I worked one of the shifts for that. It was kind of interesting to watch from the time of Apollo 8 where we had one seat at one console in somebody else's room to having a full-up backroom and then they developed a full slot for payload operations" (McEwen interview, 1995). In addition, by the time of Apollo 17 there was not only an orbital backroom but also a surface geology backroom and an ALSEP backroom with several consoles in each.

By Apollo 14 the SSR was set up for several people: the PI for the Field Geology Experiments, a person using an overhead projector to sketch and annotate diagrams associated with the progress of the traverse, a person keeping a topical log of features described by the crew for quick review by team members, a person to record questions and suggestions to be placed on closed-circuit TV for CapCom and also to record in shorthand the discussions among team members between EVAs, a person to record sample locations, descriptions, and bag numbers, a person to maintain a real-time plot of the progress of the traverse for display on TV monitors, and a person representing the sample PIs. In a second room there were three court stenographers to type the real-time communications between crew and ground during the mission, an editor for the transcript, two people to maintain a photo log of the use of Hasselblad cameras by the crew, a person to produce mosaics of the TV panoramas, the person who produced the maps used by the crew for the mission, a geologist who accompanied the crew during much of the training to help with updating traverses in the event of contingencies, and an operator for a videotape recorder to record video from the lunar TV camera. Most of these people were present in the Mission Control Center during the final simulations as well as during the mission itself.

Bill Muehlberger estimates,

"By Apollo17 there were about 29 people involved in the various backroom activities. In the science backroom itself the geophysicists with their consoles were off in one wing. The rest of the room was occupied by several people involved with the geology and sample collecting. Alongside the geology and sample team was a set of consoles manned by the science coordinator, Jim Lovell, and a couple of engineers who kept track of the Rover operations. Lovell had a direct line to the CapCom in case there were any messages that were to be passed on to the crew. Lovell could also request the TV operator (its operation was controlled by a person in Mission Control) to move the camera's position and zoom level when the geology team wanted to observe a specific location or rock. Next to Lovell was a table with the site map on it, and around the table were the Geology PI, two geologists from the PI's team, a representative of the sample PIs, and a MSC geologist who had coordinated all of the training activities. This was the team that did the analysis of the information being received from the lunar surface and decided what specific tasks or samples might be requested of the astronauts through Jim Lovell. At another table was a TV screen showing the lunar activities being covered by the TV camera on the Rover. One of the geologists at that table kept track of progress along the traverse and used a little arrow to illustrate where the crew was along the traverse. Another geologist continuously took notes about the collected samples on three-by-five cards: every rock had its own card, and he kept them sorted by kind of rocks. Another geologist was standing at an overhead projector with an endless roll of transparent acetate, and with his felt-tip pen he would write the geological information as it was described by the crew or observed on the TV screen. These notes were projected on the wall where all could see and all SSR personnel could look back over ten or fifteen minutes of the past activities before they got rolled into the long scroll. So he was sort of the time historian for the geology along the traverse.

"In another room was the photogrammetry team. At each stop, as the TV camera on the Rover got started, the first thing it did was do a 360-degree pan. That was for the photogrammetry team. They had a Polaroid camera and one person used that Polaroid camera to make a 360 degree panorama from the TV screen. Within a couple of minutes the geology team in the SSR had this whole panorama sitting in front of them, with time clicks on it, because the camera moved so many degrees per second. So the geology team could tell the TV operator to go five clicks to the right and zoom in on a rock or a small crater, or whatever they wanted. That allowed the geology team to evaluate a variety of geological features for potential sampling rather than just watching the crew. Another person operated a videotape recorder to record all of the TV from the Rover. Another geologist with the photogrammetry team and would circle the locations of various samples, trenches, cores, etc., on the panorama for each station. Another person would keep track of the magazine number and frame number of the photos being taken along the traverse. And there were also two or three court reporters taking down the entire transcript, because by the time NASA would have a transcript available, it would be months later. So the geologists had their own transcript being made during real time.

"There were also another four or five people called the Tiger Team who were over in Gene Kranz's office. Because he was the lead flight director he was not occupying that office during this time. These guys would write up what was learned on each EVA, what was missed, and how to modify the next day's EVA to add or subtract whatever was necessary. On Apollo 16 the Tiger Team was very busy. They had to completely redesign the second EVA because of a broken cable to the heat flow experiment and they ended up writing a position paper on why we had to keep the third EVA. After one of the astronauts had tripped over the heat flow cable and broken it, there was an attempt at MSC to develop a procedure to repair the cable…that was done here at JSC where they had some of that cable. I've forgotten how many connectors there were in that thing, it was a flat connector for 16 different cables or something like that. And they actually took lunar samples and scraped on them to get the plastic off to expose them. (Nobody carries along files and all the other stuff. It's just extra weight.) We had to redesign that second EVA so there was ample time to pull the cables off and get them in if that's what they wanted to do. It was hoped that the astronauts, at the end of the second EVA, could disconnect the cable and bring it inside the LM for repair. … We cut out a couple of stops. Well, the backup crew got into their suits and went out on the rock pile and did the uncoupling and all that just so they'd have a reasonable guess at the amount of time it would take. I think it was about 15 minutes. So we had to get back 15 minutes earlier than the original plan was. And they were within 100 yards of arriving at the Lunar Module before the command came that we're not going to fix the heat flow, guys. We want you to stop and sample" (Muehlberger interview, 1995).

This resulted in some quick contingency planning by the backroom scientists. The decision was to take some additional core samples to test the continuity of subsurface layers. As Muehlberger recalled it, "There were really three areas right there and theoretically then with the cores that had been sunk, there was hope that there was some lateral stratigraphy that could be found and all that kind of good stuff" (Muehlberger interview, 1995).

As for the near cancellation of the third EVA, when the LM and CSM had separated in orbit in preparation for landing, warning lights came on in the Command Module indicating an engine problem. So they stayed in orbit for several extra orbits until the problem was isolated and the mission was able to continue. However, the extra time in orbit required that once the crew landed on the lunar surface they had to sleep in the LM before starting their EVA. But the LM had a limited supply of consumables, about 72 hours' worth. Because of the amount of time taken both in orbit and for the sleep cycle the operations folks wanted to cancel the third EVA. The third EVA, however, was out to a crater as big as Meteor Crater in Arizona, the only large crater that the crew would visit. It was hoped that this crater would excavate deep-seated material and provide samples that might not be present elsewhere. In Muehlberger's words,

> *"That had been the number-one priority for sampling, and they were threatening to cancel the third EVA. That's where Dallas Peck came in handy on that mission. He was in charge of our tiger team that just sat and listened without any responsibilities. Then, in effect, summarized it in a short paper and made suggestions for the next EVA, which then became our game plan for the next EVA. So I had them write a position paper to say that we've got to have enough time to get to the North Ray Crater. That's our number one objective at this site. It's the only big one that drills through all the rocks and all that good stuff. We didn't save the whole 7 hours but we got 5 hours out of it. Which meant that we cut out all the intermediate sites and just basically made a dash to the crater itself and then one sampling site on the way back"* (Muehlberger interview, 1995).

These episodes provide a clear indication of the usefulness of all the simulations and planning that had evolved to a rather mature state by the time of Apollos 16 and 17. Only with the experience and knowledge that had accumulated within the involved personnel could these revised plans have been developed in such a meaningful manner.

Procedures

The photographic procedures were rather simple for Apollo 11. The main objective was to get some panoramic photos around the LM and some documentation photos of some of the collected samples. By Apollo 12 the procedures began to evolve, with several changes throughout the course of the training, much to the dismay of the crew, as discussed earlier in the Apollo 12 field training. By the final three missions the photo procedures became well established. A general description of these procedures is provided as follows in USGS Professional Paper 1080 on the geology of the Apollo 17 landing site:

> *"Sample documentation pictures were taken to show the in-place character of a returned sample or of a feature that could not be returned. Before sampling, a down-sun photograph for photometric study and a cross-sun stereoscopic pair were taken of the chosen sample area. After sampling, a picture from about the same place as the stereoscopic pictures was taken of the sample area to establish the identity of the collected sample by its absence from the field seen in the pre-sampling pictures. An additional photograph, also from the cross-sun position, was taken of the Lunar Roving Vehicle (LRV) to establish the position of the sample within the station area. Where time was short or footing awkward, one or more of these pictures was omitted. Additional documentation of uncollectible rock features was done with close-up stereoscopic pairs taken from less than 1 meter away.*
>
> *"Panoramas were taken at each station to permit precise location of the station by resection and to illustrate and supplement geologic descriptions by the crew. A complete panorama consists of 15 or more overlapping photographs, covering a total of 360°. The overlap zones between pictures in panoramas can be viewed stereoscopically because the aiming direction of the camera was changed and the lens position was shifted slightly each time a picture was taken. This provides a stereoscopic baseline a few centimeters long, which is useful for study of topography within 50 to 100 m of the camera. Pictures were taken with a 500-mm focal length lens on a Hasselblad camera to permit study of features inaccessible to the crew.*
>
> *"The Lunar Module Pilot (LMP) took pictures at approximately regular intervals while the LRV was in motion. These photographs were used to reconstruct the traverse and to examine surface characteristics over wide areas. During these "en route" sequences, particularly at points of*

> *deployment of explosive packages, the commander drove the LRV in a tight circle while the LMP took photographs, resulting in what has been termed an 'LRV panorama.'*
>
> *The LMP was equipped with a special sampler for collecting samples while seated on the LRV. Before sample collection, the LRV was driven toward the sample area, and a picture was taken by each astronaut, providing a stereo pair. After the sample was collected, the LMP took one or more pictures (toward distinctive features where possible) to aid in locating the sample area. Additional pictures were taken to illustrate deployment of the ALSEP and other subjects not directly related to geologic observation and sampling" (USGS Prof Pap 1080, p. 225).*

Although the above description of the photographic procedures provides a good general description of the required activities, it does not provide the detailed procedures that were actually accomplished during the lunar activities. For a better understanding of these details a more complete set of procedures for Apollo 16 is provided in Appendix P. The crews practiced these details over and over and critiqued them after each practice until they were simply a rote routine. According to Bill Muehlberger, the only modification for Apollo 17 was one additional sideways step for each frame when taking the panoramas. This allowed for better stereoscopic coverage at greater distances.

Photo procedures required coordination with many of the tasks that were performed during the EVAs. When the ALSEP and other instruments were deployed a series of photos were required to document the locations and orientations of the instruments. As the missions progressed there were more experiments on each one and the procedures for deployment and photo documentation became more complex and time-consuming. Most of these activities were practiced on the local rock and sand piles at MSC and KSC, although some of the traverse experiments were also conducted on the field trips. Some form of the Soil Mechanics Experiment was conducted on all missions. On Apollos 11, 12, and 17 the soil mechanics data were extracted from the digging of a trench and a variety of photos, returned samples, and descriptions by the astronauts; but for Apollos 14, 15, and 16 the introduction of a penetrometer required new procedures to be added to the other information. There was a new set of procedures required for the penetrometer, a long aluminum shaft with a pointed tip. On Apollo 14 the penetrometer required an astronaut to push the device into the lunar soil as far as possible, first with only the force that could be applied with one hand and then with both hands. This procedure was repeated three times at points about 4 meters apart, and the depth of penetration was read off the graduations on the penetrometer for each step.

On Apollos 15 and 16 the Soil Mechanics Experiment included a self-recording penetrometer with different-sized tips and a bearing plate that were to be attached and detached during a series of six measurements. The drum that recorded the penetrations had to be removed at the conclusion of the measurements and stowed for return. In addition, the remaining procedures had become a bit more complicated. Throughout the Apollo program it was common for the astronauts to register complaints and suggestions regarding the design of equipment and procedures. During a field trip on March 11-12, 1971 the Apollo 15 crew attempted to incorporate the new soil mechanics procedures into their traverses for the first time and both the prime and backup crews registered several complaints about the equipment, the amount of photography required, and the length of time involved. The PI was requested to further refine and demonstrate the procedures until they were acceptable to the crew (Memo, Phinney to Gast, March 1971).

The astronauts made many constructive inputs to the procedures. Some of the simpler problems that came up during the field trip could be changed on the spot in the field. When the crew would complain or suggest changes there were usually the pertinent PIs or flight directors, etc., along on the trip so the new procedures could be worked out on the spot. When Mike McEwen was asked about the inputs that the astronauts made during the training for the early missions, he indicated that they made many suggestions regarding the design of hand tools, photo procedures, etc. "It's difficult to do this, we really ought to change the way we do it, or this doesn't make sense, or there's a better way to do something. They had lots and lots of suggestions like that. If it were equipment-related, then the equipment people who participated in all of the simulations and field trips would take it from there" (McEwen interview, 1995).

During the rock study sessions the astronauts had an opportunity to observe the many types of samples that had been returned from previous missions. As the missions returned more and more samples the science trainers had an opportunity to develop notebooks with representative samples of the various rock types. It became clear that lunar breccias were the most complex of the lunar samples and obtaining representative samples of breccias was a significant problem. Although no specific procedures were developed for sampling the wide variety of breccias, Fred Hörz, the science trainer for Apollo 16, provided an outline of the approach to sampling breccias, especially the large breccia boulders that might be present on Apollo 16. This outline is provided in Appendix Q. On Apollo 17 a large boulder of an impact melt form of breccia was sampled at Station 6 on EVA 3 using very similar procedures as outlined in Appendix Q. At that location there were several well-documented samples taken of a variety of breccia units within the boulder, and photos were taken from several angles, thereby allowing construction of a very detailed map of a very complex boulder that could be seen to have rolled down the slope from a layer high up on the hillside.

Hand Tools and ALSEP

As mentioned in Section II, by 1964, MSC had contracts with Martin Marietta, monitored by Uel Clanton, which developed hand tools, a tool carrier, and a lunar drill. In March 1965 the USGS attempted to identify the basic tools required for geologic exploration of the Moon in a proposal from the USGS to NASA written by several geologists headed by Gene Shoemaker. The document was entitled 'Objectives of Apollo Geological Field Investigations and Proposal for Development of an Apollo Field Exploration System." The design and fabrication of the Apollo lunar hand tools (ALHT) was accomplished through a series of meetings chaired by A. B. Carraway of MSC's Experiments Program Office. The work began in June 1966 when MSC's Engineering Division started the preliminary design studies under G. W. Crum, Project Engineer. The meetings were labeled 'Monthly' ALHT Review meetings and took place in July and September 1966 at MSC and in November 1966, at Flagstaff. CDRs were held in February 1967 when the astronaut office was represented for the first time. Subsequent CDRs were held in March 1967 at MSC and in May 1967 at Flagstaff, by which time the hand tool package was essentially completed for the early Apollo missions (Ulrich and Swann, 1974).

Regular participants in the ALHT meetings, other than the Chairman and Project Engineer, included representatives from the Lunar Sample Receiving Laboratory (LRL): E. A. King, B. Wooley, D. A. Flory, and occasionally others; Space Sciences Division at MSC: U.S. Clanton, T. H. Foss, and occasionally others; V. B. (Jack) Slight of Crew Systems Division and Uel Clanton of the Space Sciences who shared about equally in the evaluation of tools under spacesuit constraints and in lunar gravity simulation; and the USGS: Gene Shoemaker and John M'Gonigle with assistance from M. H. Hait, Ivo Lucchitta, and M. Brock. Individual astronauts reacted unofficially to several aspects of the geological instruments that were proposed and these reactions were probably responsible for the eventual demise of instruments like the sample scriber/brush, the Lunar Surveying System, and various high-resolution, slow-scan TV cameras and film cameras that were proposed but not flown. The main concerns in designing and evaluating geological tools and instruments in these early stages of preparing for lunar exploration were, in order of decreasing priority:

1. Weight - Components were weighed to hundredths of a pound in early listings.
2. Biological contamination - Elaborate precautions were taken to maintain tools in a sterile condition before use on the Moon. Terms like "asceptic" and "cross-infect" became popular.
3. Ability to withstand the lunar environment, which was poorly understood.
4. Contribution to efficiency of scientific exploration by astronauts working in spacesuits.
5. Monetary cost.

It is interesting to note, in retrospect, that as Apollo exploration progressed and as more effective, but expensive, instruments became feasible for use, the priority of the above concerns was almost exactly reversed (Ulrich and Swann, 1974). J. Allton created an illustrated compilation of all the hand tools and containers used during the Apollo missions in 1989; it provides a rather complete list of the geological equipment the astronauts used (NASA JSC Doc 23454, March 1989).

There were two significant problems to overcome with the hand tools, ALSEP, and other surface instruments: (1) the operations folks wanted to keep down the weight on the spacecraft, and any tools or instruments that were to be justified for inclusion required strong arguments by the geologists or other scientists and (2) the ability to use the tools in a pressure suit at lunar gravity had to be demonstrated, and often the original designs required substantial revisions after testing. Gordie Swann illustrates the type of bantering that went on. "We really fought to get a hammer on board 11. If it hadn't been for drive tubes they wouldn't have got it. In fact, they didn't use it for anything but the drive tubes. So that's why it went. But there were all these arguments about a hammer. 'Well you can't swing a hammer in 1/6th g.' I said, 'Well, yes you can. I have.' You can't swing one in a suit. 'Well, yes you can. I have.' 'You'd have flying chips.' They were worried about that. I said: 'There are two things you can do if you're worried about that. One, you can put a little screened mesh or something over the rock and then whang it. The other thing is I've broken thousands of rocks. I've had chips hit my bare arm, my light field shirt and all, and it doesn't tear holes in anything. It's not going to tear holes in that heavy old suit. If it doesn't tear a hole in the light shirt that I wear in the field how's it going it going to tear one in this stuff?' So they finally got around to it. But after all this had got it to go, I think it was in one of Zedekar's meetings and they wanted a preliminary idea of the kinds of tools that ought to go on Apollo 12, I got up and I started listing them and I got to the hammer and some guy stood up and said 'Why do you want to do that? You've already done that experiment.' Those were his exact words. Then it was the same thing with the telephoto lens going on 16. 'Why do you want to do that? You've already done that experiment' " (Swann interview, 1995).

Various people at MSC tested the hand tools and other instruments and the USGS geologists in Flagstaff also tested the hand tools. Bob Sutton reported that during EVA simulations in tests at Flagstaff in May and June 1968, there were problems with some of the tools: the center leg on the tool carrier buckled, one leg of the gnomon buckled, the tongs broke, the cores were difficult to loosen at the threaded joints, and the sample bags were weak at the join between the metal strip and the plastic bag (USGS Memo dated June 7, 1968 from Sutton to Weeks). Simultaneously, the ALSEP and other equipment were being tested as part of the Lunar Surface Simulation Program at MSC. As part of this program, for example, in a May 27, 1968 27-page report to Slayton and Hess, Ray Zedekar reported the results from several days of tests by suited astronaut test subjects. The report included eleven malfunctions of ALSEP equipment during a test on April 4. In addition, Zedekar also reported several discrepancies in the training models received from the manufacturers, such as broken or missing wires, missing tools required for deployment, and parts that were not of flight design. There are also numerous suggestions for design changes and additional test conditions. A July 1, 1968 memo indicates that as a result of a CDR in April, several mandatory design changes [actually a total of about 30] had been made for the initial lunar missions and “the ALHT design is now frozen. No further changes will be made unless directed by the ALHT configuration control board” (memo Hess to Slayton, July 1, 1968). All of these many iterations of tests and suggestions resulted in modifications to the hand tools and other instruments to aid in the procedures and deployment during the actual missions. This was a continuing process throughout the entire Apollo program. All of the field trips included personnel who kept records of any tool or instrument malfunctions. The malfunctions were either corrected on the spot or reported to the engineers for further development.

Acceptance of responsibility for problems during the development of both the hardware and procedures associated with the tools and other equipment often precipitated some rather acrimonious exchanges between the personnel in science operations and those in crew operations. An example associated with the Lunar Surface Drill illustrates the nature of the problem. In a memo dated April 1, 1968 the science office responsible for the hardware stated: “There have, to date, been situations and events in this area [evaluation of hardware] which have not always yielded results which were in the best interests of the program.” The memo indicated that there have been “test and evaluation activities initiated with only a minimal familiarity with equipment design and method of operation.” Further, it stated that “a somewhat analogous situation exists with respect to operational procedures.” The memo went on to recommend that the FCO folks designate “certain personnel within your organization to be trained and maintain a detailed cognizance of scientific equipment” and also “to formulate specific procedures for a given test by personnel of your organization ***with concurrence by S&AD prior to implementation*** [emphasis by writer]” (memo Apr. 1, 1968: Hess to Slayton).

The response from the people at whom this memo was directed responded to Slayton as follows:

> *“This is a hasty, emotional, and illogical response on the author’s part [D. G. Wiseman]. He is responsible for the ALSEP and other equipment. It is generally over cost, over weight, and having qual testing difficulties. In the past he has treated inputs on crew operations with less than enthusiasm. I assume he hopes in the future to control FCOD inputs in order that they do not adversely reflect on the management of the various lunar surface equipment programs.*
>
> *Early this year we had the first generation Lunar Surface Drill in our possession and planned to run our first tests with it. The Lunar Surface Project Office (LSPO) learned of this and sent us a formal request to run this test in order to provide information for them to evaluate the drill qualification testing. After some slips due to suit availability these tests were held on Feb. 1 and 23, 1968. Although the program office was notified of the tests no one from their office attended. The results were generally disappointing to us. We immediately provided the results to the cognizant LSPO personnel in a meeting. Apparently LSPO attributed the results mainly to poor training and this precipitated their memorandum. Incidently [sic] the contractor is two months behind in qual testing generally because they have been unable to demonstrate the drill’s operational capability to drill and case holes in the specification model surfaces. Some of the comments in our interim test report (enclosed) have already resulted in contractor fixes -*

> *Wiseman is well aware that Dr. Lind and Schmitt have been assigned to lunar surface equipment for over 17 months and that the Lunar Surface Operations Office has been following the area for over 12 months. The first solution he offers has been in effect a long time.*
>
> *Although to date we have used procedures supplied to us by Wiseman's office, we have no known requirement to follow the contractor's procedures in the future if we can improve on them. His proposal that all test procedures obtain S&AD concurrence appears to be an attempt to exercise control without any special competence in the crew operations area.*
>
> *Recommend we ignore the letter"* (undated Comments on TA Memo; signed by Donald (illegible), Raymond Zedekar, and Helmut Kuehnel).

Slayton did not ignore the letter but responded in rather terse terms, indicating that "we do have specific individuals designated to maintain continuing cognizance of scientific equipment and its use. We believe they are as knowledgeable about this subject as anyone in the system." He added that "I believe the same applies to operational procedures" and concluded "Recognizing that hardware development is your problem and procedures is ours, personnel responsible for each must work closely together" (memo May 15, 1968: Slayton to Hess).

The Lunar Surface Drill presented many problems from its early tests until it was used for the first time on Apollo 15 in July 1971. Clanton had written the first proposal for a lunar drill in 1964 and Martin Marietta was awarded the contract to develop the drill. Clanton and Elbert King were the contract monitors. The initial design was for a stationary drill powered from the LM. The length and weight of the power cord, the limited power available from the LM batteries, and the restricted area in which one could drill led to a decision to change to a self-contained, portable, powered drill. Early attempts at diamond bit coring did not work; the operator could not exert enough downward force in a lunar gravity environment to make the bit cut. The Project Officer at Martin Marietta determined that the only way to provide enough energy to core with the portable system was to change to the rotary percussive drilling technique. This technique worked, and the development turned toward design of the bit, drill string, and battery. Cuttings removal from the bore hole during coring was also a major problem. In early tests, while drilling to depths of three meters, it was found that removing the drill string from the borehole was impossible. Even a two-ton hoist could not remove the drill string. It was determined that the screw-type flutes that were supposed to move the drill cuttings to the surface were still full of cuttings which locked the string in the hole. The simple solution was to reconnect the drill to the string and start the drill while holding it in position without any further penetration, thereby allowing the flutes to clear the cuttings to the surface. When no more cuttings came to the surface, the flutes were clear of cuttings and the drill string could be removed easily. There was also a safety concern. If the drill string got locked in the hole while the drill was running, could the drill rip out of the astronaut's grasp and spin out of control, or maybe even spin the astronaut? In the 1/6 g environment this would be even more pronounced than in terrestrial simulations. Clanton designed an instrumented platform and a "T"-handle on the drill with strain gauges that could measure torques. The platform was controlled by an operator to simulate torque build-ups and drill string lock-ups, and was tested in a variety of conditions, including the KC-135. Sudden torque build-ups simulating a stuck drill string would throw Jack Schmitt off the platform to be caught by other members of the flight crew while Jack was testing the drill. As a result a slip clutch set for 12 foot-pounds of torque was added to the drill for the flight models.

Clanton noted that while he was present at some of the Apollo 15 simulations involving the drill, they were drilling but not clearing the flutes at the end of the drilling as in the recommended procedures. Clanton commented to the people running the simulations what could happen if the cuttings were not cleared from the flutes. A few days later, Clanton happened to pass by the drilling simulation box and noticed that there were several drill strings stuck in the box.

On Apollo 15 the plan was to drill three holes during the lunar surface activities: two for insertion of heat flow probes and a third for extraction of a core sample. In 1966 Jack Schmitt indicated that "The complexity of assembly, drilling, and core retrieval operations, and the close dependence of the drilling procedures on the mechanical properties of lunar soils will require excessive pre-mission training and mission workloads. Estimates of the time required to accomplish the drilling and sampling of ***one hole*** [emphasis is author's] range from 30 minutes minimum to 1 or 2 hours" (memo dated Dec. 21, 1966 from Schmitt to Garriott). Although some of the problems were overcome, the first use of the drill on Apollo 15 met with serious problems that required significant redesign and new procedures for Apollo 16. When the first heat flow hole on Apollo 15 could be drilled no deeper than about half its desired depth, the drilling was stopped; and the second heat flow hole was started. This hole did not get as deep as the first before hitting a dead end, regardless of how much pressure the astronaut applied. When the drill was used for the core, it reached the desired depth, but it was nearly impossible to extract the core.

Clanton was watching the drilling on a TV monitor and noticed that Scott did not keep the drill running to clear the cuttings from the flutes after completing the drilling to the desired depth. He knew immediately that the drill string was stuck. Apparently Scott had not been informed of the extraction problem if the flutes were not cleared. It would appear that no one in the SSR knew that the correct procedure had not been followed, and no one knew the correct solution was to simply reconnect the drill and turn it on long enough to clear the flutes. Only through extreme application of the brute strength of both astronauts over an excessive amount of time was the core finally extracted. For the heat flow holes on later missions, a redesign of the flutes on the drill stems solved the problem; but the simulant used for the new tests had to be revised to supply the more compact and dense soils that were, by then, found to exist on the lunar surface. For the core sample it was found that too much pressure used while drilling forced the drill into the soil too fast, and the cuttings did not clear fast enough up the flutes. In addition, a new jacking device was developed to help the astronauts retrieve the core from the drill hole. Therefore, proper procedures were developed for future training in drilling and extracting cores. No further problems with drilling and extraction were encountered on Apollos 16 and 17 and the jacking device was not used.

As new tools were proposed there were extensive reviews of the designs, tests of the prototypes, and development of procedures. As mentioned earlier a raking tool was proposed as an efficient way to collect numerous walnut-sized samples from several locations at traverse stations. Although it was proposed too late to be carried on Apollo 14 it was hoped that the design, fabrication, testing, required modifications, further testing, and training could be completed before the Apollo 15 mission. Uel Clanton was the geologist involved with the design, testing, and procedures as they progressed over a period of several months. In January 1971 Jim Irwin had an opportunity to evaluate the engineering prototype of the rake, and Clanton provided a memo to illustrate the results. In a review of Irwin's assessment Clanton stated: "a) The existing long handle is too awkward; b) The EMU, camera, mobility, and visibility is such that the collecting is best done using one hand; c) Recommend using a "T" or "D" handle with a maximum length of approximately 36 inches (exact length to be determined); d) Collection is best done using a pulling motion; e) The most efficient collecting procedure is a series of raking motions in a radial pattern about the astronaut; and f) Bagging will probably require both crewmen" (Jan. 8, 1971 memo from Clanton to TN/Chief). The memo also stated that modifications were to be made within a week for further testing by Irwin. Any further modifications would be made by January 28-29 when the Apollo 15 crew was to test the rake while flying on the KC-135 in lunar gravity simulations. Specific questions were posed about shape and length of handle, methods of raking, bagging of samples, etc. and were to be answered during these test flights. These simulations were meant to develop the procedures for raking, sieving out the dirt, and bagging the rocks, all of which would be used in the final design of the flight hardware. The rake was available for the Apollo 15 mission and used quite successfully.

In view of the excessive time required to dismount the Rover, take a sample, bag it, document its location, then remount the Rover, a means of collecting additional samples along the traverse route between station stops was discussed at a SWP meeting in November 1971, in the hope that something could be developed for the Apollo 17 mission. After further discussions regarding a method for doing this, as well as the procedures that would be involved, a memo to the manager of ASPO was sent in January 1972 requesting that such a sampling tool be developed (memo Jan. 18, 1972: Lovell to Manager, ASPO). Following numerous tests to develop the correct length of the handle, size and shape of bags, and a method of stowing the tool, in addition to the procedures for collecting the sample, taking the sample bag off the end of the tool, and stowing the sample, the sampler was available for the last few field training exercises of Apollo 17. It worked well and provided a more thorough sampling of the Apollo 17 landing site.

Simulations

During the final couple of months before each mission there were a variety of simulations. Some were simply the final run-throughs for setting up instruments or perfecting procedures in an abbreviated EVA. Others involved simulating the traverses in a field exercise with communications being directed through Mission Control. On the last three missions the simulations became more elaborate as will be discussed below. For Apollo 11, about one month before the mission, there was one simulation to practice an EVA on one of the simulated crater fields at MSC with radio communications to Mission Control. The Geology team participated in this by staffing the SSR, or backroom, in Mission Control. For Apollo 12, about three weeks before the mission, there was a final simulation in which the astronauts carried out a traverse on a man-made crater field near Flagstaff, Arizona, while the geology team assembled in the SSR in Mission Control to carry out their respective roles that would be undertaken during the actual mission. Radio communications between Flagstaff and Houston allowed the astronauts, CapCom, flight operations personnel, and the Geology team to interact as they would during the actual mission.

For the final three missions there was a final field simulation in which the crew conducted extensive preplanned traverses. For each of the simulations there were one or two planned traverses with tasks that were very similar to the traverses on the actual mission. Furthermore, they would be conducted in field locations whose geology was similar to the lunar landing site. These were accomplished with a Rover and all the tools that would be used on the lunar surface. Communications was run through Mission Control, where the science team for the actual mission was in place in the SSR and the CapCom and flight controllers for the actual mission were in place at their consoles. For Apollo 15 this was a one-day simulation. For Apollos 16 and 17 these were two-day simulations. For Apollo 17 the geophysical traverse activities were also included.

Other types of simulations were added for the final three missions. There was the paper sim normally followed by a math model sim, and there were several of these for each of the missions. Each paper sim lasted one full day and consisted of an EVA case-study with a variety of anomalies presented by sim personnel. The EVA teams were given 4 to 5 hours (in the morning) to generate a revised EVA plan that accommodated the anomalies. At the conclusion of this exercise the flight director conducted contingency discussions (in the afternoon) involving all of the EVA teams to help develop contingency plans for the mission. The math model simulations also lasted a full day with all of the Mission Control personnel, operations, engineers, and scientists in place to carry out two or three EVAs, usually involving traverses and time lines that were being developed for the actual missions. The astronauts were role-played by other people who worked with the Simulation Supervisor to dream up a variety of problems to be introduced during the simulation to try and stump the scientists and operations personnel. There were planned glitches that had to be dealt with immediately as contingency situations. These efforts allowed the scientists to become keenly aware of the chain of command and communications mechanisms in Mission Control when problems developed. And, conversely, it allowed the operations and engineering personnel to become aware of the science objectives at various stations along the traverses.

In preparation for the Apollo 17 simulation activities the flight director for the EVAs, Pete Frank, issued a memo summarizing all of the sim activities along with their schedules.

"The three types of EVA sims are:

a. Field geology exercise (Flagstaff type) with crew participation (1 day) [actually revised to 2 days].
b. KSC exercises with crew participation (two days). Each day there will be two exercises conducted (ALSEP deploy and a traverse) with prime and backup crews each taking one. In parallel with, but separate from, these exercises, lunar orbit SIM Bay sims will be conducted.
c. Math Model (MM) exercises using simulated crew members (3 days). On each day, two to three exercises will be conducted and include the PLSS (Portable Life Support System) MM.

On the day before each of the MM days, paper simulations will be conducted. These exercises will consist of an EVA case presented by sim personnel from which the EVA team will have 4 to 5 hours to generate an EVA plan. At the conclusion of this exercise contingency discussions will be conducted by the FD" (memo Jan. 5, 1972: Frank to distribution).

Jim Head recalls some of the math model simulations in which he played the role of an astronaut:

> *"Because of my work in the integration and the kind of systems analysis stuff and my work with Jack Sevier and my geological background, I would be one of the astronauts, and an engineer, Hiram Baxter, would be another. We'd get together a week ahead of time with the SimSup [Simulation Supervisor] and work on the kinds of things he wanted to have exercised. He had a master plan. For example: the suit people needed to have a tweak or we'd have to have a water leak, the LM too warm, or we might have a wheel fall off the Rover. ..... We would sit down and work all these things out and I would have in my mind the traverses. So I might say 'Look, I can do the wheel at this point, because that will be where we're at a big rock and I'll bang it up against it or something.' We worked out these scenarios which then we'd just implement. It was one of the most fun things I've ever done if you can imagine that because I was somewhere in the basement, the guts of Mission Control, and everyone was, of course, on their toes. What would happen, we'd land and we'd get out and I'd just do the dialogue as we went along. It was great for me because I always wanted to do it anyway. And of course I knew from the traverses what was going on. I would just work my way through and make observations in my mind and try to set up things like when he wanted a suit leak. So when we were coming up on a suit leak and I'd see him. He'd be standing over there and when he dropped his hand is when he would push a button to drop the psi to such and such. He'd give me a nod and I'd go 'Oh,*

> *Houston, I think there's a giant polymict breccia over there. We're gonna head over. This is so: Whoops' and then 'I just took a little dive here on these sharp rocks here', and ssssss, the suit pressure would go down. ... We had the panels with all the buttons on it, and you could go listen to the suit people. You could hear everything while you're doing this. You could tune in to see how they were reacting. And if they got it, you could make it worse, you could kind of watch the SimSup to get ideas about what to do; to exacerbate it, or he'd go 'that's good, that's all I need.' And then we'd also do the geology. We'd say "Oh, there's some incredible 3-inch plagioclase crystals, or whatever, I'm sure this is olivine or things like that that would make people say we ought to stay here, or move on to the next station. The idea was the discovery versus sticking to the time line" (Head interview, 2004). "When I said something I could punch up any com loop. I was sitting right in front of a console and I had every com loop. So I would listen to the backroom once I did something. I was still blabbing away, but I could listen to the backroom and see what they were doing, what they were sending up to the CapCom and the discussions going on between flight and others"* (Head interview, 1995).
>
> *"One thing I remember doing that I felt really good about was on Apollo 15 [probably 17 if South Massif was involved] simulations. I felt the gravimeter could really be good stuff here and so I put in one whomping big anomaly. I was reading these numbers off and gave a whomping big anomaly right next to the South Massif. So this gradient went up like this and the question was what's in between. So I said 'isn't that a lot more than the one, isn't this really large compared to the one we—. Whoa!' So the backroom responded by saying 'we need to have a stop to get the gradient here.' And that's pretty much what happened on Apollo 17. I think they did get an extra measurement. That's the kind of thing we were supposed to be doing, introducing things that would optimize this rather than to rush off just for the sake of a time line" (Head interview, 2004).*

These simulations and other discussions led to the development of a number of contingency plans as well as the experience of reacting to problems rapidly in real time. They brought home the need for all people to know the constraints for the EVAs as well as a detailed knowledge of the traverses and the specific objectives at each station. Only with such a background could the combined scientific, operational, and engineering requirements be successfully coordinated when problems arose during the actual mission.

There were also the simulators for the spacecraft operations, which took up the majority of the crews' overall training time, but one of the simulators at the Cape was used not only as a landing module but also as a Rover. Fred Hörz, who was the science trainer for the Apollo 16 crew, recalls this simulator. "They used a gigantic, ceiling-mounted topo model of the landing site that was rastered by some TV cameras and projected onto TV screens in the simulator. The model had 10- to 20-ft dimensions with mountains 1 to 2 ft high. The simulator was a small cubicle (6 x 6ft) with two TV screens in front and one on each side; you could see nothing but the TV screen scenery and the interior of the LM (or Rover). Two types of exercises were conducted in this cubicle: (1) practice of a 'proper' landing using the TV screens in the side windows (the forward ones were blocked for this exercise) and (2) practice of Rover traverses using the two screens in the forward direction. The idea was to get some feel for the dynamic response of the real Rover when going too fast, cutting too much, etc for the type of terrain. Also orientation was an issue, and how to navigate from A to B via landmark sightings, primarily on the horizon" (Hörz, personal communication, 2004).

Field and Flyover Exercises

There was only one field trip for Apollo 11. Instructions given to the crew were to collect a representative suite of rocks at each location and describe the near-field and far-field geologic features. The crew used the hand tools and cameras and collected samples following the procedures that were provided to them. Their descriptions were recorded and the collected samples and films were returned to Houston. Transcriptions of the tapes were correlated with the photos and samples, and a debriefing was held several days after the field trip. For the following missions there were many more field exercises and they became much more like the actual EVAs.

There were six field trips apiece for Apollos 12 and 13, resulting in significantly more training with tools and cameras, especially using the procedures for photo documentation. There were time lines with specific objectives on planned traverses and more realistic simulations with a CapCom and a geologist in radio communications with the crew in a simulated SSR ("the backroom") on some of the trips. As with Apollo 11 the recorded crew descriptions, samples, and films were returned to Houston and correlated with the transcriptions for a debriefing held several days after the field trip. The final field simulations for each crew were run as specific timed traverses with associated stations and tasks on crater fields near Flagstaff, and the entire simulation was done with voice communications to the SSR team, CapCom, flight director, and other operations personnel at Mission Control in Houston.

The number of field trips increased to nine on Apollo 14 and went as high as eighteen on Apollo 16. The rule of thumb was to maintain field-efficiency with one field trip of at least two days' duration per month. Each trip consisted of a minimum of two traverses with stations, tasks, and timelines using the tools, cameras, and procedures provided by the PIs. By Apollo 17 both the prime and backup crews had already been through a cycle of field training as backup members of earlier crews, so their proficiency was even more advanced. On most of the trips the crews' descriptions were recorded and the collected samples and films were returned to Houston where transcriptions of the tapes were correlated with the photos and samples, and a debriefing was held several days after the field trip. By Apollo 15 there was a "backroom" (usually a tent out of sight of the traverses) for both the prime and backup crews with CapComs and two or more geologists in each backroom to keep track of the samples and photo frames as would be the case on an actual mission. By Apollo 17 there might be as many as four geologists in a backroom. The common procedure was to have a geologist and other pertinent personnel follow along with the crew during the traverses listening in on the radio communication between the crews and the backrooms. At the end of each EVA there was a half-hour radio debriefing between the backroom and the crew to cover any questions that either side might have about the geology, samples, photos, etc., that had arisen during the traverses. These radio debriefings were part of the planned time-lines during the actual missions. Following a lunch break all the participants would undertake a complete walk-through of the traverses and discuss all the observations made by the crews, observers, and backroom. The walk-throughs commonly brought to light many of the communication problems between the crews and backrooms and led to a better understanding of how these teams must work together.

As the importance of scientific exploration of the Moon became more and more important with each Apollo mission it became even more important for the operations personnel and other managers to better understand what the scientists were trying to accomplish. By Apollo 15 the flight directors and some of their controllers began to accompany the crews on the field trips. By Apollos 16 and 17 it was common also to have various people from NASA Headquarters on the trips, including the Head of the Apollo Program Office on some trips. The final field exercises for Apollos 15 through 17 were two-day events in terrain that mimicked the lunar landing sites and followed traverses designed to be as similar as possible to two of the EVAs on the actual missions. On both days the communications with the astronauts were run through Mission Control in Houston with a full complement of personnel that would be involved in the EVAs. There were also a few unexpected (but sometimes surreptitiously planned) events or discoveries during the EVAs that might lead to a need for real-time replanning of times and tasks during an EVA or perhaps significant replanning of the second EVA during the time between EVAs.

For Apollos 8 through 12 the major part of the orbital science training was learning to recognize targets of geological interest and how to photograph them from the best angles. By Apollo 13 the crews were using their routine flights in their T-38s to observe various geological features from high altitudes. These features were outlined on their flight paths, and they discussed the features with a geologist at the completion of the flights. By Apollo 14 flights over the volcanic and crater features in Arizona and other locations where the surface was not covered with vegetation were added. These flyovers were done at two altitudes, one at high altitudes in a T-38 to simulate observations from lunar orbit and one at low altitude in light planes over the same areas to observe the details of the structures that were also observed at high altitudes. During the low-level flyovers there were geologists along on the flights to discuss the geologic features and the best ways to describe and photograph them. The astronauts took photos and tape recordings that were used for the debriefings. By Apollos 16 and 17 a geologist-jet pilot accompanied the astronaut in both the T-38 and the light plane during the flyovers. This geologist was able to plan the locations of the flyovers and discuss the features during real time as well as in the debriefings after the flights. There were 18 days devoted to such flyovers on Apollo 16 (see Appendix M).

Section IV: SUMMARY

1. Background of the problems

When any new project as large and complex as the Apollo program is initiated it is expected that there will be a period of time, measured in years, for developing an organizational structure, hiring personnel, working out detailed objectives, outlining the progression of events, fleshing out the details, and implementing the plans. It was apparent to all who were involved that the Apollo program would include many science disciplines, completely new and extensive hardware, untested communications systems, development of innovative procedures, training of personnel in numerous untried activities, and integration of all these efforts into one of the most complex tasks ever undertaken. To accomplish this task would require many advisory committees, both internal and external to NASA, to develop the objectives and plans. It would require contracts with a wide variety of industries to develop hardware and communications. It would require the selection of PIs for the many science experiments. It would require interactions with other government agencies, not the least of which was the U.S. Congress, which controlled the purse strings. All of these aspects, in one form or another, fed into the nature and evolution of the science training of the astronauts and the associated education of the trainers.

Clearly, there would be many modifications in all aspects of the project as experience was gained and the trip along the learning curve gathered momentum. There would also be conflicts, differences of opinion, and competition for resources. Many of the problems and their evolution have been discussed in the previous Sections but will be enumerated here in order to analyze the nature of the solutions. Although the major initial goal for NASA was to successfully launch a human into Earth orbit, primarily to surpass the Soviet Union's launches of both unmanned and manned Earth satellites, it was not long before the scientists were looking for ways to use the manned orbital program to augment the unmanned science programs.

1. In 1958, as NASA began to develop a science program in tandem with the manned flight program, there was a need to develop organizations to control budgets and to plan programs in both aspects of NASA's programs. Although, at this stage, the overlap of responsibilities was relatively small, there began some internal competition between NASA centers and committees for budgets and personnel between these two major efforts. The competition between science and manned operations developed even further after President Kennedy's challenge to NASA in 1961 to land a man on the Moon and return him safely by the end of the decade in what became known as the Apollo program. This was the start of a long-standing conflict that lasted throughout much of the Apollo program and contributed to most of the other lesser issues that developed during the course of the program. Initially the manned side of the Apollo program was not much concerned about the science efforts. Their goal was simply to get a man to the Moon and back. On the science side, however, there had already been discussions of unmanned missions to study the Moon, and the prospect of men landing on the Moon brought into focus some grand new possibilities for such studies. From this point onward many programs were developed for not only a series of 10 or more Apollo missions but also a series of extensive follow-on missions that would lead to science bases on the Moon. As might be expected this led to issues over who would have control over development of science objectives, instruments, specifications, contracts, construction, testing, procedures, deployment, training, and other aspects of the science-related parts of Apollo and the follow-on missions. Complicating the attempts to resolve these issues between the two offices at NASA Headquarters, a new center, MSC, was established in Houston to oversee the day-to-day, nuts-and-bolts operations of the manned part of the program. This provided another location where both science activities and manned operations were to be dealt with. As a result there developed not only local conflicts between the groups at the new center but also with their counterparts at NASA Headquarters.
2. The issues mentioned in the previous paragraph were exacerbated by the rapid expansion in personnel, organizations, and facilities that were necessary to meet the requirement of landing a man on the Moon by the end of the decade. To illustrate the problem: the Headquarters phone directory doubled during the year 1963; and MSC grew from 750 people to 14,000 in a period of 4 years, while gradually changing locations from several buildings scattered throughout southern Houston to a new set of buildings 20 miles south of Houston. With such growth it was becoming nearly impossible to keep up with the changes in personnel, organizations, and locations. Who was in charge of what, who was doing what, and who was supposed to be doing what became rather confusing. Such rapid development led to the same things being done by more than one group, lack of knowledge that certain things were already being done, and confusion among outside contractors and scientists about which NASA office was managing their projects.

3. One of the issues that was related to the training of the astronauts was site selection for each of the Apollo missions. There were different objectives to be met by operations groups and scientists, and also between different scientists. The operations were to be limited by life support systems, fuel supply, physical hazards in the landing area, weight of instruments that could be landed on the Moon, as well as weight of samples that could be returned, communications, medical concerns, and maneuverability in pressure suits, among others. The scientists' interests varied from deciphering the origin of various surface features, to understanding the interior structure of the Moon, to analyzing samples from different lunar units, to use of the Moon as a base for studying solar and galactic radiation, and other basic science problems. Some wanted to land in, or near, large craters; others wanted to have samples from each of several volcanic structures; others wanted to visit highland areas; others wanted to set up a network of geophysical stations over a broad area of the Moon; others wanted to collect samples from polar regions; and so on. Clearly there was a need to set up a systematic approach to eventually meet the needs of as many science objectives as possible while staying within the limitations of the operational constraints.
4. Once the landing sites were selected there was a need to plan the traverses and tasks along with priorities for each activity at each site. Because the activities became more and more complex as experience was gained from each previous mission, the extent of the traverses and tasks would require more extensive planning as time passed. During planning for the first two missions there were also concerns about whether all the instruments would be ready, whether the procedures could be carried out under lunar conditions, and uncertainty about the ability to land at a specific point. As the traverses became longer in both time and distance on the later missions there was competition for amounts of time and locations among the various PIs. The sample analysts wanted more special procedures for specific types of samples, the ALSEP and other instrument PIs wanted more time as well as traverse locations for making measurements, and the geologists wanted more time for taking special photos and visiting a variety of surface features.
5. From the earliest days of Apollo planning there was an expectation by the scientists that science would be an important part of the Apollo program. This led to rather optimistic plans for instruments, hand tools, sample collection, extensive traverses, and times on the lunar surface. The engineers and flight controllers, however, knew the limitations involving weight, safety, communications, fuel, life support systems, etc. as well as the many things that could malfunction and require contingencies to be kept in mind. They were also aware of the difficulties involved with developing procedures, testing tools and instruments, and providing the necessary mobility in pressure suits. As a result there was continuing friction between the impatient scientists, who felt that more science should be included, and the highly cautious operations/engineers, who were trying to limit all unnecessary items, particularly until Apollo 11 proved that a lunar landing really could be accomplished, and Apollo 12 proved that the landing location could be pinpointed to within a few hundred feet.
6. There were several different types of training among which the astronauts allocated their time. Of prime importance was the operational training in the spacecraft simulators. There was also the training for deployment of the various instruments on the surface and operation of instruments in orbit. Finally, there was the science training, including both hand tools (including cameras) and procedures, mainly geologic in nature, on both the lunar surface and from orbit. Although the training for the simulators and instruments was quite well defined, the aspects involved in science training were more confusing. There were concerns over who should be involved in the teaching, what topics were necessary, how much time was required, and to what detail various topics should be taught. In addition the role of Headquarters versus MSC, the roles of various PIs, and the locations for the instruction were all matters for discussion. These issues have been discussed in Section II and ranged from the formation of space science institutes for astronaut training to the difficulties between the USGS and MSC when both assumed that they had been assigned the lead role in developing a geology training program.

2. <u>Overcoming the problems</u>

Eventually, nearly all the difficulties listed above were overcome. Although many of the problems required experience or trial-and-error techniques before they were solved the major question in case a similar project was undertaken was how to avoid, or at least minimize, these difficulties. The expansions of organizations and personnel discussed in Problems 1 and 2 above were certainly to be expected with such a complex project and tight timeline. In fact, with such rapid expansion it is almost miraculous that enough order was achieved in the complex activities to achieve the amazing success that was the Apollo program. One of the mistakes that was made at NASA Headquarters was trying to bridge the gap between science and manned flight by means of the Office of Manned Space Science (initially the Manned Space Science Division), which reported to two bosses who, at the time, were not in agreement on many issues. When this Office was abolished and essentially replaced by the Apollo Lunar Exploration Office, which reported directly to OMSF, things went more smoothly. As pointed out by Beattie, this change placed the head of the new office "directly in the chain of command—no more half OSSA and half OMSF, with both offices never sure whose side you were on" (Beattie, p. 100-101).

It is quite clear that adequate coordination of organizations and communication was not accomplished until the program had been under way for several years. This could have resulted from the confusion associated with rapid expansion, refusal to cede responsibilities to another group, or a combination of both. Different organizations at NASA Headquarters were continually trying to claim responsibility for similar parts of the program. Headquarters and MSC were each making plans for the training and hardware without good coordination and ended up with groups that were continually at odds because they were organizing and managing the same things. Organizational responsibilities must be made clear at the outset, so that each group involved in training or any other aspect of the program knows the limits of its responsibilities. If these groups are to develop good coordination and relations, then representatives from each group should be present for all meetings and discussions. In addition, each group should be provided with drafts of all documents related to training schedules, procedures, and suggested plan changes. This should apply also to both internal and external committees that are involved in developing overall objectives and plans. One of the first steps needed for smooth implementation for any such program is the selection of leaders for the critical offices. It is imperative that the heads of various offices are staffed with people who can cooperate and agree on who is to do what at the outset. Also, there was a desperate need in some of the leadership positions for someone who could make decisions and take the lead to get things done rather than waiting for the results of many studies and reports which, by default, essentially, left important decisions that could not be postponed indefinitely, up to others. In other words, the old maxim of having the right people in the important jobs was critical.

Item 3 above can be illustrated by GLEP, in which there was too much bickering and excessive planning for missions that were beyond budget limitations or were already cancelled. Much of this resulted because too many people and disciplines were involved in voting for various items and each wanted to preserve their own special interests. GLEP's role in site selection became ineffective, and decisions regarding site selection were made by other non-science groups. Eventually, the decision defaulted to the operations folks, or even a single individual, to pick from the several landing sites that the scientists could not agree on. Within GLEP was a smaller group that wielded more influence than the overall committee. This again illustrates the default result when too many individuals try to preserve their own special interests. The problem of landing site selection could most likely have been overcome if a committee such as SWP, which replaced GLEP, had been formed earlier. SWP included not only representatives of the sciences but also of the various engineering and operations organizations as well as the flight crews. When all these groups were able to present their objectives, strengths, and constraints to the entire committee, there was normally a consensus reached, or a strong chairperson could make an informed decision.

The problems of Items 4 and 5 above were eventually overcome by the formation of SWP in 1970, although the maximum effectiveness was not attained until early 1971 when Jim Lovell became chairman. Therefore, it is not only important to form a panel such as SWP where all parties can come together regularly, but such a panel must have the right people in the important roles. The chairperson must command respect from essentially all the involved groups, foresee problems that are likely to arise at meetings, gather information regarding these problems before meetings, and be able to make an informed decision quickly at meetings when a clear-cut consensus cannot be reached. During the first several months of SWP's existence the initial chairman had a tendency to delay necessary decisions and assign people to study problems and report at the next meeting. When Jim Lovell became the chairman he fulfilled all the desired attributes and SWP became an exceptionally efficient and successful organization. Because of the detailed coordination required for planning traverses, a similar type of person was needed to coordinate all of the complex interactions between operations, engineering, and science for traverse planning. Jack Sevier was such a person. As for integrating these various roles Bill Muehlberger has high praise for Sevier: "I can credit Jack [John R.] Sevier as an absolute genius at being able to work with us [the scientists] and with the rest of the directorates and integrating all of these different egotists…and trying to make them all work together and satisfying the time demands and the time needs that they have, squeezing it down until, yes, we can get it done in this hunk of time. Jack was the most instrumental person in that" (Muehlberger, JSC oral history project). At the meetings, Sevier was able to present the traverse plans so completely and in such detail that very little modification was required. Finding such people as Lovell and Sevier for these critical roles is not easy and requires that people in higher management positions recognize and select the appropriate personnel.

With regard to Item 6, missions became more scientifically complex, and the collaboration between the USGS an MSC became not only important but also necessary. Prior to Apollo 13 there was very little involvement of the

USGS in training the Apollo crews. Essentially all of the field trips and most of the classroom activities for Apollo 8 through 12 were planned and conducted by MSC personnel. Because the USGS housed the PIs for the geologic activities on the lunar surface and such activities controlled most of the traverse activities, it was clear that the USGS personnel should be heavily involved in training the Apollo crews. Fortunately this changed for the Apollo 13 training, and collaboration between all the involved parties became the norm. It was commonly believed that the old guard at MSC was not compatible with the USGS. Whether this incompatibility was perceived or real it led to changes in personnel and management procedures that worked well for the last five missions. As with SWP, it is again important to emphasize the importance of the right people in the leadership roles. When Lee Silver started training the Apollo 13 crew his infectious ability to enthuse and teach the crews changed the entire tone of the field exercises. Although he was not the person who developed tools, instruments, and procedures, his discussions of the geology and lunar problems involved an energy and enthusiasm that he could impart to the crewsin a friendly and jovial manner. Dave Scott's words (Scott, 2004) provided the best description of the type of person that was Lee Silver: "an inspiring teacher and a really nice guy. He made learning entertaining. He knew how to get across the complexities of what he was talking about. He knew how to fill us with enthusiasm for all that could be achieved in the geological study of the Moon." It is this rare type of person that must be sought for future projects like this to lead the field training of the crews. For the orbital observations there was an analogous person, Farouk El-Baz, who developed the same type of rapport and enthusiasm with the crews for orbital science. All the astronauts who worked closely with El-Baz had similar praise for him as Scott did for Silver. The main point here, as with SWP, is the importance of finding the right people for the lead roles. Recognition of such people is not easy and often is best recognized through personal experience, such as the test case of Silver and the Apollo 13 crew spending a week together in the field to decide on their compatibility, or the first meeting at KSC of El-Baz and Mattingly to determine whether there were any common problems that they could discuss. In any case, these people, once recognized, provided extensive and important improvements to the training.

3. Successes and disappointments in the training

As in most endeavors, hindsight provides the 20/20 vision that one hopes would be present from the beginning. To gain insight into some of the perceived successes and disappointments associated with the mission training, the perspectives of several people were solicited. Some of the reactions to the early pre-mission science training were presented at the end of Section II. The following perspectives concentrate more on the Apollo science training.

When Jack Schmitt was asked which aspects of the training were looked upon as less worthwhile or less interesting than others, his response was: "The question is: can I remember what got the least interest?. Yeah, the actual PI briefings that were contractually, I guess, part of the mission training—that is the non-geology part—I think all of the astronauts pretty much felt that the main reason they were going [on a lunar mission]—other than to go there and get home—was to do geology, and the ALSEP and the other things like that were add-ons. They understood that they had to do them and they were going to do them, but they were done by rote, totally by rote. And even though the PI might have tried to give a little science of what they were learning, I think that probably washed over most of the people. The main thing that they wanted to know, and I wanted them to know, was not only how do you deploy it, but what do you have to watch to make sure you don't screw it up. I mean where will dust hurt you and that kind of thing. And I think that got through, but it may well have worked out during the actual deployment in training. As I remember correctly, we always tried to have the PIs around for those deployments—mock up deployments—so that if some question came up, we could always get an answer" (Schmitt interview, 1995).

When Schmitt was asked which of the changes that he initiated worked out for the best, he responded: "I think essentially once we got into the 13-style mission-related training, it was about right and the build-up to that was about as fast as you could have taken it. I think all of that [previous] lecture time could have been better spent in some way, better organized, better focused. But that's hindsight that we acted upon as soon as we had scientists in the astronaut corps. And we could put the science training in the perspective of real missions, which you wouldn't have expected the non-scientist-astronauts to do very easily. I think one of the big benefits of having selected scientist-astronauts was that we sat astride the two camps and had to" (Schmitt interview, 1995).

Jack's comment on the advantage of studying the lunar samples once we got them back was mixed. "Well, it was for me, but I'm not sure that very many of the astronauts got a lot out of that, but you'd have to ask them. Dave Scott probably did, 'cause he was intensely interested. But it's not, in my mind, from a training perspective, something that added a great deal. They'd seen lots of rocks and if they weren't able to distinguish differences between rocks by the time they saw lunar samples, then we hadn't done our jobs. On the other hand, I don't see how in the world you ever could have not had them look at the lunar rocks. I mean sending a man to the Moon without having looked at a lunar rock would have been ludicrous." When asked, in particular, whether there was an advantage in studying the returned lunar breccias which were very complex, his response was: "Well, no, that was a major point of some of the field trips for each crew was breccias, either volcanic or landslides: the San Gabriel breccias, the anorthositic breccias, Sudbury. But on the other hand, Dave Scott and John Young probably got a great deal out of seeing the lunar samples. Gene and I were so deeply immersed in it I don't know how much different that made Gene's perspective" (Schmitt interview, 1995).

Schmitt also had "a strong feeling that those early lectures, before they really figured out what to do with all the astronauts, I think some of them were time-fillers, because the simulators weren't running yet and the Gemini crews were using the Gemini simulators. We never could get in them. I was only in a Gemini simulator once. The mineral name thing was a big problem that the guys complained about. And another thing that, apparently, in all those lectures, the guys didn't get until they got into the field, was how to organize your thoughts about a geological problem. For example, if you have a problem where there are a significant number of different age relationships, how do you organize this in your mind? How do you go from oldest to youngest? I remember several times when we were debriefing the field trips, the guys had a terrible time figuring out how to organize their thoughts in the debriefing. They had seen it all but couldn't put it in a framework that allowed them to discuss it. And that's something that somehow or other should be included. And I'm not sure you can get that in a lecture but you might have laid some groundwork for it. The field's the best place. And eventually they got it, all of them. Probably even Shepard and Mitchell went to the Moon with a fairly clear understanding of relative ages, and that you are always looking for clues" (Schmitt interview, 1995).

When Jack Sevier was asked to comment on what he felt was of significant importance to the training, he responded (Sevier interview, 1995): "Well, I think in the very beginning you need to get the three sides together: the science folks, the operations folks, and the engineering management folks. There's no reason that should take three years to figure out that that was a smart thing to do. That's one thing. When each side has an appreciation of what the other sides' problems are, it's just amazing how the impediments go away." Sevier offered a couple of illustrations of how these interactions worked. "We saw in [Apollo] 15 how they had to revise the descent trajectory to come in over Mount Hadley and land beside the rille. That was never dreamed possible on 11, 12, or 14. But when those [trajectory analysts] understood that Hadley was an important site, they needed to figure out a way to get in there; 17 was the same way. The initial 3-sigma ellipse that those guidance folks never revised after we had landed on a pinpoint for 12, 14, 15, and 16: it was still the same size on 17, and on 17, one side of the minor axis went up North Massif and one end of the major axis went up over the scarp downstream. So Taurus Littrow was essentially rejected at the first meeting here at MSC because of the safety factor. I remember a meeting that Sig Sjoberg chaired and I got him to agree to postpone a decision until we could get the guys to take another look at the dispersion ellipse. He said okay. So I went over to see Phil Shafner, who headed up the flight dynamics branch at that time, and explained the problem to him and explained how important the site was. So he went to see the guys that worked for him and said what is this all about. And they said, well it's the worst-case situation. He said, well I can't accept that. If you guys want to insist on this, then let's go up and make a presentation to Kraft. So then they backed down and reduced the size of the dispersion ellipse so it was possible to get in to Taurus Littrow. And that was all because one guy said I'm not going to accept this. There was another thing on 17. Paul Gast had a hankering to go to Alphonsus, but in preparation for going up to the Site Selection Board and deciding what MSC's recommendation to them would be, Gilruth had Paul and some other guys up in his office with all the photographs spread out. They talked about the two sites. Gilruth turned to Paul and said 'what do you think?' Paul could have said 'I think Alphonsus is what we should choose.' But he said 'Taurus Littrow is a good site'. Even though he wanted to go to Alphonsus, Taurus Littrow is where we ended up. That's another example of people being able to subvert their personal feelings. I thought that was really admirable. (Sevier interview, 1995)"

Jim Head had similar feelings as Sevier about having the flight controllers come on the field trips (Head interview, 2005). "I think one of the smartest things that was ever done in the overall scheme of things was to involve the Flight Control people in the field trips. That paid off so much. To think ahead, be sure one does that. Well, we're never going to do it the same way again. But involving the operations people in there from the very beginning. And maybe it's a sequential kind of thing. I don't think we lost anything because, in the beginning, the goals and objectives were a little different. People who had been on those field trips had a sense of ownership and they knew that this is really important stuff and they saw the dedication of the scientists involved and it wasn't just theoretical or counting a table or anything like that. They felt a part of it. They had some ownership. So when the engineers came back with a synergistic pad—I got my 10%, you know how it went, after you file that on up through seven layers of engineering, you got a pad that is really big—they would go back and say 'Hey, I think that ellipse fits in the Taurus Littrow Valley. Come back and tell me why it doesn't.' They would have the smarts to know that, okay, 'there's a 40% pad built up in this cumulative stuff and we're 20% overcompensating. So, it probably fits. And it's really important. We're in this together, you know, science and engineers. So, find a way of handling this.' That's just one example. That isn't a criticism. I think that's something that was done right in the latter stages."

When asked on which missions he felt that we finally got to this stage of communication, Head replied, "15 and after. Jack [Sevier] and I and others would go to talk to FCOD or have a seminar, or something, on just the traverse. Let them know what's going on, talk to all the people, not just bring them on the field trips. We'd go out of our way, when we were down for SWP and would have a break. Proselytization is really good in that sense, too. Go tell the people. I would extend that; when also every once in a while we would do something on a science debriefing in the Building 2 auditorium at the end of a mission. It was kind of integrating it together. It was not just a hot picture. It was kind of like here's what happened. That's not directly crew training, but it's part of it." During the interview with Head (2005) Bill Phinney added that the involvement of flight controllers in the field trips also allowed better friendships to develop between the different groups. It helped a lot just to develop that kind of rapport with these folks and the interchange of the language that we each used. And Head responded, "Exactly, and you need to know that lingo if you're going to make decisions in nanoseconds. Another thing, I think that largely, the astronauts felt that the geological training was a square that they enjoyed filling because it got them out of town. It was a little bit like R and R but it wasn't like that was the whole thing at all. From the crew training point of view, I think that making sure that when you go on field trips, it isn't just another square but that you actually do a little something to make it special." In nearly all the books written by the astronauts (e.g.,Irwin, 1973; Scott, 2004), the field trips were looked upon not just from the point of view of learning something that they needed to do but as sort of a respite from the rest of their hectic activities. It was a chance to get together in a less formal, less hectic situation.

When Head was asked for some other aspects of his perspectives on the training, he felt that "the kinds of things that we did in particular at the Cape before launch were favorably looked upon [by the astronauts]. But, in general, from their point of view, it's real clear that what we were telling them was really important stuff for them to know. And it was in their best interest. So we weren't boring them at that point. It was collimated down. We were talking about the actual things that they were going to do. It's like a simulation. They were having to repeat these things in their mind. We'd have the cuff checklists. It was a dress rehearsal in a way for the real thing. From that point of view, with a couple of minor exceptions that I could talk about, I never got the strong sense that this was not something they wanted to do. Plus, you knew they were taking it out of their own time. And actually that was what made it so adrenalin-rich. Here you were. These people are working 12-hour days to start with, and they're inviting you to come in and have dinner in crew quarters and then spend their spare time with you. This had better be friggin' good. There was a lot of pressure. You weren't just screwin' around. It used to drive me nuts sometimes because I like to think ahead and organize ahead a little bit. Sometimes we'd get to the Cape and I wasn't sure even what the agenda was. It just drove me nuts. Mostly because so many different people were doing so many different things.

"As far as the rest of it [the training] goes, I know that when they started looking at the samples, and you gave them good background discussions of these, they found that really productive and that was sticking because they knew they had to look at the new ones [lunar samples] that they might see. I got the strong sense that that was very helpful. I would also say—I think the best way you could epitomize the astronauts' attitude was in the lingo they used—like 'we'll fill that square.' There's no question in my mind that they had in their minds a matrix of things that had to be done before they went to the Moon and that a lot of them were just square-filling. You know: 'Hey, yeah, we got to have a briefing in front of the PI about the PI experiment. We'll probably learn something,' but more often than not I'd get the impression that, and this isn't just in the science at all…'Well we've filled that square.' It doesn't really mean that it was bad. It's just a big matrix that had to be filled out" (Head interview, 1995).

Head's comments about square-filling led to a discussion of the PI briefings that Jack Schmitt had considered among the least interesting aspects of the training. In order to set up the instruments, etc, does one really need to know how these instruments work, what wavelength they work on, what they are supposed to do, and all that kind of detail? They just need to know how to set it up and turn the knobs. It's not like the experiments where you have to describe the geology and decide what samples to collect. With the instruments, it was just sort of a rote type of thing. When Head was asked if going to hear the PIs tell you all about their instruments and what they supposed to do was nothing more than filling the squares, he responded, "Yeah, and it's one of those things where it's sort of a courtesy to the PI, too. It might be one of the biggest deals the PI ever had, to brief the crew that was doing it. That's kind of like a political decision. You probably have to have some of those squares if the total training time allows for it" (Head interview, 1995).

Head was asked what kinds of things raised the most interest during the discussions in the crew quarters during the evenings after dinner. “Most people think of the astronauts as being highly collimated and a uni-personality, which, as you know, is totally untrue. Each one of them has his own personality even though they have a lot of characteristics that are similar. It really varies. [For] the Apollo 15 crew, it would always be the prime and backup crew, and include the CMPs as well. We'd talk about the sinuous rille at the Apollo 15 site. [they would comment] ‘Yeah, there's a lot of really good stuff there. Yeah, that's really interesting.’ There's the origin and evolution. I'd try to set up observations that would test the different hypotheses. And they really got into that. And I would use that as a mechanism to help to show them how the 500-mm lens camera could be used. Of course they had been through a lot of simulations, etc., but I just made up a little thing. ‘If you're standing here, here's the field of view [for the 500-mm lens] on the far side, and if there's basalts, it will look like this and here's the things you want to get.’ But [it was done] in the context of testing these ideas. Certainly Dick Gordon, who is not the kind of guy you would automatically think of as being a science nut, he was really engaged in that and later told me that that was really an important kind of thing. It gave them a sense, at the end [of the training], of how it all fit together. Jack [Schmitt], who was on the backup crew of 15, and Dick and Dave and Jim Irwin, they all got into that kind of stuff. Actually, we spent a lot of time talking about what you would do at individual stations. It would be like testing these ideas about stuff that you guys had already drilled into their heads. Like inverted stratigraphy of impact craters, etc. It would be like, okay this is what to do here. It [the tasks and problems] varied with people persons and it varied with missions. Like on 15 [and 17], we had a much better idea of what a lot of the questions were than we did at 16 because we were not sure of exactly—You knew that when we went to North Ray Crater [on 16] there'd be this big boulder; we could see that and we could test what its relation was. But things were less explicit because we knew we were much more uncertain about the geology. That was a real exploration mission in that we had a hypothesis, but it wasn't real clear. And then, of course, they did an excellent job on the surface and their own sampling etc.” (Head interview, 1995).

Head credits the systems engineering approach for much of the success in traverse planning. “I think one of the reasons that we've all been through a role in the traverse planning was because of the systems engineering approach that we did for the site selection. Systems engineering may seem like an archaic term, but it really is an important concept. Maybe it's just because it's more of a part of our daily life now than we think, but at the time it was a major different way of planning. That's what got me into even applying for the job at Bellcomm. I was looking for a job, and I had this college placement book, and it had geology at the back. There was a picture of the Moon on that page and it said ‘Our job is to think our way to the Moon and back. If you are interested write to Bellcomm.’ I said ‘Geez, that is really neat.’ And that's exactly what systems engineering is. You do that in an integrated way. You don't just go because I want to know the age or I want to pick up this rock. It's more like there's a systems integration, systems engineering. And you can apply that to science really easily. That's helped me in my own research. I think about things now much more from a process point of view. Not just a unidirectional thing but what do we need to know. Everybody does this to some degree. But this training really helped me in my own science. I think having this attitude, that background, like in this ad about thinking your way to the Moon and back, it began to be applied to the site selection. Then people quickly realized you've got to do that in spades for the traverse planning because it's got to be integrated. Maybe a combination of ASPO and Bellcomm (especially with Bellcomm being Rocco's Headquarters mafia) is why things evolved in that way. But at the same time, we were just part of a big team that included PIs, USGS, JSC. I think in the future we're likely to have more real scientist-astronauts too. I know on 17, every once in a while, you’d get together with Jack and you could talk about different kinds of problems completely, you know, scientific problems. I think one of the things that one ought to put in your summary is that things will change in the future if there are more scientists involved” (Head interview, 1995).

When Gordie Swann was asked for his perspective on the training, he replied, “I don't think I would have changed the way the training went a lot unless it could have changed the whole philosophy of the missions. The thing that bothered me most was having to do those strict timelines and trying to stay within them. I know if we hadn't, there were about 75 vultures waiting for any minute that we couldn't take up. We had pretty much the priority on traverses but we had to take up the time. Because if we didn't…there was never a time for Jack to sit down and discuss something with Gene. And so we had to organize the training around that. I would rather it had been a little more, especially on those last few missions where they had some more time and they'd had quite a bit of training, where they could have walked around a little more on their own, they might not have collected quite as many rocks but they would have thought a little more and not been in such a hurry” (Swann interview, 1995).

It was suggested to Swann that the only way that really could have been overcome in real time was if the backroom decided that the crew had come across something really important, and they really needed to stop and work it, was to cut out the next station. This happened on Apollo 17 at Shorty Crater where Jack Schmitt spotted some orange soil and the crew was given some extra time to sample and photograph the occurrence. Swann agreed that “we did have a choice on whether to go back or not and we decided not to and the crew concurred. Jack did a marvelous job of sampling that thing in about five minutes. Really he did a three-dimensional job. That's something I don't think another astronaut would have done. That wasn't because of our training in the field. That's because of a PhD from Harvard and a Fulbright scholar and those kinds of things. And, of course, considerable experience. I don't think we could have trained an astronaut to do that kind of thing; to take that kind of sample” (Swann interview, 1995).

Swann also had some comments about the need for learning detailed descriptions of rocks and minerals. He pointed out that an astronaut on the lunar surface is not going to take the time to “sit down and pick up a rock and start describing the cleavage and the color and some little mineral grain in it. If it looks kind of like feldspar, don't be afraid to say ‘it looks like feldspar.’ If you're sure it is feldspar, go ahead and say it is, but don't be afraid to compare it. Say it looks like feldspar. We in the backroom can immediately conjure up a picture of what it looks like even though you're not necessarily saying that's what it is. It's a quick way to describe it. Just compare it. But don't say it is. I think that's more or less what Buzz was doing with that ‘it looks like biotite.’ It turned out it was ilmenite, but ilmenite can look a lot like biotite. And nobody had ever seen a lunar sample in the lab. We didn't know if there was water in those rocks or not. I never did see anything wrong with it. In fact, somebody asked me before the rocks came back, I can't even remember whether it was the press or some guy on the street, if I thought that was biotite and I said ‘I doubt it because it would take water and I doubt if there is any but I don't know yet.’ There's too damn many people, and I'd say more of them were scientists than not, who were anxious to catch those guys making a mistake. The press and some scientists loved to catch those guys making a mistake and then blowing it out of proportion” (Swann interview, 1995).

Swann also had some strong feelings about the astronauts’ early field training. “Something I would have appreciated very much, especially in the early part of the training, I would make it much more problem-oriented. Chidester and I really had some go-arounds about that. He was nominally in charge of it, and he was going to take them out and put his finger on everything and tell them what it was. And I wasn't to say any more about it. I think mostly what I would change would be that early part and try to make it a little more problem-oriented. Separate them into teams of two or three or four. I think maybe four per geologist would be okay. There were too damn many hangers on. There were too many geologists, too many photographers, too many newspaper men, and that did dilute it. It diluted the logistics. It diluted the attention. Usually in those early days I think there were more hangers on, counting the geologists, than there were astronauts. I'm not sure you need six photographers and four newsmen and a geologist for each astronaut. I think another thing I would do to help them cut down on this entourage is to put them in teams of maybe three or four, and then see to it that geologists more experienced than someone like Gordon Swann or Danny Milton or Uel Clanton were, at the time, as teachers. I would try to get them more Lee Silvers, Gene Shoemakers, and Bill Muehlbergers who were really experienced and well proven as good teachers. It wouldn’t necessarily have to be—some of the best teachers I've had were not necessarily the greatest National Academy, world-renowned geologists. But they were damned good teachers. They could teach at that level very well. I think that I would maybe try to see to it that the entourage of geologists was a little more experienced bunch of teachers. Then as you get into the more mission-oriented things, I'd bring in some specialists on mapping the Moon, etc.” Swann agreed that, for the later Apollo mission training, he probably would not change anything: “Yeah, and they were divided into small groups and it was somewhat problem-oriented. They were given a job or a problem and there wasn't someone hanging over their shoulder telling them what to do every damn minute” (Swann interview, 1995).

Swann further expanded his thoughts on problem-oriented issues: “I think as a problem-oriented thing, I would, even though they were not going to really do it on the Moon, give them some mapping exercises. Over and above that little bitty thing they did down in Big Bend, I'd give them more of that. Here's your air photos and—or make a sketch map. I didn't have anything against teaching them how to do a pace and compass map. Not because they were going to do pace and compass on the Moon, but because they'd have a better understanding of maps. It was a very discouraging thing about four years ago at that Venus meeting here and they had a bunch of mostly young people in and just out of college. Mostly young PhDs. We discussed for two days and I guess we even had a field trip, talking about mapping and it turned out that hardly one of those people out of 30 or 40 had any idea about how to make a map. They didn't have any conception of map scale. I think the astronauts had a better conception because they used maps to fly their airplanes. I think before you can understand geology you'd have to understand something about a map, either what the map means or what goes into making it. That's when you start understanding field geology” (Swann interview, 1995).

Farouk El-Baz was asked what he felt was the most important part of the orbital science training: “I think the most useful were the flyovers, which were generated out of nothing. I was not advised to plan these by anybody. These flyovers were not approved by anybody. They were performed by the astronauts on their own. The activity did several things: First it showed them what is the value of looking carefully, and to be able to ‘see’ what you are looking at. It was Vance Brand, who was Apollo 15 backup CMP, who repeated it several times ‘Oh my God you really can look but not see.’ So we would give him a flight plan and tell him to look at this and that. And then, oh my God, he was appalled to recognize for the first time such and such or a textural difference from one region to another. So, he emphasized that a human being has to be trained or else he would look but not see. And that was part of the scheme because when they were able to establish that and when they saw for themselves that they added knowledge that we did not have, that was a most significant inspiration” (El-Baz interview, 2004).

When asked what was least important or even could be omitted, El-Baz replied, “the multitude of hours, money and planning, and you name it, that we spent on the maps of the ‘targets of opportunity,’ because it turned out that the targets of opportunity were not the most significant sites, and in real life, the guys from orbit, when they learned what was necessary to do, did not follow the plan and photographed more interesting things. They could see the things that they sort of thought were important, and we at the time did not really have the privilege of learning what is the most important. If they took pictures only of the places that we assigned, they would have had taken additional pictures of the places that we knew were interesting to start with. This way we did not learn something new. It was a target that we knew was interesting and they photographed it. But, that was not what they brought back. For example, the kinds of things that Ken Mattingly looked at and photographed. Such was a dark thing coming from a bright edge of King Crater and he took a picture of it and this turned out to be something we haven’t even actually figured out what it is up till now. These are the things that worked out best. We spent, or the NASA system spent, months with the Defense Mapping Agency (DMA) on the map production and briefing them on how to make them, with back and forth flights between Houston and DMA guys in Washington and St. Louis to produce these maps with the numbers of the targets of opportunity. That was the least effective of the whole thing and we had spent most of the time and money on it. If you want to photograph something, let the guys figure it out, but let them know what it is and let them do it themselves” (El-Baz interview, 2004).

4. <u>Recommendations for future training efforts of this nature</u>

During the initial stages of planning for any such manned planetary exploration missions such as Apollo, it is absolutely essential that there be a committee that includes representatives from all mission activities. The SWP was such a committee; unfortunately, it was not formed until the final 2½ years of the Apollo program. SWP was formed in early 1970 as the single forum to integrate all the inputs from the science community and coordinate them with engineering, traverse planning, and flight operations. It included PIs, astronaut trainers, traverse planners, site selection representatives, equipment personnel, an astronaut crew representative, the Apollo Spacecraft Program Office, and other groups who had a need for input to the missions. SWP met once a month, generally at MSC where most of the detailed planning activities were concentrated, and information bearing on operations and equipment could be obtained from various MSC sources within a matter of minutes or hours. SWP provided a place where the science input was coordinated with the operational constraints and everyone got a fair shake. The operations folks began to have a much better appreciation for what the science folks were trying to do and, at the same time, the science folks began to get a real appreciation for what the real operational constraints were.

It is also important to place the proper personnel in the most responsible and critical positions on a committee such as SWP. This cannot be overemphasized. Most important is the chairman. As an example of how this position was dealt with on SWP: the first chairman was prone to delaying decisions until the problem could be studied in more detail and he was apt to assign a few people to look into the matter and report back at some time in the future. Such delays prompted the appointment of a new chairman who was able to make decisions at the meetings and instructions for actions were given immediately. To be effective, the chairman must be able to anticipate problems and discuss them with cognizant personnel before meetings. With that capability, the chairman can listen to everyone’s input, provide solutions, get a consensus, and make a decision on the spot rather than authorizing a study of the different alternatives before making the decisions. The chairman must also have the respect of his contacts and the committee members as well as the management who must rule on any final decisions. That type of chairman allowed SWP to become quite effective for the last few Apollo missions.

The second most important individual on SWP was the liaison person, essentially the person who did the legwork, who maintained contact with traverse planners, scientists, management, and other operations personnel. Much of this person’s job involved recognizing problems ahead of time, contacting the relevant personnel in order to understand all of the ramifications of each problem, and keeping the chairman informed of what progress has been made. This allowed many, if not most, of the problems to be solved before the meetings. Such a person could make presentations at the meetings and provide enough background material to allow the members to reach a consensus. This person required knowledge of the scientific objectives as well as the engineering and operational constraints, and very importantly, knowing who to talk to for the details of each activity. And such a person must have the perfect personality for this liaison role. He must be easygoing but intense; have a laser-like vision of what needs to be done and how to do it, but with a completely comfortable and easygoing manner about him.

Future classroom training should not go into the details of each of the sciences for all the astronauts. All the crew members do not need to know how to identify a wide variety of minerals and rocks, understand solar physics, calculate internal structures of planets, understand the evolution of many geologic structures and petrologic processes, etc. The best solution for these scientific details is a combination of astronauts who are experts in these fields. For all crew members, however, there is a need for lectures on the general nature of the overall problems associated with any form of planetary exploration as well as the current stage of understanding of these problems. Such lectures provide a basis for understanding what type of data is required to solve the problems and allow for a better understanding of what the exploration crews can do to provide the necessary information. As this type of approach came into being during the last few Apollo missions, there developed a competitive attitude among the crews to become more proficient in their activities in order to provide the most useful information.

Field training serves both as an essential introduction to geology as well as practice for mission-related activities. Field training is generally considered to be the most meaningful and efficient means to learn the basic perspectives of the various geologic, geophysical, geochemical, and many other scientific objectives. A few very basic introductory lectures combined with a few field trips should suffice for the geology training. Although a cursory knowledge of minerals, rock names, petrology, structures, and geophysical objectives is useful, there is no need for all astronauts to know the details of each of these topics. The scientists who are experts in these fields, whether astronauts or not, are the ones who can best handle the detailed knowledge of such topics. Simulations for field activities, including setting up instruments and sampling techniques, should be commonplace for all crew members in the training. All astronauts should be cross-trained in these deployments in case of the need for ingenuity in unforeseen circumstances. The field training should be set up to replicate as closely as possible the communications, personnel, procedures, and traverses that will occur on the actual missions.

Field training locations and the associated objectives should be planned and executed by people who have well-established experience both as good teachers and with research credentials. These people must be able to develop an excellent rapport with the crews as well as other personnel involved in the missions. NASA hired new PhDs in the early to mid 1960s to do this and ran into several problems. In the practical sense, there was a need for experienced people who already had many contacts with people who were well known in their respective fields. Such people were best able to use their experience and contacts to set up the best replicas of field situations for realistic simulations and also provide experienced leadership for the field trips. On the more managerial level, there was a lack of respect among the science community and NASA Headquarters for people with no research beyond their PhD theses. When good teachers were recruited for the field exercises of the last few missions, they received the respect and attention of astronauts, other scientists, flight controllers, and NASA management. All such field training should include representatives from all these areas from the very beginning in order to develop a mutual understanding of the constraints and objectives of all relevant personnel. Debriefings after each field exercise should also involve representatives from each of these areas to best develop familiarity with the terminology and communications that will be used during missions.

Simulations should be as realistic as possible, with exact replicas of the tools and instruments to be used on the actual mission, and involve all the relevant personnel: scientists, flight controllers, medical personnel, mission planners, life support systems, etc. Similarly, the PIs, engineers, flight controllers, and traverse planners should jointly develop the procedures for using these tools and instruments before presenting them to the crews for simulations. All such procedures should be tested and modified as required in suited and lunar gravity conditions before asking the crews to spend time doing what could have been accomplished already by the cognizant personnel. This recommendation would also apply to robotic mechanisms that might be developed and to laboratory procedures if labs are to be set up on other planetary surfaces. It may be worth mentioning that during the Apollo training during 1969 and 1970, astronauts and NASA management made two trips to the Antarctic to investigate the logistics and conditions under which exploration was conducted under extreme conditions both at the Pole and in the dry valleys, but no training was ever planned for these locations (personal communications with Everett Gibson, Bob Thompson, and Andy Cameron). In a discussion with Pete Conrad in 1987, Andy Cameron's notes indicate a suggestion Conrad made that “after space station has reached IOC (Initial Operating Configuration), we should consider building a small station in Antarctica and figure out what will work/fail on a return to the Moon and then Mars.” No matter where the simulations are to be carried out, once the procedures are perfected, the crews should practice them and undergo debriefings until the procedures become second nature and their exploration time can be spent thinking about the science activities rather than how to accomplish the procedures.

Flyovers for orbital observations should be included in the training of all crew members who will be describing and photographing surface features from orbit. Both high-level overflights to experience the types of observations possible from orbit and low-level flights to better understand the details of features seen from high levels should be included. As with the field activities, the procedures for photography and descriptions should be practiced and debriefed until they are second nature; and the crew can spend time thinking about the science activities rather than how to accomplish the procedures. As with the field training, good teachers are a necessity. They must have the respect and attention of astronauts, other scientists, flight controllers, and NASA management. They must have the energy and infectious ability to enthuse and teach the crews in a friendly and jovial manner.

As actual mission time is approached and plans for the missions are reasonably well established, there should be several simulations that closely follow the plans for the missions but with numerous problems introduced to train the flight controllers, engineers, scientists, and other personnel in Mission Control how to communicate and react in real-time to provide solutions for any troubles that might arise. Debriefings after such simulations should include personnel from all these areas. Such simulations and debriefing discussions provide an excellent basis for contingency planning, which should be a joint effort among all mission participants as was done during the paper simulations before the last three Apollo missions. Such tests and communications develop the respect, trust, and familiarity needed among personnel from all the fields involved in the missions.

Section V: APPENDICES

APPENDIX A: TRAINING SCHEDULES: EARLY TRAINING

Basic Science Program for the first two groups of astronauts (16)

Date	Expected Attendance	Topic & Instructor
Oct. 29, 1962	All astronauts	2 hrs: **Rocket Propulsion I** by Dave Hammock (MSC) 2 hrs: **Flight Mechanics I** by several persons in the Flight Operations Division at MSC 2 hrs: **Astronomy I** by E. J. Prouse (Univ. Texas)
Oct. 30, 1962	All astronauts	2 hrs: **Computers I** by Robert Smith (Texas A & M)
Nov. 5, 1962	All astronauts	2 hrs: **Rocket Propulsion II** by Dave Hammock (MSC) 2 hrs: **Flight Mechanics II** 2 hrs: **Astronomy II** by E. J. Prouse (Univ. Texas)
Nov. 6, 1962	All astronauts	2 hrs: **Guidance and Navigation I** by Milton Trageser (MIT) and several persons at MSC 2 hrs: **Computers II** by Robert Smith (Texas A & M)
Nov. 12, 1962	All astronauts	2 hrs: **Rocket Propulsion III** by Dave Hammock (MSC) 2 hrs: **Flight Mechanics III**
Nov. 13, 1962	All astronauts	4 hrs: **Guidance and Navigation II & III** 2 hrs: **Computers III** by Robert Smith (Texas A & M)
Nov. 19, 1962	All astronauts	2 hrs: **Rocket Propulsion IV** by Dave Hammock (MSC) 2 hrs: **Flight Mechanics IV** 2 hrs: **Astronomy IV** by E. J. Prouse (Univ. Texas)
Nov. 20, 1962	All astronauts	4 hrs: **Guidance and Navigation IV & V** 2 hrs: **Computers IV** by Robert Smith (Texas A & M)
Nov. 26, 1962	All astronauts	2 hrs: **Aerodynamics I** by several persons in the Space Technology Division at MSC 2 hrs: **Flight Mechanics V** 2 hrs: **Astronomy V** by E. J. Prouse (Univ. Texas)
Nov. 27, 1962	All astronauts	4 hrs: **Guidance and Navigation VI & VII** 2 hrs: **Communications I** by several persons in the Space Technology Division at MSC
Dec. 3, 1962	All astronauts	2 hrs: **Aerodynamics II** 2 hrs: **Flight Mechanics VI** 2 hrs: **Astronomy VI** by E. J. Prouse (Univ. Texas)
Dec. 4, 1962	All astronauts	4 hrs: **Guidance and Navigation VIII & IX** 2 hrs: **Communications II**
Dec. 10, 1962	All astronauts	2 hrs: **Rocket Propulsion V** by Dave Hammock (MSC) 2 hrs: **Flight Mechanics VII** 2 hrs: **Astronomy VII** by E. J. Prouse (Univ. Texas)
Dec. 11, 1962	All astronauts	4 hrs: **Guidance and Navigation X & XI** 2 hrs: **Computers V** by Robert Smith (Texas A & M)
Dec. 17, 1962	All astronauts	2 hrs: **Aerodynamics III** 2 hrs: **Mechanics VIII** Flight 2 hrs: **Astronomy VIII** by E. J. Prouse (Univ. Texas)
Dec. 18, 1962	All astronauts	4 hrs: **Guidance and Navigation XII & XIII** 2 hrs: **Communications III**
Jan. 2, 1963	All astronauts	2 hrs: **Flight Mechanics IX** 2 hrs: **Communications IV**
Jan. 3, 1963	All astronauts	2 hrs: **Medical Aspects of Space Flight I** by several persons in the Aerospace Medical Operations Office MSC 2 hrs: **Physics of the Upper Atmosphere and Space I** by John

Date	Expected Attendance	Topic & Instructor
		O'Keefe (GSFC) and W. N. Hess (GSFC)
Jan. 4, 1963	All astronauts	2 hrs: **Communications V**
Jan. 7, 1963	All astronauts	2 hrs: **Flight Mechanics X** 2 hrs: **Communications V** 2 hrs: **Selenology I**: motion of the moon in space and its solid body characteristics by Gene Shoemaker (USGS)
Jan. 8, 1963	All astronauts	4 hrs: **Guidance and Navigation XIV & XV** 2 hrs: **Selenology II:** lunar topography and physical properties of the lunar surface by Gene Shoemaker (USGS)
Jan. 9, 1963	All astronauts	2 hrs: **Medical Aspects of Space Flight II**
Jan. 10, 1963	All astronauts	2 hrs: **Medical Aspects of Space Flight III** 2 hrs: **Physics of the Upper Atmosphere and Space II**
Jan. 14, 1963	All astronauts	2 hrs: **Environmental Control Systems I** by several persons in the Crew Systems Division MSC 2 hrs: **Meteorology I** by Ken Nagler (US Weather Bureau) 2 hrs: **Selenology III**: stratigraphy and structure of the lunar surface by Gene Shoemaker (USGS)
Jan. 15, 1963	All astronauts	2 hrs: **Guidance and Navigation XVI** 2 hrs: **Meteorology II** by Ken Nagler (US Weather Bureau)
Jan. 16, 1963	Gemini Group	**Field Trip** to Meteor Crater, Sunset Crater cinder cone and associated lava flows of the San Francisco volcanic field near Flagstaff, Arizona. Several hours of night time telescopic observations of geological features on the lunar surface and examination of Mars, and a discussion of the problems involved in lunar topographic mapping at the Lowell Observatory, the U.S. Naval Observatory, and The Atmospheric Research Laboratory at Arizona State College.
Jan. 17, 1963	Gemini Group	2 hrs: **Selenology IV** at Flagstaff by Gene Shoemaker (USGS)
Jan. 18, 1963	All astronauts	2 hrs: **Selenology V**: lunar history and the outstanding problems to be solved by lunar exploration by Gene Shoemaker (USGS)
Jan. 21, 1963	All astronauts	2 hrs: **Environmental Control Systems II** 2 hrs: **Meteorology III** by Ken Nagler (US Weather Bureau) 2 hrs: **Physics of the Upper Atmosphere and Space III**
Jan. 22, 1963	All astronauts	4 hrs: **Guidance and Navigation XVII & XVIII** 2 hrs: **Meteorology IV** by Ken Nagler (US Weather Bureau)
Jan. 23, 1963	All astronauts	2 hrs: **Medical Aspects of Space Flight IV**
Jan. 24, 1963	All astronauts	2 hrs: **Medical Aspects of Space Flight V** 2 hrs: **Physics of the Upper Atmosphere & Space IV**
Jan. 28, 1963	All astronauts	2 hrs: **Environmental Control Systems III**
Jan. 29-30, 1963	All astronauts	**Celestial Recognition Training**: Morehead Planetarium, Chapel Hill, N.C.-coordinate system, constellations, prominent stars, special devices for Mercury Program by A. F. Jenzano
Feb. 1, 1963	All astronauts	4 hrs: **Guidance and Navigation XIX & XX**
Feb. 4, 1963	All astronauts	5 hrs: **Orbital Mechanics** by Harm Buning (U of Mich.)
Feb. 5, 1963	All astronauts	5 hrs: **Orbital Mechanics** by Harm Buning (U of Mich.)
Feb. 6, 1963	All astronauts	5 hrs: **Orbital Mechanics** by Harm Buning (U of Mich.)
Feb. 11, 1963	All astronauts	3 hrs: **Seminar on space science** by Homer Newell (NASA Headquarters)
Feb. 12, 1963	All astronauts	4 hrs: **Guidance and Navigation XXI & XXII**
Feb. 18, 1963	All astronauts	3 hrs: **Seminar** by White
Mar. 11, 1963	All astronauts	3 hrs: **Seminar on Ranger and Surveyor Projects**
Mar. 18, 1963	All astronauts	3 hrs: **Seminar on Solid Rocket Roosters**

Date	Expected Attendance	Topic & Instructor
Apr. 1, 1963	All astronauts	3 hrs: **Seminar on Nuclear Rocket Propulsion** by Harry Finger
Apr. 8, 1963	All astronauts	3 hrs: **Seminar** by Walter Studhalter
Apr. 15, 1963	All astronauts	3 hrs: **Seminar** by Dave Aldrich
Apr. 19, 1963	All astronauts	3 hrs: **Seminar on Astronomy** by Dr. Switzer of Princeton
May 9, 1963	All astronauts	4 hrs: s**eminar on Circulation, Respiration, Hyperventilation, Hypoxia, And Hypercapnia**

Science Training Schedule for the first 3 Groups of Astronauts (29)

Includes Series I of Geology Program and Gemini Computers for all 3 groups (29). Other courses are for the 3rd group (14) and whoever else might want to sit in.

Date	Expected Attendance	Topic & Instructor
Feb. 3, 1964	All astronauts	2 hrs: **Geology I**: introduction to geology and geologic processes by Dale Jackson (USGS) 2 hrs: **Mineralogy & Petrology I:** minerals, crystal systems, and abundance of elements in the Earth by Uel Clanton (MSC)
Feb. 10, 1964	All astronauts	2 hrs: **Geology II**: comparison of lunar and terrestrial processes including volcanoes, impact craters and erosion by Don Wilhelms (USGS). 2 hrs: **Mineralogy & Petrology II**: classification of minerals by physical properties by Uel Clanton (MSC).
Feb. 17, 1964	All astronauts	2 hrs: **Flight Mechanics I**: math of vector dot products by Dave Lang (MSC) 3 hrs: **Geology III**: geologic laws, mapping, time scales and a movie, "The Grand Canyon Story" by Dale Jackson (USGS) 1hr: **Geology IV**: lunar crater photos and interpretation of lunar processes by Wilhelms (USGS)
Feb. 18, 1964	All astronauts	4 hrs: **Mineralogy & Petrology III & IV**: mineralogy including bonding, coordination numbers, definitions, and formation of solids by Elbert King (MSC) 3 hrs: **Astronomy I**: the known universe, the Earth's position in it, and celestial coordinate system by I. J. Prouse (U of TX)
Feb. 19, 1964	3rd group	2 hrs **Flight Mechanics II**: vector cross products by Dave Lang (MSC)
Feb. 24, 1964	3rd group All astronauts All astronauts	2 hrs **Flight Mechanics III**: vector cross and dot products and rules of vector differentiation by Dave Lang (MSC) 2 hrs: **Mineralogy & Petrology V**: classification of rocks plus lab study of rocks by Ted Foss (MSC) 2 hrs: **Geology V**: clastic and chemical sediments in stratigraphy by Dale Jackson (USGS).
Feb. 25, 1964	3rd group	3 hrs: **Astronomy II**: planet orientation, astronomical properties of Earth, rotation, revolution, spherical trig, and time by I. J. Prouse (U of TX) 2 hrs: **Flight Mechanics IV**: vector differentiation and coordinate systems by Dave Lang (MSC)
Mar. 2, 1964	3rd group 3rd group All astronauts	2 hrs: **Flight Mechanics V**: intercept problems with vectors by Dave Lang (MSC) 4 hrs: **Digital Computers I & II:** procedures, number systems, logic, form by Robert Smith (TX A&M) 1 hr **Geology Briefing** for Grand Canyon field trip by Dale Jackson (USGS)
Mar. 3, 1964	3rd group	4 hrs: **Digital Computers III & IV**: memory, logic, FORTRAN by Robert Smith (TX A&M) 3 hrs: **Astronomy III**: precession, nutation, atmospheres by I. J. Prouse (U of TX)
Mar. 4, 1964	3rd group	2 hrs: **Flight Mechanics VI**: Newton's law by Dave Lang

Date	Expected Attendance	Topic & Instructor
		(MSC)
Mar. 5-6, 1964	18 astronauts	**Geology Field Trip to Grand Canyon**. see Appendix E for details
Mar. 12-13	9 astronauts	Same **Grand Canyon Field Trip** as above for remaining astronauts
Mar. 16, 1964	3rd group	2 hr: **Flight Mechanics VII**: vectors in spherical coordinates by Dave Lang (MSC) 2 hrs: **Physics of the Upper Atmosphere and Space II** atmospheric phenomena during the day and night by A. B. Meinel (U of Ariz.) 4 hrs: **Digital Computers V & VI**: fortran, subroutines, monitoring, real-time computing, and data transmission by Robert Smith (TX A&M)
Mar. 17, 1964	All astronauts	4 hrs: **Gemini Computers I & II**: characteristics, flow diagrams, input/output by Al Minnick (IBM) 4 hrs: **Geology VI**: large and small scale structural geology, folds and joints by Al Chidester (USGS).
Mar. 18, 1964	3rd group	2 hrs: **Flight Mechanics VIII:** equations for reentry and the energy theorem by Dave Lang (MSC)
Mar. 19, 1964	3rd group	3 hrs: **Astronomy IV**: constellations, stellar magnitudes, stellar characteristics, Milky Way and comets by I. J. Prouse (U of TX)
Mar. 23, 1964	All astronauts	5 hrs: **Gemini Computers III & IV**: functional block diagram analysis by Al Minnick (IBM) 2 hrs: **Mineralogy and Petrology VI**: primary and derivative geologic magmas plus convection in the Earth by Ted Foss (MSC)
Mar. 24, 1964	3rd group	2 hrs: **Flight Mechanics IX**: the Potential Function by Dave Lang (MSC) 3 hrs: **Astronomy V**: Solar system, the Moon, planets & satellites-I. J. Prouse (U of TX)
Mar. 25, 1964	3rd group	2 hrs: **Flight Mechanics X**: vector field theory, moment, angular momentum by Dave Lang (MSC)
Mar. 26-27, 1964	3rd group	**Celestial Recognition Training**: Morehead Planetarium, Chapel Hill, N.C.-coordinate system, constellations, prominent stars, by A. F. Jenzano
Mar. 30, 1964	3rd group All astronauts	2 hrs: **Flight mechanics XI**: angular momentum, force fields, motions in gravity field by Dave Lang (MSC) 4 hrs: **Gemini Onboard Computer V & VI**: functional block diagram analysis-Al Minnick (IBM)
Mar. 31, 1964	All astronauts	4 hrs: **Gemini Onboard Computer VII & VIII**: functional block diagram analysis-Al Minnick (IBM) 2 hrs: **Geology VII**: structures and landforms of intrusive rocks, volcano types by Al Chidester and Dale Jackson (USGS).
Apr. 1, 1964	3rd group	2 hrs: **Flight Mechanics XII**: equations of motion by Dave Lang (MSC) 2 hrs: **Rocket Propulsion Systems I**: by William Scott (MSC)
Apr. 2-3, 1964	18 astronauts	**Geology Field Trip to Marathon Basin and Big Bend, West Texas** See Appendix C for details
Apr. 6, 1964	3rd group	2 hrs: **Flight Mechanics XIII**: motion in a force field, characteristics of circular orbits by Dave Lang (MSC) 1 hr: **Rocket Propulsion Systems I** (cont.): by William Scott (MSC)

Date	Expected Attendance	Topic & Instructor
Apr. 13, 1964	3rd group All astronauts	2 hrs: **Flight Mechanics XIV**: orbital characteristics and rendezvous by Dave Lang (MSC) 2 hrs: **Gemini Onboard Computer IX**: Operational sequence by Ray Wannser (MacDonnell Aircraft Corp.) 2 hrs: **Geology VIII**: impact features and maria on the Moon by Don Wilhelms (USGS).
Apr. 14, 1964	All astronauts 3rd group	4 hrs: **Gemini Onboard Computer X & XI**: operational sequence by Marvin Czarnik and John Schraeder (MacDonnell Aircraft Corp.) 2 hrs: **Rocket Propulsion Systems II**: by Hugh White (MSC) 2 hrs: **Physics of the Upper Atmosphere and Space I**: solar activity, interplanetary medium, radiation belts, aurora by B. J. O'Brien (Rice Univ.) 2 hrs: **Flight Mechanics XV**: equations of motion by Dave Lang (MSC)
Apr. 15, 1964	3rd group	2 hrs: **Aerodynamics I**: forces, axis systems, aerodynamicparameters, drag, motion by Harm Buning (U of Mich.)
Apr. 16-17, 1964	9 astronauts	**Marathon Basin-Big Bend Field Trip**; same as April 2-3 above for remaining astronauts
Apr. 20, 1964	3rd group All astronauts	2 hrs: **Flight Mechanics XVI**: equations of orbital motion 2 hrs: **Geology IX**: structures and landforms of the moon by Don Wilhelms (USGS).on by Dave Lang (MSC) 2 hrs: **Mineralogy & Petrology VII**: origins of igneous rocks including chemistry, crystallization, cooling rates, distribution in time and space by Ted Foss (MSC)
Apr. 21, 1964	3rd group	2 hrs: **Physics of the Upper Atmosphere and Space III**: asteroids, comets, zodiacal light, meteors and meteoroid impact by Fred Whipple (Smithsonian Astrophysical Observatory) 2 hrs: **Rocket Propulsion Systems III**: by Harold Lambert (MSC)
Apr. 22, 1964	3rd group	2 hrs: **Aerodynamics II**: equations of motion by Harm Buning (U of Mich.) 2 hrs: **Flight Mechanics XVII**: 2-body problem and 3-body problem by Dave Lang (MSC) 2 hrs: **Physics of the Upper Atmosphere and Space IV**: temperature variations, variation of electrons , chemistry, mean free path, and helium with altitude, molecular reactions by G. B. Field (Princeton Univ. Observatory)
Apr. 27, 1964	3rd group All astronauts	2 hrs: **Flight Mechanics XVIII**: Rendezvous considerations by E. E. Aldrin (MSC) 2hrs: **Geology X**: geologic mapping of the Moon by Don Wilhelms (USGS). 2 hrs: **Mineralogy & Petrology VIII**: classification of igneous rocks by Uel Clanton (MSC)
April 28, 1964	3rd group	2 hrs: **Flight Mechanics XIX:** Rendezvous considerations by E. E. Aldrin (MSC) 2 hrs: **Physics of the Upper Atmosphere and Space V**: chemical reactions in the atmosphere by R. D. Cadle (National Center for Atmospheric Research) 2 hrs: **Rocket Propulsion Systems IV**: by Henry Pohl (MSC)
Apr. 29, 1964	All astronauts	2 hrs: **Aerodynamics III**: shallow angle, non-lifting, atmospheric entry by Harm Buning (U of Mich.)

Date	Expected Attendance	Topic & Instructor
	3rd group	2 hrs: **Physics of the Upper Atmosphere and Space VI:** meteorology of the upper stratosphere, mesosphere and lower thermosphere plus solar and magnetic storms by W. W. Kellogg (Rand Corp.)
Apr. 30-May 2, 1964	17 astronauts	**Geology Field trip to Flagstaff Ariz. and Kitt Peak Observatory**; See Appendix C for details
May 4, 1964	3rd group All astronauts	2 hrs: **Flight Mechanics XX**: equations of motion for 3-body problem by Dave Lang (MSC) 2 hrs: **Geology XI**: geologic mapping of Earth and interpretation of geologic maps by A. H. Chidester (USGS). 2 hrs: **Mineralogy & Petrology IX**: lab study of igneous rocks by Uel Clanton (MSC)
May 5, 1964	All astronauts 3rd group	2 hrs: **Geology XII**: lunar mapping techniques by Don Wilhelms (USGS). 2 hrs: **Guidance and Navigation I**: techniques measurements and errors by R. Battin (MIT) 2 hrs: **Rocket Propulsion Systems V**: by W. Eichelman (MSC)
May 11, 1964	3rd group	2 hrs: **Aerodynamics V**: Newtonian flow and launch vehicle aerodynamics by Paul Kramer (MSC) 4 hrs: **Guidance and Navigation Systems II & III**: requirements, equipment, and functional analysis by Derwin Fox (A. C. Sparkplug Corp.)
May 12, 1964	3rd group All astronauts	4 hrs: **Guidance and Navigation systems IV & V**, requirements, equipment, and functional analysis (cont.) by Derwin Fox (A. C. Sparkplug Corp.) 2 hrs: **Mineralogy & Petrology X**: lab study of igneous rocks by Uel Clanton (MSC)
May 13, 1964	3rd group 3rd group	2 hrs: **Communications I**: energy propagation, antenna theory, and frequency spectra by John Painter (MSC) 2hrs: **Rocket Propulsion Systems VI**: by H. Brasseaux (MSC)
May 18, 1964	3rd group	2 hrs: **Medical Aspects of Space Flight I**: human physiology and medical monitoring by C. Berry (MSC) 4 hrs: **Guidance and Navigation Systems VI & VII**: functional analysis (cont.) by Derwin Fox (A. C. Sparkplug Corp.)
May 19, 1964	3rd group All astronauts	4 hrs: **Guidance and Navigation Systems VIII & IX**: functional analysis (cont.) and inertial subsystem by Derwin Fox (A. C. Sparkplug Corp.) 2 hrs: **Mineralogy & Petrology XI**: lab study of igneous rocks by Uel Clanton (MSC)
May 20, 1964	3rd group	2 hrs: **Communications II**: concepts, radar, telemetry, voice, television by John Painter (MSC) 2 hrs: **Medical Aspects of Space Flight II**:-genitourinary and gastrointestinal systems, body fluids, and radiation effects by F. Kelly and R. Pollard (MSC)
May 20-22, 1964	12 astronauts	**Flagstaff Ariz. and Kitt Peak Observatory Field Trip**; same trip as as Apr. 30-May 2 for additional astronauts
May 25, 1964	3rd group	2 hrs: **Communications III**: telemetry, tracking, command from Earth orbit and the Moon by John Painter and George Hondros (MSC) 4 hrs: **Guidance and Navigation X & XI**: inertial systems

Date	Expected Attendance	Topic & Instructor
		including axes, stabilization loops, accelerometer loops and coupling displays by Derwin Fox (A. C. Sparkplug Corp.)
May 26, 1964	3rd group All astronauts	4 hrs: **Guidance and Navigation XII & XIII**: inertial systems including modes, power supplies signal monitoring and detection, and servos by Derwin Fox (A. C. Sparkplug Corp.) 2 hrs: **Geology XIII**: geophysical measurements and mapping of the Earth and Moon by Martin Kane (USGS).
May 27, 1964		2 hrs: **Communications IV**: telemetry, tracking, command the Moon by John Painter and George Hondros (MSC)
June 1, 1964		2 hrs: **Medical Aspects of Space Flight III:** cardiovascular system and bioinstrumentation by J. Gordon (MSC) 4 hrs: **Guidance and Navigation XIV & XV**: optical systems including telescopes and sextants by Derwin Fox (A. C. Sparkplug Corp.)
June 2, 1964		4 hrs: **Guidance and Navigation XVI & XVII**: computer subsystems including programs and interfaces by Derwin Fox (A. C. Sparkplug Corp.)
June 3-6, 1964	20 astronauts	**Geology Field Trip to Philmont Ranch, New Mexico**. See Appendix E for details
June 8, 1964	All astronauts	2 hrs: **Medical Aspects of Space Flight IV**: respiratory system, pulmonary mechanics, environmental control, equipment by D. Coons and G. Smith (MSC) 2 hrs: **Geology XIV**: geophysical models of the Earth and Moon by Kane (USGS). 2 hrs: **Mineralogy & Petrology XII**: lab study of metamorphic rocks by Foss (MSC)
June 9, 1964		2 hrs: **Medical Aspects of Space Flight V**: special senses, disorientation, neurophysiology, and acceleration by H. Minners (MSC) 4 hrs: **Meteorology I & II**: meteorology and general circulation related to space flight, forecasting, systems as seen from above by K. Nagler (U.S. Weather Bureau)
June 15, 1964	All astronauts	2 hrs: **Medical Aspects of Space Flight VI**: medical self-aid, hygiene and sanitation in space flight by G. Smith (MSC) 2 hrs: **Geology XV**: Engineering applications of geology and geophysics by Kane and Wilhelms (USGS) 2 hrs: **Mineralogy & Petrology XIII**: meteorites and tectites by Elbert King (MSC)

Start of Series II of Geology program for first 3 groups (22 available)

Date	Expected Attendance	Topic & Instructor
Sept. 14, 1964	19 astronauts	4 hrs: **Mineralogy & Petrology I & II**: classification of volcanic materials by Ted Foss (MSC)
Oct. 2, 1964	14 astronauts	3 hrs: **Geology I**: volcanology-types of volcanoes, terrestrial flood basalts, possible composition of lunar maria by Aaron Waters (Univ. Cal.)
Oct. 7-9, 1964	5 astronauts	**Geology Field trip to vicinity of Bend, Oregon**. See Appendix E for details
Oct. 15-17	7 astronauts	**Geology Field trip to vicinity of Bend, Oregon** for additional astronauts
Oct. 19, 1964	13 astronauts	2 hrs: **Mineralogy & Petrology III**: Comparison of Newbury Crater and Valles Caldera, New Mexico which is to be visited on the next field trip. Description and differences between ash flows and ash falls by Ted Foss (MSC)
Oct. 22-23, 1964	7 astronauts	**Geology Field trip to Valles Caldera, New Mexico**. see Appendix E for details
Oct. 29-31, 1964	7 astronauts	**Geology Field trip to Valles Caldera, New Mexico**. For additional astronauts
Nov. 9, 1964	9 astronauts 9 astronauts	2 hrs: **Mineralogy & Petrology IV**: laboratory study of volcanoclastic rocks by Ted Foss (MSC) 2 hrs: **Geology II**: possible explanations of the origin of lunar surface features including discussion of Ranger photos by Hal Masursky (USGS)
Nov.?, 1964	9 astronauts	2 hrs: **Mineralogy & Petrology V**: metamorphic rocks by Foss (MSC)
Nov. 13-14, 1964	2 astronauts	**Geology Field trip to Valles Caldera, New Mexico**. For additional astronauts
Dec. 7, 1964	11 astronauts 14 astronauts	3 hours: **Geology III**: on Lunar impact structures and crater densities by Gene Shoemaker (USGS) and Henry Moore (USGS) 2 hrs: **Mineralogy & Petrology VI**: metamorphic rocks by Foss (MSC)
Jan. 4, 1965	10 astronauts	2 hrs: **Mineralogy & Petrology VII**: sedimentary rock classification and composition by E. King (MSC)
Jan. 18-25, 1965	8 astronauts	**Field trip to Hawaii**. see Appendix E for details
Jan. 25-Feb. 1, 1965	7 astronauts	**Field trip to Hawaii**. see Appendix E for details
Feb. 17-18,1965	6 astronauts	**Field trip to Nevada Test Site**. see Appendix E for details
Feb. 24-25, 1965	6 astronauts	**Field trip to Nevada Test Site**. see Appendix E for details
Mar 3-4, 1965	2 astronauts	**Field trip to Nevada Test Site**. see Appendix E for details
Mar.?, 1965	13 astronauts	4 hrs: **Mineralogy & Petrology VIII & IX**: optical mineralogy and petrology by Foss (MSC)
Mar. 29, 1965	11 astronauts 14 astronauts	2 hrs: **Geology IV**: Shock metamorphism and sampling of impact craters by Ed Chao (USGS) 2 hrs: **Mineralogy & Petrology X**: petrographic microscope and recognition of optical properties of minerals by Foss (MSC)
April, 1965	11 astronauts	**Field trip to Meteor Crater.** see Appendix E for details

Date	Expected Attendance	Topic & Instructor
May 10, 1965	8 astronauts 7 astronauts	2 hrs: **Geology V**: photo geologic mapping by Jim Derrick 2 hrs: **Mineralogy & Petrology XI**: thin section characteristics under the petrographic microscope by Foss (MSC)
May 17, 1965	8 astronauts	4 hrs: **Mineralogy & Petrology XII & XIII**: lab on descriptions of thin sections under petrographic microscope by Foss (MSC)
May 24, 1965	9 astronauts	3 hrs: **Geology VI**: relative importance of lunar volcanism and impact structures by Jack Green, Hal Masursky (USGS), and John O'Keefe (NASA)

Series III of Geology Training for first three groups (11 astronauts available)

Date	Expected Attendance	Topic & Instructor
June 21, 1965	6 astronauts	2 hrs: **Mineralogy & Petrology I**: Geochemical abundance, distribution and migration of elements by K. Richardson (MSC)
June 29-July2, 1965	10 astronauts	**Field Trip to Katmai, Alaska**. See Appendix E for details
July 12-16, 1965	10 astronauts	**Field Trip to Iceland**. See Appendix E for details
Aug. 2, 1965	6 astronauts	2 hrs: **Geology I**: history of geophysics, application to the moon and suggested lunar experiments by Kane (USGS) 2 hrs: **Mineralogy & Petrology II**: magmatic differentiation and age determinations by Richardson (MSC)
Aug. 30, 1965	2 astronauts	**Geology II**: Field Trip Briefings on sampling and field checking on Medicine Lake trip by Foss (MSC) and geophysics work on Zuni Salt Lake trip by Kane (USGS)
Sept. 13, 1965	7 astronauts	2 hrs: **Mineralogy & Petrology III**: Determination of Na and Ca content of plagioclase feldspar by Foss (MSC)
Sept. 2-4, 1965	3 astronauts	**Field Trip to Medicine Lake, California**. See Appendix E for details
Sept. 9-11, 1965	3 astronauts	**Field Trip to Medicine Lake, California**. See Appendix E for details
Sept. 21-24, 1965	4 astronauts	**Field Trip to Zuni Salt Lake, Arizona**. See Appendix E for details
Oct. 4, 1965	7 astronauts 8 astronauts	2 hrs: **Geology III**: Lunar cold traps and volatiles on the moon by Ken Watson (USGS) 2 hrs: **Mineralogy & Petrology IV**: ash flow characteristics and thin sections of same by Foss (MSC)
Nov. 1, 1965	7 astronauts	2 hrs: **Mineralogy & Petrology V**: variations in volcanic compositions in different geographic areas by Foss (MSC)
Nov. 2, 1965	8 astronauts	2 hrs: **Geology IV**: current status of Lunar geologic mapping and review of terrestrial craters by Hal Masursky (USGS)
Nov. 8-10, 1965	4 astronauts	**Field Trip to Pinacates, Mexico**. see Appendix E for details
Nov. 15, 1965	8 astronauts	2 hrs: **Geology VI**: structure of the Earth's crust: it's analogs in the Moon and Planets by Wallace Cady (USGS)
Dec. 27-29, 1965	3 astronauts	Make-up **Field Trips to Pinacates and Zuni Salt Lake**. See Appendix E for details

Science Training Schedule for the 4th & 5th Group of Astronauts (24 total) selected June 28, 1965 and Apr. 4, 1966

General Science Including Series I of Geology Training

Date	Actual Attendance (where known)	Topic & Instructor
May 9, 1966	19 astronauts	2 hrs: **Geological Processes I**: orientation by Chidester (USGS)
May 9, 1966		2 hrs: **Physics of Upper Atmosphere and Space I** by O'Brien
May 9, 1966		2 hrs: **Digital Computers I**
May 10, 1966	19 astronauts	2 hrs: **Mineralogy and Petrology I**
May 10, 1966		3 hrs: **Astronomy I**
May 11, 1966		2 hrs: **Medical Aspects of Space Flight I**
May 11, 1966		2 hrs: **Digital Computers II**
May 16, 1966	19 astronauts	2 hrs: **Geological Processes II**: terrestrial geological processes by Waters, (Univ. Calif.)
May 16, 1966		2 Hrs: **Physics of Upper Atmosphere and Space II** by Michel
May 16, 1966		2 Hrs: **Digital Computers III**
May 18, 1966		2 Hrs: **Digital Computers IV**
May 19, 1966	20 astronauts	2 Hrs: **Mineralogy and Petrology II**
May 19, 1966		3 Hrs: **Astronomy II**
May 23, 1966		4 Hrs: **Medical Aspects of Space Flight II & III**
May 23, 1966	20 astronauts	2 Hrs: **Geological Processes III**: geologic principles by Waters (Univ. Calif.)
May 24, 1966	20 astronauts	2 HRS: **Mineralogy and Petrology III**
May 24, 1966		3 HRS: **Astronomy III**
May 31 1966	2 astronauts	2 HRS: **Geological Processes IV**: stratigraphy and geologic time by Waters (Univ. Calif.)
May 31, 1966		2 HRS: **Physics of Upper Atmosphere and Space III** by Whipple
May 31, 1966		3 HRS: **Astronomy IV**
June 1, 1966	18 astronauts	2 HRS: **Mineralogy and Petrology IV**
June 2-3, 1966	20 astronauts	**Field Trip to Grand Canyon**-see Appendix E for details
June 6, 1966	19 astronauts	2 hrs: **Geological Processes V**: lunar geologic processes by Masursky (USGS)
June 6, 1966	19 astronauts	4 hrs: F**light Mechanics I & II**
June 7, 1966	19 astronauts	2 hrs: **Flight Mechanics III**
June 7, 1966		3 hrs: **Astronomy V**
June 8, 1966	21 astronauts	2 hrs: **Mineralogy and Petrology V**
June 8, 1966	21 astronauts	2 hrs: **Flight Mechanics IV**
June 9-10, 1966		**Celestial Recognition Training**: Planetarium at Morehead Planetarium, Chapel Hill, N. C. by A. F. Jenzano
June 13, 1966	21 astronauts	2 hrs: **Geological Processes VI**: structural geology by Chidester (USGS)
June 14, 1966	21 astronauts	4 hrs: **Flight Mechanics V & VI**
June 14, 1966		2 hrs: **Physics of Upper Atmosphere and Space IV** by Johnson
June 15, 1966	19 astronauts	2 hrs: **Mineralogy and Petrology VI**
June 15, 1966	17 astronauts	2 hrs: **Flight Mechanics VII**
June 15, 1966		2 hrs: **Medical Aspects of Space Flight I**

Date	Actual Attendance (where known)	Topic & Instructor
June 16, 1966	16 astronauts	2 hrs: **Flight Mechanics VIII**
June 16, 1966		2 hrs: **Medical Aspects of Space Flight II** by Conley
June 20, 1966	21 astronauts	2 hrs: **Geological Processes VII**: geologic mapping by Chidester (USGS)
June 20, 1966	19 astronauts	2 hrs: **Flight Mechanics IX**
June 20, 1966		2 hrs: **Physics of Upper Atmosphere and Space V** by Cadle
June 21, 1966		2 hrs: **Medical Aspects of Space Flight III** by Fred Kelly
June 21, 1966	19 astronauts	4 hrs: **Flight Mechanics X & XI**
June 22, 1966	18 astronauts	2 hrs: **Flight Mechanics XII**
June 23-24, 1966	22 astronauts	**Geology Field Trip to West Texas**-see Appendix E for details
July 11, 1966	21 astronauts	2 hrs: **Geological Processes VIII**: rock-forming processes by Waters (Univ. Calif.)
July 11, 1966	20 astronauts	2 hrs: **Guidance and Navigation I**
July 11, 1966		2 hrs: **Medical Aspects of Space Flight IV** by Droecher
July 12, 1966		4 hrs: **Meteorology I & II**
July 13, 1966	20 astronauts	2 hrs: **Mineralogy and Petrology VII**
July 13, 1966		2 hrs: **Physics of Upper Atmosphere and Space VI** by Kellogg
July 18, 1966	20 astronauts	2 hrs: **Geological Processes IX**: Earth structures and landforms by Waters (Univ. Calif.)
July 18, 1966	20 astronauts	4 hrs: **Guidance and Navigation II & III**
July 19, 1966	20 astronauts	4 hrs: **Guidance and Navigation IV & V**
July 20, 1966	20 astronauts	2 hrs: **Mineralogy and Petrology VIII**
July 20, 1966	20 astronauts	2 hrs: **Rocket Propulsion I**
July 25, 1966	20 astronauts	2 hrs: **Geological Processes X**: Earth structures and landforms by Waters (Univ. Calif.)
July 25, 1966	21 astronauts	2 hrs: **Communications I**
July 25, 1966	21 astronauts	2 hrs: **Mineralogy and Petrology IX**
July 27-29, 1966	22 astronauts	**Geology Field Trip to Bend, Oregon**-see Appendix E for details
Aug. 1, 1966	22 astronauts	2 hrs: **Geological Processes XI**: geophysics by Kane (USGS)
Aug. 1, 1966	22 astronauts	4 hrs: **Guidance and Navigation VI & VII**
Aug. 2, 1966	23 astronauts	4 Hrs: **Guidance and Navigation VIII & IX**
Aug. 3, 1966	22 astronauts	2 Hrs: **Mineralogy and Petrology X**
Aug. 3, 1966	23 astronauts	2 Hrs: **Rocket Propulsion II**
Aug. 3, 1966	23 astronauts	2 Hrs: **Communications II**
Aug. 8, 1966	19 astronauts	2 Hrs: **Geological Processes XII** : geophysics by Kane (USGS)
Aug. 8, 1966	20 astronauts	4 Hrs: **Guidance and Navigation X & XI**
Aug. 9, 1966	21 astronauts	4 Hrs: **Guidance and Navigation XII & XIII**
Aug. 10, 1966	20 astronauts	2 Hrs: **Mineralogy and Petrology XI**
Aug. 10, 1966	19 astronauts	2 Hrs: **Rocket Propulsion III**
Aug. 10, 1966	19 astronauts	2 Hrs: **Communications III**
Aug. 15, 1966	22 astronauts	2 Hrs: **Mineralogy and Petrology XII**
Aug. 15, 1966	22 astronauts	4 Hrs: **Guidance and Navigation XIV & XV**
Aug. 16, 1966	23 astronauts	4 Hrs: **Guidance and Navigation XVI & XVII**
Aug. 17, 1966	24 astronauts	2 Hrs: **Rocket Propulsion IV**

Date	Actual Attendance (where known)	Topic & Instructor
Aug. 17, 1966	24 astronauts	2 Hrs: **Communications IV**
Aug. 18, 1966	24 astronauts	4 Hrs: **Geological Processes XIII & XIV**: lunar structures, stratigraphy and landforms by Masursky (USGS)
Aug. 18, 1966	24 astronauts	2 Hrs: **Communications V**
Aug. 22-26, 1966 24		**Geology Field Trip to Katmai, Alaska**-See Appendix E for details
Sept. 16, 1966		2 Hrs: **Mineralogy and Petrology XIII**
Sept. 25, 1966	24 astronauts	**Geology Field Trip to Valles Caldera, N. M**.-See Appendix E for details
Nov. 30-Dec. 2, 1966 20		**Geology Field Trip to Pinacates, Mexico**-See Appendix E for details

Series II in Geology Training for 4th & 5th Groups (24 astronauts)

Date	Actual Attendance (where known)	Topic & Instructor
Feb. 6, 1967	18 astronauts	2 hrs: **Geologic Processes I**
Feb. 6, 1967	9 astronauts	2 hrs: **Mineralogy & Petrology I**: History and Classification of meteorites by Don Elston
Feb. 12-19, 1967	16 astronauts	**Geology Field Trip to Hawaii**-See Appendix E for details
Feb. 27, 1967	7 astronauts	2 hrs: **Geologic Processes II**: lunar depressions, cold traps and heat flow by Ken Watson
Feb. 27, 1967	8 astronauts	2 hrs: **Mineralogy & Petrology II**: tektites and shock metamorphism in rocks by Ed Chao (USGS)
Mar. 6, 1967	14 astronauts	2 hrs: **Geologic Processes III**: impact cratering by Gene Shoemaker (USGS)
Mar. 6, 1967	9 astronauts	2 hrs: **Mineralogy & Petrology III**
Mar. 13, 1967	9 astronauts	2 hrs: **Geologic Processes IV**: structure and petrology of large impact craters by Mike Dence (Canadian Ministry of Energy)
Mar. 13, 1967	9 astronauts	2 hrs: **Mineralogy & Petrology IV**
Mar. 20-26, 1967	7 astronauts	**Geology Field Trip to Hawaii**-make-up, see Appendix E for details
Mar. 27, 1967	12 astronauts	2 hrs: **Geologic Processes V**: remanent magnetism in extraterrestrial materials by Robert DuBois (Univ., Ariz.)
Mar. 27, 1967	13 astronauts	2 hrs: **Mineralogy & Petrology V**
Apr. 10, 1967	1 astronaut	2 hrs: **Geologic Processes VI**: shock metamorphosed rocks and tectites by Ed Chao (USGS)
Apr. 17, 1967	18 astronauts	2 hrs: **Geologic Processes VII**: Interpretation of Orbiter 2 and 3 photos
Apr. 17, 1967	17 astronauts	2 hrs: **Mineralogy and Petrology VI**
Apr. 24, 1967	19 astronauts	2 hrs: **Mineralogy and Petrology VII**
May 1, 1967	17 astronauts	2 hrs: **Mineralogy & Petrology VIII** by Clanton and Chao
May 8, 1967	17 astronauts	2 hrs: **Mineralogy & Petrology IX**
May 8, 1967	12 astronauts	2 hrs: **Geologic Processes VIII**:, soil mechanics by T. William Lambe of MIT
May 15, 1967	12 astronauts	2 hrs: **Mineralogy & Petrology X**
May 16-19, 1967	19 astronauts	**Geology Field Trip to Zuni Salt Lake, Hopi Buttes & Meteor Crater, Ariz.**-see Appendix E for details
May 22, 1967	18 astronauts	2 hrs: **Mineralogy & Petrology XI** by Clanton and McKay
May 22, 1967	10 astronauts	2 hrs: **Geology IX** by Marty Kane: geophysics
May 29, 1967	19 astronauts	2 hrs: **Mineralogy & Petrology XII** by Clanton and McKay
May 29, 1967	17 astronauts	2 hrs: **Geology X**: tektites by Paul Lowman
May 31-June 2	4 astronauts	Make-up **Geology Field Trip to Zuni Salt Lake, Hopi Buttes & Meteor Crater, Ariz.**
June 5, 1967		2 hrs: **Geology XI**
June 5, 1967		2 hrs: **Mineralogy & Petrology XIII**
June 22-23, 1967		**Geology Field Trip to Medicine Lake, Calif**.-postponed because of snow
July 3-8, 1967	23 astronauts	**Geology Field Trip to Iceland**-see Appendix E for details
Sept. 21-22, 1967		Make-up **Field Trip to Pinacates** (on Zedekar's calendar but no details)

Training Schedule for the 6th Group of Science-Astronauts (10) selected Aug. 4, 1967

Includes ≈225 hrs of science but only 35 in geology and no field trips

Date	Actual Attendance (where known)	Topic & Instructor
Oct. 2, 1967	Scientist-astronauts	6 hrs: **Life Sciences**: physiological training by Lt. Col. Pittman (MSC)
Oct. 3, 1967	Scientist-astronauts	2 hrs: **Computers**: by Woods (MSC)
Oct. 3, 1967	Scientist-astronauts	2 hrs: **Space Science**:-Solar wind by F. C. Michel (MSC)
Oct. 4, 1967	Scientist-astronauts	4 hrs: **Communications**: by Batson and Dawson
Oct. 5, 1067	Scientist-astronauts	2 hrs: **Rocket Propulsion**: rocket performance and propulsion by C. Vaughn (MSC)
Oct. 5, 1967	Scientist-astronauts	2 hrs: **Space Science**: solar wind by F. C. Michel (MSC)
Oct. 9, 1967	Scientist-astronauts	2 hrs: **Space Science**: cosmic radiation by Hugh Anderson (Rice Univ.)
Oct. 10, 1967	Scientist-astronauts	2 hrs: **Computers**: by Bill Raney (MSC)
Oct. 12, 1967	Scientist-astronauts	2 hrs: **Rocket Propulsion**: liquid rocket propulsion by Polifka (MSC)
Oct. 12, 1967	Scientist-astronauts	2 hrs: **Space Science**: geomagnetic field by Alex Dessler (Rice Univ.)
Oct. 13, 1967	Scientist-astronauts	2 hrs: **Astronomy**: basic astronomy, coordinate systems, time, spherical astronomy by K Henize (MSC)
Oct. 13, 1967	Scientist-astronauts	2 hrs: **Life Sciences**: medical accomplishments of Mercury and Gemini, Future medical experiments for Apollo by Berry and Catterson, (MSC)
Oct. 17, 1967	Scientist-astronauts	2 hrs: **Communications**: by Barron
Oct., 18, 1967	Scientist-astronauts	2 hrs: **Life Sciences**: cardiovascular system: outline, methods of observing, responses to weightlessness, testing by J. Warren (Ohio State Univ.)
Oct. 18, 1967	Scientist-astronauts	2 hrs: **Space Science**: geomagnetic field by Alex Dessler (Rice Univ.)
Oct. 19, 1967	Scientist-astronauts	2 hrs: **Rocket Propulsion**: solid rocket propulsion by Brasseaux (MSC)
Oct. 19, 1967	Scientist-astronauts	2 hrs: **Computers**: by Woods and Raney (MSC)
Oct. 20, 1967	Scientist-astronauts	2 hrs: **Astronomy** : telescopes, magnitude, scale by R. Parker (MSC)
Oct. 20, 1967	Scientist-astronauts	2 hrs: **Space Science**: lunar atmosphere, magnetic field, shock and Explorer 35 observations by F. C. Michel (MSC)
Oct. 23, 1967	Scientist-astronauts	2 hrs: **Astronomy**: spectral classification, H-R diagram by R. Parker (MSC)
Oct. 23, 1967	Scientist-astronauts	2 hrs: **Communications**: by Teasdale
Oct. 24, 1967	Scientist-astronauts	2 hrs: **Astronomy**: stellar distances and motion by K. Henize (MSC)
Oct. 24, 1967	Scientist-astronauts	2 hrs: **Life Sciences**: pulmonary system outline, functions, responses in space, tests by U. Luft (Lovelace Foundation for Medical Education & Research, N. M.
Oct. 25, 1967	Scientist-astronauts	2.5 hrs: **Earth Resources**: by Badgley
Oct. 25, 1967	Scientist-astronauts	2.5 hrs: **Space Science**: Radiophysics of the moon, planets and sun by James Warwick (Univ. Colorado)
Oct. 26, 1967	Scientist-astronauts	2 hrs: **Rocket Propulsion**: reaction control systems by J. B. Lee (MSC)
Oct. 30, 1967	Scientist-astronauts	2 hrs: **Life Sciences**: hematology and laboratory medicine: reviews of past findings and future programs by S. Swisher (Mich. State Univ.)

Date	Actual Attendance (where known)	Topic & Instructor
Oct. 30, 1967	Scientist-astronauts	2 hrs: **Communications**: by Arndt
Oct. 31, 1967	Scientist-astronauts	2 hrs: **Astronomy**: interstellar matter by R. Parker (MSC)
Oct. 31, 1967	Scientist-astronauts	2 hrs: **Earth Resources**: oceanography and relations to commercial fishing by Robert Stevenson
Nov. 2, 1967	Scientist-astronauts	2 hrs: **Life Sciences**: time study experiment: human factors applied to Apollo Program by E McLaughlin
Nov. 13-14	Scientist-astronauts	**Celestial Recognition Training**: Planetarium course at Morehead Planetarium, Chapel Hill, N. C. by Tony Jenzano
Nov. 15, 1967	Scientist-astronauts	2 hrs: **Astronomy**: optical studies of planets by B. O'Leary (MSC)
Nov. 15, 1967	Scientist-astronauts	2 hrs: **Life Sciences**: neurological system and psychological considerations of flight and long-term confinement by D. Flinn (UCLA)
Nov. 16, 1967	Scientist-astronauts	2 hrs: **Astronomy**: The Milky Way Galaxy by Bart Bok (Univ. Ariz.)
Nov. 22, 1967	Scientist-astronauts	2 hrs: **Space Science**: aeronomy, structure and composition of the neutral atmosphere, description and dynamics of the ionosphere by Owen Garriot (MSC)
Nov. 22, 1967	Scientist-astronauts	2 hrs: **Planetology**: U. S. and Soviet planetary probes by Ralph Miles (Caltech)
Nov. 27, 1967	Scientist-astronauts	2 hrs: **Planetology**: by Richard Jahns (Stanford)
Nov. 27, 1967	Scientist-astronauts	2 hrs: **Space Science**: solar physics, Structure, surface features, corona, chromosphere, and cycles by Bob Clayton (Rice Univ.)
Nov. 27, 1967	Scientist-astronauts	2 hrs: **Life Sciences**: vestibular system: description, function, response in space, Gemini results, Apollo plans by A. Graybiel (Naval Aviation Medical Center, Pensacola, Fla.)
Nov. 28, 1967	Scientist-astronauts	2 hrs: **Astronomy**: the exterior galaxies by Thornton Page (Wesleyan Univ., Conn.)
Nov. 28, 1967	Scientist-astronauts	2 hrs: **Planetology**: impacts and craters by Gene Shoemaker (US Geol. Surv.)
Nov. 29, 1967	Scientist-astronauts	2 hrs: **Astronomy**: stellar structure and evolution by M. Schwarzchild (Princeton)
Nov. 29, 1967	Scientist-astronauts	2 hrs: **Planetology**: by Jack Schmitt (MSC)
Nov. 30, 1967	Scientist-astronauts	2 hrs: **Astronomy**: stellar structure and evolution by M. Schwarzchild (Princeton)
Nov. 30, 1967	Scientist-astronauts	2 hrs: **Space Science**: solar physics: dynamics, solar activity and solar flares by Robert Noyes (Smithsonian Astrophysical Observatory)
Dec. 1, 1967	Scientist-astronauts	2 hrs: **Earth Resources**: oceanography by Charles Bates
Dec. 1, 1967	Scientist-astronauts	2 hrs: **Space Sciences**: solar physics by Robert Noyes (Smithsonian Astrophysical Observatory)
Dec. 4, 1967	Scientist-astronauts	2 hrs: **Space Science**: aeronomy measurements and experiments from satellites and other means by Owen Garriot (MSC)
Dec. 4, 1967	Scientist-astronauts	4 hrs: **Meteorology**: upper atmosphere structure and composition by Francis Johnson (Graduate Center of the Southwest, Dallas)
Dec. 6, 1967	Scientist-astronauts	2 hrs: **Planetology**: petrology by James Hays (Harvard)
Dec. 6, 1967	Scientist-astronauts	2 hrs: **Space Flight Dynamics**: by Chapman (MSC)
Dec. 7, 1967	Scientist-astronauts	2 hrs: **Planetology**: petrology by James Hays (Harvard)

Date	Actual Attendance (where known)	Topic & Instructor
Dec. 7, 1967	Scientist-astronauts	2.5 hrs: **Life Sciences**: visual system: description, relation to other senses, response in space by T. Duane (Jefferson Medical College, Philadelphia, PA)
Dec. 8, 1967	Scientist-astronauts	2.5 hrs: **Space Flight Dynamics**: by Chapman (MSC)
Dec. 11, 1967	Scientist-astronauts	2 hrs: **Planetology**: geophysics by Gene Simmons (MIT)
Dec. 11, 1967	Scientist-astronauts	2 hrs: **Planetology**: geomorphology by Robert Sharp (Caltech)
Dec. 11, 1967	Scientist-astronauts	2 hrs: **Flight Mechanics**: by Harm Buning (Univ. Michigan)
Dec. 12, 1967	Scientist-astronauts	2 hrs: **Planetology**: geophysics by Gene Simmons (MIT)
Dec. 12, 1967	Scientist-astronauts	2 hrs: **Planetology**: geomorphology by Robert Sharp (Caltech)
Dec. 12, 1967	Scientist-astronauts	2 hrs: **Flight Mechanics**: by Harm Buning (Univ. Michigan)
Dec. 13, 1967	Scientist-astronauts	2 hrs: **Planetology**: geophysics by Gene Simmons (MIT)
Dec. 13, 1967	Scientist-astronauts	2 hrs: **Planetology**: geomorphology by Robert Sharp (Caltech)
Dec. 13, 1967	Scientist-astronauts	2 hrs: **Flight Mechanics**: by Harm Buning (Univ. Michigan)
Dec. 14, 1967	Scientist-astronauts	4 hrs: **Planetology**: geomorphology by Gene Simmons (MIT)
Dec. 14, 1967	Scientist-astronauts	2 hrs: **Flight Mechanics**: by Harm Buning (Univ. Michigan)
Dec. 15, 1967	Scientist-astronauts	2 hrs: **Planetology**: geomorphology by Gene Simmons (MIT)
Dec. 15, 1967	Scientist-astronauts	2 hrs: **Flight Mechanics**: by Harm Buning (Univ. Michigan)
Dec. 18, 1967	Scientist-astronauts	2 hrs: **Planetology**: geochemistry by Paul Gast (Lamont Geological Observatory) and Lee Silver (Caltech)
Dec. 18, 1967	Scientist-astronauts	2 hrs: **Astronomy**: space astronomy: recent accomplishments in space astronomy by A Boggess (Goddard SFC)
Dec. 19, 1967	Scientist-astronauts	2 hrs: **Planetology**: geochemistry by Lee Silver (Caltech) and Paul Gast (Lamont Geological Observatory)
Dec. 19, 1967	Scientist-astronauts	2 hrs: **Astronomy**: future plans for space astronomy by K. Henize (MSC)
Feb. 5, 1968	Scientist-astronauts	2 hrs: **Meteorology**: oceanographic effects, interrelations of water masses and clouds by Dale Leipper (Texas A & M)
Feb. 5, 1968	Scientist-astronauts	2 hrs: **Biology**: definition of life, origin of life and terrestrial biology by Harold Morowitz (Yale) and Wolf Vishniac (Univ. Rochester)
Feb. 6, 1968	Scientist-astronauts	2 hrs: **Biology**: diversity, relation of structure and function, nutrition and metabolism, ecological niches by Wolf Vishniac (Univ. Rochester) and Harold Morowitz (Yale)
Feb. 6, 1968	Scientist-astronauts	3 hrs: **Earth Resources**: geology, hydrology and cartography by Wm. Fischer (US Geol. Surv.)
Feb. 7, 1968	Scientist-astronauts	2 hrs: **Biology**: ecosystems, ecological themes, biogeochemical cycles and environment by Harold Morowitz (Yale) and Wolf Vishniac (Univ. Rochester)
Feb. 8, 1968	Scientist-astronauts	4 hrs: **Biology**: ecological imbalance, infectious diseases, epidemics, infection interactions among organisms by Thomas Luckey (Univ. Missouri)
Feb. 9, 1968	Scientist-astronauts	4 hrs: **Earth Resources**: agriculture and forestry by Robert Coldwell
Feb. 12, 1968	Scientist-astronauts	2 hrs: **Meteorology**: cloud physics including structure and meteorological implications by Horace Byers (Texas A & M)
Feb. 19, 1968	Scientist-astronauts	2 hrs: **Meteorology**: description of troposphere to middle stratosphere by William Kellogg (NCAR)

Date	Actual Attendance (where known)	Topic & Instructor
Feb. 20, 1968	Scientist-astronauts	4 hrs: **Biology**: genesis of organic compounds, detection of organized elements and life forms, exobiology by Carl Sagan (Harvard Observatory) and Richard Young
Feb. 21, 1968	Scientist-astronauts	2 hrs: **Biology**: rationale for biological experiments in space by Carl Sagan (Harvard Observatory) and Richard Young
Feb. 21, 1968	Scientist-astronauts	2 hrs: **Astronomy**: radio galaxies, quasars, and observational cosmology by A. Sandage (Mt. Wilson Observatory)
Feb. 26, 1968	Scientist-astronauts	2 hrs: **Meteorology**: observing the atmosphere with satellites by Vern Suomi (Univ. Wisconsin)
Feb. 28, 1968	Scientist-astronauts	2 hrs: **Meteorology**: infrared measurements from satellites by Wm. Nordberg (Goddard SFC)
Mar. 25, 1968	Scientist-astronauts	5 hrs: **Planetology**: lunar mapping by Trask (USGS), photometry by Holt (USGS) and geology hand tools by Schmitt (MSC)

APPENDIX B: OUTLINE OF COURSE CONTENT:

FEBRUARY-JUNE, 1964 TRAINING PROGRAM

Course	Time (Hours)	Responsible Instructors
GEOLOGY (Terrestrial and Lunar) To be presented in six segments labeled Series I-VI.	58 in Series I	Dr. Dale Jackson, U.S. Geological Survey, Uel Clanton, Advanced Spacecraft Technology Div., MSC

GEOLOGY TRAINING SERIES I

PRINCIPLES OF TERRESTRIAL AND LUNAR GEOLOGY

1. Introduction
    a. Purpose and aims of astronaut training program in geology
    b. Content of the program
    c. Scope of geology

2. Geologic Processes
    a. Terrestrial processes
        i. Crustal movements
        ii. Igneous activity
        iii. Erosion and sedimentation
        iv. Metamorphism
        v. Impact processes
    b. Lunar processes – comparison with Earth
        i. Impact processes
        ii. Igneous activity
        iii. Crustal movement
        iv. Erosion

3. Geologic Principles
    a. Axioms involving time and space
        i. Law of uniformity
        ii. Law of superposition
        iii. Law of original horizontality
        iv. Law of truncation and intersection
    b. Geologic space
        i. Measurement of spatial arrangement
        ii. Correlation in space
        iii. Geologic maps
    c. Geologic time
        i. The concept of geologic time
        ii. Methods of measurement
            1. Relative
            2. Absolute
        iii. Correlation in time
        iv. The terrestrial time scale
        v. The lunar time scale
    d. The concept of geologic history
        i. History of the Grand Canyon area
        ii. History of the Archimedes area of the Moon

4. Stratified Rocks
    a. Stratigraphic principles – Earth and Moon

        i. Gravity and transport
        ii. The effects of presence or absence of an atmosphere
    b. Features of terrestrial stratified rocks
        i. Sedimentary rocks
            1. Features of bedded units
            2. Nature of constituent grains
        ii. Extrusive igneous rocks
            1. Features of bedded units
            2. Nature of constituent grains
        iii. Metamorphic rocks – Relict stratification
    c. Probable features of lunar stratified rocks
        i. Sedimentary rocks
        ii. Igneous rocks
        iii. Modifications by impact and radiation
        iv. Problems of observation and description on the lunar surface
    d. Field Trip: Field relations of stratified rocks

5. Structure & Landforms: Earth
    a. General principles
    b. Properties of earth materials
        i. Strength
        ii. Strain
        iii. Scale factors
    c. Intersection of rock units
        i. Truncation
        ii. Dislocation
        iii. Intrusion
    d. Relations between structural process and landforms
    e. Structures and landforms produced by crustal movement
        i. Folds
            1. General terminology
            2. Geometry of folds
            3. Types of folds
            4. Recognition of folding
        ii. Joints
        iii. Faults
            1. General terminology
            2. Movement on faults
            3. Types of faults
            4. Recognition of faulting
    f. Structures and landforms of igneous extrusions
        i. Dikes
        ii. Sills
        iii. Laccoliths
        iv. Batholiths
    g. Structures and landforms produced by igneous extrusions
        i. Volcanoes
            1. Icelandic type
            2. Hawaiian type
            3. Strombolian type
            4. Vulcanian type
            5. Pelean type
            6. Maars
        ii. Cones, craters, and calderas
        iii. Bodies of extrusive material
            1. Flows

        2. Ash falls
        3. Ash flows
        4. Welded tuffs
- h. Structures and landforms resulting from erosion and sedimentation
    - i. Unconformities
        1. Angular unconformities
        2. Parallel unconformities
    - ii. Mass movement
        1. Soil creep
        2. Slumps
        3. Talus
        4. Landslides
        5. Terrestrial erosional features
        6. Terrestrial sedimentary features
        7. Floodplains and deltas
        8. Alluvian fans
        9. Sedimentary basins
        10. Continental shelves
- i. Structures and landforms caused by impact and explosion
    - i. Nuclear craters
    - ii. Terrestrial impact features
- j. Landforms on an earth without an atmosphere

6. Structure & Landforms: Moon
    - a. Relations between structure and landforms on the lunar surface
    - b. Impact features
        - i. General features
            1. Rim
            2. Floor
            3. Walls
            4. Ejecta blankets
            5. Secondary craters
            6. Rays
        - ii. Distinguishing characteristics
        - iii. Distribution
        - iv. Age
    - c. The maria
        - i. The maria as impact basins
            1. Distribution
            2. Concentric scarps
            3. Radial structures
            4. Ejecta blankets
            5. Subsequent flooding
            6. Mare ridges
        - ii. Possible non-impact maria
    - d. Structures and landforms produced by crustal movements
        - i. Folds
        - ii. Faults
            1. Types of faults
            2. Evidence of faulting
        - iii. Other linear features
            1. Regional joints
            2. Straight rills

   e. Structures and landforms produced by igneous activity
      i. Types of features
         1. Domes
         2. Maars
         3. Rills and chain craters
         4. Calderas
      ii. Extrusive material
         1. Flows
         2. Ash falls
         3. Ash flows
   f. Structures and landforms caused by erosion
      i. Sinous rills
      ii. Mass movement
   g. Describing small structures on the lunar surface
   h. Field trip: Surface expression of structural features

7. Geologic Mapping
   a. Introduction
      i. Significance of geologic mapping
      ii. Principles of mapping
   b. Terrestrial maps
      i. The base
         1. Planimetric maps
         2. Aerial photographs
         3. Topographic maps
      ii. What to map
         1. Rock units
         2. Time-rock units
         3. Structures
         4. Other rock properties – geophysical and geochemical maps
      iii. Mapping methods
         1. Recognition of units
         2. The local section
         3. Problems of cover and correlation
         4. Recognition of structures
         5. Attitude: dip and strike
         6. Problems of intersecting structure and topology
      iv. Map interpretation
         1. Geologic map symbols
         2. Geologic sections
         3. Study of representative geologic time
   c. Lunar maps
      i. The base
         1. ACIC charts
         2. Kuiper atlas photographs
         3. Rectified photographs
         4. High resolution photographs
      ii. Lunar stratigraphic section
      iii. What to map
         1. By remote methods
         2. On the lunar surface
   d. Description vs. interpretation in geologic mapping
   e. Field trip – Geologic mapping
   f. Field Trip: Telescopic observation of the lunar surface

8. Geophysical Properties of the Earth & Moon
    a. Models of the Earth and the Moon
        i. Radius
        ii. Geosphere
        iii. Hydrosphere
        iv. Atmosphere
        v. Density
        vi. Other properties
    b. Terrestrial materials
        i. Crust
            1. Covering sediments
            2. Basement rocks
        ii. Interior
    c. Geophysical measurements
        i. Contrast and correlations with geological measurements
            1. Methods
            2. Models
        ii. Measurement of fields
            1. Linear and planar arrays
            2. Dynamic fields
            3. Static fields
            4. Noise limitation
            5. Instruments
    d. Geophysical mapping
        i. Local maps
        ii. Regional maps

9. Engineering Applications of Geology & Geophysics
    a. Properties of terrestrial materials
        i. Construction sites, foundations and tunnels
        ii. Groundwater, mineral resources, and geothermal energy
        iii. Terrain analysis
    b. Properties of lunar materials
        i. Lunar landing sites and bases
        ii. Potential sources of water, oxygen and minerals
        iii. Terrain analysis
    c. Engineering geologic and terrain maps

INTRODUCTION TO MINERALOGY AND PETROLOGY

1. Introduction
    a. Purpose
    b. Abundance of the elements
        i. Rock and mineral composition
        ii. Rock forming minerals
        iii. Economic minerals

2. Crystallography
    a. The crystalline state
    b. Elements of symmetry
        i. Planes of symmetry
        ii. Axes of symmetry
        iii. Center of symmetry
    c. Crystal systems
    d. Classes of symmetry
    e. Crystal lattices
        i. Geometry of lattices

        ii. Relation to crystal systems

3. Physical Mineralogy
    a. Physical properties
        i. Hardness
        ii. Cleavage, parting and fracture
        iii. Tenacity
        iv. Specific gravity
        v. Taste, odor and touch
        vi. Habit
    b. Properties dependent on light
        i. Luster
        ii. Color
        iii. Streak
        iv. Luminescence
    c. Electrical and magnetic properties

4. Chemistry of Minerals
    a. Bonding
    b. Coordination principles
    c. Composition variations and isomorphism
    d. Polymorphism
    e. Psuedomorphs

5. Classification of Minerals
    a. Chemical
    b. Structural

6. Introduction to Petrology
    a. Definitions and relations of major rock types
    b. The rock cycle
    c. Methods of studying rocks
        i. Field mapping
        ii. Hand specimens
        iii. Optical techniques
        iv. Chemical techniques

7. Igneous Rocks
    a. Magma
        i. Origin
        ii. Composition of primary magmas
        iii. Crystallization
            1. Phase relations
            2. Differentiation
            3. Rate of cooling
        iv. Migration of magmas
            1. Intrusion
            2. Extrusion
    b. Distribution of igneous rocks in time and space
    c. Petrographic provinces

    d. Classification of igneous rocks
        i. By mineralogy and texture
            1. Deep-seated intrusives
            2. Shallow intrusives
            3. Flows
            4. Pyroclastics
        ii. By chemical composition

8. Sedimentary Rocks
    a. Sedimentary processes
        i. Origin and composition of material
        ii. Transportation and sedimentation
        iii. Lithification
        iv. Cementation and crystallization
        v. Compaction and dessication
    b. Classification of sedimentary rocks
        i. Terrigenous sediments
            1. Composition
            2. Texture
        ii. Chemical sediments
            1. Orthochemical
            2. Allochemical
        iii. Composition
    c. Features of sedimentary rocks

9. Metamorphic Rocks
    a. Metamorphic processes
        i. Contact
        ii. Regional
        iii. Dislocation
    b. Classification of metamorphic rocks
        i. Parent rock
        ii. Mineral composition
        iii. Structure and texture
        iv. Chemical composition
        v. Metamorphic facies

10. Tektites & Meteorites
    a. Theories of origin
    b. Composition and texture
    c. Classification
        i. Siderites
        ii. Siderolites
        iii. Aerolites
        iv. Tektites

GEOLOGY TRAINING SERIES II

TERRESTRIAL AND LUNAR VOLCANOLOGY

Lecture Schedule (two hours each)

1. Review of volcanic process and terrestrial volcanic features
2. Silicic volcanoes, calderas, and ash flows
   Field Trip: Valles caldera, New Mexico
3. The eruption of Paracutin

4. Flood basalts
   Field Trip: Volcanic rocks of northern Oregon and Idaho
5. Inclusions in basaltic rocks
6. Hawaiian volcanoes
   Field Trip: Island of Hawaii
7. Maars
8. Lunar analogues of terrestrial volcanic features
9. Seminar on lunar volcanism
10. Experimental impact structures in rocks
11. Terrestrial explosion structures
    Field Trip: Nevada Test Site, Mercury, Nevada
12. Terrestrial impact structures
13. Lunar impact structures
    Field Trip: Meteor Crater, Arizona and Kitt Peak Observatory, Tucson, Arizona
14. Solid state effects in shocked rocks
15. Shock metamorphism
16. Crater density on the lunar surface

ADVANCED MINERALOGY AND PETROLOGY

Lecture and laboratory schedule (two-hours each)

1. Petrography laboratory
2. Petrography laboratory
3. Petrography laboratory
4. Geochemistry
5. Age Dating
6. Organic Matter in Rocks
7. Optical Mineralogy
8. Petrography laboratory
9. Petrography laboratory
10. Petrography laboratory
11. Iron and stony meteorites
12. Tektites and Micrometeorites
13. Special problems in lunar petrology
14. Sedimentary Rocks
15. Petrology laboratory
16. Petrology laboratory

GEOLOGY TRAINING SERIES III

GEOLOGY OF THE LUNAR SURFACE

Approximately 12 hours lecture, plus field trips for telescopic observation of the Moon. Structure, stratigraphy, composition, and historical geology of the lunar surface. Techniques and practice of lunar geologic and terrain maps.

LUNAR APPLICATIONS OF ENGINEERING GEOLOGY

Approximately 8 hours lecture, plus field trips and field demonstrations. Geological and geophysical techniques in engineering. Application of these techniques to problems on the lunar surface.

THEORY AND PRACTICE OF EXPLORATION GEOPHYSICS

Approximately 12 hours lecture, plus field trips and field demonstrations. Gravimetric, magnetic, elastic wave, and electrical theory and practice. Geophysical instruments.

GEOLOGY TRAINING SERIES IV AND V

SCIENTIFIC INSTRUMENTS

Instruction in technique and application of various laboratory instruments used to analyze and identify rock and mineral specimens (X-ray diffraction, X-ray fluorescence, differential thermal analysis, electron probe, infra-red spectrometer, gas chromatograph, etc.)

Instruction in the operation of prototype analytical instruments which will be included in the scientific instrument package for deployment on the lunar surface.

STUDIES OF FRAGMENTAL ROCKS

Lectures plus field trips. Discrimination of fragmental material of different origins. Volcanic tuffs and breccias, explosion products, tectonic breccias, impact products, spalling products, landslides, and talus.

THEORY AND PRACTICE OF ROCK SAMPLING

Lectures plus field trips. Practical sampling problems. Sampling for scientific and engineering purposes. Statistical sampling techniques in geology; the problem of cover. Special problems of lunar sampling. Sampling instruments.

ADVANCED FIELD TECHNIQUES

Lectures plus field trips. Detailed geologic mapping of small areas. Mapping on topographic and photographic bases; location. Oral descriptions of geologic features. Assessment of optimum geophysical techniques and their uses.

RECENT ADVANCES IN LUNAR GEOLOGY AND EXPLORATION TECHNIQUES

A series of short courses and seminars for systematic briefing on new knowledge gained from continued research and pre-Apollo missions. Additional other short background courses as required by these advances in knowledge.

GEOLOGY TRAINING SERIES VI

OPERATIONAL ASPECTS OF LUNAR EXPLORATION FOR MISSION PLANNING

Mission profiles with prototype scientific instruments performed under field conditions simulating time of stay, area covered and terrain of the lunar landing area.

OTHER SCIENCE TRAINING

FLIGHT MECHANICS: 40 hours by Dave Lang, Flight Crew Support Division, MSC

1. Mathematics Refresher
    a. Vector calculus
    b. Matrix algebra
2. Basic Particle Mechanics
    a. Newton's Law for a single particle
    b. Angular momentum theorem for a single particle
    c. Energy theorem for a single particle
    d. General central force field problem
        (1) Properties of motion
        (2) Inverse square central force field
            (a) Determination of characteristic motions
            (b) Various specific aspects and relations pertaining to orbital motion
3. Mechanics Of A System Of Particles
    a. Newton's Law
        (1) Linear momentum theorem
        (2) Angular momentum theorem
    b. Classical two-body problem
        (1) Determination of relative motions
        (2) Determination of inertial motions
    c. The classical three-body problem
    d. The classical N-body problem
4. Application Of Particle Mechanics To Specific Flight Situations
    a. Boost dynamics
        (1) Equations of motion simulating the boost phase of space vehicles
        (2) Design criteria for boost trajectories
    b. Orbital transfer and rendezvous
        (1) Evaluations of motion describing general orbital transfer
        (2) Various equations describing the relative motion at terminal rendezvous and docking
        (3) Energy considerations
    c. Reentry Dynamics
        (1) Equations of motion for simulating the reentry of a body with roll modulated lift (including ballistic reentry)
        (2) Reentry from near satellite and super satellite velocities
    d. Mechanics of Earth-Moon Flight
        (1) Restricted three-body problem
            (a) General equations of motion
            (b) Further restrictions implied by application to Earth-Moon system
            (c) Characteristics of Earth-Moon motion
        (2) Approximate solutions to Earth-Moon trajectories
        (3) Major perturbations which degrade the accuracy of restricted three-body problem solutions

ASTRONOMY: 15 hours by Dr. I. J. Prouse, University of Texas

1. Panoramic View Of The Visible And Known Part Of The Universe
2. Celestial Coordinate Systems
3. Constellations
4. Orientation Of Planets
5. Stellar Magnitudes
6. Earth As An Astronomical Body
    a. Dimensions
    b. Mass
    c. Triangulation

        - d. Principle of determination
- 7. Proof Of Sphericity, Rotation, And Revolution
- 8. Precession And Nutation
- 9. A Spherical Trigonometry Problem
- 10. Time
    - a. Intervals of time
    - b. Time at any instant
    - c. Standard and zone time
    - d. Transformation to another type of time
- 11. Light
    - a. Velocity, reflection, refraction, and dispersions
    - b. Electromagnetic radiation and Planck's radiation curve
    - c. Atmospheric absorption and transmission of light
- 12. Moon
    - a. Lunar statistics
    - b. Sidereal and synodic months
    - c. Motion and phases of the moon
- 13. Solar System
    - a. Distances of planets from sun - Bode's Law
    - b. Revolution of planets
    - c. Positions of planets relative to sun and earth
- 14. Planets And Their Satellites
- 15. Comets
- 16. Stars And Stellar Characteristics
- 17. Population Of The Milky Way

DIGITAL COMPUTERS: 12 hours by Dr. Robert Smith, Texas A & M Univ.

- 1. Problem Solving Procedure
- 2. Topics To Be Covered
- 3. Number Systems
    - a. Decimal
    - b. Binary
- 4. Computer Logic
    - a. Building Blocks
    - b. Boolean Algebra
    - c. Half Adder
    - d. Full Adder
- 5. Computer Form
    - a. Form
    - b. Input-Output Devices
    - c. Arithmetic
    - d. Memory
    - e. Logic
    - f. Buffering
    - g. Trapping
- 6. Stored Program
    - a. Instructions
    - b. Constants
    - c. Data
    - d. Instruction Arithmetic
- 7. Problem Solving
    - a. Statement of Problem
    - b. Numerical Analysis
    - c. Flow Chart
    - d. Code

    - e. Debug
    - f. Run
- 8. Programming Methods
    - a. Machine Language
    - b. Assembly Programs
    - c. Compilers
- 9. FORTRAN
    - a. Arithmetic Statement
    - b. Declarative Statement
    - c. Conditional Statement
    - d. Do Statement
    - e. Input-Output Statement
- 10. Sub-Routines
    - a. Linkage
    - b. Uses
- 11. Monitor
    - a. Concept
    - b. Compilation
    - c. Execution
    - d. Loader
- 12. Real Time Computing
    - a. Input
    - b. Interrupt
    - c. Priority
    - d. Control
    - e. Override
    - f. Output
- 13. Data Transmission

GEMINI ONBOARD COMPUTER: 24 hours by personnel from IBM and McDonnell Aircraft Corporation

- 1. Digital Computer (IBM)
    - a. Characteristics
        - (1) Memory
        - (2) Arithmetic
        - (3) Clock rates
        - (4) Inputs/Outputs
    - b. Central Computer Information Flow Diagram Analysis
    - c. Input-Output Instructions
        - (1) Clear and load discretes (CLD)
        - (2) Process input or output data (PRO)
    - d. Computer Interface Diagram Analysis
        - (1) Emphasis on MDIU/DCS Control
        - (2) Analysis of data inputs from radar, horizon sensor, and IGS
        - (3) Display outputs to attitude display group and IVI
        - (4) Miscellaneous interface
            - (a) Time reference system
            - (b) Launch vehicle
            - (c) Data acquisition system
    - e. Functional Block Diagram Analysis
        - (1) Prelaunch mode
            - (a) Computer loading/interface
            - (b) Executor and prelaunch routines
        - (2) Ascent mode
            - (a) Backup guidance function
            - (b) Abort check

        - (c) Orbital insertion
        - (d) Launch vehicle interface
      - (3) Catch-up mode
        - (a) Function
        - (b) IGS interface
        - (c) IVI interface
      - (4) Rendezvous mode
        - (a) Radar interface
    - (1) Range data
    - (2) Angle data
        - (b) IVI interface
      - (5) Touchdown predict
        - (a) Function
        - (b) Operational procedures
      - (1) Normal
      - (2) Override and re-initiate
      - (3) When time to retrofire is less than 512 seconds
      - (6) Reentry mode
        - (a) Operational procedures
        - (b) Time to retro sequence
        - (c) Down-range and cross-range error computations
        - (d) Roll rate command
      - (7) Correlation between computer modes and FDI presentation
    - f. Malfunction Detection
      - (1) Probable causes
      - (2) Astronaut's corrective action
      - (3) Malfunction detection circuit analysis
- 2. Operational Sequence (MAC)
    - a. Prelaunch
      - (1) Computer loading
      - (2) Countdown procedures
      - (3) Platform alignment
      - (4) Equipment checkout
      - (5) Targeting
    - b. Ascent
      - (1) Lift-off discrete
      - (2) Roll sequence
      - (3) Pitch program
      - (4) Velocity updates
      - (5) Staging
      - (6) Pitch steering
      - (7) Yaw steering
      - (8) Switch-over smoothing
      - (9) Sustainer cut-off
      - (10) Post-separation velocity correction
    - c. Orbit Control
      - (1) Power down
      - (2) Attitude control
      - (3) IGS power up
      - (4) IMU alignment
    - d. Catch UP
      - (1) Ground commands
        - (a) Voice
        - (b) DCS
      - (2) IVI inputs
      - (3) Maneuvering control

- e. Rendezvous
  - (1) Radar acquisition
  - (2) Data collection
  - (3) Maneuver estimates
  - (4) Initial maneuver
  - (5) Intermediate maneuvers
  - (6) Braking maneuver
  - (7) Agena commands
- f. Retrograde Prediction
  - (1) Ground updates
  - (2) Touchdown prediction
  - (3) Mapping
  - (4) Reentry initialization
- g. Reentry
  - (1) Retrograde control
  - (2) Gain changes at separation
  - (3) Post-retro control
  - (4) Navigation
  - (5) Range prediction
  - (6) Bank angle control
  - (7) Flight director bias
  - (8) Full lift at 80 K
  - (9) Fuel jettison

ROCKET PROPULSION SYSTEMS: 12hours by C. Yodzis, Propulsion and Energy Systems Division, MSC

1. Physics of Rocket Propulsion
   - a. Equations defining stage performance
   - b. Theoretical optimization of stages
   - c. Trajectory losses
   - d. Rocket engine performance
   - e. Solid propellant grain design
2. Ablative Material Chambers
   - a. Materials and fabrication techniques
   - b. Chamber and nozzle form
   - c. Ablative design considerations
3. Thrust Chamber Design Considerations - Combustion Instability
4. Injector Design
5. Propellant Pressurization Systems
6. Propellant Systems

AERODYNAMICS: 8 hours by Paul Kramer, Flight Crew Support Division, MSC

1. Newtonian Flow Theory, Including Gemini And Apollo
2. Reentry Configurations
3. Reentry Performance
   - a. Entry corridor
   - b. Footprint
   - c. Lift modulation
4. Spacecraft Heating
   - a. Causes
   - b. Heating environment
   - c. Heat protection

5. Launch Vehicle Aerodynamics
    a. Wind induced oscillation on launch pad
    b. Typical launch aerodynamic time history
    c. Pressure distribution and wind profiles

PHYSICS OF THE UPPER ATMOSPHERE AND SPACE: 12 hours by Lunar and Planetary Laboratory, Tucson, Ariz.

1. Solar Activity; Electron Density Of The Interplanetary Medium; Radiation Belts Of The Earth
2. Aurorae And Airglow
3. Particles In The Interplanetary Medium And Earth's Upper Atmosphere; Zodiacal Light; Counterglow; Meteors And Meteorites
4. The Earth's Upper Atmosphere - Exosphere And Ionosphere
5. Chemical Reactions In The Upper Atmosphere; The Ozonosphere
6. Tides And Circulations In The Upper Atmosphere

GUIDANCE AND NAVIGATION: 34 hours by personnel from MIT and AC Spark Plug

1. Apollo Navigation Technique (MIT)
2. Introduction Of G & N System
3. G & N System Description
4. G & N System Operations
    a. Preflight checkout and alignment
    b. IMU alignment
    c. Optical measurements
    d. Attitude control of spacecraft
    e. Velocity correction
5. Inertial Subsystem Mechanizations
    a. IMU structure
    b. Navigation base
    c. Axes
    d. Temperature control
    e. Stabilization loops
    f. Gyro caging
    g. Accelerometer loops
    h. Coupling display units
    i. Modes of operation
    j. Power supplies
    k. Display and control panels
    l. Signal monitoring and detection
    m. Power and servo assembly
6. Optical Subsystem Mechanization
    a. Telescope
    b. Sextant
    c. Modes of operation
    d. Integrating and positioning loops
    e. Power supplies
    f. Display and control panels
7. Computer Subsystem Organization

COMMUNICATIONS: 8 hours by J. Painter, Ground Support Project Office, MSC

1. Basic Communications Concepts
    a. Energy Propagation
    b. Noise
    c. Frequency spectra

    - d. Modulation
    - e. Antenna Theory
2. Radio Ranging (Radar)
    - a. Basic types
    - b. Theory
3. Radio Telemetry
    - a. Multiplexing
4. Gemini Telecommunications Systems (Spacecraft And Ground System)
    - a. Description
    - b. Limitations
5. Apollo Telecommunications Systems (Spacecraft And Ground System)
    - a. Modified Gemini System
    - b. Deep Space System
    - c. Performance Considerations
    - d. Limitations

MEDICAL ASPECTS OF SPACE FLIGHT: 12 hours by Dr. C. Berry, Center Medical Operations Office, MSC

1. Introduction: Normal Environmental Envelope
2. Theory of Homeostatic Mechanisms
3. Respiration and Cardiology
4. Normal Physiology and Physiology as Altered by Space Environment
5. Physiology of Vision and Ear, Nose. And Throat
6. Disorientation and Vertigo
7. Neuromuscular and Skeletal System
8. G.I. System and Nutrition
9. Urinary System and Fluid Balance
10. Acceleration and Weightlessness
11. Vibration
12. Radiation
13. Bioinstrumentation: Present and Future

GLOBAL METEOROLOGY: 4 hours by Kenneth Nagler, U.S. Weather Bureau

1. Meteorological Conditions Affecting Space Flight Operations
2. Weather As Observed From Above
    - a. Weather systems
    - b. Observations of interest to meteorology

APPENDIX C: BOOKS AND SUPPLIES FOR GEOLOGY TRAINING OF ASTRONAUTS, 1964

FIELD EQUIPMENT

Nomenclature

Quantity	Nomenclature
50	Hand lens, Hastings 10X, Cooper-Trent, Wilson Blvd. & Danville St., Arlington, Va.
35	Brunton, Pocket Transit #6620, (Azimuth), without case, Eugene Dietzgen Co., 5600 2nd St. N.E., Washington, D.C.
35	Pocket Transit Case for Brunton, leather, Roy Gfeller, Big Timber, Montana
35	Carriers, leather, for geologic hammer, Roy Gfeller, Big Timber, Montana
50	Hammer - Stanley 24 oz. pickpoint, Stanley Tool Co.
35	Stereoscopes, single prism, Mechanical Technology Co., Inc., 5821 Seminary Road, Bailey Crossroads, Virginia
35	Cases for above, same source
10	Stereoscopes, Riker-type, Kinsman Optical Co., 1320 F St. N.W., Washington, D.C.
35	Rucksacks - small, with frame, Bergens Model 27, USGS, Branch of Service & Supply, Denver Federal Center, Denver, Colorado, 80225
35	Canteens - military type with cover, Surplus Sales, Co., 925 Pennsylvania Ave. N.W., Washington, D.C.
35	Notebooks - 5 1/4 x 8 ½, USGS, Branch of Service & Supply, Denver Federal Center, Denver, Colorado, 80225
35	Cases, notebook – leather, same source as above
50	Magnets, horseshoe, Ward's Natural Science Inc., P.O. Box 1712, Rochester 3, N.Y.
50	Scales, 1:24,000 - 6" wood, General Services Administration, Federal Supply Center, Denver, Colorado
50	Scales, 1:62,500 - 6" wood, same source as above
50	Protractors, 4" semi-circular transparent, Frederich Post & Co., 1830 Jefferson Place N.W., Washington, D.C.
50	Triangle 30°-60°, 4" transparent, same source as above
1,000	Sample bags,Ward's C2020
35	Sand grain-size kits, pocket clip, USGS, Branch of Service and Supply, Acorn Bldg., Eastern Ave. & Newell St., Silver Spring, Md.
35	Rock Color Charts, Geological Society of America, 419 W. 117th St., New York 27, N.Y.
35	Sleeping bags, Eddie Bauer, Washington
Also tents, lanterns, cooking gear, plates, and eating utensils, etc for camping on field trips	

TEACHING SUPPLIES

Quantity	Nomenclature
1 set	C4710, Plastic relief maps of USGS quads - Ward's
1 set	Geomorphological models, C4695 - Ward's
2 units	Nega file units - C884a - Ward's
1 unit	Nega file units - C884c - Ward's
1 set	Faulting Demonstration Models, C4700 - Ward's
1 set	Faulting Demonstration Models, C4702 - Ward's
1	Slated Globe, C4757 - Ward's
5	Kuiper Lunar Atlas, Loose Leaf - University of Chicago Press, Chicago, Ill
2	Globe of Moon - Adler Planetarium, Chicago
368	Color slides of geologic features for lectures - from various sources
137	Photographs of geologic features for classroom use
75	Maps and charts of the moon

BOOKS

Quantity	Nomenclature
5	*Sedimentary Rocks*, Pettijohn, F.J., Harper & Bros., N.Y.
35	*Glossary of Geology* (abridged paperback, edition of AGI Glossary), American Geologic Institute, Anchor Doubleday, 1963
5	*Fabric of Geology,* Albritton, Claude C., ed., Addison, Wesley Publishing Co., Reading, Mass, 1963
5	*Erosion and Sedimentation,* Termier, H., and Termier, G., trans. by Humphries, D. and Humphries, E.D. Van Norstrand Co., Princeton, N.Y., 1963
5	*Crust of the Earth*, Geol. Soc. Amer. Spec. Paper 62, Poldervaart, A., ed., Geologic Soc. of America, 1955
35	*The Moon - Symposium No. 14 of the International Astro. Union,* Kopal, Z. and Mikhailov, Z.K., eds., Academic Press, 1963
16	*Physics and Astronomy of the Moon,* Kopal, Z., ed., Academic Press, 1961
5	*Face of the Moon*, Baldwin, R.B., University of Chicago Press, 1949
35	*Measure of the Moon*, Baldwin, R.B., University of Chicago Press, 1963
5	*The Solar System*, v.3, Kuiper, G.P., ed., University of Chicago Press, 1961
35	*The Solar System*, v.4, Kuiper, G.P., ed., University of Chicago Press, 1963
5	*The Moon,* Markov, N.P., ed., University of Chicago Press, 1962
5	*Introduction to Geophysical Prospecting*, 2nd ed., Dobrin, M.D., McGraw-Hill, 1960
5	*Principles of Engineering Geology and Geotechniques,* Krynine, P.D. and Judd, W.R., McGraw-Hill, 1957
5	*Sequence in Layered Rocks,* Shrock, R.R., McGraw-Hill, 1948
35	*Volcanoes in History, in Theory, in Eruption*, Bullard, F.M., University of Texas
35	*Textbook of Geology*, Garrels, R.M., Harper, 1951
16	*Principles of Geology, 2nd ed.,* Gilluly, J., Waters, A.C., and Woodford, A.O., W.H. Freeman, 1959
16	*Structures of the Moon's Surface,* Fielder, G., Pergamon, 1961
5	*Glossary of Geology and Related Sciences, with supplement, 2nd ed.,* American Geological Institute, 1960
16	*Orthographic Atlas of the Moon, Parts I and II,* Kuiper, G.P., ed., University of Arizona Press, 1961
5	*Earth Science Manual, Parts I and II,* Tuttle, S.D.,Wm. C. Brown, 1958
10	*Geological Map Symbols Data Sheets 1, 2, 3, 20,* American Geological Institute
35	*Outline of the Principles of Geology,* Field, R.M, Barnes and Noble, 1951
	Volcanoes as Landscape Forms, Cotton, C.A., Wiley, 1952

APPENDIX D: EVALUATION FORM FOR FIRST SET OF GEOLOGY TRAINING

QUESTIONNAIRE ON ASTRONAUT - GEOLOGY COURSES

To date the first two courses in geology are about two-thirds complete. These are:

a. Principles of Geology
Instructors: Chidester, USGS
Jackson, USGS
Wilhelms, USGS

b. Mineralogy and Petrology
Instructors: Foss, NASA
Clanton, NASA
King, NASA

In order to plan the second set of courses certain information on the level of instruction and course material is needed now. Please indicate your feelings on these two courses to date and the instructors on the attached questionnaire.

Where applicable use the following key:

E = Excellent G = Good F = Fair P = Poor

(signed) John M. Eggleston
Assistant Chief for Space Environment

Enclosure

CONCURRENCE: (signed) Donald K. Slayton
Assistant Director for Flight Crew Operations

COURSE MATERIAL:

1. Do the courses follow a logical sequence?
Principles Mineralogy/Petrology
Too Slow, Just Right, Too Fast Too Slow, Just Right, Too Fast

2. Are the courses keyed to your level of comprehension and interest?
Principles Mineralogy/Petrology
Too Slow, Just Right, Too Fast Too Slow, Just Right, Too Fast

3. Do you see a need for the information being presented?
Principles Mineralogy/Petrology

INSTRUCTOR:

1. Is the instructor effective in his presentation?

Chidester Clanton Foss Jackson King Wilhelms

2. Does the instructor present the lecture in a clear and concise manner?

Chidester Clanton Foss Jackson King Wilhelms

3. Does the instructor answer questions from the class adequately?

Chidester Clanton Foss Jackson King Wilhelms

4. Does the instructor talk to the class or does he talk to the blackboard or floor?

Chidester Clanton Foss Jackson King Wilhelms

5. Does the instructor keep the course interesting?

Chidester Clanton Foss Jackson King Wilhelms

6. Are there any mannerisms by an instructor that distract attention from the presentation?

Chidester Clanton Foss Jackson King Wilhelms

ILLUSTRATIONS:

Blackboard:
1. Do the diagrams, sketches and other drawings illustrate the feature proposed or does the information have to be inferred?

Chidester Clanton Foss Jackson King Wilhelms

2. Are the illustrations explained in an acceptable manner?

Chidester Clanton Foss Jackson King Wilhelms

Slides and Movies:
1. Do the projected illustrations show the data, information, structure, and/or feature or must the instructor explain in detail which cannot be seen?

Chidester Clanton Foss Jackson King Wilhelms

2. Do the projected illustrations contribute to the presentation or do they act only as fillers to lengthen the presentation?

Chidester Clanton Foss Jackson King Wilhelms

OUTSIDE READING ASSIGNMENTS:

1. How well have the outside reading assignments contributed to your understanding of the courses?

Principles	Mineralogy/Petrology

2. Are the outside reading assignments too long for the time you have available?

Principles		Mineralogy/Petrology	
Yes	No	Yes	No

3. What percentage of the assigned outside readings have you done?

Principles	Mineralogy/Petrology
%	%

4. Have all of the outside reading assignments been of equal value to you or should the assignments be more selective?

Principles	Mineralogy/Petrology
Equal Value	Equal Value
More Selective	More Selective

FIELD TRIPS:

1. Has the lecture adequately prepared you for the field trips?
   a. Yes
   b. Should have additional information

2. What is your opinion of the usefulness of the field trips?
   a. Grand Canyon
   b. W. Texas

3. What level of instruction did you receive during the field trip by your instructor?
   a. Grand Canyon Instructor _______________
   b. W. Texas Instructor _______________

4. If time were available should the second course have:
   a. Same number of field trips?
   b. Same number of field trips but of longer duration?
   c. More field trips but of the same duration?
   d. Less field trips?

What is your overall impression of the "Principles" course?

What recommendations do you have for improving the presentation?

What is your overall impression of the "Mineralogy/Petrology" course?

What recommendations do you have for improving the presentation?

APPENDIX E: GEOLOGY FIELD EXERCISES: EARLY TRAINING

Field Training Schedule for the first 3 Groups of Astronauts (29)

Phase I of Geology Training

March 5-6, 1964 **Grand Canyon, Arizona** Aldrin, Anders, Armstrong, Bassett, Bean, Carpenter, Cernan, Chaffee, Collins, Cunningham, Eisele, Freeman, Gordon, Schweikart, Scott, See, Shepard, Williams

Fundamental geologic stratigraphic concepts of geology such as: layering, superposition, ages, structures. Mainly show and tell with questions. Led by Grand Canyon Expert Ed McKee (USGS). Other geologists present: Jackson, Milton, Wilhelms, and Chidester of USGS and Foss, Clanton, and King of NASA. The trip was preceded by a briefing in Houston using geologic maps and aerial photos of the Grand Canyon. On the 1st day in the field everybody walked down the Kaibab trail in groups of 2 or 3 astronauts with a geologist. The entire sequence of rocks is well exposed from top to bottom of the canyon and provides excellent examples of many different rock types and basic geologic principles. The geologist accompanying each group of astronauts described and discussed geologic features, history, rock types and processes on the way down. All of the geologic units were located on geologic maps and aerial photos as the descent was made into the canyon thereby providing the astronauts with the experience of locating oneself on topographic maps and aerial photos. 2nd day-The astronauts and geologists went up the Bright Angel Trail in the same groups as they had come down the day before. Students were asked to identify and discuss the units in the perspective of the previous day's observations.

Mar. 12-13, 1964 **Grand Canyon, Arizona** Borman, Conrad, Cooper, Grissom, Lovell, McDivitt, Schirra, Slayton, Stafford, Young, White

Geologists: Jackson, Chidester, McCauley of USGS and Foss and Clanton of NASA

Same procedure as previous trip on March 5-6.

April 2-3, 1964 **Big Bend-Marathon, TX** Aldrin, Anders, Bassett, Bean, Borman, Cernan, Chaffee, Collins, Cooper, Cunningham, Eisele, Freeman, Gordon, Schweikart, Scott, Shepard, Williams, Young

Another basic geology study for interpretation and mapping of well exposed structural and stratigraphic relationships. Also included was an introduction to volcanic rocks along the Rio Grande River west of Big Bend National Park. The trip was led by local expert Bill Muehlburger (Univ. of Texas). Other geologists present: Jackson, Milton, Wilhelms, and Chidester of USGS and Foss and Clanton of NASA. As on the Grand Canyon trip 2 or 3 astronauts were assigned to a geologist. The first day started with an overflight of the area in a NASA Gulfstream learning to describe geological features from the air. Following the overflight they traversed the observed geology on the ground and mapped 2 folded and faulted structures on aerial photos. These exercises included all of the major types of structures: an anticline, a syncline, a normal fault, a reverse fault, and a strike-slip fault. They then went to a field area along the same structural trend to see if they could observe similar rock-types and structures to determine if they could project the same features that had been mapped on the aerial photos. On the second day there were 4 stops in the show-and-tell manner. Two at road cuts of layered volcanic lavas and ash flows , a third at Bee Mountain to study an igneous intrusion, and a fourth at Santa Elena Canyon to study a large fault scarp. Radios were used to communicate between the cars thereby allowing discussion of the geology while on the move.

Apr. 15-16, 1964 **Big Bend-Marathon, TX**Armstrong, Carpenter, Conrad, Lovell, McDivitt, Schirra, See, Stafford, White

Geologists: Muehlberger, Swann, Chidester, Foss, E. King

Same procedure as previous trip on April 2-3.

April 30-May 2, **Flagstaff, Arizona** Aldrin, Anders, Bassett, Bean, Borman, Cernan, Chaffee 1964
Kitt Peak Observ. Collins, Cunningham, Eisele, Freeman, Gordon, McDivitt,
Schweikart, Scott, See, Williams

The astronauts were split into three groups of six astronauts that alternated through three separate exercises: 1. largely show and tell of volcanic features such as lava flows, maars, cinder cones, and spatter cones in the vicinity of Sunset crater and the Bonita lava flow led by Dale Jackson and Al Chidester (USGS). The use of geologic maps and aerial photos to locate oneself and geologic features was stressed again as in the two previous trips. 2. fly-overs of the same features as well as Meteor crater to get the orbital perspective. They used two four-place aircraft in which either Gene Shoemaker or Jack McCauley (USGS) led the observations. 3. at Kitt Peak the solar telescope was used at night to project images of the lunar surface for observation and discussion led by Spence Titley (Univ. Ariz.), Don Wilhelms, Jack McCauley, and Hal Masursky (USGS).

May20-22, 1964 **Flagstaff, Arizona** Armstrong, Carpenter, Conrad, Cooper, Grissom, Lovell,
Kitt Peak Observ. Shepard, Shirra, Slayton, Stafford, White, Young

This trip followed the same procedure as the previous trip on April 30-May 2 except there were only two groups of six astronauts. The geology personnel were also the same except that Clanton (MSC) was also on this trip.

June 3-6, 1964 **Philmont Ranch,** Aldrin, Anders, Armstrong, Bassett, Bean, Cernan, Chaffee,
New Mexico Collins, Conrad, Cooper, Cunningham, Eisele, Freeman,
Gordon, Lovell, Schweikart, Scott, See, White, Williams

This trip involved more complex geology that was more difficult to follow than in previous locations; more like typical geologic problems and probably more like lunar geology. It included both igneous and sedimentary rocks, orientation with geologic maps, measuring and describing stratigraphic sections, strike and dip measurements, and recording of field notes. The local expert was Dr. G. D. Robinson (USGS) who had just finished a report on the geology of the area. Other geologists present: Jackson, Milton, Wilhelms, Pillmore, Swann, Johnson, Gill, Watkins, and Chidester of USGS and Foss, Clanton, and King of NASA. Divided into two astronauts per geology instructor for 3 days. One day spent sketching, describing and defining the exposures on Slate Hill where a section of marine sediments is overlain by continental sediments. Note-taking and section measurements were emphasized. A second day was spent on two parallel traverses trying to correlate vertically dipping sedimentary units faulted against older metamorphic rocks all of which are overlain by volcanic flows. Mapping of the units, dip and strike measurements and note-taking were emphasized. Half of a third day was spent mapping a dike and sill that cut into shale. The other half was spent on geophysical traverses that included taking measurements with magnetometers, gravimeters and seismometers in an attempt to determine subsurface structure under the instruction of Gordon Bath, Marty Kane and Joel Watkins, all of the USGS. On the fourth and final day the entire group traveled by car and made several stops at significant geologic exposures for brief discussions. The trip finished at noon.

Start of Phase II of Geology Training

October 7-9 **Newberry Crater,** Cernan, Chaffee, Collins, Schweikart, Scott
Bend, Oregon

Oct 15-17, 1964 **Newberry Crater,** Aldrin, Armstrong, Bassett, Bean, Cunningham, See, Williams
Bend, Oregon

A third running of this trip for the remaining astronauts was canceled because of the death of one of the astronauts (Freeman) in an airplane crash on Oct. 31, 1964.

The major objective of this trip was to observe, analyze and discuss various volcanic features in the vicinity of Newbury Crater, a large (50x30 mile) shield volcano. This is a complex of nested craters with an extreme range of differentiated volcanic rocks, obsidian flows, pumice cones, cinder cones and tuff rings. Aaron Waters of the

University of California was the local expert. Other geologists present: Jackson, Milton, Wilhelms, Snavely, and Chidester of USGS and Foss, Clanton, and King of NASA. The first day was spent on cinder cones, lava flows, ash flows, and a lava tube at several locations. The origins, time sequences, compositions, and flow mechanisms were discussed at each location. The second day commenced with a lecture by Waters on the formation of Newbury Crater. The remainder of the day was spent in and around the 5-mile diameter crater viewing and discussing pumice cones, a pumice plain, obsidian flows, and an overall view of the crater from the highest point on the rim. The third day was spent at Hole-in-the-Ground, a crater of 5,000ft diameter whose origin might be either volcanic or impact. Traverses were made across the crater with the objective of gathering data that would prove one origin or the other. The final stop of the third day was at Fort Rock to observe a ring of rock formed by development of a cinder cone eruption under lake water rather that in air.

October 23-25, **Valles Caldera, N. M.** Aldrin, Anders, Bean, Chaffee, Collins, Freeman, Williams

Oct. 29-31, 1964 & Armstrong, Bassett, Cernan, Cunningham, Gordon, Scott, See

Nov. 13-14, 1964 Eisele, Schweikart

The primary objective of this trip was to view the typical characteristics of ash flow tuffs and another caldera, the 25x35 km Valles caldera in the Jemez Mountains of New Mexico, whose history is somewhat different from that seen at Newbury Caldera. The local experts were Roy Bailey, Bob Smith, R. Doell, and L. Cordell of the U.S. Geological Survey. Bailey has spent 15 years studying the area. Other geologists present: Clanton, Foss of MSC; Chidester, Watkins and Wilhelms of USGS. The first day commenced with a discussion by Bailey of the probable reason for the location and volcanic activity that produced the caldera. The remainder of the day was spent inside the caldera at various roadcuts and vantage points observing and discussing rhyolite domes, pumice air falls, doming at the center of the caldera, comparison of the different types of volcanic materials, geophysical characteristics, and active sulfur springs. The second day included a briefing on welding and crystallization in ash flows. The group then made close inspections of several ash flows with different degrees of welding and crystallization. Comparisons with the features seen at the Newberry Volcano in Oregon were discussed.

Jan. 11-15, 1965 **Hawaii** Aldrin, Bean, Chaffee, Conrad, Eisele, Gordon, Scott, Williams

Jan. 18-23, 1965 **Hawaii** Anders, Armstrong, Bassett, Collins, Cunningham, Schweikart, See

Incomparable display of recent basaltic volcanic features. Fresh, recent, and ancient lava-flow surfaces could be compared and related to possible lunar surface features. Howard Powers, Director of the USGS Hawaii Volcano Observatory and J. P. Eaton, Willy Kinoshita, Dallas Peck, Dave Hill, Jim Moore (USGS) were the local experts. Other geologists present Chidester, Jackson, Wilhelms, and Kane of USGS, Foss, Clanton, Richardson, and King of MSC. The first day consisted of a bus trip to several volcanic features including lava tree molds, gas and lava vents, spatter ramparts and cones, flank eruptions of aa and pahoehoe flows, fissure eruptions and beach sands of eroded lava. The second day included foot and bus traverses to observe lava tubes, lava lakes, lava blisters, Pele's tears and hair, Halemaumau fire pit, and pit craters. In the evening a briefing utilized photos of the lunar surface that were analogous to features seen during the past 2 days. The third day started with fly-overs in a 12-passenger aircraft to observe the volcanic features from the air. During the afternoon a lecture was given on the various geophysical measurements that are used to keep track of volcanic activity and determine the structure of the subsurface volcanoes. On the 4th day the crews were taken to the saddle area between Muana Loa and Muana Kea where problems were posed by the geologists for the crews to solve. They then went to the summit of Muana Loa for a view of the summit crater and its features. The 5th day included only a half day which was spent investigating "cored bombs", lava-covered crystalline rocks from either the Earth's mantle or from chambers in which the lava had crystallized and settled.

Feb. 17-18 **Nevada Test Site** Aldrin, Anders, Armstrong, Gordon, Schweikart, Scott

24-25, 1965 Bassett, Bean, Cernan, Collins, Cunningham, Eisele, Williams

March 3-4, 1965 Chaffee, See

First experience with non-volcanic craters to help prepare for the study of impact craters. This allowed a view of craters that were produced by a force more similar to the impacts that were thought to produce many of the lunar craters. In addition, the NTS is in a volcanic complex, the Timber Mountain Caldera, thereby allowing for a study of volcanic features next to the nuclear craters. Local experts were Will Carr, K. Sargent, D. Cickey, R. Hazelwood, G. Bath, and Bob Christiansen (USGS). Other geologists present: Wilhelms, Moore, Shoemaker, Watkins, Regan, and Chidester (USGS), Foss (MSC). This trip provided an opportunity to examine in detail the craters and ejecta formed by detonation of subsurface nuclear devices in lavas and unconsolidated sediments. Use of aerial photos for interpretation of the ejecta was introduced. Gravity and magnetics training and observation of seismic experiments were included.

April 22-23, 1965 **Meteor Crater, Arizona** Anders, Bassett, Cernan, Chaffee, Collins, Cunningham, Eisele, Gordon, Schweikart, Scott, Williams

This was the first experience with the detailed rocks and structures of a real impact crater led by local expert Gene Shoemaker (USGS). Other geologists present: Clanton (MSC), Chidester, Swann, Schmitt, O'Connor (USGS). A half day tour through the crater introduced the crews to overturned units at the crater rim, surrounding ejecta deposits, and fallback units. Astronauts were then required to recognize and document these features by mapping them on aerial photographs. They also participated in a seismic examination of the crater floor.

Phase III of Geology Training

June 28-July2, 1965 **Katmai, Alaska** Aldrin, Anders, Bassett, Bean, Cernan, Chaffee, Cunningham, Schweikart, Scott, Williams

Explosive eruptions in 1912 deposited silica-rich pumice and ash over a large area in the Valley of Ten Thousand Smokes in an eruption of 1912. Therefore, there is well documented historic data on the eruption. Furthermore, subsequent stream erosion has cut deep gorges through the deposits allowing study and interpretation of details in vertical sections. The summit of Katmai collapsed by 1500 feet during the eruption. Fumaroles and vents formed in the hot ash flows and evidence for these was studied. The volcanic features are quite fresh and offer an excellent opportunity to view volcanic materials and landforms in nearly pristine condition. The group stayed at a fishing lodge and utilized helicopters from the military Air-Sea rescue group stationed nearby (see letter offering this support). Leader: Bob Smith and Garniss Curtis (USGS). Other geologists present: Clanton, McKay, Foss, Richardson (MSC), Wilhelms, Chidester, Stephens, McCord (USGS) This was the first of several exercises that were meant to be the start of simulations of lunar missions. This was known as "playing the Moon game" in which astronauts were divided into pairs, placed in a field location with very little prior information about the area, and pretended that they were on the moon. They also had to plan traverses and collect important and representative samples from the areas. The astronauts were equipped with radios by which they communicated with their geologist instructors. These communications were recorded and later discussed for comparison with the interpretations of the field trip leader and to improve the procedures for good communications between astronauts and scientists.

July 12-16, 1965 **Iceland** Anders, Bassett, Bean, Cernan, Chaffee, Cunningham, Eisele, Schweikart, Scott, Williams

Beautiful volcanic geology with practically no vegetation cover. Features include calderas, ash cones, steaming volcanic vents, cinders, pumice, various types of lava flows. Probably the most moon-like of the field areas. Leaders: Sigurdur Thorarinsson and Gudmundar Sigvaldson. Other geologists present: Clanton, Foss (MSC), Chidester, Wilhelms, Stephens, Lee (USGS). The "Moon game" described on the previous trip was utilized in some of the training. The geologic observations made by the astronauts around the edge of Askje Caldera produced a revision in the interpretation by Icelandic geologists of the origin of some of the units erupted from the caldera.

Sept. 1-3, 1965 **Medicine Lake, Calif.** Anders, Bean, Schweikart, Chaffee

Sept. 8-10, 1965 **Medicine Lake, Calif.** Bassett, Cunningham, Williams

2nd group returned after the 8th because of a hurricane warning in Houston

The Medicine Lake Highlands include an 8 km. eroded caldera in a large volcanic area with volcanic flows and obsidian domes. Local expert was Aaron Waters (Univ. Calif.) for the 1st trip and Charles A. Anderson (USGS) for the 2nd trip. Other geologists present: Clanton, Foss, King (MSC) Wilhelms, Chidester (USGS). Also on this trip were two MSC photographers, Don Beattie and Dick Allenby from NASA Headquarters and three USGS persons for logistical support. The "Moon game" and some independent mapping were included in the 1st and 2nd days of training. The 3rd day consisted of a half day tour of the regional geology.

Sept. 21-24, 1965 **Zuni Salt Lake, N. M**. Anders, Bean, Cunningham, Schweikart

Geologists present: Clanton, Foss (MSC) Chidester (USGS). Large volcanic crater with structurally complex rim material. Geophysical exercises were conducted and the astronauts helped lay out the traverses and used geophysical instruments to gather data and interpret the results.

Nov. 8-10, 1965 **Pinacates, Mexico** Anders, Cunningham, Schweikart, Williams

Volcanic area with explosive craters and subsidence along ring fractures. Dick Jahns (Stanford Univ.) was the local expert. Other geologists present: Foss, Clanton, McKay (MSC), Chidester, Swann, Brock (USGS).

Dec. 27-29, 1965 **Pinacates & Zuni** Make-up trips for Bassett, Cernan, Chaffee.

Field Training Schedule for the 4th and 5th Groups of Astronauts (24)

Phase I of Geology training

June 2-3, 1966 **Grand Canyon, Arizona** Brand, Bull, Carr, Duke, Engle, Evans, Haise, Irwin, Lind, Lousma, Mattingly, Michel, Mitchell, Pogue, Roosa, Swigert, Weitz, Worden

Led by Grand Canyon Expert Ed McKee. Other geologists present: Foss, Clanton and McKay from MSC; Brock, Chidester, Swann, and Schleicher from USGS. See field trip of March 5-6, 1964 for details. A make-up trip was held later in June for astronauts Garriot, Gibson, Givens, Kerwin, McCandless and Schmitt some of whom were in flight training at the time of the first trip.

June 23-24, 1966 **West Texas** Brand, Bull, Carr, Duke, Engle, Evans, Givens, Haise, Irwin, Kerwin, Lind, Lousma, Mattingly, McCandless, Michel, Mitchell, Pogue, Roosa, Schmitt, Swigert, Weitz, Worden

Led by local expert Bill Muehlberger. Other geologists present: Foss, Clanton and McKay from MSC; Chidester, Hait, Swann, from USGS. See field trip of April 2-3, 1964 for details.

July 27-29, 1966 **Bend, Oregon** Brand, Bull, Carr, Duke, Engle, Evans, Garriot, Givens, Haise, Irwin, Kerwin, Lind, Lousma, Mattingly, McCandless, Michel, Mitchell, Pogue, Roosa, Swigert, Weitz, Worden

Aaron Waters of the University of California was the local expert. Other geologists present: Foss, Clanton and McKay from MSC; Chidester, Brock, Dahlem of USGS. See field trip of October 7-9, 1964 for details.

Aug. 21-25, 1966 **Katmai, Alaska** Brand, Bull, Carr, Duke, Engle, Evans, Garriot, Gibson, Givens, Haise, Irwin, Kerwin, Lind, Lousma, Mattingly, McCandless, Michel, Mitchell, Pogue, Roosa, Schmitt, Swigert, Weitz, Worden

Geologists present: Foss, Clanton and McKay from MSC; Chidester, Kane, Shoemaker, Smith, Bailey of USGS and Waters of the Univ. of Calif. Others: Rhoder, Zedekar and Ream of MSC. See field trip of June 29-July 2, 1965 for details.

Sept. 25, 1966 **Valles Caldera, New Mexico** Brand, Bull, Carr, Duke, Engle, Evans, Garriot, Gibson, Givens, Haise, Irwin, Kerwin, Lind, Lousma, Mattingly, McCandless, Michel, Mitchell, Pogue, Roosa, Schmitt, Swigert, Weitz, Worden

Geologists present: Foss, Clanton and McKay from MSC; Chidester, Hait, Swann, and Smith of USGS See field trip of October 23-25, 1964 for details.

Nov. 29-Dec. 2, 1966 **Pinacates, Mexico** Brand, Bull, Carr, Duke, Evans, Gibson, Givens, Haise, Irwin, Lind, Lousma, Mattingly, Michel, Mitchell, Pogue, Roosa, Schmitt, Swigert, Weitz, Worden

Local expert: R. Jahns of Stanford Univ. Other geologists present: Foss, Clanton, Laidley, and McKay from MSC; Chidester, Kane, Swann, Ulrich, Masursky, Bailey, Regan, Rust, Mills, Begay of USGS; and Waters of the Univ. of Calif. Others present: Jack Riley, Ray Zedekar, Vic Rhoder, Charles Nelms and Jack Eggleston of MSC; Don Beattie of NASA Hdqtrs. The astronauts were divided into groups of two or three accompanied by one or two geologists. See field trip of Nov. 8-10, 1965 for details.

Feb. 12-19, 1967 **Hawaii** Bull, Carr, Duke, Engle, Evans, Garriot, Gibson, Haise, Irwin, Lousma, Mattingly, McCandless, Michel, Mitchell, Pogue, Worden

Howard Powers, Director of the USGS Hawaii Volcano Observatory was the local expert. Other geologists present: Foss, Clanton, and McKay from MSC; Chidester, Swann, Brock, Kinoshita, Eaton, Fiske, Kane, Rust, Wright of USGS. Others present Bob Workman and Jack Ottinger of MSC. See field trip of Jan. 19-24, 1965 for details.

Mar. 16-17, 1967 **Pinacates, Mexico** Make-up trip for Engle, Garriott, Kerwin, McCandless

Geologists present: Chidester, Swann, Regan, Ulrich, and Kane from USGS. See earlier trip of Nov. 29-Dec. 2, 1966

March 20-24, 1967 **Hawaii** Make-up trip for Brand, Kerwin, Lind, Roosa, Schmitt, Swigert, Weitz,

Geologists present: Dietrich and McEwen of MSC; Shoemaker of USGS. See earlier trip of Feb. 12-19, 1967

May 16-19, 1967 **Zuni Salt Lake, Hopi Buttes & Meteor Crater, Arizona** Brand, Carr, Duke, Evans, Garriot, Gibson, Haise, Irwin, Kerwin, Lind, Lousma, Mattingly, McCandless, Michel, Mitchell, Roosa, Swigert, Weitz, Worden

Geologists present: Local Experts Cummings and Shoemaker: Clanton, McKay, McEwen, Laidley of MSC; Chidester, Cummings, Dahlem, James, Karlstrom, Sutton of USGS; Waters of the Univ. of Calif. See field trip of Sept. 21-24, 1965 and April 22-23, 1965 for details.

May 31-June 2, 1967 **Zuni etc**. Make-up trip for Bull, Engle, Evans, Givens, Pogue

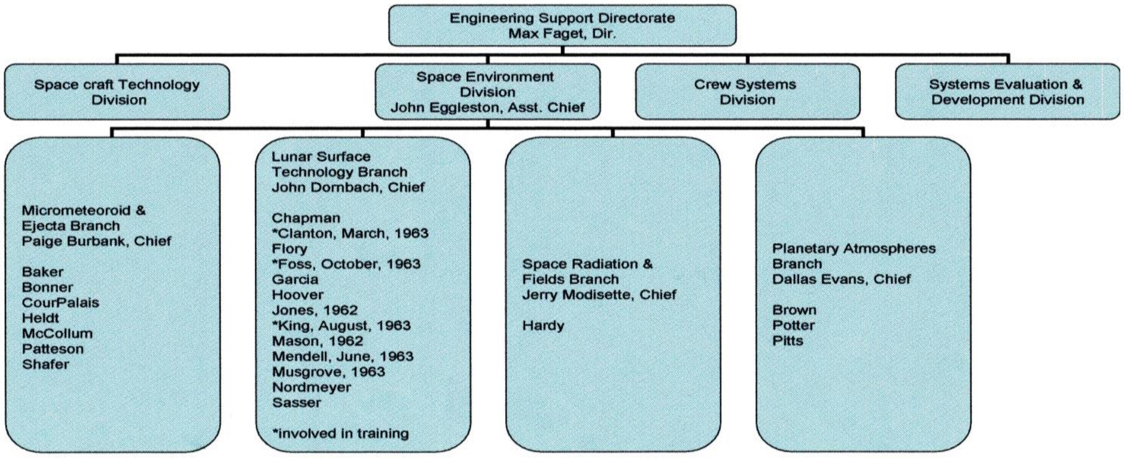
June 25-27, 1967 **Medicine Lake, Calif.** Brand, Carr, Duke, Engle, Evans, Garriott, Gibson, Haise,
Irwin, Kerwin, Lind, Lousma, Mattingly, McCandless
Michel, Mitchell, Pogue, Roosa, Schmitt, Swigert, Weitz, Worden.
See trip of Sept. 1-3, 1965 for details.

July 2-8, 1967 **Iceland** Anders, Armstrong, Brand, Carr, Duke, Engle, Evans, Garriot
Gibson, Haise, Irwin, Kerwin, Lind, Lousma, Mattingly,
McCandless, Michel, Mitchell, Pogue, Roosa, Schmitt,
Swigert, Weitz, Worden

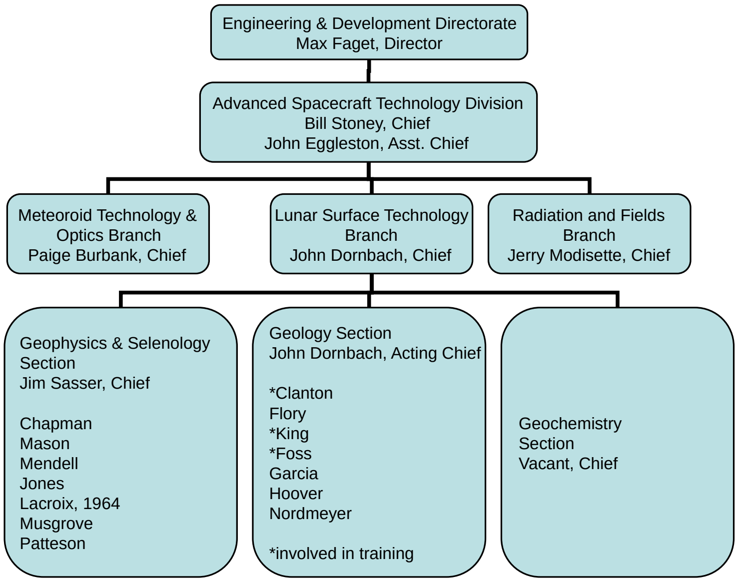
Leaders: Sigurdur Thorarinsson and Gudmundar Sigvaldson. Other geologists present: Clanton, Foss, McKay, Laidley (MSC), Chidester, Kane, Stephens, Lee, McCauley, Schleicher (USGS). Others: Rhoder, Riley, Nelms of MSC. See field trip of July 12-16, 1965 for details.

APPENDIX F: ORGANIZATIONAL CHARTS FOR SCIENCE TRAINING AT MSC: 1963-1970

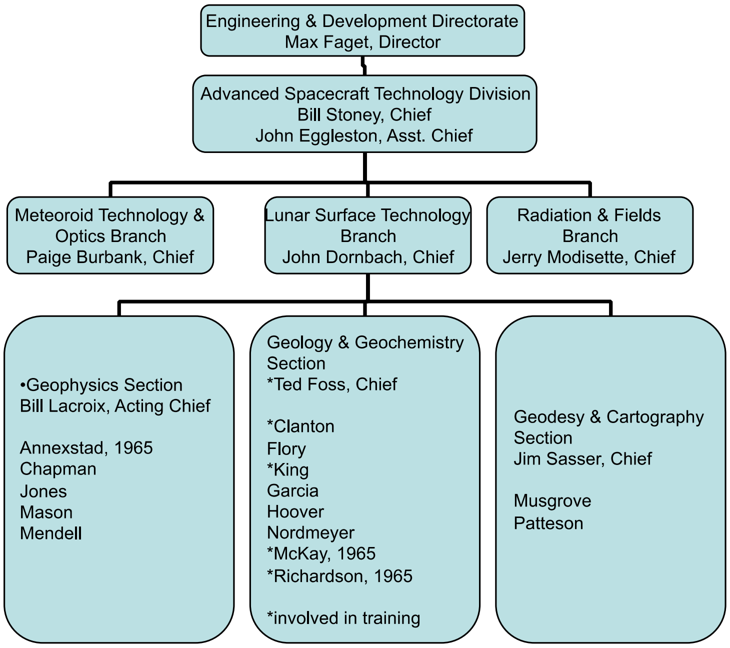
1963 MSC ORGANIZATION RELEVANT TO ASTRONAUT TRAINING



LATE 1964 MSC ORGANIZATION RELEVANT TO ASTRONAUT TRAINING



LATE 1965 MSC ORGANIZATION RELEVANT TO ASTRONAUT TRAINING



Engineering & Development Directorate
Max Faget, Director

Advanced Spacecraft Technology Division
Bill Stoney, Chief
John Eggleston, Asst. Chief

Meteoroid Technology & Optics Branch
Paige Burbank, Chief

Lunar Surface Technology Branch
John Dornbach, Chief

Radiation & Fields Branch
Jerry Modisette, Chief

•Geophysics Section
Bill Lacroix, Acting Chief

Annexstad, 1965
Chapman
Jones
Mason
Mendell

Geology & Geochemistry Section
*Ted Foss, Chief

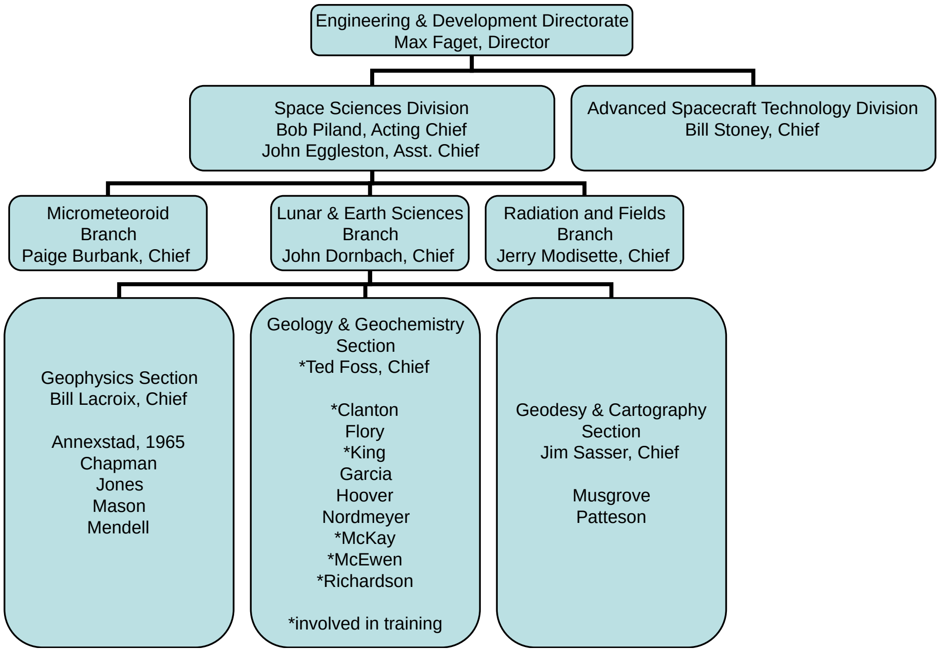
*Clanton
Flory
*King
Garcia
Hoover
Nordmeyer
*McKay, 1965
*Richardson, 1965

*involved in training

Geodesy & Cartography Section
Jim Sasser, Chief

Musgrove
Patteson

APRIL 1966 MSC ORGANIZATION RELEVANT TO ASTRONAUT TRAINING



Engineering & Development Directorate
Max Faget, Director

Space Sciences Division
Bob Piland, Acting Chief
John Eggleston, Asst. Chief

Advanced Spacecraft Technology Division
Bill Stoney, Chief

Micrometeoroid Branch
Paige Burbank, Chief

Lunar & Earth Sciences Branch
John Dornbach, Chief

Radiation and Fields Branch
Jerry Modisette, Chief

Geophysics Section
Bill Lacroix, Chief

Annexstad, 1965
Chapman
Jones
Mason
Mendell

Geology & Geochemistry Section
*Ted Foss, Chief

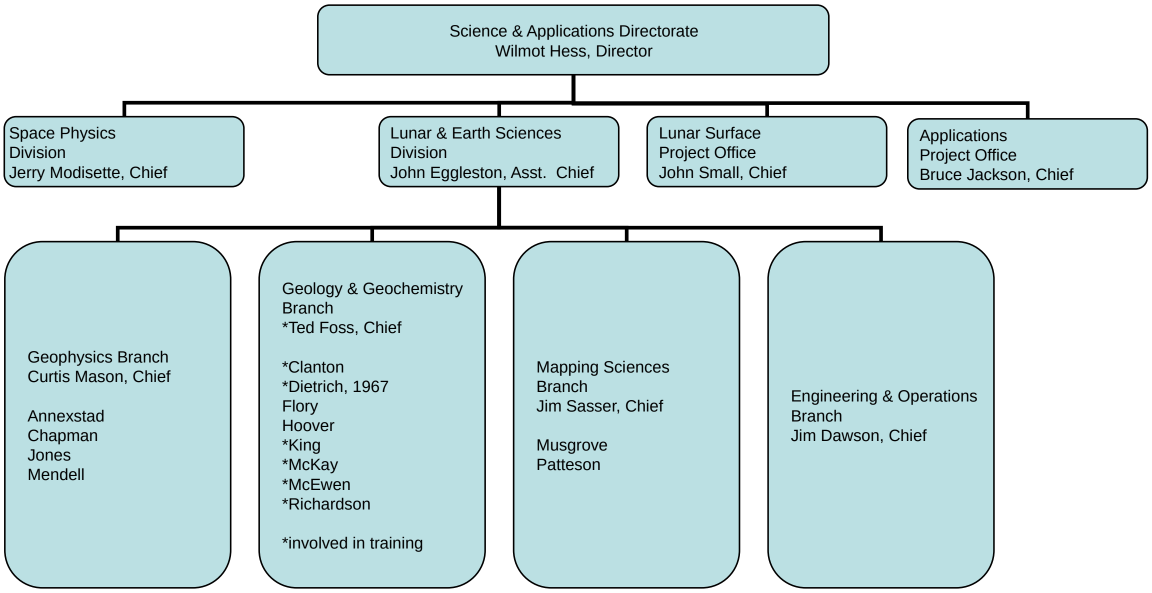
*Clanton
Flory
*King
Garcia
Hoover
Nordmeyer
*McKay
*McEwen
*Richardson

*involved in training

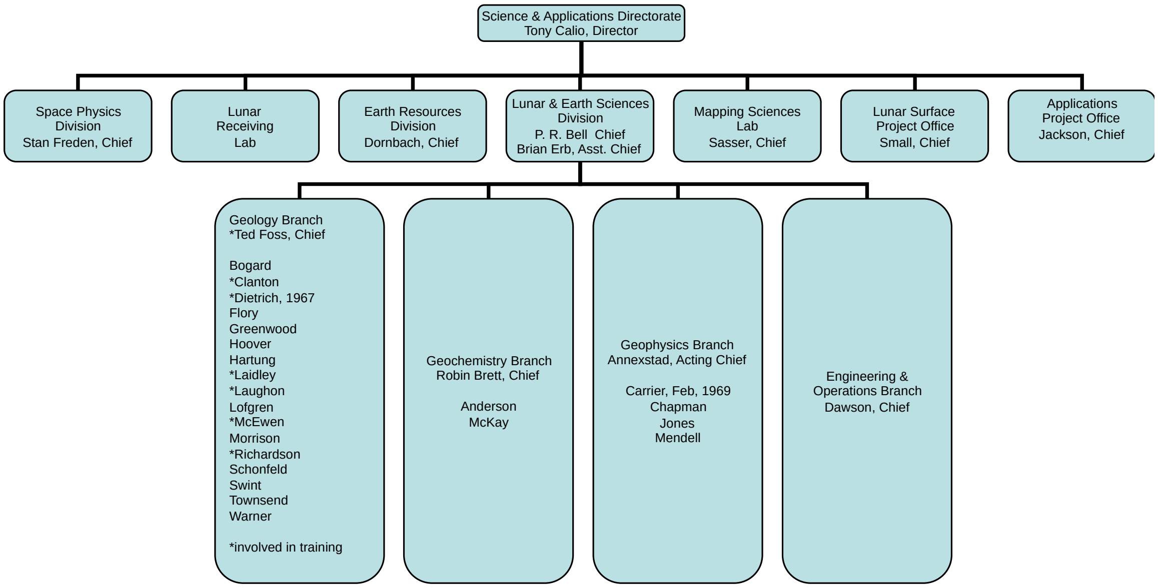
Geodesy & Cartography Section
Jim Sasser, Chief

Musgrove
Patteson

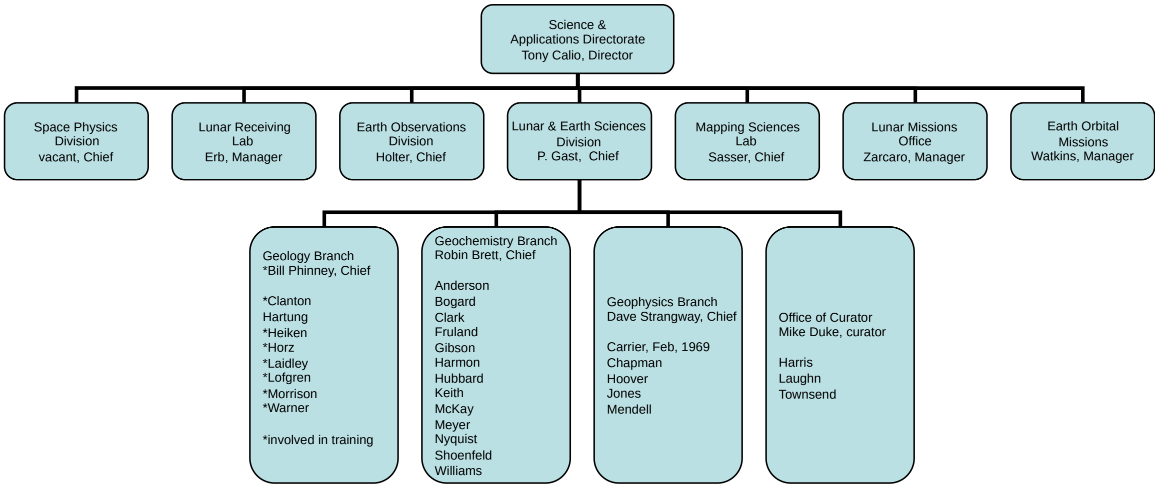
JANUARY 1967 MSC ORGANIZATION RELEVANT TO ASTRONAUT TRAINING



AUGUST 1969 MSC ORGANIZATION RELEVANT TO ASTRONAUT TRAINING



NOVEMBER 1970 MSC ORGANIZATION RELEVANT TO ASTRONAUT TRAINING



APPENDIX G: SCIENCE EXPERIMENTS ON THE APOLLO MISSIONS

ALSEP/EASEP INSTRUMENTS		11	12	13	14	15	16	17
S-031	Passive Seismic Experiment	x	x	x	x	x	x	
S-033	Active Seismic Experiment				x		x	
S-034	Lunar Surface Magnetometer		x			x	x	
S-035	Medium Energy Solar Wind Spectrometer					x		
S-036	Suprathermal Ion Detector		x		x	x		
S-037	Heat Flow Experiment		x			x	x	
S-038	Charged Particle Lunar Environment			x	x			
S-058	Cold Cathode Ion Gauge		x		x	x		
S-078	Laser Ranging Retroreflector	x			x	x		
S-202	Lunar Ejecta and Meteorites							x
S-203	Lunar Seismic Profiling							x
S-205	Lunar Atmospheric Composition							x
S-207	Lunar Surface Gravimeter							x
M-515	Lunar Dust Detector	x	x	x	x	x		

SURFACE EXPERIMENTS		11	12	13	14	15	16	17
S-059	Lunar Field Geology	x	x	x	x	x	x	x
S-080	Solar Wind Composition		x			x	x	
S-152	Lunar Surface Cosmic Ray Experiment						x	x
S-198	Portable Magnetometer				x		x	
S-199	Lunar Gravity Traverse							x
S-200	Soil Mechanics	x	x	x	x	x	x	x
S-201	Far-UV Camera/Spectrograph						x	
S-204	Surface Electrical Properties						x	
S-299	Lunar Neutron Flux Probe							x

ORBITAL EXPERIMENTS		11	12	13	14	15	16	17
S-158	Multispectral Photography		x				x	
S-160	Gamma-ray Spectrometer					x	x	x
S-161	X-ray Fluorescence Spectrometer					x	x	x
S-162	Alpha-particle Spectrometer					x	x	
S-164	S-band Transponder (Command Module/Lunar Module)			x	x	x	x	x
S-165	Mass Spectrometer					x	x	
S-169	Far-ultraviolet Spectrometer							x
S-170	Bistatic Radar			x	x	x	x	x
S-171	Infrared Scanning Radiometer							x
S-176	Apollo Window Meteoroid				x	x	x	x
S-177	Ultraviolet Photography-Earth/Moon				x	x	x	
S-178	Gegenschein from Lunar Orbit			x	x	x		
S-209	Lunar Sounder							x
	Laser Altimeter					x	x	x
	Metric Mapping Camera					x	x	x
	Panoramic Camera					x	x	x
	Handheld Hasselblad Camera Photography	x	x	x	x	x	x	x
S-164	S-Band Transponder (sub-satellite)					x	x	
S-173	Particle Shadows/Boundary Particles (subsatellite)					x	x	
S-174	Magnetometer (subsatellite)					x	x	

APPENDIX H: EQUIPMENT REQUIRED FOR APOLLO FIELD TRAINING

4 "RCU" Mount Camera Holders
4 Retractable Tethers
4 Electric Hasselblad Cameras
4 Bracket/Handle Trigger Sets for Cameras
4 Collection Bags (2 SRC Type, 2 Extra Type)
2 Pr. Tongs
2 Adjustable Scoop
2 Tool Extension
2 Gnomon
6 Core Tubes and Caps (+ rammer)
2 Hammer
16 Film Magazines
20 Sets of 20 Sample Bags
4 PLSS Mockup
1 Rake
2 LM Sampling Tools
1 16mm DAC with 2 or 3 magazines
1 Hand Tool Carrier
2 Special Environmental Sample Containers
4 Wrist Mirror
4 Belts
1 500 mm Camera
2 FM Transceivers
8 VOX Portable FM Transceivers
8 Ni-Cd Batteries
2 Portable Antenna (20 ft)
2 Tape Recorders
2 Rover-Type Vehicles

APPENDIX I: GEOLOGY FIELD EXERCISES FOR APOLLO MISSIONS

APOLLO 8 (Originally Apollo 9)

Feb. 13-14, 1968 **Big Bend, Texas** Astronauts: Borman, Lovell, Anders, Armstrong, Aldrin, Haise, Collins, Schmitt
Geologists: Clanton, McKay, Laughon, Dietrich, and Hait

This was a refresher course that emphasized rock identification and interpretation of field relationships in the Big Bend National Park. The crews used aerial photos to plan geology traverses and carried out the traverses collecting samples, taking photos, and giving verbal descriptions.

APOLLO 11

Feb. 24, 1969 **Sierra Blanco, Texas** Astronauts: Armstrong, Aldrin, Swigert, Schmitt
Geologists: Clanton, Dietrich, Foss, Laidley, McKay, McEwen

This is a volcanic center with a wide variety of volcanic rocks.

Feb. 24: The exercises consisted of one short stop and three different traverses, one of the traverses was the so-called ‘broken gate’ area, another one was the ‘sand dune’ area, and the third was the so-called '50-foot circle' reflecting the possibility that the crew might move in only a 50-foot, or maybe 100-foot radius, from the LM. In the first two locations the astronauts were to locate themselves on aerial photographs, photograph and sample a suite of representative samples from a gravelly stream bed and surrounding surface, and, using tape recorders and VOX microphones, describe the geology of the area and the samples that they collected. They were also to infer how the samples might be related to the observed volcanic stratigraphy in the surrounding Quitman Mountains.

Leave El Paso at 7:45 am and arrive at field area at 9:00 am.

Exercise 1 was a two-hour walk-through of the Broken Gate area with the geologists illustrating what should be observed, how it should be described, and what should be sampled.

Exercise 2 was a short stop of about 15 minutes to observe some vertical exposures related to Exercise 1. This allowed a third dimensional view of the geology.

Exercise 3 was similar to Exercise 1 except the astronauts did the observing, describing, photographing, and collecting during a three-hour traverse using hand tools, sample bags, cameras, and maps.

Exercise 4 was similar to Exercise 3 but with time limited to 1 ½ hours and space restricted to a 50-foot circle as might be the case during a lunar EVA. Also the area was “salted” with a few different rocks that had not been seen on the earlier exercises.

Depart field area for El Paso at 5:30 pm.

Feb. 25: **Note: A Feb. 25th show and tell exercise at Kilbourne Hole, New Mexico to acquaint the crews with maar deposits, tuff breccias, and xenoliths as well as stratigraphy and structures of volcanic and non-volcanic rocks is mentioned by Bob Sutton in his personal recollections written in 1975 but did not occur according to Clanton and others involved in this exercise. Sutton was probably recalling a later trip with either the 12 or 14 crew.**

APOLLO 12

March 13, 1969 **Quitman Mountains, TX** Astronauts: Conrad, Bean, Gibson
Geologists: Clanton, Laughon

This trip was to the same area as the Apollo 11 trip and consisted of the same four exercises. The Quitman Mountains consist of an old, partially eroded volcanic complex. The exercises were conducted on an alluvial outwash fan at the edge of the mountains.

March 13: Clanton and Laughon had flown to El Paso on March 10 with field gear and cameras to pick up vehicles and confirm the traverse arrangements. On the morning of March 13 they met Conrad, Bean, and Gibson at a small dirt landing strip near Terlingua, a few miles west of Big Bend National Park. The astronauts had flown there in a twin-engine Beechcraft from Houston. The group of five arrived at the field area about 9:00 am and followed the same schedule of exercises as the Apollo 11 crew. The astronauts were returned to the landing strip at about 5:00 pm for their return flight to Houston.

Exercise 2 was a short stop of about 15 minutes to observe some vertical exposures related to Exercise 1. This allowed a third dimensional view of the geology.

Exercise 3 was similar to Exercise 1 except the astronauts did the observing, describing, photographing, and collecting during a three-hour traverse using hand tools, sample bags, cameras, and maps.

Exercise 4 was similar to Exercise 3 but with time limited to 1 ½ hours and space restricted to a 50-foot circle as might be the case during a lunar EVA. Also the area was "salted" with a few different rocks that had not been seen on the earlier exercises.

Depart field area for El Paso at 5:30 pm.

April 9, 1969 **Kilbourne Hole, N. M.** Astronauts: Conrad, Bean, Gibson, Carr, Irwin, Schmitt
Geologists : Clanton, McEwen, Laughon, McKay, Richardson, Wolfe

This is a volcanic area with maar deposits, tuff breccias, and xenoliths with well developed stratigraphy and structures of both volcanic and non-volcanic rocks. Part of the problem here was to determine origin and age relations of the different units. There were three exercises conducted here.

Depart El Paso at 7:15 am and arrive at field area at 8:30 am. Exercise 1 was a one-hour walk-through at Hunt's Hole with geologists pointing out the pertinent geologic features, illustrating what should be observed and how it should be described. An example of a LM description was provided by one of the geologists.

Exercise 2 was similar to Exercise 1 at Kilbourne's Hole 1 with the astronauts doing the observing, describing, photographing, and collecting during a 2 ½ hour traverse using tools, sample bags, cameras, and maps. The exercise started with LM description. A similar three-hour traverse was conducted after lunch at Kilbourne's Hole.

Exercise 3 allowed the astronauts to pick and plan a 1 ½ hour traverse to follow as they were going to deploy the ALSEP and return from the deployment. Further, the astronauts decided what geology tasks they would conduct going to, and returning from, the deployment. These tasks were carried out following the practiced procedures.

May 1-2, 1969 **Big Bend, Texas** Astronauts: Conrad, Bean, Gibson
Geologists: Clanton, Wolfe, Laughon

May 1: Exercise 4 was a four-hour traverse at 3-Dike Hill and emphasized the field relationships between lava flows, ash falls, dikes, and gravels. Procedures and equipment were the same as previous exercise.

Exercise 5 was a simulated EVA of 2 ½ hours duration using the sampling and photographic procedures of the Lunar Surface Geology Experiment.

May 2: Exercise 1, near Lajitas, was to observe relationships between ash flows, ash falls, and lava flows during a two-hour traverse.

Exercise 2 was a two-hour walk-through of a gravel-covered area with geologists illustrating observations, descriptions, and sampling.

Exercise 3 was a simulated EVA of three hours duration using the sampling and photographic procedures of the Lunar Surface Geology Experiment. There was a backroom with Capcom in radio communication with the astronauts who used the tools, sample bags, cameras, and maps that were replicas of those to be used on the actual mission.

The trip concluded with a short lecture on ash flow/ash fall eruptions and observations on caldera features.

July 10, 1969 **Meteor Crater, Arizona** Astronauts: Bean
Geologists: Clanton, Wolfe

Aug. 9-11, 1969 **Hawaii** Astronauts: Conrad, Bean Gibson, Scott, Irwin, Schmitt
Geologists: Clanton, Laughon, Wolfe, Crosland

Aug. 9: Tour of recent eruption sites in vicinity of Kilauea Iki by Crosland

Aug. 10: Traverses in Kilauea Iki area (2 exercises: 1st in am, 2nd in pm) (dead trees, ash cinders, collapse features) with similar procedures and equipment as previous day. Astronaut Schmitt was in back room with Capcom. The exercises started with LM descriptions followed by traverses using the standard sampling and photographic procedures with tools, sample bags, cameras, and maps. The traverses were designed by the crew based on their observations from the LM windows. At the end of the LM description the crew provided the backroom with the directions and landmarks that they planned to use for the traverses. A discussion between the backroom and the crew followed in which the geologic features and objectives were outlined along the proposed traverse. Backroom with Capcom and geologists was in radio contact with the crews as they described their observations and reported sample bag numbers and photo frame numbers during the traverses.

Aug. 11: Traverses in Kapoho area (2 exercises: 1st in am, 2nd in pm). Equipment and procedures for the exercises were similar to those of the preceding day.

Oct. 9-10, 1969 **Sunset Crater, Arizona** Astronauts: Conrad, Bean, Gordon, Scott, Irwin, Gibson, Lind
Geologists: Clanton, Wolfe

Oct. 9: The day was spent as a familiarization exercise and dry-run by Gibson and Lind for the CapComs in preparation for the activities involving the crew on the following day.

Oct 10: Morning was spent discussing cratering mechanics and the use of craters to solve geologic problems with the crews. Also reviewed were sampling and photo techniques and verbal descriptions. A walk-through of the traverse was conducted before lunch. A debrief of the walk-through was conducted during lunch. The afternoon was spent in a two-hour "shirtsleeve" geology traverse that was meant to simulate a lunar traverse including voice communication with Mission Control in Houston. The Science Support Room in Mission Control was staffed by the same team that was to be on duty during the mission.

APOLLO 13

Mid-Sept., 1969 **Orocopias, California** Astronauts: Lovell, Haise, Young, Duke, Schmitt
Geologists: Silver and Grad Asst. Tom Anderson

This was a "geology boot camp" as Chaiken describes it (Chaiken, p393-394). The Orocopia Mountains are nearly devoid of vegetation thereby displaying excellent examples of geologic structures and strata. From a valley location Silver started the exercise by asking the astronauts, one by one, to pretend that they were looking out the window of the LM and describe what they saw. For 7 days Silver coaxed and prodded them to collect and describe representative sets of samples, describe sequences of rock layers, and verbally sketch the structures that they were observing. The primary objective was to teach non-geologists how to geologically describe and sample an area that they were exploring for the first time.

1st day: Field lab on the outcrops to learn how to observe and describe the physical, structural, and mineral characteristics of crystalline and sedimentary rocks. Use of these field observations to address larger regional geologic problems was discussed in order to illustrate how this would apply to later exercises during the week.

2nd day: Introduction to local rock types and how to observe and describe a detailed rock sequence. This included a 2 and 1/2 hour walk through of the sequence. Later the crews were given their first exercise on their own. This included descriptions, sampling and mapping on a 3 hour walking traverse.

3rd day: Debriefing on the descriptions and sampling of the first exercise followed by a walk-through of the exercise. The crews were then assigned their second independent exercise: a three hour traverse of a new area with descriptions, sampling, mapping and photography.

4th day: debriefing of the second exercise followed by a walk-through of the exercise. A third exercise with a time limit of two hours was assigned. The crews were to get from one peak to another one while conducting descriptions, sampling, mapping, and photography with self-determined time limits at each stop to stay within the time limit.

5th day: Debrief of the third exercise followed by an instructor's demonstration of how to conduct the 2-hour traverse. A fourth exercise was done in a pseudo crater with a two hour limit. The crews were to perform the usual descriptions, sampling, mapping, and photography. A debriefing followed the exercise.

6th day: The fifth exercise was in a monotonous volcanic terrain to simulate mare conditions. The crews were to determine and conduct the traverses on their own. A debrief and walk-through followed.

7th day: Recapitulation of the activities of the week.

Sept. 24-Oct. 1, 1969 **Mono Crater, California** Astronauts: Lovell, Haise, Young, Duke
Geologists: Dietrich, Silver

Oct. 24, 1969 **Meteor Crater, Arizona** Astronauts: Lovell, Haise, Young, Duke
Geologists: Dietrich, Silver, Clanton, Lofgren

Nov. 11, 1969 **Kilbourne Hole, N. M**. Astronauts: Lovell, Haise, Young, Duke
Geologists: Dietrich, Hait, Swann, Silver, Clanton, Lofgren

Dec. 17-20, 1969 **Hawaii** Astronauts: Lovell, Haise, Young, Duke
Geologists: Dietrich, Clanton, Lofgren, Swann, Hait, Silver, Crosland

Dec 17, 1969 Tour of recent eruption sites in vicinity of Kilauea Iki by Crosland
Dec 18-20, 1969 Traverses were accomplished in the Kilauea Volcano area.

Jan. 4, 1970 **Cape Canaveral** Astronauts: Lovell, Haise, Young, Duke
Geologists: Clanton, Dietrich

Jan. 4: A few days prior to this date Clanton and Dietrich received a call from Lovell asking them to set up a traverse simulation among the sand dunes near the “family houses” where the astronauts families stayed for short periods of time when the astronauts were in intensive training activities at the Cape. Clanton selected 70 pounds of rocks and minerals from the collections in Houston to take with him to the Cape as specimens that would be “salted” among the dunes. Clanton and Dietrich laid out a traverse and flagged the locations of the specimens so that the astronauts could find them among the dunes and vegetation. Cameras and sampling tools were used and the exercise was taped, but there was no Capcom. Clanton and Dietrich had dinner with the crew and, after dinner, held a debriefing of the traverse with the crew.

Mar. 15-16, 1970 **Flagstaff, Arizona** Astronauts: Lovell, Haise, Young, Duke
Geologists: Silver, Dietrich, Head, Clanton, Chidester, Sutton, Roddy, Moore, plus several NASA Hdqtrs. and Bellcom people

Mar. 16: Black Mesa Crater Field. This was a newly created crater field made by the USGS and being used for the first time for training of astronauts. The exercise was a simulation using full-up lunar equipment in the field with radio communications to Mission Control in Houston where Tony England was CapCom; Swann, Hait, Dahlem, Schliecher, and Batson from Flagstaff listened to the astronauts descriptions, sample locations, and photo numbers; and 3 court reporters transcribed the astronauts’ observations. Following a briefing on crater geology the crews provided a LM location and LM-window description, and then proceeded on a walking traverse during which they reported their observations, took photos, and collected samples. The simulation was conducted as though it were a lunar mission. The Mission Control team recorded and analyzed the information being provided by radio from the crews in the crater field. Following the traverse exercise a 24 foot crater was blasted for the crews’ to observe and study immediately after its formation.

APOLLO 14

Aug. 14, 1969 **Flagstaff, Arizona** Astronauts: Shepard, Mitchell, Engle
Geologists: Moore

One day included both a lecture on cratering and visit to the USGS Crater Field near Flagstaff.

Aug. 22-23, 1969 **Craters of the Moon, Idaho** Astronauts: Shepard, Mitchell, Cernan, Engle
Geologists: Foss, McEwen, Richardson

The two-day “show and tell” trip included the Craters of the Moon National Monument, Butte Crater lava tubes, Ammon pumice quarries, and the Wapi volcanic field. Because the Apollo 14 mission was initially meant to land in a volcanic terrain the reasons for visiting this area was to observe a wide variety of volcanic features in a relatively recently active locale with very little vegetation.

Aug. 22: Following a flyover of the area the crew was driven to an area of volcanic flows in the southern end of the Craters of the Moon Monument where they could observe the surface features of flows and their flow fronts, determine relative ages of flows, see a cinder cone, estimate relative ages of the cone and flows, and observe lava tubes, collapse pits, spatter cones, volcanic bombs, and fresh glassy surfaces of flows. Butte Crater was viewed only from the air in an extensive flyover. The flight provided views of a small crater which was the source of a large volume of extremely fluid lava some of which formed a channel about two miles long the end of which becomes a lava tube with much of the roof still intact. This may be similar to lunar rilles. At Ammon there are displayed some layers of pumice formed by the explosive eruptions of rhyolite which accompanied extensive eruptions of rhyolite in southern Idaho. These pumice beds wre visited briefly.

Aug. 23: The visit to Wapi Dome involved two stops on the way to the Dome. The first was at King's Bowl to observe a collapse pit and a lava tube. The second was in an area where the flows are covered by several feet of silt and two drainage craters have allowed the silt to filter down into fissures in the underlying flows. The Wapi area is a dome of lava built by successive eruptions of basaltic lavas with many collapse pits at the top of the dome. The very fluid lavas ran down the slopes of the dome like rivers to produce channels with levees and collapsed lava tubes, and flowed out over the lower slopes to distances of up to 15 miles.

Feb. 14-18, 1970 **Pinacates, Mexico** Astronauts: Shepard, Mitchell, Cernan, Engle, Schmitt
Geologists: Foss, McEwen, Hait, Jahns

Objective was to study, discuss, photograph and sample relatively young and well preserved and exposed volcanic units and structures in a series of large volcanic craters and extensive areas of air-fall volcanic debris. This was the first trip to use training models of lunar surface equipment and conduct traverses. Emphasis was placed on: 1. Techniques for description of topographic, structural, and textural features, 2. Study of regional and local geologic features, 3. Sampling techniques, 4. Lunar surface procedures, and 5. Simulated lunar surface traverses using training models of lunar surface equipment. Zedekar and Wood of MSC accompanied the crews to provide equipment and supervise procedures.

Feb. 14: Exercises (8:00am to 6:30pm) in description of a playa and the crater at Cerro Colorado, examination and description of lava flows near Cerro Colorado, and a traverse in the interior of the crater.

Feb. 15: Exercises (8:00am to 7:30pm) in examination and description of lava flows and general geology at Crater Elegante, study of a gravelly surface at the base of Rojas Cone, and a traverse in tuff breccias, cinders, and lava flows on east side of Crater Elegante.

Feb. 16: Exercises (8:00am to 5:30pm) in examination and description of rim at McDougall Crater emphasizing comparison with previous day's observations, general description of rim of Molina craters, and traverses at both McDougall and Molina craters using all of the lunar surface equipment including the first use of the Mobile Equipment Transporter (MET) for sampling, photographing and decriptions.

Feb. 17: Exercises (8:00am to 6:00pm) in examination and description of features around Crater Grande. There were also two traverses with full equipment.

Feb 18: Detailed traverse (8:00am to noon) over flat ground northwest of Cerro Colorado with complete descriptions of features and full use of lunar equipment for sampling and photographing.

April 2-4, 1970 **Hawaii** Astronauts: Shepard, Mitchell, Cernan, Engle, Pogue, McCandless
Geologists: Chidester, Hait, Batson, Foss, McEwen, Crosland

April 1, evening: Lecture by Crosland on geology of volcanic areas to be visited and planning of traverses by the crews. On the evenings prior to each traverse the crews were provided with aerial photos of the traverse areas and asked to map on overlays the different units that could be distinguished on the photos based on texture, color, patterns, or any other things in the same way that lunar maps were done. They were then asked to figure out a traverse that would allow them to sample and identify the various units that they had identified on their maps. There were three days of field exercises in various volcanic areas for practice of procedures for location, sampling, photography, and verbal description. After each traverse there was a debriefing to discuss the geology and interpretations of the areas that had been traversed as well as to determine what was done well and could have been done better.

April 2: In the morning visit the Aloi-Alae volcanic vent area. In the afternoon accomplish the Kilauea Iki devastation area traverse as planned the previous evening. Evening was spent with separate crews planning their traverses for the next day.

April 3: Prime crew accomplished the two Kapoho traverses as planned the previous evening. Backup crew did traverse south of the caldera. Evening again was spent with separate crews planning their traverses for the next day.

April 4: Prime crew accomplished the traverse south of the caldera area as planned the previous evening and th backup crew did the two Kapoho traverses.

June 3-4, 1970 **Sierra Blanco, TX.** Astronauts: Shepard, Mitchell, Cernan, Engle
& Kilbourne Hole, N. M. Geologists: Sutton, Hait, Wilshire, Foss, McEwen
See Apollo 12 trip on April 8-9, 1969 for details.

June 18-19, 1970 **Flagstaff, Arizona** Astronauts: Roosa, Evans, Chapman, Allen
Geologists: Elston, Hait, El-Baz, McEwen
This was a fly-over exercise by the CMPs for geological observation of the San Francisco and Hopi Butte volcanic fields. It consisted of a pre-flight briefing, a four-and-one-half hour flight and a post-flight debriefing.

Aug. 11-13, 1970 **Ries Crater, Germany** Astronauts: Shepard, Mitchell, Cernan, Engle
Geologists: Horz, Stoeffler, von Englehardt, McEwen, Gault
July 20, 29, 31: Pre-trip briefings by Gault and Horz in Houston on impact cratering, geology of the Ries, and study of rocks from the Ries and Nevada Test Site.
Aug. 4-8: Visits to the field sites to plan final details for crew's visit. Also a flight over the area determined that there was too little to be seen from the air for a flyover with the crew.
Aug. 10: Pre-trip briefings by Stoeffler, and von Englehardt on shock effects, geology of the Ries Crater area, and study of Ries rocks compared to lunar samples.
Aug. 11: The three days in the field were largely show and tell at first with the astronauts becoming more familiar and recognizing features themselves as time went on. The day started with visits to outcrops of the undisturbed rocks in which the impact occurred. Further stops included an overview of the crater from the SW rim, shattered rocks on the raised rim, shatter cones in the central uplift, the highly shattered limestone which was the surface rock at the time of impact, and the lowermost breccia unit.
Aug. 12: There were six stops, mostly at quarries to observe large blocks of breccia with many striated surfaces, breccias with shatter cones, breccias containing fragments of clays and shales, dike of breccia into basement rock, large blocks of displaced granite and metamorphic rocks, and blocks of crystalline rocks up to one meter in size in a crystalline breccia.
Aug. 13: Visits to two quarries. The first was to observe the many features associated with partially melted suevites in contact with breccias. The second to observe the upturned beds around the rim of the crater.

Sept. 10-11, 1970 **Nevada Test Site** Astronauts: Shepard, Mitchell, Cernan, Engle, Chapman, McCandless, Fullerton
Geologists: Sutton, Schaber, Moore, McEwen, Orkild, Sargent
Sept 10: There was a 2.7 km traverse around Schooner Crater planned entirely from photogeology and plotted on a data pack of the crater. Schooner is about the same size as Cone crater which was one of the objectives of the 14 mission. The prime and backup crews followed the same procedures for sample collection, documentation, photography, and descriptions as they were to follow on the actual mission. They were also to determine the underlying stratigraphic sequence from what they could determine from their overall observations. For the Schooner traverse there were backrooms set up near the crater with astronauts as CapComs and geologists as support personnel.
Sept 11: This day was devoted to a show and tell session at Sedan Crater
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Nov. 16, 1970 **Cottonwood, Ariz.** Astronauts: Shepard, Mitchell
Geologists: Moore, Lucchitta, Ulrich, Wolfe, Jahns, Heiken
The Black Mesa crater field was seriously eroded during a heavy rain in September and required blasting of 14 new craters to prepare for the final field exercise of the Apollo 14 crew. The crew completed their planned walking traverse while pulling the two-wheeled modular equipment transporter (MET) which was to be used for the first time on Apollo 14. They undertook their scheduled tasks of sampling, photographing, documenting, describing, etc. and were in continuous audio contact with Mission Control in Houston. A science support team (Swann, Schaber, Hait, Sutton, Bailey, Loman, and Larson) was in place in Houston to receive and analyze the incoming information from the crew.

APOLLO 15

May 18-23, 1970 **Orocopia Mtns., Calif.** Astronauts: Scott, Irwin, Gordon, Schmitt
Geologists: Silver, Dietrich

Mike Brzezinski's training log for the Apollo 15 crew has this trip on May 6-8 and 11-13, 1970. It is not clear which is the correct date.

This was an introduction to basic field geology concepts similar to what Silver did for his first exercise with the Apollo 13 crew. The Apollo 15 crews completed geologic field mapping exercises including traverse mapping, sample collecting, and photographic documentation of geologic features and samples. The area contains igneous and sedimentary rocks in a variety of structures to provide an increasing degree of challenges with each day. Chaiken describes the initiation of the crew to Silver's approach in the first training session after they pulled off the road. "Silver led his party to a small valley strewn with cobbles and boulders. …… These rocks were the legacy of a hundred thousand rainy winters, rolled and nudged from the surrounding hills an inch or two at a time. 'Get me the suite,' Silver said quickly. 'You've got ten minutes.' Silver watched as (the astronauts) hunted among the boulders (to collect a representative suite of rocks). ….. But in this case, Silver had asked the impossible. There was too much variety here to be captured …. in just ten minutes. But that was the point; it wouldn't be any easier on the moon." (Chaiken, p398)

June 3, 1970 **Mojave Desert, Calif.** Astronauts: Scott, Irwin, Gordon, Schmitt
Geologists: Sharp, Clanton

June 1: There was a one hour meeting for a preliminary briefing on the three days of upcoming field exercises at Mojave and Flagstaff.

June 3: This was a one-day study of the significance of geomorphic landforms. Exercises included descriptions and discussions of the detailed features associated with landslides, debris flows and recent faulting. Bob Sharp, who conducted the trip, also had the crews look closely at very small-scale features that could be observed only by getting on one's hands and knees and observing the finer-grained material that makes up the regolith. He called it "belly geology".

June 4-5, 1970 **Flagstaff, Arizona** Astronauts: Scott, Irwin, Gordon, Schmitt
Geologists: Roddy, Moore, Clanton

Study of craters: one day at Meteor crater and another at the man-made Black Mesa crater field of the USGS.

June 4, 1970: Fly-over of Meteor crater followed by a traverse around the rim and into the crater to observe Features such as the overturned flap, ejecta rays, shocked rocks, meteorite fragments and ejecta blankets. At 7:30 pm there was a lecture session on crater processes and photo procedures.

June 5, 1970: Show and Tell type walk through and discussion of crater processes.

July 15-17, 1970 **Flagstaff, Arizona** Astronauts: Scott, Irwin, Worden, Gordon, Schmitt, Brand
Geologists: Swann, Silver, Ulrich, Elston, Hait

This was a one and one-half day field exercise for the Lunar Module prime and backup crews in the Crater 160, San Francisco Peak, and Merriam Crater areas. This included the first EVA exercise with equipment. It was followed by a fly-over of the traversed areas.

Elston and Hait took the prime and backup Command Module pilots, Worden and Brand, on a two-day fly-over of the San Francisco and Hopi Buttes volcanic fields and the volcanic terrains of the Mogollon Rim and Black Hills areas of Arizona. This consisted of a pre-flight briefing involving volcanic landforms and stratigraphy, followed by six hours of aerial observations, and finally a post-flight debriefing. The pilots then studied these areas from high altitude in their jet aircraft.

July 22, 1970 **Medicine Hat, Alberta, Canada** Astronauts: Gordon, Brand, Schmitt
Geologists: Roddy, Lofgren

This was a one-day observation of an experimental explosion using a 500 ton TNT charge to simulate crater formation. The explosion formed a crater (Dial Pack Crater) of 230 feet diameter, 15 feet deep with a central mound. The astronauts watched the explosion, then went into the crater within 10 minutes after the explosion. They examined the overturned flap, backwash, and glass beads and walked around the crater at the edge of the continuous ejecta blanket. Both blocky and powdery rays were also observed.

July 23, 1970 **Medicine Hat, Alberta** Astronauts: Scott, Irwin, Worden, Gordon, Schmitt, Brand
Geologists: Roddy, Lofgren

The astronauts watched films of the previous day's explosion and examined the crater and its products as described for the previous day.

Aug. 26-28, 1970 **San Juan Mtns., Col.** Astronauts: Scott, Irwin, Gordon, Schmitt, Allen
Geologists: Silver, Lofgren, Clanton, Hait

There was a one hour briefing on August 21 by Lee Silver to prepare for the San Juan field exercise.

Aug.26: First there was a flyover from Albuquerque, New Mexico to Durango, Colorado going around the Valles Caldera and the eastern edge of the San Juan Basin to observe the upturned strata and fault contact of the younger volcanic rocks with the older pre-Cambrian basement.

Aug. 27: There were several show and tell type walking exercises. The exercises included metamorphic and granitic pre-Cambrian rocks in fault contact with much younger volcanic rocks. Contact relations, differentiation of igneous rocks from metamorphic rocks, relative age relations, large scale folding and faulting, and preferred orientation of hand specimens were emphasized.

Aug. 28: EVA exercise was a two-hour walking traverse of about 1.2 miles. This was the first traverse for the crews in a geologic setting with cameras, hand tools, radios, etc. The area included a rock slide and scree slopes that provided ample evidence of the origin of the scree material in the nearby cliffs. The materials were nearly all of volcanic origin. The exercise simulated a landing site at the base of an extensive mountain range. The problem was to obtain a representative sample of the rocks that were present and relate them to bedrock exposures in the cliffs.

Sept. 16-18, 1970 **Buell Park, Arizona** Astronauts: Scott, Irwin, Gordon, Schmitt, Allen, Parker
Geologists: Silver, Swann, Hait, Sutton, Lofgren, Clanton
Flight Directors: Lunney, Griffin, Sharpe

There was a one hour briefing by Clanton a few days prior to the trip to plan for the exercises.

Sept 16: The entire day was spent with the Flight Directors going over the geology of the area and the exercises that were to be done by the astronauts on the following days. The purpose was to develop an understanding of basic geology, recognize the variety of rock types available, and present the methods used by the astronauts to communicate their activities and procedures to the scientists. This included the terms used in verbal descriptions and the reasoning behind collecting of samples and taking of photos. At 7:30 pm there was a briefing for all of the participants in the following two days of exercises to outline the logistics and schedules.

Sept. 17: There was a 2-hour exercise in the morning to familiarize the crews with the rock types in the area. The objective was to recognize the difference between the kimberlite intrusions and the surrounding volcanic rocks and distinguish these from the inclusions in the kimberlite which come from all the underlying strata within the Colorado plateau. A three and one-half-hour walking traverse was accomplished in the afternoon with tools, cameras, radios, etc.. The exercise was carried out along a preplanned traverse in and around a kimberlite pipe that intrudes volcanic rocks. Tasks included sampling of the pipe, surrounding rocks, and any xenoliths brought up by the pipe as well as photographic procedures to document the sampling. Both exercises included time for debriefing including a walk-through of the traverse.

Sept. 18: There was a 4-hour walking traverse in the morning among a series of low, parallel ridges with outcrop on the ridges and alluvial material in the valleys. The kimberlite outcrops contained a wide variety of rock types as inclusions. Procedures were similar to the previous day. A 2-hour walk-through debrief took place after lunch.

Oct. 7-9, 1970 **Northern Minnesota** Astronauts: Scott, Irwin, Gordon, Schmitt
Geologists: Phinney, Silver, Lofgren, Laidley

Oct. 7: Walking traverse with several stops around a large anorthosite knob within gabbro. One of the problems was how to determine the differences between inclusions, intrusions, or segregations of anorthosite in the gabbro. Also observed were many sedimentation features within the gabbroic rocks.

Evening of Oct. 7: briefing on local geologic setting and role of anorthosites on Moon and Earth.

Oct. 8: Traverses with radios, cameras, and backroom were planned but rainy weather caused this to be modified to three short walking traverses to study gabbroic intrusion into anorthosite with discussions of sedimentary features in anorthositic rocks, orientation of crystals, inclusions, contacts, and variations within a single unit.

Oct. 9: Used two open pit iron mines to describe hundred feet deep sections of glacial sediments in walls of the pits. At the first open pit the first part of the exercise was to describe the strata from a distance as though from the LM (estimates of thickness, boulder content and size, and other distinguishing features). The second part of the exercise was to traverse down a road into the pit describing, photographing, and sampling each of the units along the way. At the second open pit the same procedure was followed and the crew was asked to correlate the units of the second pit with the units seen at the first open pit.

Nov. 2-3, 1970 **Flagstaff, Ariz.** Astronauts: Scott, Irwin, Gordon, Schmitt, Allen, Parker
Geologists: Swann, Lofgren, Phinney, Silver, Ulrich

Nov. 2: First use of the GROVER, a USGS-built vehicle to simulate the lunar rover during field trips. This was done in the man-made crater field at Cinder Lake using maps, hand tools, and cameras. The effects of craters and boulders on the route of travel, the use of cameras from the vehicle, selection of points to stop for samples or photos, etc. were evaluated while completing a traverse in the crater field.

Nov. 3: A two-hour preplanned driving traverse of 5 km with seven stations using GROVER in the volcanic terrain around Merriam Crater. The traverse covered tuff rings, cinder cones, lava tubes, and cinder deposits and required sampling and photographing of volcanic flows, tuffs, ash, and bombs. Keeping track of locations, recognizing the potential of unscheduled stops for important samples or photos, and ability to describe features while riding were among the problems being evaluated.

Nov. 19-20,1970 **San Gabriel Mtns., Calif.** Astronauts: Scott, Irwin, Gordon, Schmitt
Geologists: Silver, Phinney, Lofgren, Wolfe, Ulrich

This is an area of deformed anorthosites in contrast to the fresh anorthosites seen on the trip to Minnesota in October. These were more like those to be expected on the moon. There were two simulated EVA traverses. On both traverses the crews used cameras and sample collection equipment to practice their photo documentation and sampling procedures.

Nov. 19: Combined walking and riding traverse of 4 hours and 50 minutes. Started with 20 minute simulated LM description of geologic setting followed by a 3.5 km traverse along Mill Creek using aerial photos with eight critical points indicated thereon. Problem was to collect and document a representative sample of the variety of rock types as well as recognize the various degrees of deformation suffered by the different rocks. Also the structural relationships of the various bedrock outcrops was to be observed insofar as possible. There was an extensive debrief including walk-through of the traverses. A later critique of the developed photos indicated that, in many cases, the photos did not make it clear which sample in a group of rocks was actually collected. It was suggested that some of the future training trips include a comprehensive review of photography which would be correlated with a transcript of the tapes, collected samples, and the traverse map.

Nov. 20: 3 hours of stops at road cuts in Soledad Canyon to practice rock descriptions, photography, and sampling techniques. One stop at a talus pile required sampling of the talus with challenge to correlate samples with rock units on canyon wall. Afternoon required a 20 minute LM description followed by a 1.5 km walking traverse for 150 minutes at Mt Parker using aerial photos with eight important stops marked on them. This location had more altered samples and many talus slopes where samples had to be obtained. The emphasis was on the structural relations of sedimentary strata plus a test of the crews ability to recognize a unit that appeared to be an igneous in origin but was actually a breccia consisting entirely of anorthosite. Again a representative set of samples was part of the objective. A walk-through debrief followed the traverse.

Dec. 5-12, 1970 **Hawaii, Oahu** Astronauts: Scott, Irwin, Gordon, Schmitt, Allen, Parker
Geologists: Jackson, Peck, Swann, Schaber, Sutton, Silver, Phinney, Lofgren, Head, Wolfe, Ulrich, Peck, Muehlberger

Evening Dec. 5: Visit to an active eruption area at the vent of Muana Ulu near Chain-of-Craters Road. Briefing on geology, traverses, and logistics for prime and back-up crews, CapComs, backroom, and equipment personnel to prepare for the following day's exercise.

Dec. 6: Kilauea Volcano (Kapoho Traverse). This was designed to study a small volcanic flow and a complex cone along with many associated small scale features of volcanic units. There was also to be a search for xenoliths that might represent deep units that were disrupted by the rising lavas. From the LM there was a 1.75 km driving traverse with two stops followed by 1.5 km walking traverse plus return to LM with eight stops for a total of four hours. A cuff check list was utilized to provide details on the tasks to be performed at each stop. The overall set of tasks was the same as listed for the previous trip to the Coso Hills. Also provided to the crew was a list of about 12 special tasks that were not built into the timeline because the location for these tasks cannot be predicted in advance and depend on real-time judgment of the crew. These include such things as samples from a split boulder, samples from under a boulder that can be turned over, etc.

Evening Dec. 6: Briefing on geology, traverses, and logistics for prime and back-up crews, Capcoms, backroom, and equipment personnel to prepare for the following day's exercise.

Dec. 7: Kilauea Volcano (Desert Traverse) This traverse was designed to study a smooth mare-like surface with many distinctive textural units within a large caldera complex. From the LM there was a 5.2 km driving traverse (not including return to LM) with seven stops totaling about four hours. Tasks and procedures similar to previous day.

Evening Dec. 8: Briefing on geology, traverses, and logistics for prime and back-up crews, Capcoms, backroom, and equipment personnel to prepare for the following day's exercise.

Dec. 9: Hualalai Volcano (Head of Rille Traverse). A walking traverse that included a large flow with well-displayed flow structures and a collapsed lava tube (simulating a lunar rille) with several layers of volcanic units including some coarse-grained xenoliths brought up from deeper levels through which the rising lava traversed. Representative samples of the xenoliths was to be recognized as an important task. From the LM there was a 1.6 km walking traverse (not including return to LM) with eight stops totaling about four hours. Tasks and procedures similar to previous day.

Evening Dec. 9: Briefing on geology, traverses, and logistics for prime and back-up crews, Capcoms, backroom, and equipment personnel to prepare for the following day's exercise.

Dec. 10: Muana Kea Volcano (Hale Pohaku Traverse). Traverse required distinguishing the characteristics and age relationships of several cinder cones, study of regoliths, study of a small "rille" (lava tube) and photos and description of a large remote "rille". From the LM there was a 3.6 km rover traverse (not including return to LM) with 6 stops totaling about four hours. Tasks and procedures similar to previous exercise. After completion of field exercise fly to Honolulu.

Evening Dec. 10: Briefing on geology, traverses, and logistics for prime and back-up crews, Capcoms, backroom, and equipment personnel to prepare for the following day's exercise.

Dec. 11: Muana Loa Volcano (Saddle Traverse in Pohakuloa Finger Flows). A riding traverse that required recognition of several small flows and sampling of cinder cones. The possibility of finding xenoliths was also to be considered. From the LM there was a 4.2 km rover traverse (not including return to LM) with 11 stops totaling about four hours. Tasks and procedures similar to previous exercise.

Dec. 12: Salt Lake Traverse (Oahu) starting at 9:00 AM finishing at lunch time. Show and tell exercise without any equipment with several stops in dissected volcanic tuffs. Emphasis on recognizing various tuffs and how to sample them.

Jan. 18, 1971 **Kilbourne Hole, N. M.** Astronauts: Scott, Irwin, Gordon, Schmitt, Allen, Parker
Geologists: Swann, Sutton, Ulrich, Lofgren, Carter, Heiken

Walking traverse with full-up equipment, CapComs (Allen and Parker), and back rooms for prime and backup crews. There was a 20 minute LM description followed by a 4-hour walking traverse with 10 stations on east rim of crater with objectives to adequately collect, describe, and photograph representative samples from all of the volcanic units and relate them to geologic features. Backrooms were set up with CapComs and geologists. There was a walk through and debrief of the entire traverse with all personnel in afternoon.

Feb. 10-12, 1971 **Ubehebe Craters, Calif.** Astronauts: Scott, Irwin, Gordon, Schmitt, Allen, Parker
Geologists: Freeman, Ulrich, Wolfe, Roddy, Lovelace, Lofgren, Heiken, Crowe

Ubehebe is a large maar-type volcano in a series of overlapping volcanoes formed by magmatic and steam eruptions. The craters are quite young and free of vegetation. There were two walking EVAs with cameras and sample collecting equipment.

Feb. 10: An overflight of the area was accomplished in order to familiarize the crews with the nature of the geology and prepare them for the following days of traverses.

Feb. 11: There was a 20 minute LM description followed by a walking traverse with seven stations and a duration of three hours and 30 minutes crossing eight craters and their ejecta rims. The problem of relating the ejecta samples to their respective craters was a significant problem. Also to be worked out were the relative ages of the craters and their relationship to the pre-volcanic topography.

Feb. 12: Walking traverse of three hours duration. This traverse came in from the opposite direction from the previous day and added several new craters. One of the problems was to relate the craters from the previous day to the new ones. Also the stratigraphy exposed in crater walls was described from the opposite side of the craters and samples were collected to relate to this stratigraphy. The problems of sampling and photographing while negotiating the steep terrain of the crater walls was well illustrated during this EVA.

Mar. 11-12, 1971 **Rio Grande Canyon, Taos, New Mexico**

Astronauts: Scott, Irwin, Gordon, Schmitt, Allen, Parker
Geologists: Silver, Muehlberger, Freeman, Swann, Hait, Lofgren, Phinney

Near Taos, in north-central New Mexico, is a site that offers a number of striking similarities to the lunar landing site for Apollo 15. At the 15 site the Hadley Rille is about one mile wide and about 1,000 feet deep. Near Taos, different segments of the Rio Grande Gorge are from 1,000 feet to over 4,000 feet wide, with a depth of about 650 feet. Both the Gorge and the Rille are entrenched in basalt lava flows.

Evening March 10: briefing for the crews, geologists, and support personnel on the photo interpretation of the geology in the traverse area, the objectives of the traverses, and the logistics for the following day.

There were two traverses with rovers and backrooms.

March 11: Rover traverse of four hours along the edge of the gorge with the task of describing the walls of the gorge, recognizing the number of lava flows in the walls of the gorge, and documenting these observations with the 500 mm camera. Traverse started with a LM window description followed by a photo pan, collection of a contingency sample, and documented sampling and general descriptions of landing site. Throughout the traverse there was panoramic photography at each stop, documented rock and soil sampling, trenching of the regolith, penetrometer readings, 500mm photos of the stratigraphy on the opposite wall of the river gorge, distinguishing of separate rock units, correlations of units along the gorge and across the gorge, noting of changes in the regolith, and rake sampling. Backrooms were set up with CapComs and geologists. There was a walk through and debrief of the entire traverse with all personnel in afternoon.

March 12: Combined walking and riding traverse of three hours and 30 minutes along a different part of the gorge where slumping of the walls has widened the canyon to the width and depth of Hadley Rille. Procedures were the same as previous day. In the afternoon there were two short traverses along the margins of more hilly terrain to simulate the conditions at the Apennine front. There were many slumped blocks of basalt that had fallen from the basalt capped mesas.

April 28-30, 1971 **Coso Hills, Calif.**

Astronauts: Scott, Irwin, Worden, Gordon, Schmitt, Allen, Brand, Parker, Henize
Geologists: Swann, Silver, Muehlberger, Hait, Sutton, Ulrich, Wolfe, Schaber, Freeman, Phinney, Lofgren, Head
Headquarters: Petrone, Lee, Scherer, Beattie
Others: Calio, McDivitt, Duff, Reim, and 7 support personnel
There were also 20 from news media

April 16: Briefing at MSC by Silver on the geology of the Coso Hills area in preparation for upcoming field exercise.

April 28: CMPs do flyovers of area where traverses are to be run on following days. Support crews set up back rooms and prepare equipment. Evening briefing at Conference Room of China Lake Naval Weapons Center on geology, traverses, and logistics for prime and back-up crews, Capcoms, backroom, and equipment personnel to prepare for the following day's exercise.

April 29: Support crews leave at 6:00am for field areas. Crews and others leave at 6:15. Backup crew begins four hour and 15 minute EVA I at 7:30am and prime crew starts 15 minutes later. Radio debriefings for each crew for one hour after completion of EVAs. After lunch there were 45 minutes for press interviews. About two hours for walk-through debriefing after the press interviews. Photo maps for the EVA were of same resolution as those for the actual lunar landing site. The exercise was on a relatively flat area adjacent to some steep slopes just as would be the case at the landing site. The EVA started with a LM window description and a comprehensive sample near the LM. The comprehensive sample consisted of: a trench with 200-500 g samples from the bottom , side, and top; a double or triple core tube, a rake sample, 1 kg of soil, a special environmental sample in its dedicated special container, and representative rocks too large for to be raked. There were several distinct units within the flat area and the objective was to determine the nature of the differences and sample the rock types and regolith within each unit. The steep slope offered a chance to describe and possibly sample some of the rocks from the older units concealed by the regolith. In particular, any features that indicate bedrock should be sampled.

Evening April 29: Evening briefing at Conference Room of China Lake Naval Weapons Center on geology, traverses, and logistics for prime and back-up crews, Capcoms, backroom, and equipment personnel to prepare for the following day's exercise.

April 30: Similar logistics as previous day with similar length riding traverse. The exercise was in a large basin with several elevated domes of various sizes and shapes. The traverse started with a LM description and approached several different sizes and shapes of domes. The comparison of the material in the different domes was a major part of the exercise.

May 19-21, 1971 **Nevada Test Site** Astronauts: Scott, Irwin, Gordon, Schmitt, Allen, Parker
Geologists: Silver, Ulrich, Hait, Wolfe, Swann, Sutton, Lofgren, Phinney, Roddy, Orkild, Sargent

May 19: All support crews gather at NTS to clear vehicles and equipment at gate and travel to EVA site to set up LM, backrooms and other equipment.

Evening May 19: Briefing for crews and backroom personnel at hotel in Las Vegas.

May 20: Crews, geologists and observers gather at AEC heliport in Las Vegas at 6:15 AM for helicopter transport to traverse locations at NTS. Crews with geology observers and other observers from flight control, mission operations, and NASA Headquarters follow the traverse. Prime crew starts four and one-half hour traverse at 8:00 AM followed by backup crew one-half hour later. EVA I was a rover traverse across the ejecta blanket of Schooner Crater starting at the outermost portion of the blanket. After a LM window description and several tasks in the vicinity of the LM there were 3 stops in the ejecta blanket on the way to the crater rim. Sampling and descriptions along the ride between stops was at the discretion of the crew. At the crater rim there was much to photograph and describe including 500mm photos of the opposite crater wall. Traversing below the rim was suggested insofar as possible to better sample the various layers exposed by the crater and ejected onto the surrounding blanket. Activities included photos, sampling of rocks and soils, trenching, coring, raking, descriptions, polarizing photos, and radial sampling. Following the traverse there was a 45 minute radio debriefing between the crew and backroom regarding the traverse. Following lunch there was a 2 to 3 hour walk-through of the traverse with all interested parties. At this point the support personnel dismantled the tents and equipment and transported them to the site for the following day's exercise.

Evening May 20: Briefing for crews and backroom personnel for next day's traverse at Buckboard Mesa.

May 21:

June 25, 1971 **Flagstaff, Arizona** Astronauts: Scott, Irwin, Gordon, Schmitt, Allen
Geologists: Boudette, Freeman, Regan, Lofgren

This was the final simulation for Apollo 15. It was run at Coconino Point, Arizona and the science support teams were at Mission Control in Houston. The exercise was to simulate EVAs II and III in an area with similar morphology to the Apollo 15 landing site. Coconino Point on Gray Mountain simulated the Apennine Front and the Little Colorado River Gorge simulated Hadley Rille. EVA II was a rover traverse to and along the mountain front as scheduled for the actual mission and was scheduled for about 3 hours of descriptions, sampling with photo documentation, panorama photos, trenching, coring, raking, and 500mm photos. EVA III was a rover traverse to and along the gorge for about 3 hours and included the same tasks as EVA II plus penetrometer measurements. The Science Operations Room (SOR) in Mission Control consisted of Lovell as the leader, Swann, Silver, Phinney, Pepin, Sutton, Schaber, and Hait. There were also four court stenos to copy all of the communications between the astronauts and CapCom, Joe Allen. A planning team consisting of Muehlberger, Jackson, Strangway, Hinners, Ulrich, Head, and Wolfe was also available in another room to keep track of any difficulties that would require replanning of any activities and access to the contingency plans. At the conclusion of each EVA there was a radio debrief between the astronauts and personnel in the SOR. The geologists in the field also participated in the debrief in order to verify the geologic observations. In addition to the above personnel in the field there were: three from NASA Headquarters in D.C., four to support the vehicles, four to support the communications network, two to organize logistics, two to handle public relations with the several media persons, five who were responsible for the data packages, five to handle the science and other equipment needed by the astronauts, and the chairman with four of his friends of the Navajo tribe on whose land the exercise was being run.

APOLLO 16

July 8-10, 1970 **San Juan Mtns, N. M**. Astronauts: Young, Duke, Haise, Pogue, Carr, England
Geologists: Silver, Hait

See Apollo 15 trip of Aug. 26-28, 1970 for details.

July 23, 1970 **Medicine Hat, Alberta**, **Canada** Astronauts: Young, Duke, Haise, Pogue, Carr

See Apollo 15, July 22-23, 1970.

Sept. 1-2, 1970 **Colorado Plateau** Astronauts: Young, Duke, Haise, Pogue, Carr, England
Geologists: McGetchen, Sutton, Wones, Horz

Evening of Aug. 31: Briefing on regional geology, nature of lunar interior, and discussion of landing site by McGetchen.

Sept. 1: Walk through with discussions of Rattlesnake craters including xenoliths in basalt and airfall with inclusions of entire stratigraphic column, Chinle formation erosion, and sedimentary features, and Coliseum Maar formation with ash falls and xenoliths.

Sept. 2: Walk through and discussion of sediments and dikes in the Comb monocline, contact of Moses Rock dike with country rock with sampling procedures, and formation of "monuments" in Monument Valley.

Morning of Sept. 3: test driving in Flagstaff of new simulated lunar Rover (nicknamed "GROVER") built by USGS.

Oct. 12-14, 1970 **Northern Minnesota** Astronauts: Young, Duke, England
Geologists: Phinney, Muehlberger, Horz

Evening of Oct. 11: briefing on local geologic setting and role of anorthosites on Moon and Earth.

Oct. 12: three short walking traverses to study gabbroic intrusion into anorthosite with discussions of sedimentary features in anorthositic rocks, orientation of crystals, inclusions, contacts, and variations within a single unit.

Oct. 13: Used two open pit iron mines to describe hundred feet deep sections of glacial sediments in walls of the pits. At the first open pit the first exercise was to describe the strata from a distance as though from the LM (estimates of thickness, boulder content and size, and other distinguishing features). The second exercise was to traverse down a road into the pit describing, photographing, and sampling each of the units along the way. At the second open pit the same procedure was followed and the crew was asked to correlate the units of the second pit with the units seen at the first one.

Oct. 14: Traverse with several stops around a large anorthosite knob within gabbro. Discussed how to determine difference between inclusion, intrusion, or segregation of anorthosite in the gabbro. Also observed many sedimentary features within the gabbroic rocks.

Nov. 12-13, 1970 **Nevada Test Site** Astronauts: Young, Duke, England
Geologists: Roddy, Sargent, Ulrich, Horz

Nov. 12: Briefing on cratering mechanics, regional geology, and introduction to 3 craters to be visited. Sedan Crater in alluvium: describe as from LM, rock units and structures in crater and traverse through ejecta blanket with sample collection and photos emphasizing correlation of ejected rocks with units in crater. Danny Boy Crater in volcanic rocks: similar activities as at Sedan with additional emphasis on shock features in the rocks. Debriefing on photo procedures and sampling immediately afterward. Observed differences between collapsed craters and open craters first from helicopter and then on the ground.

Nov. 13: Local geology discussed on drive to Schooner crater. Start with description of crater and ejecta blanket as seen from LM. Detailed walking traverse using aerial photos and list of objectives discussed before traverse. In one hour debrief it was discussed how crew could be more systematic in rock descriptions and less bogged down on small geologic features. The traverse was designed for 3 hours but took over 4 because of the bogging affect. After debrief a guided walk-around was taken through the ejecta blanket around the entire crater for 2 hours.

Nov. 21-22, 1970 **San Gabriel Mtns., Cal**. Astronauts: Young, Duke, Haise, England
Geologists: Silver, Horz, Phinney

Evening Nov. 20: Briefing on general geology of west coast with emphasis on how San Gabriel Mtns. fit into picture. Importance of anorthosite units as well as the scope and purpose of planned traverses.

Nov. 21: Started with 20 minute simulated LM description of geologic setting. Then 200 minute walking traverse of 3.5 km along Mill Creek using aerial photos with eight critical points indicated thereon. Crews (both prime and backup) were entirely on their own with geology trainers walking along as silent observers. Photography and sample collection were incorporated in attempt to obtain and describe representative rock and soil samples. Extensive debrief including walk-through of the traverses indicated an excellent job on photographic sites, sampling, and recognition of geologic relations. Rock and mineral descriptions need improvement.

Nov. 22: 3 hours of stops at road cuts in Soledad Canyon to practice rock descriptions, photography, and sampling techniques. One stop at a talus pile required sampling of the talus with challenge to correlate samples with rock units on canyon wall. Afternoon required a 1.5 km walking traverse for 150 minutes at Mt Parker using aerial photos with eight important stops marked on them. This location had more altered samples and many talus slopes where samples had to be obtained. Procedures and debriefing as for previous day. Crews did much better with rock and mineral descriptions and continued to do well with photographing and sampling.

Jan. 19, 1971 **Kilbourne Hole, N. M**. Astronauts: Young, Duke, England
Geologists: Lofgren, Carter, Muehlberger, Horz

Jan. 19: First field trip with full-up equipment, CapCom (England), and back room (Muehlberger, Horz) for prime crew. LM description and 4-hour walking traverse on east rim of crater with objectives to adequately collect, describe, and photograph representative samples from all of the volcanic units and relate them to geologic features. Walk through and debrief of entire traverse with all personnel in afternoon. Crew was talking and describing constantly allowing good communication with back room. Sampling was excellent job of sampling and describing. Timing was a bit on slow side. Details that need attention: reporting every bag and its number when samples taken, frame and magazines numbers for photos, positions in field. Back room should do more reminding of need for bag, frame, and magazine numbers. Inexperience of back room was apparent when questions were not asked or were asked too late. 30 pounds of samples collected.

Jan. 20, 1971 **Kilbourne Hole, N. M.** Astronauts: Haise, England
Geologists: Horz

Same traverse and walk through as previous day but for back-up crew only with no equipment except cameras. Very similar comments for geology as for prime crew except for a few missed sample types.

Feb. 25-26, 1971 **Meteor Crater, Arizona** Astronauts: Young, Duke, Haise, England
Geologists: Roddy, Horz, Muehlberger, Lucchitta, Freeman,
Brock, Regan, Schafer

Feb. 25: Riding , 4 km, 4 1/2 hour traverse with full equipment and backroom for both prime and back-up crews. Objectives were to adequately collect, describe, and photograph representative samples from the ejecta blanket along a radial traverse to the rim, then walk along the rim again sampling and describing geologic features and collecting samples. Traverses were terminated after 3 hours because of 70 mph winds. A LM debriefing was improvised to allow all participants to discuss results of the abbreviated traverse and suggest how what was accomplished could be correlated with what remained to be done.

Feb. 26: Walking traverse without equipment or backroom. Crews completed the traverse from point where they stopped the day before. There was a nearly 3 hour walk through and debriefing over the entire traverse. Crews did an excellent job of sampling, photographing and interpreting the geology. They had a bit of difficulty distinguishing some of the rock types.

Mar. 29-30, 1971 **Flagstaff, Arizona** Astronauts: Young, Duke, Haise, England
Geologists: Ulrich, WolfeHorz, Clanton, Lucchitta,
Muehlberger, Scott, Hait, Freeman Bailey, Schafer, Clanton

Mar. 16: Lab preparation in Houston for field exercise at Merriam Crater with stereo pairs of aerial photos of the area which were used by the crew to study the geology and outline their own traverses. They were thereby familiarized with the area in detail as they would be for their actual lunar landing site.

Evening Mar. 28: briefing on photogeology of area, traverse plans, and logistics.

Mar. 29: LM description plus full-up riding traverses for both prime and back-up crews with cameras, radios, tape recorders, hand tools, core tubes, TV camera on vehicle, Grover and back rooms with CapComs. No astronaut CapComs were available (England was with Haise as the back-up crew) so Regan and Hanish substituted in this role. There were 15 support personnel for the transport and upkeep of equipment. Traverse was for 8 km lasting 5 hours with 7 designated stops. Objectives were to adequately collect, describe, and photograph representative samples from the various volcanic units, determine the origin of various features, and determine age relations of various flows and ash-falls. Walk through debriefing was abbreviated to only one hour. It was agreed that a 5 hour traverse was too long. Travel to the site, preparation of equipment, traverse time, stowing of equipment, a late lunch, and a full walk-through debrief was too much. Everyone was exhausted after only half of the debrief which was much too short for adequate discussion but it was determined that the crews did well in all categories. The prime crew took 370 photos and nearly 100 pounds of samples with good information about frames, magazines, and sample numbers to the backroom.

Mar. 30: Operational aspects exactly the same as previous day but for a 3 km, 4 hour traverse. Exercise was in an artificially produced crater field in volcanic cinder deposits overlying lava flows at Cinder Lake near Flagstaff. Objectives were to adequately collect, describe, and photograph representative samples from the various volcanic units as well as the ejecta blankets from the craters. There were also some boulders along the traverse which were not from the local rock units as might be the case in rays from distant craters on the moon. The crews were to determine which boulders were "foreign" to the area. Walk-through debrief determined that both crews did quite well in all aspects but did have a problem determining whether all boulders were from outside sources. Sampling was very impressive; prime crew collected about 175 pounds with good documentation.

Later in May Horz and Wolfe met with 16 crew to review photos taken on this trip. Procedures for adequate coverage in pans and sample documentation were examined on the assembled photographs.

April 26-27, '71 **Camp Verde, Ariz.** Astronauts: Young, Duke, Haise
Geologists: Elston, Scott, Muehlberger, Horz, Clanton

April 23: Three-hour pre-trip meeting which included photogeologic mapping of units in the Verde River canyon. The crew designed their own traverse which was to meant to distinguish tentative volcanic units that might be present in the canyon.

April 26: Seven hour exercise in Cottonwood Basin and Verde River Gorge. Each crew member acted independently and developed his own geological map with interpretation. The geology consisted of interbedded lava flows and sandstone which were to be traced laterally as far as possible. A few faults displaced some of the units and complicated the problem. A red baked zone at the bottom of each flow was recognized as a method of distinguishing individual flows.

April 27: Five hour exercise in Sycamore Canyon. The astronauts extended their mapping of the previous day to another area where they recognized the same flows as the previous day, but as they continued along the Canyon additional flows were recognized below the original flows. By the end of the exercise they had mapped 12 separate flows. A debriefing with walk-through followed the exercise. This is a very suitable area for an intermediate level mapping exercise and the crew appeared to enjoy it.

May 24-25, 1971 **Capulin Mtns., N. M**. Astronauts: Young, Duke, Haise
Geologists: Muehlberger, Elston, Freeman, Lovelace, Horz

May 13: Two-hour pre-briefing in which each crew member used aerial photos to plot a geologic map with a tentative stratigraphic sequence. They then planned traverses that could verify their map interpretations.

May 24: Capulin is a volcanic cinder cone with flows emanating from it. In a five hour exercise the crew traversed an area around Capulin and traced various flows originating from Capulin. They learned to distinguish these flows from other flows emanating from other close-by sources. This required recognition of subtle mineralogic and textural criteria that varied from flow to flow. Age relations were recognized and the crew was able to develop a stratigraphic sequence for the flows. A Polaroid camera was used for documentation of significant observations. The entire traverse was reviewed from the top of Mount Capulin which provided an excellent view of the volcanic sequences that had been studied.

May 25: In a four-hour traverse along the Cimarron River the volcanic units of the previous day were traced along strike. Complicating this traverse were some additional units of distinctively different volcanic flows plus some interlayered sediments and some volcanic tuff layers. Again, after the traverse, there was a review of the days exercise and a geologic synthesis of the two days observations.

June 10-11, 1971 **Mono Crater, Calif.** Astronauts: Young, Duke, Haise, England
Geologists: Sheridan, Wones, Wolfe, Heiken, Horz, Freeman, Ulrich, Boudette, Muehlberger, McGetchen

June 8: Two-hour pre-trip briefing at MSC on geological setting by Wones, Heiken, and Sheridan and a discussion of the traverses by Wolfe. Both traverses utilized a local backroom in radio communication with the astronauts who wore simulated backpacks.

June 10: A four-hour and 10 minute walking traverse in the South Coulee flow area. In addition to detailed descriptions of the volcanic domes and talus fans the crew attempted to correlate samples from the talus fans with in-situ rock units that included lavas, ash-falls and tuffs. In a two-hour debriefing the day’s traverse was reviewed as well as the overall geologic history of the area.

June 11: A Two and a half hour walking traverse down a road-cut into the steep canyon of the Bishop Tuff Gorge displayed a continuous outcrop of volcanic tuff. This is a very thick single tuff deposit that displays a variety of textural changes from top to bottom in response to the change in temperature and pressure from top to bottom. Although the crew described the textural changes quite well they interpreted the changes as separate flows. In the walk-through debriefing after completion of the traverse the textural varieties were shown to result from changes in density, porosity, crystallization, and squishing of glass shards in response to the changing temperature and pressure conditions from top to bottom. This provides an analogy to the textural changes found in a thick impact melt or fallback deposit produced by an impact. In fact, several terrestrial impact deposits were initially misinterpreted as of volcanic origin before the return of lunar samples led to a better understanding of impact products.

July 7-9, 1971	**Sudbury, Ontario**, **Canada**	Astronauts: Young, Duke, Haise, England Geologists: Dence, French, Horz, Muehlberger, Ulrich, Wolfe, Boudette, Clanton, Lucchitta

Evening July 6: Two-hour briefing by Dence on the regional geology of the Sudbury Basin, a large basin of meteorite impact origin which was incorrectly interpreted for nearly 100 years as totally of igneous origin. The formations at Sudbury represent the units formed during a very large impact into solid rocks. Erosion has allowed exposure of many different types of rocks associated with such a large impact. Dence reviewed the recognition of shock effects from impact origin as the necessary proof of impact origin. The traverses and their objectives were reviewed. On each of three days there were to be walking traverses of three to four hours in the morning and several show and tell stops of two to three hours total in the afternoon utilizing road cuts and other good exposures.

July 7: A four-hour walking traverse at Kelly Lake in the crater wall displaying steeply dipping quartzites, glass-like units, breccias, and some brecciated in-situ materials containing shatter cones. The crew was able to recognize all of the units but had some difficulty interpreting some of the breccias. There was a two-hour debriefing that covered the entire traverse. A one-hour exercise was conducted on the shore of Lake Wanapitei which is a more recent and much smaller impact structure that produced impact breccias that are now intermingled with glacial deposits. Although the exercise focused on the breccias the crew was expected also to describe and collect components of the glacial deposits.

July 8: A four hour and 30 minute walking traverse at High Falls. This is one of the key areas for interpreting the Sudbury Basin as being of impact origin. The traverse crossed from the top of the coarse igneous rocks through a tuff-like unit (Onaping Tuff) into a variety of breccias and some impact melt. The crew was to describe and sample these units, especially the nature of the contacts between them. Also the overlying glacial deposits were to be sampled and described as regolith material. A three-hour debriefing was conducted as a walk-through of the traverse. Another two hours was spent stopping at outcrops along Highway 144 to provide a general cross-section of the Sudbury Basin. In the evening a trip through an underground mining operation was conducted in the Creighton Mine. A discussion of the still-problematic origin of the ores was presented.

July 9: A two and one-half hour traverse in the foot wall at South Creighton. This area displays a granite with sandstone inclusions all of which were highly brecciated by the impact and contains veins of a glassy breccia that were produced by the impact. To complicate things a later period of igneous dikes cross-cut the entire mixture indicating how complex some impact structures can be. There was a one and one-half hour field debriefing following completion of the traverse.

Sept. 9-10, '71	**Rio Grande Canyon**, **Taos, N. M.**	Astronauts: Young, Duke, Haise, Mitchell, England, Peterson, Mattingly Geologists: Silver, Muehlberger, Phinney, Horz, Wolfe, Ulrich, Freeman, Elston, Boudette, Laidley

Evening Sept. 8: Briefing by Lee Silver for crews and backrooms to discuss logistics, general geologic observations from aerial photos, objectives of traverses, and plans for each stop on the first day of traverses. Prior to this all of the equipment including GROVER and EXPLORER (the two simulated lunar rovers) had been unloaded and checked out, the locations of the backrooms had been scouted out, and the traverses had been planned and plotted on aerial photos with enough copies for crews, backrooms, and observers.

Sept. 9: This was a full-up simulation with all personnel and gear that would be used on the mission except the ALSEP instruments. Vehicles and personnel with equipment leave at 8:00 AM to set up backrooms, radios, rovers, cameras and other equipment for use by the crews. Three and one-half hour EVA starting at 10:00 AM with the backup crew starting one-half hour ahead of the prime crew. Crews with geology observers and other observers from flight control, mission operations, and NASA Headquarters followed the traverse. Flight Director, Pete Frank, recalls being on this trip. Traverses were in volcanic rocks displayed in cross section along the Rio Grande River gorge. Traverse started with a LM window description followed by a photo pan, collection of a contingency sample, and documented sampling and general descriptions of landing site. Throughout the traverse there was panoramic photography at each stop, documented rock and soil sampling, trenching of the regolith, magnetometer readings, penetrometer readings, 500mm photos of the stratigraphy on the opposite wall of the river gorge, distinguishing of separate rock units, correlations of units along the gorge and across the gorge, noting of changes in the regolith, and rake sampling. Because the drainage system has transported rocks from distant sources into the local area it is important to recognize which of the samples are from outside sources just as would be the case on the Moon when distant craters have ejected material for long distances and deposited them in the local landing site. Following completion of the traverse there was a radio debrief between crews and backrooms for about 30-40 minutes. After lunch there was a complete walk-through debriefing of the entire traverse with all relevant personnel. At this point the support crews left to prepare backrooms and equipment for the next day's traverse.

Evening Sept. 9: Similar briefing as previous evening by Lee Silver for crews and backrooms to discuss logistics, general geologic observations from aerial photos, objectives of traverses, and plans for each stop on the second day of traverses.

Sept. 10: Essentially the same logistics and procedures as for previous day except that this traverse was on the opposite side of the gorge. Also on Sept. 10, during the traverses, the Command Module pilot, Tom Mattingly, did a fly-over of the traverse area with Silver and pilot-geologist Dick Laidley and applied the tasks described in the section on command module training to the area of the field exercises.

Oct. 27-28, 1971	**Nevada Test Site**	Astronauts: Young, Duke, Haise, England, Peterson, Mattingly, Roosa, Hartsfield Geologists: Muehlberger, Swann, Jackson, Roddy, Moore, Wolfe, Freeman, Boudette, Sutton, Ulrich, Horz, Phinney, Head, Orkild, Sargent, Laidley NASA Hdqtrs.: Petrone, Lee, O'Bryant, Beattie

Oct. 26: All support crews gather at NTS to clear vehicles and equipment at gate and travel to EVA site to set up LM, backrooms and other equipment. This trip required logistical support from the Atomic Energy Commission, the U. S. Air Force, the U. S. Army, and the USGS offices in Denver, Colorado and Mercury, Nevada.

Evening Oct. 26: Briefing for crews and backroom personnel at hotel in Las Vegas. Schooner crater, to be studied in the first exercise is about the same size as North Ray Crater at the Apollo 16 landing site.

Oct. 27: Crews, geologists and observers gather at AEC heliport in Las Vegas at 6:15 AM for helicopter transport to traverse locations at NTS. Crews with geology observers and other observers from flight control, mission operations, and NASA Headquarters follow the traverse. Prime crew starts four and one-half hour traverse at 8:00 AM followed by backup crew one-half hour later. EVA I was a rover traverse across the ejecta blanket of Schooner Crater starting at the outermost portion of the blanket. After a LM window description and several tasks in the vicinity of the LM there were 3 stops in the ejecta blanket on the way to the crater rim. Sampling and descriptions along the ride between stops was at the discretion of the crew. At the crater rim there was much to photograph and describe including 500mm photos of the opposite crater wall. Traversing below the rim was suggested insofar as possible to better sample the various layers exposed by the crater and ejected onto the surrounding blanket. Activities included photos, sampling of rocks and soils, trenching, coring, raking, descriptions, polarizing photos, and radial sampling. Following the traverse there was a 45 minute radio debriefing regarding the traverse. During lunch there was a review of the tapes made by Mattingly during a 10-mile high fly-over of the field area that morning with Laidley assisted by Sargent and Roddy while the crews were making their ground traverses. Hartsfield had acted as the orbital CapCom for Mattingly during the fly-over. Following lunch there was a 2 to 3 hour walk-through of the traverse with everyone including the orbital crew. There was also a brief show and tell session at Sedan and Danny Boy Craters. At this point the support crews dismantled the tents and equipment and transported them to the site for the following day's exercise.

Oct. 28: Second day was cancelled because of rain and snow. An impromptu session was held at the AEC in Las Vegas. Henry Moore led a discussion on impact cratering and the problems associated with sampling craters and their ejecta. Movies were shown of various American and Soviet nuclear explosions with emphasis on ejecta trajectories and the base surge. Boudette discussed the photogeology of the Descartes landing site planned for Apollo 16.

Nov. 17-18, 1971 **Coso Hills, Calif**. Astronauts: Young, Duke, Haise, Mitchell, England, Peterson, Schmitt, Cernan, Parker
Geologists: Silver, Muehlberger, Wolfe, Ulrich, Jackson, Sutton, Hait, Boudette, Freeman, Horz, Phinney, Head
Support and other personnel: total of 15 plus several media

Nov. 16: All support crews gather at China Lake Naval Weapons Center to get badges, clear the vehicles and equipment at gate, and travel to EVA site to set up LM, backroom tents, and other equipment for first EVA. PAO personnel establish logistics for media coverage.

Evening Nov. 16: Briefing for crews and backrooms to discuss logistics, general geologic observations from aerial photos, objectives of traverses, and plans for each stop on the first day of traverses. These were to be full-up exercises with all of the hand tools, cameras, and geophysical traverse experiments aboard the Grover and Explorer vehicles.

Nov. 17: Depart for McCloud Flat field area at 6:15 AM and commence four and one-half hour, 8.5 km EVA at 8:00 AM. This is a volcanic terrain with many types of volcanic structures and rocks. The EVA started with the usual LM window description followed by panoramas, descriptions, and sampling in the vicinity of the LM. There were 8 stops each of which included panoramic photos, documented sampling of various units recognized on the aerial photos as well as any other units that appeared to the astronauts to be different, 500mm photos of unreachable hills, trenching, coring, penetrometer readings (not at all stops), rake samples, and some special samples that required special equipment or techniques. A cuff check list was utilized to provide details on the tasks to be performed at each stop. All samples and photographs were accompanied by sample-bag numbers plus magazine and frame numbers for photos. In addition reports of odometer and compass headings were given along the way and additional short stops were made if the astronauts determined that it was warranted because of any unusual observations. A one and one-half hour radio debrief was held at the end of the EVA. After lunch a two and one-half hour walk-through debrief was conducted with all relevant personnel. During this debrief the support crews packed up the equipment and backroom and moved them to the site of the next day's EVA.

Nov. 18: Depart for Volcano Peak field area at 6:15 AM and commence four and one-half hour, 5.1 km EVA at 7:45 AM. For this EVA the Apollo 17 crew arrived and observed the traverses. There were 7 stops with similar tasks as the previous day but in different types of volcanic structures and units. Again there was a radio debrief before lunch. Before the walk-through there was a period of time set aside for press interviews with the astronauts.

Dec. 7-13, 1971 **Hawaii and Oahu** Astronauts: Young, Duke, Haise, Mitchell, England, Peterson
Geologists: Jackson, Muehlberger, Horz, Phinney, Peck, Head, Boudette, Freeman, Schafer, Ulrich, Wolfe

Evening Dec. 6: Briefing on geology, traverses, and logistics for prime and back-up crews, Capcoms, backroom, and equipment personnel to prepare for the following day's exercise.

Dec. 7: Kilauea Volcano (Kapoho Traverse). This was designed to study a small volcanic flow and a complex cone along with many associated small scale features of volcanic units. There was also to be a search for xenoliths that might represent deep units that were disrupted by the rising lavas. From the LM there was a 1.75 km driving traverse with two stops followed by 1.5 km walking traverse plus return to LM with eight stops for a total of four hours. A cuff check list was utilized to provide details on the tasks to be performed at each stop. The overall set of tasks was the same as listed for the previous trip to the Coso Hills. Also provided to the crew was a list of about 12 special tasks that were not built into the timeline because the location for these tasks cannot be predicted in advance and depend on real-time judgment of the crew. These include such things as samples from a split boulder, samples from under a boulder that can be turned over, etc.

Evening Dec. 7: Briefing on geology, traverses, and logistics for prime and back-up crews, Capcoms, backroom, and equipment personnel to prepare for the following day's exercise.

Dec. 8: Kilauea Volcano (Desert Traverse) This traverse was designed to study a smooth mare-like surface with many distinctive textural units within a large caldera complex. From the LM there was a 5.2 km driving traverse (not including return to LM) with seven stops totaling about four hours. Tasks and procedures similar to previous day.

Evening Dec. 8: Briefing on geology, traverses, and logistics for prime and back-up crews, Capcoms, backroom, and equipment personnel to prepare for the following day's exercise.

Dec. 9: Hualalai Volcano (Head of Rille Traverse) A walking traverse that included a large flow with well-displayed flow structures and a collapsed lava tube (simulating a lunar rille) with several layers of volcanic units including some coarse-grained xenoliths brought up from deeper levels through which the rising lava traversed. Representative samples of the xenoliths was to be recognized as an important task. From the LM there was a 1.6 km walking traverse (not including return to LM) with eight stops totaling about four hours. Tasks and procedures similar to previous day.

<u>Evening Dec. 10:</u> Briefing on geology, traverses, and logistics for prime and back-up crews, Capcoms, backroom, and equipment personnel to prepare for the following day's exercise.

Dec. 11: Muana Loa Volcano (Saddle Traverse in Pohakuloa Finger Flows) A riding traverse that required recognition of several small flows and sampling of cinder cones. The possibility of finding xenoliths was also to be considered. From the LM there was a 4.2 km rover traverse (not including return to LM) with 11 stops totaling about four hours. Tasks and procedures similar to previous exercise.

<u>Evening Dec. 11:</u> Briefing on geology, traverses, and logistics for prime and back-up crews, Capcoms, backroom, and equipment personnel to prepare for the following day's exercise.

<u>Dec. 12:</u> Muana Kea Volcano (Hale Pohaku Traverse). Traverse required distinguishing the characteristics and age relationships of several cinder cones, study of regoliths, study of a small “rille” (lava tube) and photos and description of a large remote “rille”. From the LM there was a 3.6 km rover traverse (not including return to LM) with 6 stops totaling about four hours. Tasks and procedures similar to previous exercise. After completion of field exercise fly to Honolulu.

<u>Dec. 13:</u> Salt Lake Traverse (Oahu) starting at 9:00 AM finishing at lunch time. Show and tell exercise without any equipment with several stops in dissected volcanic tuffs. Emphasis on recognizing various tuffs and how to sample them.

Feb. 17-18, 1972 **<u>Boulder City, Nev.</u>** Astronauts: Young, Duke, Haise, Mitchell, England
Geologists: Horz, Jackson, Moore, Anderson, Hodges, Freeman, Schaber, Schafer, Strobell, Elston, Bailey

<u>Evening Feb. 16:</u> Briefing on geology, traverses, and logistics for prime and back-up crews, Capcoms, local backroom, and equipment personnel to prepare for the following day's exercise. The prime backroom personnel (Lovell, Muehlberger, Pepin, Silver, Phinney, Wolfe, Sutton, Ulrich) for these traverses were actually back in Houston in their regular positions in the mission control building. All communications were to be relayed to Houston and the activities would be as similar as possible to the actual mission. In the backroom they would keep track of location, sample numbers, and photos taken as well as carefully watch the time line to determine whether all objectives were met and whether to modify any plans as a result of unexpected discoveries or malfunctions. Over the next two days there were to be two traverses designed to be very similar to the second and third EVAs on the actual mission with stops 4 through 10 on the first traverse and stops 11 through 17 on the second traverse.

<u>Feb. 17:</u> A four-hour, 7.35 km traverse starting at 9:00 am with all equipment and vehicles, cuff check-lists, and silent geology and operations observers. This traverse commenced with a 20 minute LM window description of the geologic surroundings followed by loading of equipment onto a vehicle that was to simulate the lunar rover. Odometer readings and compass headings were provided to the backroom periodically along with running descriptions of the geology, samples, and photography. The traverse was in relatively smooth plains units next to the McCullough mountains. Representative rock and soil samples were taken, trenches were dug and sampled, rake samples were taken, cores were collected, penetrometer readings were made, stereo panoramic photos were taken at each station, and documentation photos of all samples was accomplished. After returning to the LM there was a 1/2 hour radio debrief between the crew at the LM and the personnel in the backroom in order to settle any questions from any of the parties and to consider potential modifications to the next EVA. Following lunch all personnel in the field did a 2-hour walk through of the entire traverse to critique the entire set of activities.

<u>Evening Feb 17:</u> Again, in order to prepare for the following day's exercise, there was a briefing on geology, traverses, and logistics for prime and back-up crews, Capcoms, local backroom, and equipment personnel.

<u>Feb. 18:</u> A four-hour, 7.45 km traverse starting at 7:00 am for the back-up crew with all equipment and vehicles, cuff check-lists, and silent geology and operations observers. The back-up crew started the traverse five hours ahead of the prime crew in order to give the prime crew an opportunity to monitor the backroom activities during part of the back-up crew traverse. The prime crew also had a half hour press meeting before starting

their traverse. Traverses contained similar activities to previous day but in a more hilly area with addition of 500mm camera photos of the hills. Similar debriefs as on previous day.

APOLLO 17

Oct. 19-22, 1971 **Big Bend, Texas** Astronauts: Cernan, Schmitt, Parker
Geologists: Muehlberger, Lofgren

This was an introductory session to establish geological proficiency of the ability of the crew to work together and initiate the preparation for the geologic tasks of their mission. Many exercises were similar to those of the trip for the beginning groups on April 2-3, 1964.

Nov. 17-18, 1971 **Flagstaff, Arizona** Astronauts: Evans
Geologists: Laidley, Elston

Two days of fly-overs of the San Francisco volcanic area of Arizona: the first day at low altitude and second day at high altitude in T-38 jet plane.

Nov. 18, 1971 **Coso Hills, Calif.** Astronauts: Cernan, Schmitt

This was an observational exercise to watch the Apollo 16 crew go through their training traverses described under the Apollo 16 field training for November17-18, 1971. Schmitt had actually been through these exercises when he was in the back-up crew of Apollo15. Although the Apollo 17 crew participated in discussions they did not take part in any of the simulations.

Dec. 20-21, 1971 **Kilbourne Hole, N. M**. Astronauts: Cernan, Schmitt, Parker
Geologists: Wolfe, Sutton, Hoffer, Lofgren, Morrison

Jan. 24-25, 1972 **Boulder City, Nev**. Astronauts: Cernan, Schmitt, Evans, Parker, Allen
Geologists: Muehlberger, Sutton, Wolfe, Ulrich, Anderson, Jackson, Morrison, Laidley, Swann, Phinney
The President's Science Advisor, Dr. Edward David, and his wife were observers on this trip.

See Apollo 16 trip of February 17-18, 1972 for details of traverses. In addition there was a fly-over by Evans and Laidley on the 23rd to review the traverses in the context of the regional geology.

Feb. 22-25, 1972 **Chocolate Mtns, Calif.** Astronauts: Cernan, Schmitt, Scott, Irwin
Geologists: Silver, Anderson, Swann

This was a substitute trip to the Little Chuckwalla Mountains when the Mexican Government cancelled its permits for a training trip to Baja California.

Feb. 23-24, 1972 **Flagstaff, Ariz.** Astronauts: Evans

March 14-15, '72 **Sierra Madera** Astronauts: Cernan, Schmitt, Parker, Irwin
Geologists: Wilshire, Jackson, Morrison, Phinney, Freeman, Sutton, Ulrich

This is an eroded impact structure in limestones and other sedimentary rocks. The exercise utilized a backroom with Parker as CapCom and Irwin acted as one of the scientists. There was one walking and one riding traverse both of which started near the crater rim and proceeded towards the central peak.

Mar. 13: 1:00 pm: Logistics personnel go over traverses and plan for locations of their gear.

Mar. 13: 8:00 pm: Briefing on nature of geology from aerial photos and problems that are suggested. All discussion of the geology emphasized that the mapped units are interpretations only and need to be verified or reinterpreted by the crew during the traverses. Also details of the logistics for all participants.

Mar. 14: At 7:00 am radio and backroom personnel leave for backroom area and Grover crew leaves for LM site to erect LM and get Grover ready. At 7:20 am equipment personnel leave for LM site. Start four hour and 30 minute exercise at 8:00 am with LM window description followed by sampling and photography at LM site. Crew started on riding traverse consisting of seven stations over 5 km to accomplish coring, trenching, sampling, raking, photography, special sampling, and descriptions. A radio debriefing followed the traverse. Ride-through debriefing of the traverse with crew, observers, backroom personnel. Logistics personnel leave to set up sites for following day.

Mar. 14: 8:00 pm: Briefing similar to previous night.

Mar. 15: At 7:00 am radio and backroom personnel leave for backroom area. At 7:10 crew, observers, and equipment personnel leave for LM site. Start four hour and 10 minute EVA at 8:00 am with LM window description followed by sampling and photography at LM site. Crew had walking traverse of eight stations over about 2 km with similar tasks as previous day. A radio debriefing followed the traverse. Talk on the geology of Sierra Madera during lunch followed by two hour walk-through debriefing for crew, observers, backroom personnel.

Apr. 10-12, 1972 **San Gabriel Mtns., Calif.** Astronauts: Cernan, Schmitt, (Scott on 10th only)

May 24-25, 1972 **Sudbury, Ontario Canada**
Astronauts: Cernan, Schmitt, Scott, Irwin, Evans (24th only), Parker, Fullerton
Geologists: Muehlberger, Ulrich, Lucchitta, Boudette, Strobell, Morrison, Dence, Jackson, Wolfe, Freeman, French
Others included Flight Director Pete Frank, several Public Affairs persons from MSC, Hanley from NASA Hdqtrs., and several support personnel.

May 23 evening: Briefing on geology and logistics for the two days of field exercises. Dence presented a briefing on the regional geology of the Sudbury Basin, a large basin of meteorite impact origin which was incorrectly interpreted for nearly 100 years as totally of igneous origin. The formations at Sudbury represent the units formed during a very large impact into solid rocks. Erosion has allowed exposure of many different types of rocks associated with such a large impact. Dence reviewed the recognition of shock effects from impact origin as the necessary proof of impact origin. The traverses and their objectives were reviewed.

May 24: Two and one-half hour aerial reconnaissance in morning by astronauts in NASA Gulfstream. The afternoon included a five-stop show and tell exercise around Lake Wanapitei which is a more recent and much smaller impact structure than the Sudbury structure and produced impact breccias that are now intermingled with glacial deposits.

Evening May 24: Discussion and debrief of day's exercises and planning for next day's exercises.

May 25: Seven-stop show and tell exercise at Windy Lake and High Falls (see July 8, 1971 discussion of Apollo 16 field trips). This was followed by a two-hour summary and discussion of the two days observations by the crew and accompanying geologists.

June 22-28, 1972 **Hawaii**
Astronauts: Cernan, Schmitt, Scott, Irwin, Parker, Evans (on 27-28 only)
Geologists: Jackson, Muehlberger, Phinney, Morrison, Freeman, Wolfe, Schaber, Ulrich, Peck, Christiansen
Others: Beattie, Petrone, Lee

There were six days of EVA-type traverses in various types of volcanic terrain using all of the routine procedures that would be accomplished on the accrual mission. In addition the USGS brought along a photo team, and every night they'd be in their photo lab processing all the day's film, setting up the panoramas and documentation photos from the traverse. These photos would then be used at the next briefing to critique the adherence to the photo procedures and the crew could correct any problems during the coming traverses. By the end of the six traverses the procedures had become quite routine.

June 21, 7:00 pm: Briefing on nature of traverses, problems to be approached, and logistics for next day.

June 22, 8:30 am: Kilauea Volcano (Kau Desert) Traverse. This four hour Rover traverse was designed to study a smooth mare-like, or plains-type, surface with many distinctive textural units within a large caldera complex. From the LM there was a 5.2 km driving traverse (not including return to LM) with seven stops totaling about four hours. The EVA started with the usual LM window description followed by panoramas, descriptions, and sampling in the vicinity of the LM. There were 7 stops each of which included panoramic photos, documented sampling of various units recognized on the aerial photos as well as any other units that appeared to the astronauts to be different. There were also Rover samples, 500mm photos of unreachable hills, trenching, coring, rake samples, and some special samples that required special equipment or techniques. A cuff check list was utilized to provide details on the tasks to be performed at each stop. All samples and photographs were accompanied by sample-bag numbers plus magazine and frame numbers for photos. In addition reports of odometer and compass headings were given along the way and additional short stops were made if the astronauts determined that it was warranted because of any unusual observations. A one-half hour radio debrief was held at the end of the EVA. After lunch a two and one-half hour walk-through debrief was conducted with all relevant personnel. During this debrief the support crews packed up the equipment and backroom and moved them to the site of the next day's EVA.

June 22, 8:00 pm: Briefing on nature of traverses, problems to be approached, and logistics for next day.

June 23, 9:45 am: South Point Traverse. This four hour Rover traverse was designed to study many textural units (lava flows) with considerable cover (regolith) and the relationship of the regolith to the flows. From the LM there was an 8 km driving traverse with six stops totaling about four hours. The EVA started with the usual LM window description followed by panoramas, descriptions, and sampling in the vicinity of the LM. Tasks and procedures on the traverse were similar to previous day. A one-half hour radio debrief was held at the end of the EVA. After lunch a two and one-half hour walk-through debrief was conducted with all relevant personnel. During this debrief the support crews packed up the equipment and backroom and moved them to the site of the next day's EVA.

June 23, 8:00 pm: Briefing on nature of traverses, problems to be approached, and logistics for next day.

June 24, 8:15 am: Pakini Nui Traverse. This Rover traverse was designed to study many textural units (lava flows) with considerable cover (regolith) and the relationship of the regolith to the flows. From the LM there was a 6.5 km driving traverse with six stops totaling about four hours and 15 minutes. The EVA started with the usual LM window description followed by panoramas, descriptions, and sampling in the vicinity of the LM. Tasks and procedures on the traverse were similar to the previous day. A one-half hour radio debrief was held at the end of the EVA. After lunch a one and one-half hour walk-through debrief was conducted with all relevant personnel. Briefing after dinner for June 26 traverse.

June 26, 8:30 am: Kahuku Traverse. This Rover traverse was designed to study the relationships of flows, cones, and ash in an area of large scale eruptions. There were also small scale features such as layering and channels (rilles). From the LM there was a 3.4 km driving traverse (not including return to LM) with six stops totaling about four hours and 15 minutes. The EVA started with the usual LM window description followed by panoramas, descriptions, and sampling in the vicinity of the LM. Tasks and procedures on the traverse were similar to the previous days. A one-half hour radio debrief was held at the end of the EVA. After lunch a two hour walk-through debrief was conducted with all relevant personnel.

June 26, 8:00 pm: Briefing on nature of traverses, problems to be approached, and logistics for next day.

June 27, 9:30 am: Hualalai Summit Traverse. Traverse started rather late because of a two-hour drive to the starting point and the time required for backroom and equipment set up. This Rover traverse was designed to study the relationships of flows and cones. From the LM there was a 7.4 km driving traverse (not including return to LM) with six stops totaling about four hours and 20 minutes. The EVA started with the usual LM window description followed by panoramas, descriptions, and sampling in the vicinity of the LM. Tasks and procedures on the traverse were similar to the previous days. A one-half hour radio debrief was held at the end of the EVA. After lunch a two hour walk-through debrief was conducted with all relevant personnel.

June 27, 7:15 pm: Briefing on nature of traverses, problems to be approached, and logistics for next day.

June 28, 8:50 am: Muana Kea Traverse. Again the traverse started rather late because of a two-hour drive to the starting point plus the time required for backroom and equipment set up. This Rover traverse was designed to study the relationships of flows and cones with mantle. From the LM there was a 6.1 km driving traverse (not including return to LM) with six stops totaling about four hours and 15 minutes. The EVA started with the usual LM window description followed by panoramas, descriptions, and sampling in the vicinity of the LM. Tasks and procedures on the traverse were similar to the previous days. The exercise was cut short by order of Rocco Petrone because of cold temperatures and drizzle of mixed snow and rain a little over half way through the traverse. The conditions were made even worse by the high altitude of this exercise (10,000 ft.). Petrone was afraid that the astronauts might get sick and make NASA management look bad.

July 24-25, 1972 **Stillwater, Montana** Astronauts: Cernan, Schmitt, Evans (24th only), Young, Fullerton, Parker
Geologists: Jackson, Muehlberger, Phinney, Morrison, Ulrich, Sutton, Schafer, Wolfe, Page

The Stillwater Complex is a large, layered igneous intrusion into older metamorphic rocks. The rocks in the Complex range from a thick sequence of ultramafic units in the lower section through a variety of gabbroic units as one traverses up the section. Within the gabbroic units are some layers of anorthosite that contain a variety of internal structures. The complex displays contacts with the older rocks, rhythmic layering, evidence of sinking of more dense minerals in the melt, and an overall fractionation trend from bottom to top. There are many good exposures and the traverses provided an excellent opportunity to study the formation of a coarse-grained igneous intrusion.

July 23: 8:00 pm Briefing on geology and logistics for the next day

July 24: 6:45 am Leave for EVA I site. Start four hour 15 minute EVA at 8:15 am. 30 minute radio debrief immediately after completing EVA. Two and one-half hour field walk-through in afternoon.

July 24: 8:00 pm Briefing on geology and logistics for the next day

July 25: 6:45 am Leave for EVA I site. Start four hour 15 minute EVA at 8:30 am. 30 minute radio debrief immediately after completing EVA. Two and one-half hour field walk-through in afternoon.

Aug. 7-8, 1972 **Nevada Test Site** Astronauts: Cernan, Schmitt, Evans (7th only), Young, Duke, Roosa (8th only), Fullerton, Parker, Overmeyer
Geologists: Roddy, Wilshire, Jackson, Muehlberger, Sutton, Wolfe, Hait, Ulrich, Swann, Freeman, Horz, Morrison, Scott, Moore, Schaber, Head

Evening Aug. 6: Briefing for crews, geologists, and support personnel for geologic context, traverses, and logistics.

Aug. 7: Evans and Laidley leave on high altitude fly-over at 7:30am. Remainder of persons leave Las Vegas by helicopter for Nevada Test Site at 6:00am. Prime crew commences four hour GROVER traverse at Schooner Crater at 8:00am followed by backup crew one-half hour later. Laidley and Evans do low altitude fly-over at 9:30am. After the fly-overs Laidley and Evans go to EVA site to participate in debriefings and lunch. Radio debriefing before lunch and Walk-through debrief after lunch for all parties. Depart NTS at 4:00pm and arrive Las Vegas at 5:00pm.

Evening Aug.7: Briefing for traverse on following day.

Aug. 8: Similar schedule as previous day but traverses were at Danny Boy Crater on Buckboard Mesa. Fly-overs were by Roosa and Overmeyer on this day.

Sept. 6-7, 1972 **Tonapah, Nevada** Astronauts: Cernan, Schmitt, Young, Duke, Parker, Fullerton
Geologists: Muehlberger, Phinney, Morrison, Ulrich, Trask, Smith, Scott, Sutton, Freeman, Wilshire, Wolfe, Head

Two EVAs at Lunar Crater near Tonapah, Nevada. This is a relatively young, little-eroded volcanic feature similar to some of the features expected at the Apollo 17 landing site. Both exercises were rover traverses with data packs, cuff check lists, tools, and cameras.

Sept. 5, 2:00 pm; Support personnel travel to EVA site to set up backrooms and radios.

Sept. 5, 8:00 pm: Briefing for observers and backroom personnel to provide detailed logistics for next day's traverse.

Sept. 6, 7:15 am: Travel to EVA site. Prime crew starts EVA at 9:30 am with LM activities followed by rover traverse with four stations in a total time of four hours and 30 minute over a distance of 10 km. The backup crew started their LM activities after the prime crew started on the traverse. Each crew had their own CapCom and backroom. Flight Director Pete Frank was also along as an observer. The crews accomplished coring, trenching, sampling, raking, photography, special sampling, rover sampling, and descriptions as suggested on their cuff check-lists. Radio debriefings followed the traverses. Following lunch all personnel in the field did walk-throughs of the traverses to critique the entire set of activities.

Sept. 6, 8:00 pm: There was a photo debriefing from the previous month's field trip to the Nevada Test Site followed by a traverse briefing to outline the activities for the upcoming day.

Sept. 7, 6:00 am: Depart for EVA site. Prime crew starts EVA at 8:00 am with LM activities followed by rover traverse with five stations in a total time of four hours and 30 minute over a distance of 10.4 km. Tasks were the same as previous day as outlined on cuff check-list. Radio debriefings followed the traverses. Following lunch all personnel in the field did walk-throughs of the traverses to critique the entire set of activities.

Oct. 6, 1972 **Blackhawk Slide & Mojave Desert, Calif**. Astronauts: Cernan, Schmitt, Young, Duke, Parker, Fullerton
Geologists: Schreve, Muehlberger, Ulrich, Phinney, Howard, Wilshire, Jackson, Wolfe, Morrison, Sutton, Talwani, Swann, Freeman, Head, Hodges, Strangway, Kovach, Watkins, Buck
Others: Sevier, Hanley, Barnes, and support personnel

This one-day exercise was to provide experience in interpreting landslide features in preparation for the landing site where one of the prominent features is a slide on the South Massif. Traverses were run with vehicles and traverse experiments.

Oct. 5, 12:00 noon: Support crews meet in field to set up backrooms and communications systems.
Oct. 5, 7:00 pm: Briefing on geology associated with slides of the type to be visited the following day.
Oct. 6, 6:00 am: Crews, backroom personnel, and observers depart for EVA site. Prime crew starts LM window description at 7:00 am and starts driving traverse at 7:30 am to cover five stations for a total of five hours over a distance of about 7.4 km. The backup crew followed 30 minutes behind the prime crew. Both crews accomplished coring, trenching, sampling, raking, photography, special sampling, Rover sampling, and descriptions. A radio debriefing followed the traverse. Following a 2-hour walk-through debriefing the crews and backroom personnel were led through a four hour and 30 minute driving traverse that had a LM stop plus five other stops over a distance of about 6.5 km. The tasks were similar to those of the earlier exercise. The plan was to either complete this traverse or proceed until darkness caused an end to the exercise.

Nov. 2-3, 1972 **Flagstaff, Arizona** Astronauts: Cernan, Schmitt, Fullerton, (Young, Duke 2nd day only)
Geologists: Wolfe, Moore, Jackson, Morrison, Wilshire, Holt, Lucchitta, Scott, Schaber, Strobell, Schafer, Stuart-Alexander, Watkins, Buck

Final geology exercise for A-17 crews. There were two simulated EVAs: one at Sunset Crater and the other at Cinder Lake in the San Francisco Volcanic field. These exercises incorporated the Traverse Gravimeter, Seismic Profiling, and Surface Electrical Properties Experiments into the traverses. The SOR in Houston was staffed by the same four teams that would be on duty during the mission. In contrast to the actual mission there was no TV available for the simulations.
Nov. 2: Traverse at Sunset crater starting with the LM site and proceeding through six stations for a total of five hours and 15 minutes over a distance of about 20 km. Tasks throughout the traverse included coring, trenching, sampling, raking, photography, special sampling, gravity readings, LM sampling, and descriptions. A radio debriefing between crew and Mission Control followed the EVA. During the traverse and the EVA it was recognized that for a variety of real time shuffling of times and tasks on the EVA some of the top priority objectives had not been met. This information was passed on to the planning team for planning revisions to the next EVA.
Nov. 3: A completely revised plan to make sure that all of the highest priority tasks were satisfied for today's EVA was radioed to the crew before they left the LM. This included elimination of several stations, returning to some of the previous day's stations, revisions of tasks and times on the cuff check lists, and new headings and distances between stations. The new plans started with activities at the LM followed by stops at five stations for a total of six hours over a distance of 12.75 km. Tasks throughout the traverse included coring, trenching, sampling, raking, photography, special sampling, gravity readings, LM sampling, surface electrical properties measurements, and descriptions. A radio debriefing between crew and Mission Control followed the EVA.

APPENDIX J: APOLLO 14 SCIENCE TRAINING SCHEDULE

OVERALL SUMMARY (total 17 months)

Geology Reviews and Lectures	40 hours
Field Training	8 trips totaling 19 days
Apollo 11 & 12 results	20 hours
Traverse Briefings	25 hours
Orbital Science	80 hours

DETAILED BREAKDOWN

Aug 11, 1969	Mineralogy review by Foss
Aug 12, 1969	Rocks and petrology review by Clanton
Aug 13, 1969	Discussion on impact craters by Moore
Aug 13, 1969	Lecture on impact metamorphism by Morrison and Greenwood
Aug. 14, 1969	lecture on cratering and field trip to the USGS Crater Field near Flagstaff
Aug 15, 1969	Lecture on explosive volcanism by Foss
Aug 18, 1969	Lecture on basaltic volcanism by Foss
Aug 19, 1969	Results from Lunar Orbiter and Surveyor by Trask and Holt
Aug 20, 1969	Results from Apollo 11 by several investigators
Aug. 22-23, 1969	Field trip to Craters of the Moon, Idaho (see Appendix ?)
Oct. 30, 1969	Briefings by ALSEP PIs
Jan 29, 1970	Discussion of photo procedures by Swann and geology team
Feb 5, 1970	Apollo 12 magnetometer results by Dyal
Feb 5, 1970	Photo procedures by Holt and geology team
Feb. 14-18, 1970	Field trip to Pinacates volcanic area, Mexico (see Appendix ?)
Date uncertain	Lecture on volcanism in Oregon by McBirney
Date uncertain	Lecture on volcanism at Katmai by Forbes
Date uncertain	Lectures on volcanism at Yellowstone and Valles Caldera by Bob Christenson and Bob Smith
Spring, 1970	Jackson gave lecture on Stillwater and Hawaii
April 2-4, 1970	Field trip to volcanic areas in Hawaii (see Appendix ?)
April 13, 1970	Orbital science briefings by various persons
May 1, 1970	Orbital science briefing by El-Baz and McEwen
May 11, 1970	Orbital science briefing by Masursky
May 18, 1970	Orbital science briefing by Trask
May 25, 1970	Orbital science briefing by El-Baz
May 28, 1970	Briefing for upcoming field trip on June 3-4by Foss, Carrier, McEwen & Heiken
June, 1970	Muehlberger gave introductory geology lecture
June 3-4, 1970	Field trip to Sierra Blanco, TX and Kilbourne Hole, N. M. (see Appendix ?)
June 18-19, 1970	Fly-over exercise by the CMPs at Flagstaff, Arizona consisting of a pre-flight briefing, a four-and-one-half hour flight and a post-flight debriefing.
July 10, 1970	Burchfiel gave talk on structural geology and global tectonics
July, 1970	Briefing on seismology and lunar structure by Kovach
July 20, 1970	Briefing on impact cratering by Don Gault

July 29 & 31, 1970	Lecture on geology of the Ries Crater by Horz for upcoming field trip
Aug. 11-13, 1970	Field trip to the Ries Crater, Germany (see Appendix ?)
Aug. 27 & Sep. 1, 1970	Lunar geology talk by Jack Green
Date uncertain	Roddy, Moore, Shoemaker gave talk on crater geology and impact phenomenon
Date uncertain	Lecture on petrology by Jim Hayes
Sept. 10-11, 1970	Field exercise among craters at Nevada Test Site (see Appendix ?)
Sept. 16, 1970	PI briefing-Soil Mechanics for both crews Landmarks Briefing for CMP
Sept. 20, 1970	Geology Briefing for Engle
Sept. 22, 1970	Lunar Topography briefing for CMPs
Sept. 23, 1970	ALSEP deployment Lunar Topography briefing
Oct.-Dec., 1970	All ALSEP & other PIs were to be scheduled for briefings beginning in October according to a memo from P. K. Chapman Mission Scientist, dated Sept. 2, 1970
Oct. 1, 1970	Orbital geology briefing by El-Baz for Roosa
Oct. 5, 1970	Lunar science lecture by Urey for entire crew
Oct., 1970	Orbital geology briefing by Trask for Roosa
Nov. 2, 1970	Surface Geology briefing by Hait
Nov. 3, 1970	Orbital geology briefing by El-Baz for Roosa
Nov. 6, 1970	Orbital geology briefing by Trask for Roosa and Evans
Nov. 10, 1970	Orbital geology briefing by El-Baz for entire crew
Nov. 11, 1970	Orbital geology briefing by Trask for Roosa and Evans
Nov. 16, 1970	Final field simulation at Flagstaff (see Appendix ?) Orbital geology briefing by El-Baz for Evans
Nov. 20, 1970	Orbital geology briefing by El-Baz for Roosa
Nov. 30, 1970	Lunar rock study by Heiken for both crews
Dec. 2, 1970	Briefing and discussion of traverses for both crews
Dec 7, 1970	Briefing on photo procedures by Hait
Dec. 9, 1970	Briefing on EVA by Holt
Dec 14, 1970	Lee Silver gave talk on anorthosites
Dec. 14, 1970	Briefing on EVA 2 with traverse maps by Swann
Dec 21, 1970	Lunar rock study by Heiken
Jan. 5, 1971	Objectives and procedures for comprehensive sample by Gast
Jan. 6-7, 1971	Orbital Geology briefing by El-Baz for CMPs
Jan. 13, 1971	Final briefing on EVAs with traverse maps by Swann

Between Oct. 6, 1970 and Jan. 19, 1971 there were seven EVA simulations through either Houston or KSC, four for EVA I and three for EVA II, for each of the backup and prime crews.

APPENDIX K: APOLLO 15 SCIENCE TRAINING SCHEDULE

OVERALL SUMMARY

General Geology Lectures	
39 @ approx. 3 hrs. each	116 hrs.
Lunar Rock Study Sessions	
9 @ 3 or 4 hrs. each	28hrs.
Geology Laboratory	
4 @ 3 hrs. each	12 hrs.
Geologic Field Training (See Appendix ? for details)	
10 Rover exercises	38 hrs.
10 Walking exercises	32 hrs.
General exercises including briefings and debriefings	200 hrs.
Principal Investigator Briefings	
Surface	20 hrs.
Orbital	10 hrs.

DETAILED BREAKDOWN

GENERAL GEOLOGY LECTURES

(3 to 4 hours duration)

January 16, 1970: Geology Briefing, 3 hrs. (from training log)
January 23, 1970: Geology Briefing, 3 hrs. (from training log)

February 2, 1970: Geology Briefing, 3 hrs. (from training log)
February 6, 1970: Geology Briefing, 3 hrs. (from training log)
February 13, 1970: Geology Briefing, 3 hrs. (from training log)
February 20, 1970: Geology Briefing, 3 hrs. (from training log)
February 23, 1970: Geology Briefing, 3 hrs. (from training log)

March 5, 1970: Geology Briefing, 3 hrs. (from training log)

According to Clanton some of the above briefings involved the study of rocks that were earth analogs of the returned lunar samples. The emphasis was on anorthosites, gabbros, basalts, breccias, and other lunar type rocks

March 13, 1970: Dr. H. Masursky, Doug Rille, 4 hrs.
March 20, 1970: Geology Planning Meeting, 2 hrs.
March 27, 1970: Drs. T. Foss, D. S. McKay, Ash Flows and Base Surge, 4 hrs,

April 27, 1970: Dr. James Hays, Petrology, 4 hrs.

May 15, 1970: Dr James Hays, Planetology, 6 hrs.
May 25, 1970: Dr. Robert Sharp, Geomorphology

June 17, 1970: Dr. H. Masursky, Orbital Geology
June 19, 1970: Dr. G. Swann, Geologic Documentation

July 8-9, 1970: Dr. F. El Baz and N. Trask, Orbital Geology, Lunar
July 21, 1970: Dr. F. El Baz, Orbital Geology, Lunar

August 11-12, 1970: Dr. H. Masursky, Orbital Geology, Lunar

August 18, 1970: Dr. F. El Baz, Orbital Geology, Lunar
September 1, 1970: Dr. J. Green, Lunar Volcanism
September 17, 1970: Dr. F. El Baz, SIM-Bay briefing for CMPs
September 28, 1970; Dr T, Ringwood, Lunar Processes

October 5, 1970; Dr. H. Urey, Lunar History

November 7, 1970: Dr. R. Brett, Lunar Geochemistry
November 16, 1970: Photo Procedures for Lunar Surface
November 17, 1970: Dr. G. Swann, PI Briefing (from training log)

January 19, 1971: Flyover out of El Paso for Worden and Brand
January 28, 1971: Traverse Briefing (from training log)

February 3, 1971: Dr. G. Swann, Apollo 14 Science Mission Objectives
February 4, 1971: Briefing with Apollo 12 crew
February 11-12, 1971: Dr. F. El Baz, Orbital Geology
February 20, 1971: Attended Apollo 14 Science and Photo Debriefs
February 24, 1971: Traverse Briefing (from training log)

March 9, 1971: Dr. F. El Baz, Orbital Geology
March 10, 1971: Dr. D. Wilhelms, Orbital Geology and Lunar Maps
March 16, 1971: Dr. G. Swann, Review of Apollo 14
March 16, 1971: Head and Schaber, Maps and Traverses for Apollo 15
March 18, 1971: Lunar Photo Team (LPT), Orbital Geology
March 29, 1971: Flyover out of southern California for Worden and Brand

April 5, 1971: Dr. G. Swann & Dr. G. Lofgren, Results of Apollo 11, 12
April 12, 1971: G. Lofgren, LGE, Traverse Planning
April 16, 1971: Dr. L. Silver, Geology Briefing (from training log)
April 19, 1971: Dr. R, Brett, Apollo 14 Results from Preliminary Exam of Samples
April 19-20, 1971: Orbital Geology Briefings (from training log)
April 26-27, 1971: Dr. G. Swann, Traverse Planning for Apollo 15

May 11, 1971: Zisk, Shorthill, Thompson, Lofgren: Remote sensing
May 14, 1971: Flyover of Northern California for Worden and Brand
May 18, 1971: Whitaker, Orbital Geology (from training log)
May 25-26, 1971: Schaber and Head, Sampling Rationale for Hadley site and Traverse Briefing
May 25-26, 1971: Dr. F. El Baz, Orbital Geology

June 4-5, 1971: Flyovers by Worden and Brand of central Arizona with Elston, Boudette, Wolfe, and Lovelace
June 7, 1971: Schaber & Lofgren, format for traverse map and sampling procedures and documentation.
June 9, 1971: Dr. F. El Baz, Orbital Geology
June 10, 1971: Swann, Hait & Lofgren, Geology of Apollo 15 Site
June 10, 1971: Dr. F. El Baz, Orbital Geology
June 21-22, 1971: Swann, Head, Schaber, Lofgren, Apollo 15 Traverse Maps & Review of Apollo 14
June 26, 1971: Geology Team, Field Trip Debrief from Previous Day's Final Simulation

July 1, 1971: Dr. F. El Baz, Orbital Geology
July 6, 1971: Swann, Schaber, Silver, Sevier, and Head, Traverses for Apollo 15
July 7, 1971: Dr. F. El Baz, Orbital Geology
July 16, 1971; Dr. F. El Baz, Orbital Briefing
July 19, 1971: Dr. F. El Baz, Orbital Briefing
July 22, 1971: Swann, Schaber, Silver, Sevier, and Head, Geology and Traverses for Apollo 15

LUNAR ROCK SESSIONS

January 6, 7, and 8, 1970:	Apollo 11 rock observations. 24 hrs.
September 28, 1970:	Rocks: 10018, 10017, 10046, 10058, 10049. 3 hrs.
October 12, 1970:	Rocks: 12055, 12035, 12054, 12073. 4 hrs.
December 2, 1970:	Rocks: 10022, 10065, 10019, 12017, 12034. 3 hrs.
January 5, 1971:	Rocks: 0018, 10058, 12054, 12055, 10047, 10044. 3 hrs.
January 26, 1971:	Rocks-general review of most of above rocks. 3 hrs,
May 3, 1971:	Rocks-review of lunar rock textures and obvious surface features using above and Apollo 14 rocks. 3 hrs.
May 19, 1971:	Quick rock identification practice.
June 18, 1971:	Rock description practice and review of rock diagnostic features. 3 hrs.
June 28, 1971:	Final review of all rocks studied previously. 3 hrs.

Conducted by Dr. Gary Lofgren

GEOLOGY LABORATORY

January 23, 1970:	Rock identification	3 hrs.
January 30, 1970:	Rock identification	3 hrs,
February 6, 1970:	Rock identification	3 hrs.
February 13, 1970:	Rock identification	3 hrs.

Instructors: Drs. R. B. Laughon, U. S. Clanton, and G. E. Lofgren

LUNAR SURFACE AND ORBITAL EXPERIMENT BRIEFINGS

	Exp. #	Date
Passive Seismic: G.V. Latham	S-031	5-3-71
Lunar Surface Magnetometer: Palmer Dyal	S-034	3-2-71
Solar Wind Spectrometer: C.W. Snyder	S-035	11-17-70
Suprathermal Ion Detector: J. W. Freeman	S-036	11-17-70
Heat Flow: M. E. Langseth	S-037	10-28-70
Cold Cathode Ion Gauge: F, S. Johnson	S-058	11-17-70
Laser Ranging Retro-reflector: J. E. Faller	S-078	3-12-71
Solar Wind Composition: J. Geiss	S-080	3-12-71
Soil Mechanics: J. K. Mitchell	S-200	10-28-70
Lunar Dust Detector: B. J. O'Brien	M-515	3-12-71
Gamma Ray Spectrometer: J. R. Arnold	S-160	1-4-71
X-Ray Fluorescence: Isidore Adler	S-161	1-4-71
Alpha Particle Spectrometer: Paul Gorenstein	S-162	1-4-71
Mass Spectrometer: J. H. Hoffman	S-165	3-2-71
S-Band Transponder (Subsat): W. L. Sjogren	S-164	4-14-71
S-Bond Transponder: (CSM/LM)		
Particle Shadows/Boundary Layer (Subsat): Kinsey A. Anderson	S-173	4-14-71
Subsatellite Magnetometer: Paul J. Coleman, Jr.	S-174	4-14-71
Bistatic Radar: H.T. Howard	S-170	5-3-71

APPENDIX L: INFORMAL NAMES FOR SURFACE FEATURES IN THE APOLLO 15 LANDING AREA

Alligator Chain - Chain of craters resembling, an alligator.
Apennine Front - Part of the Apennine Mountain Range.
Arbeit - German for toil or work; a crater near a complex station.
Arrowhead - Several craters forming an arrowhead pointing north from the South Cluster.

Blinky - Astronaut nickname.
Brandy - Named for the liquor.
Bridge - Crater in Rima Hadley; the rim appears to form a bridge across the rille.

Canyon - Crater at edge of Hadley canyon.
Chain - Named for the chain of craters (rio) leading away from the southern rim of the crater.
Cliff - Crater located on edge of Rima Hadley.
Contact - A crater located on the geologic contact between the Apennine Front and the mare.
Contour - A crater high up on the Apennine Front located on the contours of the topographic map.
Crescent - A half-moon shaped crater in the South Cluster.
Crook - Crater located at crook in elbow.
Crystal - Crater named for geology term crystal.

Dandelion - A crater named for R. Bradbury novel “Dandelion Wine”.
Diamond - A small crater on the edge of Ring crater.
Distant - Crater located on the far side of the rille.
Dome - Geologic term often applied to volcanic structures.
Domingo - Spanish for Sunday, the day this EVA traverse will take place.
Dune - Crater named for the classic science fiction novel by Frank Herbert; also for a dune-like structure on the southeast rim of the crater.
Durins Bridge - Place name from the “Lord of the Rings” trilogy by J.R.R. Tolkien.

Eaglecrest - Named for high area in the North Complex.
Earthlight - a crater named for an Arthur C. Clarke novel of the same name.
Elbow - Crater and area at bend in Rima Hadley resembling an elbow.
Epic - Signifying the journey to the moon
Exupery - From “The Little Prince”, a story about a little prince who came from asteroid B-612 (Antoine de Saint-Exupery).

Fan - Crater located at the front of a geologic feature mapped as a possible ancient flow, slide, or
Fifty-one - The year Lunar Module Pilot James Irwin graduated from the U. S. Naval Academy.
Fifty-four - The year Apollo 15 Commander David R Scott graduated from the U. S. Military Academy.
Fifty-five - The year Command Module Pilot Al Worden graduated from the U. S Military Academy.
Flow - Crater located on a geologic feature mapped as a possible ancient flow or Slide deposit.
Front - Large crater located along base of Apennine Front.

Gateway - This crater is on the traverse route leading to the North Complex, at the “gateway”.
Ghostbead - Named for a musical composition.

High - A crater high up on the Apennine Front.

Icarus - Crater named for character in Greek mythology. Icarus, with Daedalus, escaped from the Cretan labyrinth by building wings with feathers and wax.
Index - A prominent crater near the landing site serving as a landmark from orbit and upon landing.

Kimbal - For Kimbal Kennison, a hero of E. E. Smith’s Lensman series, a set of science fiction novels about the galactic patrol, written in the 1930’s.

Last - One of the last craters at the end of the last traverse.
Lightning - Named for the fact that lightning struck the spacecraft on the launch pad numerous times prior to launch.
Link - A crater linking Chain crater to Rio.
Lonely - Single crater on opposite wall of Rima Hadley.
Luke - Biblical character.
Lundi - Monday in French; this EVA should take place on Monday, August 2.

Mark - Biblical character.
Matthew - Biblical character.
Misty Doublet - from Misty Mountains, place name from the “Lord of the Rings” trilogy by J. R. R. Tolkien.

Nameless - Prominent crater with no name.
North Complex - Complex of hills, craters, scarps, and apparent flow fronts to the north of the landing site.
North Twin - One of a pair of craters at edge of Pima Hadley.
November - Late in the last traverse, a late month in the year.

Offset - Elongate crater slightly offset from base of Apennine Front.
Orville - The Wright Brother.
Os - Large crater on far side of Rima Hadley named for first letters of “other side”.

Pitane - A crater in the secondary crater cluster. The material which produced these secondary craters, is thought to have been derived from the crater Autolycus, to the north. Pitane was the city in Asia Minor in which Autolycus worked about 310 B.C.
Pluton - Geologic term for a large body of rock which has crystallized deep under the surface.
Pooh - Winnie the Pooh and Poo, a computer program that places the CSM and LM flight computers in readiness for most of the other flight programs near the beginning of first traverse.

Quadrant - Named for the seaman’s reflecting quadrant, a precursor of the modern sextant. This quadrant was invented by John Hadley (1682—1744), for whom Hadley Rille is named.
Quark - Name applied to a three crater complex; the name of a hypothetical subatomic particle, coined by Murray Gell-Mann, Cal-Tech Nobel Laureate.

Rhysling - A crater named for Rhysling, the blind poet of “The Green Hills of Earth” a science fiction story of Robert Heinlein.
Ridqe - Crater located on a slight topographic rise.
Rim - Crater at the rim of Rima Hadley.
Ring - A ring-shaped crater.
Rio - River, for the chain-like channel leading south from Chain Crater.

Salyut - Crater named for the Russian space station.
Samstag - German for Saturday, the day this EVA traverse will take place
Scarp - Crater located near small scarp at rille edge.
Side - Small crater located on the side of Pluton.
Slide - Crater located near a geologic feature mapped as a possible ancient flow or slide deposit.
South Cluster - A cluster of secondary craters located to the south of the landing site.
South Twin - One of a pair of craters at edge of Rima Hadley.
Spur - Crater located on a small spur of the Apennine Front.
St. George - A type of wine with which the crew members celebrated a successful launch in Jules Verne’s “From The Earth to the Moon”.

Tecumseh - Named in honor of the U, S. Naval Academy.
The Plain - A flat area of mare.
The Terrace - Slight projection of mare out into Rima Hadley.
Trophy Point - Named for the point of land which protrudes into the Hudson River at West Point.

Uttermost West - Place name from the "Lord of the Rings" trilogy by J. R. R. Tolkien.

Wilbur - The Wright Brother.
Window - A crater which may provide a "window" through to the material below the surface of the Apennine Front.

APPENDIX M: APOLLO 16 SCIENCE TRAINING SCHEDULE

OVERALL SUMMARY

Surface-related training	
39 Sessions @ average of 4 hours	142 hours
Simulations through Mission Control	12 days
Orbital geology	
12 Sessions @ average of 3 hours	36 hours
Fly-over exercises	18 days
Field trips (see Appendix XY)	36 days
Geology lectures (lunar and terrestrial)	
45 sessions @ average of 2 3/4 hours	124 hours
Lunar Rock study	
17 sessions @ average of 3 hours	50 hours

DETAILED BREAKDOWN

SURFACE-RELATED TRAINING

December 14, 197	0Silver: Debriefing of field trip to San Gabriel Mountains
January 15, 1971	Phinney: Review and discussion of photo procedures
March 16, 1971	Ulrich, Muehlberger: Pre-briefing for Merriam Crater field trip
March 16, 1971	Muehlberger, El-Baz: Results of Apollo 14 photography of Descartes and photomapping exercise for crew to make their own geological map of Descartes area.
March 22, 1971	Clanton: photo debriefing using Apollo 14 photography
March 24, 1971	Horz: Merriam crater traverse mapping exercise
April 20, 1971	Horz: Photo debriefing from Meteor Crater exercise
April 23, 1971	Elston: Pre-briefing for Verde River traverses
May 13, 1971	Muehlberger: Pre-briefing for field trip to Capulin Mountain
May 13, 1971	Horz: photo debriefing from Flagstaff cinder field exercise
May 17, 1971	Horz: review of effectiveness of photography from Merriam crater exercise
June 7, 1971	Wolfe: review of effectiveness of photography from Merriam crater exercise.
June 8, 1971	Wones, Wolfe: Pre-briefing for Mono Craters field trip
July 6, 1971	Dence: Pre-briefing for Sudbury field trip
July 30-31 & Aug. 1, 1971	Apollo 16 crew observed SSR activities during Apollo 15 EVAs
August 16, 1971	Silver: Apollo 16 crew observed tapes of Apollo 15 with Apollo 15 crew
August 17, 1971	Attended science debriefing of Apollo 15
September 16, 1971	Elston: Used stereo plotter to study Descartes site
September 16, 1971	Muehlberger: discussion of traverse planning for Apollo 16
September 28, 1971	Clanton: Photo debriefing using Apollo 15 surface photos
October 13, 1971	Wolfe, Horz, Moore: Review of all photos from the Rio Grande trip. All 70mm photos were compiled as panoramas, documented sample shots, rover shots, telephoto, and close-up stereo and were reviewed with the crews to gain a full evaluation before the next trip to the Nevada Test Site. Pre-briefing for Nevada Test Site trip
October 13, 1971	Head, Sevier: Traverse planning for Apollo 16
November 15, 1971	Wolfe, Horz: photo debriefing from Nevada Test Site and Pre-briefing for Coso Hills trip
November 16, 1971	Elston, Schaefer, Horz: Used stereo plotter to study Descartes site
November 15, 1971	Wolfe: met with all 4 crew of 16 to review and evaluate their photos from the NTS exercise and brief them on the upcoming Coso exercise.
November 1971	Elston and Shafer: met with crews and others for presentation of geologic interpretation of the Descartes site.

January 5, 1972	Head, Muehlberger: Traverse briefing at KSC in evening
January 6, 1972	Head, Muehlberger: Traverse briefing at KSC in evening
January 18, 1972	Head, Muehlberger: Traverse briefing at KSC in evening
January 19, 1972	Head, Muehlberger: Traverse briefing at KSC in evening
February, 1972	Head, Muehlberger: Traverse briefings at KSC in evenings
March, 1972	Muehlberger and Ulrich: training session at MSC on descriptions, sampling, and photo procedures.
March, 1972	Elston, Shafer, and Phinney: met with Young to review traverses and trafficability at Apollo 16 site.
March 1-2, 1972	Muehlberger, Boudette: Traverse briefings at KSC
March 14, 1972	Muehlberger, Boudette: Traverse briefings at KSC
March 22, 1972	Muehlberger, Boudette, Ulrich and Swann: Traverse briefings at KSC

SIMULATIONS THROUGH MISSION CONTROL

January 14, 1972	Paper simulation at Houston
February 2, 1972	Paper simulation at Houston
February 3, 1972	Math Model Simulation at Houston
February 9, 1972	Paper simulation at Houston
February 10, 1972	EVA 1 simulation with ALSEP deployment on sand pile at KSC through SSR in Houston
February 17-18, 1972	EVAs 2 and 3 simulations at Boulder City, Arizona through SSR in Houston
March 9, 1972	Paper sim at Houston
March 10, 1972	Math model sim at Houston
March 22, 1972	ALSEP and EVA sim at KSC through Mission Control in Houston
March 27, 1972	Paper sim at Houston
March 28, 1972	Math model sim at Houston

ORBITAL GEOLOGY

January 31, 1972	El-Baz: Photo and visual targets
February 7, 1972	El-Baz: Ground tracks
March, 1972:	Elston, Shafer, and Laidley: review geologic targets for orbital descriptions in the Descartes landing region with Mattingly and Hartsfield.
March 6, 1972	El-Baz, Howard: Groundtracks
March 13, 1972	Hodges: Landing site geology, Moore: North Ray crater, El-Baz: Groundtracks
March 20, 1972	El-Baz: Photo & visual targets-entire crew
March 20, 1972	El-Baz: Groundtracks-CMP
March 27, 1972	El-Baz: photo and visual targets
April 3, 1972	El-Baz: Groundtracks-entire crew
April 3, 1972	El-Baz: photo & visual targets-CMP
April 10, 1972	El-Baz: Groundtracks-entire crew
April 10, 1972	El-Baz: Flight Plan review-CMP

FLY-OVERS

April 4, 1971	Elston: briefed Mattingly and Fullerton at MSC on fly-over of San Francisco volcanic field of northern Arizona.
May 5-6, 1971	Elston, El-Baz: Fly-over of San Francisco volcanic field with Laidley and Mattingly
June 23-25, 1971	Elston: Flyover of volcanic terrain at Craters of the Moon, Idaho; Butte Crater, Idaho; land slides and mud flows, Idaho; lake terraces at Salt Lake; and Wasatch mountains, Utah with Laidley and Mattingly.

July 19-21, 1971	Elston: Flyover of Pinacate volcanic field, New Mexico; Meteor Crater and Hopi Buttes, Arizona with Laidley and Mattingly
September 7-8	Silver: Flyover of Rio Grande Valley in coordination with field traverses on ground and of Valles Caldera with Laidley and Mattingly.
October 13-15, 1971	Muehlberger: 2 day fly-over from Lassen Peak, California to Bend, Oregon with Laidley and Mattingly. Also a high altitude only fly-over of Capulin volcanics, New Mexico on the 15th.
October 27-28, 1971	Moore, Roddy, Sargent: Fly-over of Nevada Test Site in conjunction with traverse training exercise on ground with Laidley and Mattingly. Walk through on ground afterwards.

GENERAL GEOLOGY LECTURES

(Lectures lasted from 1 to 4 hours with average of 2 ½ hours)

mid-1970s, no dates	Muehlberger, McEwen, Clanton, Foss: Basic geology review totaling about 20 hours
mid-1970s, no date	Hayes: Petrology (4 hours)
October 5, 1970	Gast: Chemistry of Apollo 11 and 12 rocks
October 7, 1970	Ringwood: Implications of Apollos 11 & 12 materials for lunar origins
October 29, 1970	Horz: Shock Metamorphism
December 2, 1970	Horz: Surface phenomena of lunar rocks
January 8, 1971	Wood: Lunar anorthosites
January 27, 1971	Strangway: Magnetic properties of terrestrial and lunar rocks
February 27, 1971	Gault: Experimental impact cratering
March 5, 1971	Carrier, Lindsay: Lunar soil
March 16, 1971	El-Baz: discussion of Descartes landing site
March 22, 1971	Walker: Radiation history of lunar materials
April 14, 1971	Dyal: Planetary magnetic fields
May 12, 1971	Zisk, Shorthill, Thompson: Remote sensing
May 21, 1971	Langseth: Heat Flow
June 2, 1971	Brett: Apollo 14 Preliminary Examination Team results
July 2, 1971	Bogard: Gas chronology
July 15, 1971	Urey: Origin and Evolution of the Moon I
July 22, 1971	Urey: Origin and Evolution of the Moon II
July 29, 1971	Head: The Apollo 15 landing site
August 6, 1971	Urey: The Moon
August 25, 1971	Shoemaker: Impact cratering
October 8, 1971	Heiken: Pyroclastic rocks
October 28, 1971	Moore: Impact cratering
October 29, 1971	Gast, Reid: Lunar geochemistry
November 1, 1971	Horz: Ries crater and impact ejecta
November 8, 1971	Sjogren: Lunar gravity
November 22, 1971	Mitchell: soil mechanics and Kovach: Active seismic experiment
November 23, 1971	Phinney: Apollo 15 Preliminary Examination Team results
November 29, 1971	Arnold: Apollo 15 gamma-ray spectrometer results, Gorenstein: Apollo 15 alpha particles and x-ray fluorescence results, Zisk: 3.8cm radar
December 20, 1972	McKay: Lunar breccias
January 3, 1972	Wasserburg: Geochronology and special samples
January 31, 1972	McCauley: Lunar highlands volcanism
February 7, 1972	Mutch: Lunar stratigraphy
February 15, 1972	Green: Volcanic landforms
February 15, 1972	Baldwin: Lunar surface features
February 22, 1972	Masursky: Lunar history
February 22, 1972	Whitaker: Color boundaries and, Strom: Lunar grid

February 28, 1972	Zisk, Thompson: Radar Data, Shorthill: IR data, El-Baz & Head: Geological significance of radar and IR data
February 28, 1972	Green: Basaltic landforms
February 28, 1972	Greeley: Earth analogs

LUNAR ROCK SESSIONS

September 22, 1970	Clanton, Horz: Rock classification
September 29, 1970	Horz: Rock classification
November 3, 1970	Horz: Shock metamorphism
December 3, 1970	Horz: Apollo 11 rocks: 10046, 10059, 10084, 10162
December 18, 1970	Horz: Apollo 12 rocks: 12055, 12021, 12037
January 6, 1971	Horz: Apollos 11 and 12 rocks: 10049, 12054, 12065
April 4, 1971	Anderson, Horz: Apollo 14 rocks: 14301, 14305, 14308, 14311, 14318, 14321
April 23, 1971	Horz: Apollo 14 rock: 14310
May 5, 1971	Horz: Apollo 14 rock: 14066
May 6, 1971	Horz: Apollo 14 rocks: 14053, 14082, 14016
May 11, 1971	Horz: Apollo 14 rocks: 14307, 14318
May 28, 1971	Horz: Apollo 14 rocks: 14305, 14306
June 16, 1971	Horz: Apollo 14 rocks: 14307, 14318
August 19, 1971	PET members: Apollo 15 rocks: 15095, 15455, 15064
August 25, 1971	Horz: Apollo 15 rocks: 15405, 15556, 15405, 15555, 15015
September 8, 1971	Horz: Apollo 15 rocks: 15459, 15555
November 29, 1971	Horz: Apollo 15 rocks: 15015, 15059, 15418, 15426, 15459, 15565, 15566

APPENDIX N: APOLLO 17 SCIENCE TRAINING SCHEDULE

In April there were 2 lab sessions for review of minerals and rocks and another session by Clanton to review the Apollo 14 photos

August 25, 1971	Shoemaker: Apollo 16 geology
September22, 1971	Lofgren: lab session on lunar rocks
September 29, 1971	Lofgren: lab session on lunar rocks
Late September, 1971	Muehlberger: meets 17 crew to discuss field trip philosophy.
November 4, 1971	Muehlberger: subject unknown
November 10, 1971	ALSEP PIs: lectures on Heat Flow, Soil Mech, Seismic Profiling experiment, Traverse gravimeter, Lunar ejecta and meteorites
November 15, 1971	Wolfe: met with 17 crew at MSC to review photos from Apollo 16's NTS trip and to brief them on geology of Coso Hills for upcoming Apollo 16 trip where Apollo 17 would be observers.
November 22, 1971	Morrison: A15 rock study
November 29, 1971	Orbital science PI: SEP briefing
November 30, 1971	Muehlberger: study of Capulin volcanic terrain using air photos, rock samples and ground photos at MSC.
December 14, 1971	Morrison: Apollo 15 rocks
December 15, 1971	PI briefing: UV spectrometer by Fastie
December 16, 1971	Morrison: Apollo 15 rocks
January 7, 1972	Reid: Lunar basalts and Morrison: A11, 12 and 15 rocks
January 17, 1972	Lunar rocks
January 18, 1972	PI briefing: lunar sounder
January 20, 1972	Ross Taylor: geochemistry lecture
January 23, 1972	Flyover of Boulder City Nevada area of Apollo 17 surface traverses
January 25, 1972	Henry Moore: Orbital Geology
February, 1972	McGetchin: briefing at MIT
February, 1972	Phinney: Discussion of anorthosites
February, 1972	McKay: Lunar breccias and study of Apollo 16 rocks
February, 1972	Morrison: Debriefing of Boulder City field trip
February 25, 1972	Wilhelms, Moore, Alexander: Orbital Geology
March 2, 1972	Orbital Geology
March, 1972	Flyover of Meteor Crater and Hopi Buttes
March 22, 1972	Fred Doyle: Orbital Geology
March 29, 1972	Muehlberger: briefing for a flyover exercise in West Texas which was conducted on March 29
March 31, 1972	Horz: Cratering processes
April 13, 1972	Bogard: Gas chronology
April 13, 1972	Field trip debrief
May 11, 1972	El-Baz: Orbital geology
May 12, 1972	El-Baz: Orbital geology
May 24, 1972	Head: Site geology
May 30, 1972	Apollo 16 rock review
June 6, 1972	Orbital Geology
June 12, 1972	Howard: Crater morphology
June, 1972	Flyover of Rio Grande gorge near Taos, NM
June 1972	At an unknown date in this general time frame there was a review of the Apollo 15 and 16 surface photography by Clanton.
July 7, 1972	El-Baz: Orbital geology
July 18, 1972	Warner: Orbital geology
July 19, 1972	Apollo 16 rock review

July, 1972	Flyover of volcanic terrain at Craters of the Moon, Idaho; Butte Crater, Idaho; land slides and mud flows, Idaho; lake terraces at Salt Lake; and Wasatch mountains, Utah
July 26, 1972	Moore: Orbital geology
July 31, 1972	Wilhelms: Orbital geology
August 2, 1972	Head: traverse planning
August 7-8, 1972	Flyover of Nevada Test Site in conjunction with traverse training exercise on ground
August 16, 1972	El-Baz: Orbital geology
August 17, 1972	El-Baz: Orbital geology
August 21, 1972	Carr: Orbital geology
August 31, 1972	Geology lecture
September, 1972	Flyover from Lassen Peak, California to Bend, Oregon
September 1, 1972	Muehlberger, Silver, Wolfe, Morrison, and others from MSC: meet with crews at MSC to discuss special sampling plans.
September 8, 1972	Muehlberger, Wolfe, and Freeman: brief crews on EVA I procedures.
September 11-12, 1972	Muehlberger, Wolfe, Morrison: at MSC to review site geology and traverse plans.
September 13, 1972	Scott, Luchitta: Orbital geology
September 18, 72	EVA paper sim, Houston
September 19, 72	EVA math model sim Houston
September 20, 1072	El-Baz: Orbital geology
September 21, 1972	ALSEP simulation at KSC
September 28, 1972	EVA I simulation at KSC.
September 28, 1972	Scott: Orbital geology
October, 1972	Tests and simulations for the Lunar Sounder: no dates.
October 3, 1972	El-Baz: Orbital geology
October 4, 1972	El-Baz: Orbital geology
October, 1972	Flyover of San Andreas fault area of California
October 6, 1972	ALSEP simulation at KSC
October 10, 1972	Discussion of procedures and traverses at KSC
October 11, 1972	Discussion of procedures and traverses at KSC
October 11, 1972	El-Baz: Orbital geology
October 12, 1972	Lunar geology lecture at KSC
October 17, 1972	ALSEP simulation at KSC
October 25, 1972	Procedures discussion
October 26, 1972	Paper sim at Houston.
October 26, 1972	Eggelton: Orbital geology
October 27, 1972	Math model sim at mission control in Houston.
October 27, 1972	Orbital geology
October 30, 1972	Head, Muehlberger, Sevier: Traverse briefing
October 31, 1972	Lunar geology discussion
November 1, 1972	ALSEP simulation at KSC
November 2, 1972	EVA 2 at Flagstaff through Mission Control in Houston
November 3, 1972	EVA 3 at Flagstaff through Mission Control in Houston
November 4, 1972	Traverse plans reviewed with SSR personnel in Houston after final geology simulation.
November 7, 1972	ALSEP deployment exercise at Hangar S, KSC, prime and backup.
November 8, 1972	Paper sim at MSC
November 8, 1972	El-Baz: orbital geology all crews 1900-2100
November 9, 1972	Math model sim at MSC
November 10, 1972	Mission Rules discussion at Houston
November 13, 1972	Muehlberger and Freeman: EVA 3 briefing at KSC.
November 13, 1972	El-Baz: orbital geology
November 14, 1972	El-Baz: orbital geology
November 15, 1972	ALSEP simulation at KSC
November 16, 1972	Paper sim at MSC, includes all traverse experiments
November 17, 1972	Math model sim at MSC, includes all traverse experiments
November 21, 1972	El-Baz: orbital geol all crews 1900-2100

November 22, 1972	ALSEP simulation at KSC
November 22, 1972	El-Baz: orbital geol all crews 1900-2100
November 22, 1972	Muehlberger: crew briefing at KSC
November 24, 1972	El-Baz: orbital geol all crews 1900-2100
November 27, 1972	paper sim at MSC
November 28, 1972	El-Baz: orbital geol all crews 1900-2100
November 28, 1972	Muehlberger, Swann, Wolfe, Freeman: geology briefing of crews (orbital and surface) at KSC
November 29, 1972	Math model sim at MSC
November 29, 1972	ALSEP deploy by prime KSC and EVAs 2 and 3 by backup KSC
December 4, 1972	El-Baz: Orbital geol briefing for Evans
December 4, 1972	El-Baz: orbital geol all crews 1900-2100

APPENDIX O: SCIENCE WORKING PANEL CHARTER

Revised: July 20, 1971

Charter of the Science Working Panel
Office of Prime Responsibility: Deputy Director of Science and Applications

I. Purpose

The Science Working Panel is established to define and integrate lunar surface and orbital science requirements. This Panel shall be the prime scientific body responsible for the overall planning of traverses on the lunar surface, traverse activities, and timelines for surface activities. The planning function of the Panel will be to coordinate activities proposed by and arising from individual experiments and investigator teams. The Panel will establish priorities for different scientific tasks and activities that go into the exploration of the lunar surface. The Panel will also establish relative priorities for orbital experiments where such priorities are required to resolve conflicts that arise from overlapping requirements. Directorate recommendations from this group will be provided to Center management to influence activities relative to mission planning, crew training, and hardware development.

II. Organization

The Science Working Panel shall consist of a Chairman from Science and Applications Directorate, Panel Members representing scientific disciplines that are relevant to lunar exploration, and representatives from Headquarters and the Manned Spacecraft Center to represent operations and experiment management.

Appointment of Panel Members is the responsibility of the Science and Applications Director. Panel appointments will require the concurrence of the Chairman. Duration of Panel membership and selection of Apollo missions for which Panel functions will apply shall be specified by the Science and Applications Director.

Membership on the Panel does not preclude an individual from participating in the analysis of Apollo mission data for scientific investigations.

III. MSC/Panel Interface and Reporting Requirements

The Panel Chairman shall submit all Panel recommendations and reports to the Science and Applications Director- Copies of all Panel recommendations will also be forwarded to;

1) Apollo Spacecraft Program Manager (MSC)

2) Director of Flight Crew Operations (MSC)

3) Director of Flight Operations (MSC

4) Apollo Lunar Exploration Director (NASA Headquarters)

IV. Panel Responsibilities

The Apollo Science Working Panel will participate and will be responsible for providing written recommendations in the following areas

1. Use of Time on the Lunar Surface

The Panel will review all science planning for each mission from the time a particular site for that mission is announced until the mission is flown. Traverse locations and sampling activities on the lunar surface will normally be reviewed by the Panel before they are accepted by the Directorate or ASPO.

2. Science Hardware Development

a) The Panel shall recommend orbital science experiment functional requirements.

b) The Panel shall recommend surface science experiment functional requirements.

3. Science Hardware Utilization

a) The Panel shall participate in review of plans for scientific utilization of the science hardware.

b) The Panel shall establish priorities to maximize the scientific return for experiments where is constrained.

c) The Panel shall provide recommendations on experiment operational requirements to flight planners to facilitate mission planning.

d) The Panel shall provide the vehicle for development and coordination of traverse plans with USGS, Bellcomm, MSFC, and MSC.

4. Crew Training

The Panel shall provide technical advice for and will support, as required, astronaut training related to scientific tasks.

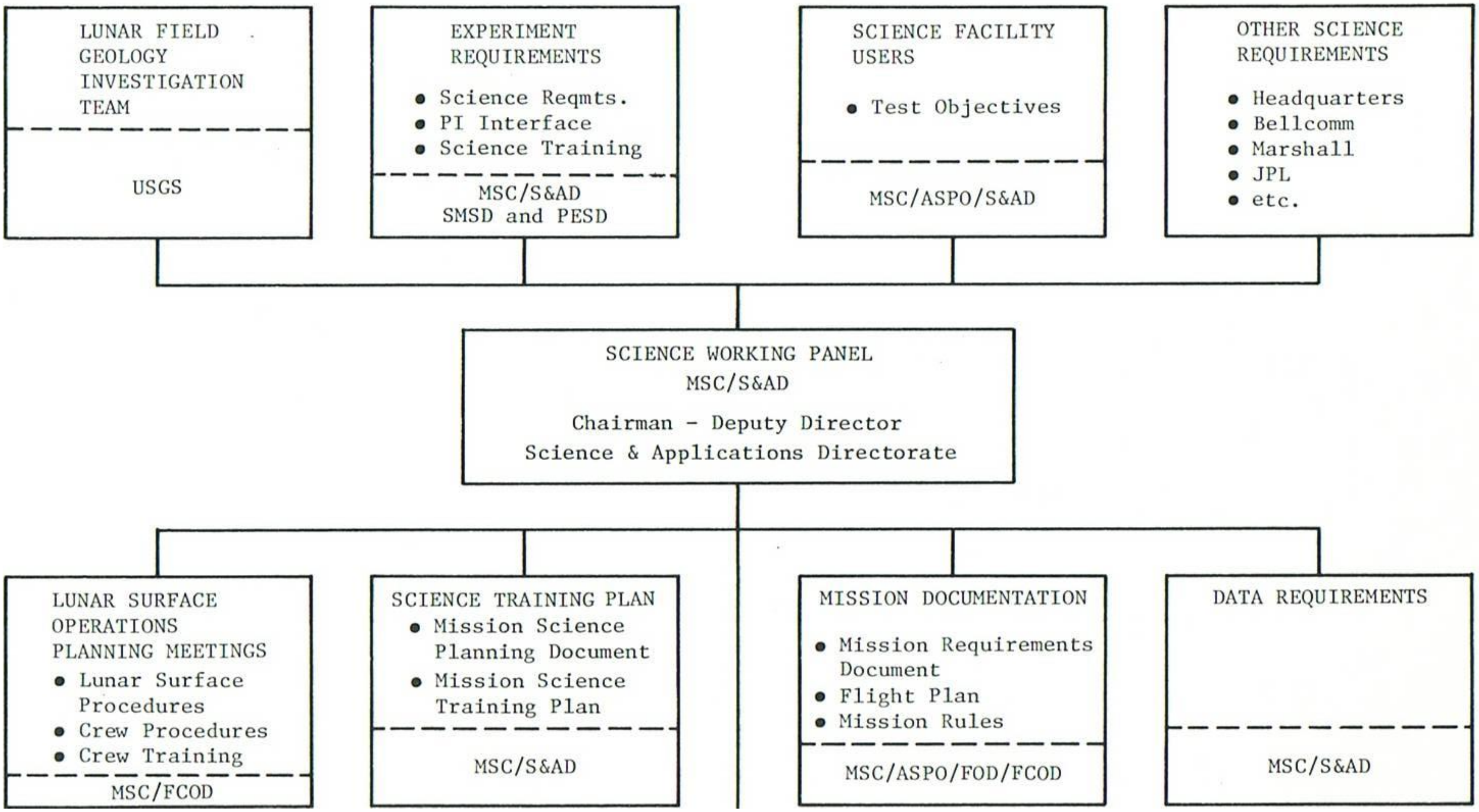
5. Operational Support

The Panel shall support operations, as requested, by providing real-time scientific and technical advice to astronauts for scientific tasks.

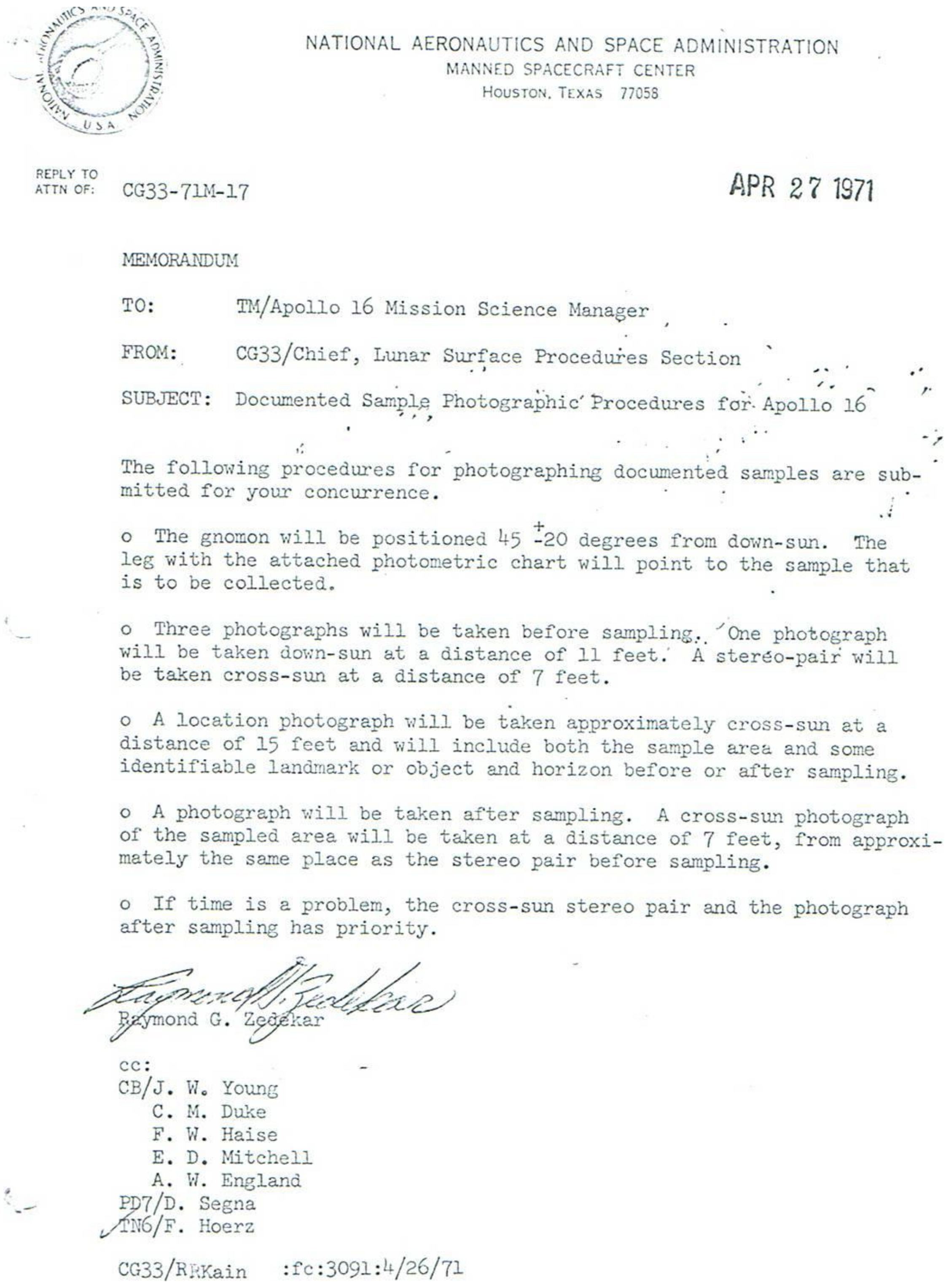
6. Data Analysis

The Panel shall review proposed data reduction requirements to assure the full utilization of MSC’s data reduction capabilities.

DISSEMINATION OF SCIENCE REQUIREMENTS FOR LUNAR MISSION PLANNING



APPENDIX P: PHOTOGRAPHIC PROCEDURES



NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
MANNED SPACECRAFT CENTER
HOUSTON, TEXAS 77058

REPLY TO
ATTN OF: CG33-71M-17

APR 27 1971

MEMORANDUM

TO: TM/Apollo 16 Mission Science Manager

FROM: CG33/Chief, Lunar Surface Procedures Section

SUBJECT: Documented Sample Photographic Procedures for Apollo 16

The following procedures for photographing documented samples are submitted for your concurrence.

- o The gnomon will be positioned 45 ±20 degrees from down-sun. The leg with the attached photometric chart will point to the sample that is to be collected.
- o Three photographs will be taken before sampling. One photograph will be taken down-sun at a distance of 11 feet. A stereo-pair will be taken cross-sun at a distance of 7 feet.
- o A location photograph will be taken approximately cross-sun at a distance of 15 feet and will include both the sample area and some identifiable landmark or object and horizon before or after sampling.
- o A photograph will be taken after sampling. A cross-sun photograph of the sampled area will be taken at a distance of 7 feet, from approximately the same place as the stereo pair before sampling.
- o If time is a problem, the cross-sun stereo pair and the photograph after sampling has priority.

Raymond G. Zedekar

cc:
CB/J. W. Young
   C. M. Duke
   F. W. Haise
   E. D. Mitchell
   A. W. England
PD7/D. Segna
TN6/F. Hoerz

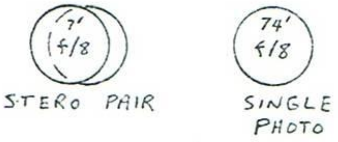
CG33/RRKain :fc:3091:4/26/71

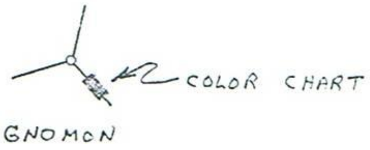
KEY

CDR


7'
f/8
STERO PAIR
74'
f/8
SINGLE PHOTO
FOCUS DISTANCE
CAMERA f STOP SETTING

LMP


7'
f/8
STERO PAIR
74'
f/8
SINGLE PHOTO


COLOR CHART
GNOMON

PANORAMIC PHOTOGRAPHS

15 TO 20 PHOTOS

HORIZON NEAR TOP

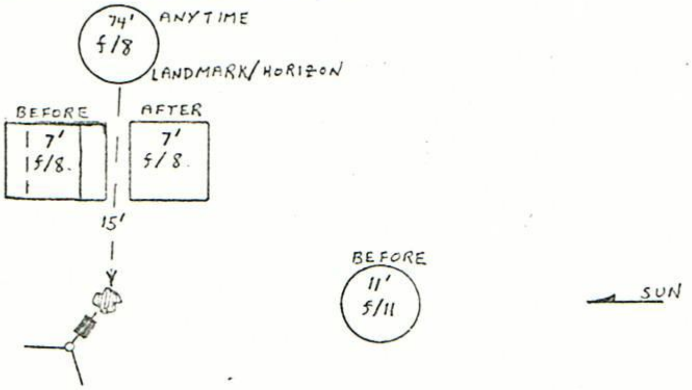
Large areas of the landing site will be documented by panoramic photographs. Each set will consist of at least 15 TO 20 photographs, overlapped to provide 360-degree coverage. The far-field (74-foot) detent will be used for all panoramic photographs. The astronaut will aim the HEDC so that the horizon will appear near the top of each photograph.

Three sets of panoramic photographs will be taken in the immediate proximity of the LM (i.e., at locations approximately 20 feet from the LM quad 2, from LM quad 3, and the LM +Z strut). Additional panoramics of areas of interest and prominent distant features will be taken during the traverse. These photographs will be based on the following criteria:

- Geological features of scientific interest along the planned traverse.
- From high elevation points along the traverse from which the unobstructed horizon can be seen.
- Items of geological interest at the discretion of the crew.

SINGLE SAMPLE

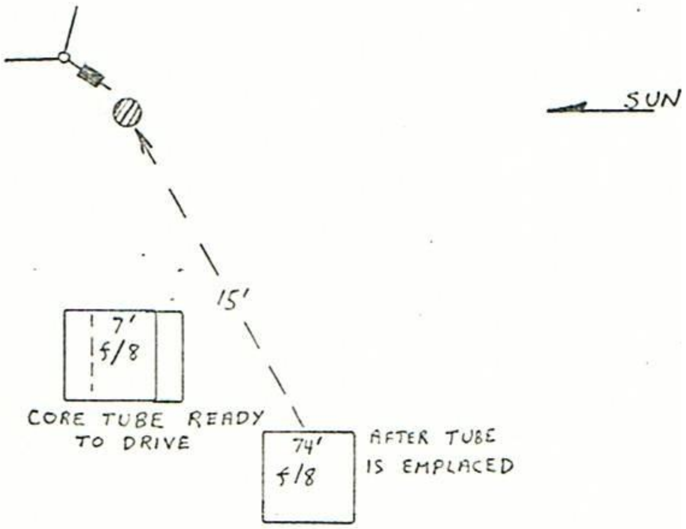
COMPREHENSIVE SAMPLE



At each sample site the exposed rocks and soil will be examined for variations in color, texture, shape and degree of rounding, and possible mineral composition where obvious difference occurs. Samples of the different types will be collected. Where rocks are too large to be collected, it is desirable to remove chips by chipping or prying from the large rocks. The number and location of chips to be taken will be determined by rock texture, mineralogy, and structure.

Comprehensive sample areas will be selected, and rocks larger than approximately 3/8 in. diameter will be collected. The size and nature of the comprehensive sampling areas will be dependent on astronaut assessment of the task; however, it is highly desirable that at least 1 kilogram of rocks in the size range approximately 3/8 in. to approximately 1-1/2 in. diameter be collected from each area. These samples will be placed in a collection bag. A 2-kilogram soil sample will be taken from within the sample area and placed in the collection bag for that area. Additional bags may be used if a single bag is inadequate.

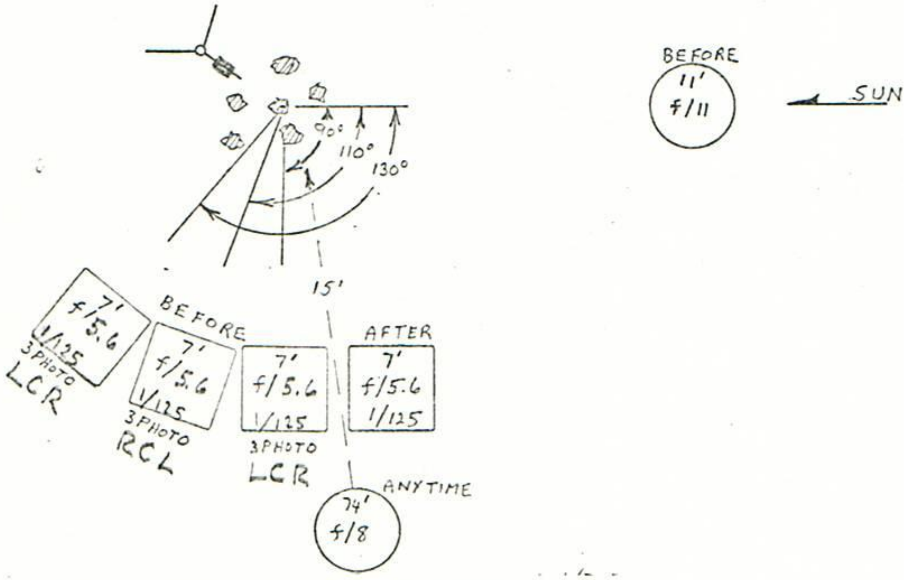
CORE SAMPLE



Core tube soil samples will be collected from places that represent different occurrences of layering in the lunar surface material, as follows:

- A triple core tube sample will be obtained from an intercrater area (between craters) at a distant point on the traverse. It is desirable that this core be taken in the vicinity of the trench excavated as part of Soil Mechanics Experiment S-200. (Upper core tube may be used as additional sample under single core sample if no sample is obtained in the upper core tube during triple coring.)
- Two double core tube samples will be obtained from an expected multiple layer area (such as the ejecta from a fresh crater).
- Single core tube in at least one of the comprehensive sample areas.
- Single core tubes at targets of opportunity, e.g., a mound, a fillet, patterned ground.

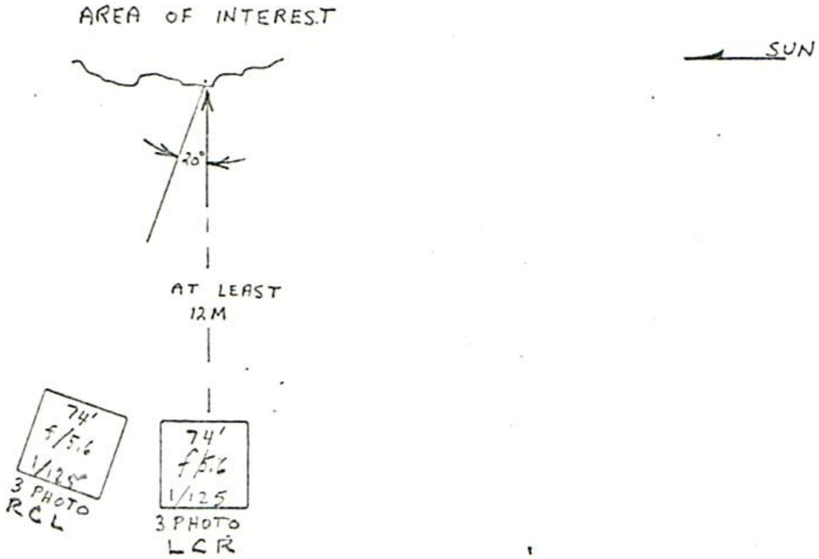
NEAR-FIELD POLARIMETRIC MEASUREMENT



Near-field polarimetric measurement photographs will be obtained with an HEDC to provide local calibration data. The film data will provide new "in situ" measurements of the photometric properties of the fine-grained material and rock fragments, and will provide stereo-coverage of the sample area.

Following the near-field polarimetric measurements, at least four rock samples will be collected from the rock area which has been photographed. Samples will be placed in a documented prenumbered sample bag.

FAR-FIELD POLARIMETRIC MEASUREMENT



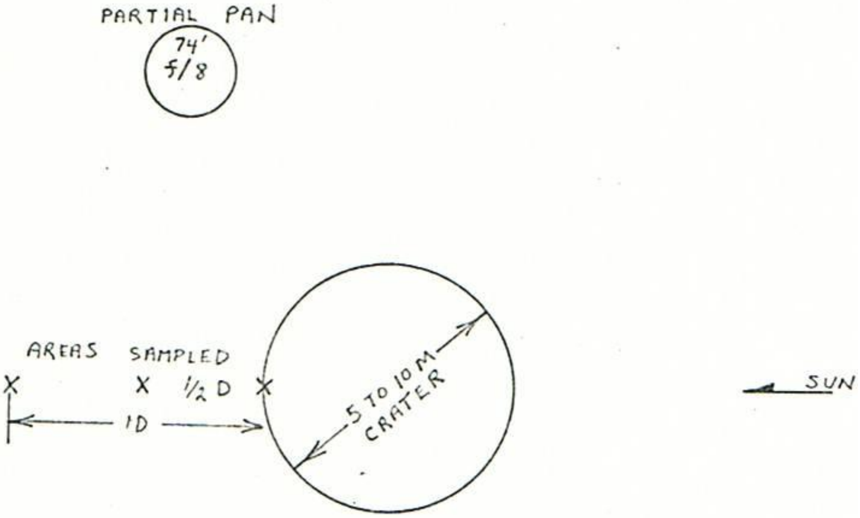
Far-field polarimetric measurement photographs will be obtained with an HEDC of an area such as a rocky area or an inner crater wall (crater diameter will be greater than 12 meters). If the photographs are of a rocky area, the camera will be at least 12 meters from the scene. If the photographs are of an inner crater wall, the camera will be used from the edge of the crater wall opposite the photographed wall. The following procedure will be used:

- The astronaut will select a far-field area of interest and maneuver to about cross-sun so that the central area is observed at a phase angle between 50 and 130 degrees. The polarizing filter will be attached to the camera lens, and positioned at the left-most position. The camera will be focused at 74 feet.

Three photographs will be taken of the field of interest through the filter, moving the filter control between photographs from the left position, to center position, and then to right position. The f/stop and shutter speed between photographs will not be changed during a polarization sequence.

The astronaut will maneuver to about 20 degrees down-sun from the first position such that the same area is viewed at a phase angle 20 degrees different from the phase angle used for the first series of photographs, and will then repeat the preceding steps.

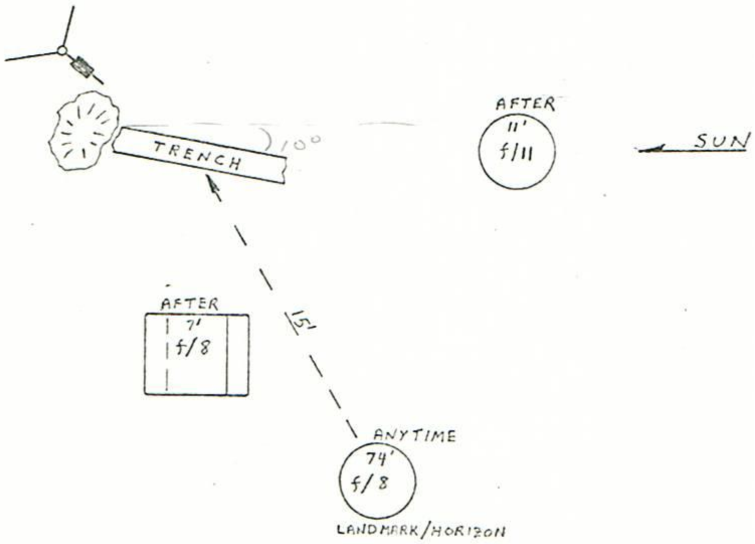
RADIAL SAMPLING



Radial sampling of a fresh crater (≈10 meters) in relatively flat territory will be accomplished to include three soil-plus-rock samples from the following locations: the crater rim; one-half the crater diameter outward from the crater rim, and one crater diameter outward from the crater rim. If time and crew assessment of the task permits, the crew will continue and perform diametric sampling of the crater from the following locations: the crater center; the diametrically opposite crater rim; one-half crater diameter outward from this crater rim.

SMALL TRENCH SAMPLE

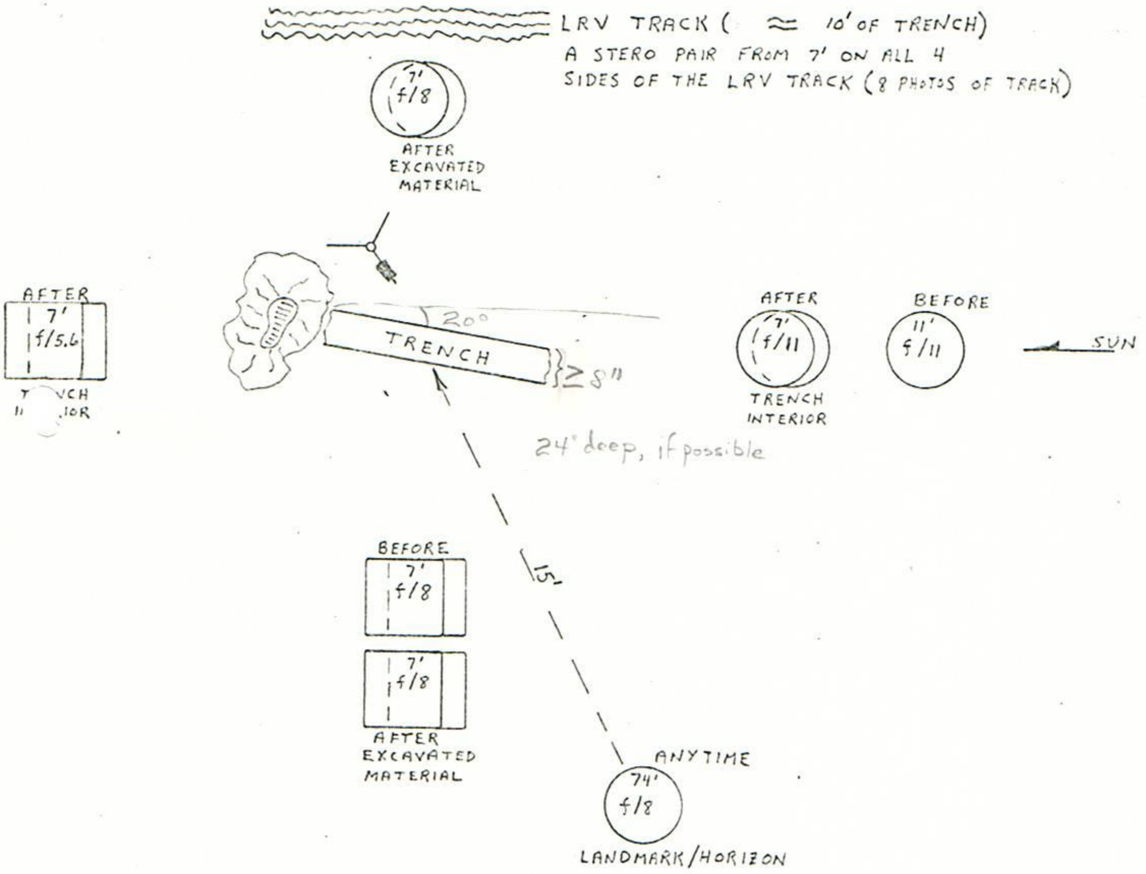
same as
doc samp



The trenches will be dug 10 degrees off the sun line and to a depth of 3 to 8 inches depending on crew judgment. Listed below are types of sites the crew will consider for trenching:

- Near rim in the ejecta from a crater in a mare area.
- In a mound.
- In an area where there is a change in surface characteristics such as color, surface patterns, or mechanical properties.
- In a distinct crater ray.

SOIL MECHANICS TRENCH



SAMPLE LIST:

BOTTOM : 1 IN BAG

1 IN SESC (3/4 FULL)

SIDES : 1 FOR EACH ~~STRATA~~ STRATUM (IF NO STRATIFICATION, 1 ONLY)

TOP : 1 IN BAG

APPENDIX Q: BRECCIA SAMPLING PROCEDURES

Breccia sampling procedures

Breccias are the most difficult of rock units to study, sample, and describe in the limited time available at the typical lunar station. Outcrops that can be photographed and sampled are unlikely to be found. Large boulders are partial samples of certain (and maybe unknown) layers derived from hill-slopes above or thrown from craters below; it is conceivable, for example, that House Rock may be a fragment from a still coarser breccia beneath North Ray crater.

Basic elements of a breccia boulder that require analysis are: distribution, size, proportions, and coherence of fragment types and matrix; their interrelationships; and planar features.

Driving or walking through a boulder field prior to selecting a boulder(s) for sampling is desirable to ensure an understanding of the range of breccia types in the sampling area. Photographs while driving or walking through the field make a valuable supplement to the station panorama(s) by providing views from different directions.

Photographic sequence that should be followed is:

1. Flight-line stereo of all accessible faces of boulder to be sampled
2. Close-up stereo pairs of as many major fragment types as practical showing their nature and relationships to the matrix.

Sampling should begin with the most abundant fragment type and should guarantee representatives of each fragment and matrix type. The most coarsely crystalline fragments may be the best samples from which to infer the environment of the source area.

The smaller the boulder the less representative it may be of the original outcrop layer, unless the layer is homogeneous on the scale of the boulder. Comparison of small boulders with the larger ones should demonstrate whether or not a correlation can be made.

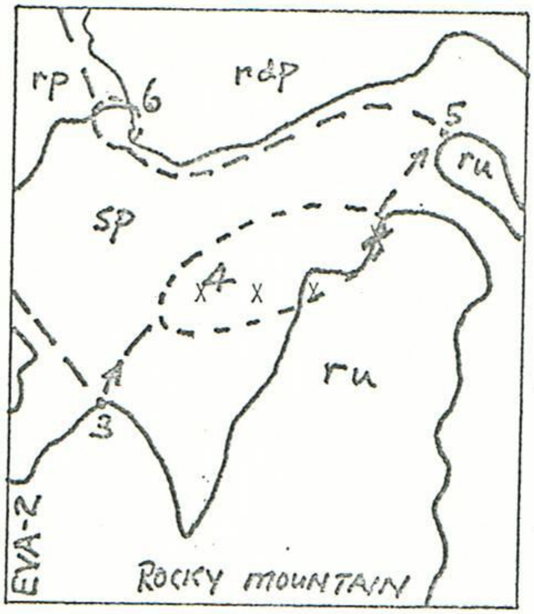
Differences in coherence of matrix or fragments will show up in the proportions of materials found in the fillet formed from the disintegration of large boulders. The regolith should be dominated by the less coherent types; the rocks should be mainly the resistant fragments with little or no matrix attached, or vice versa. The fragments and matrix of lunar breccias seldom have the same coherence; rake samples of breccias are non-representative for this reason.

Structures that should be photographically documented in boulders include:

layering; continuity, spacing, regularity
contacts; both sedimentary and/or fragment boundaries
glass; restricted to single fragments or penetrates several
fragments; in planar fractures or anastomosing throughout fracturing; systematic patterns, spacing

APPENDIX R: CUFF CHECK LISTS

From Apollo 16 training trip to Coso Hills



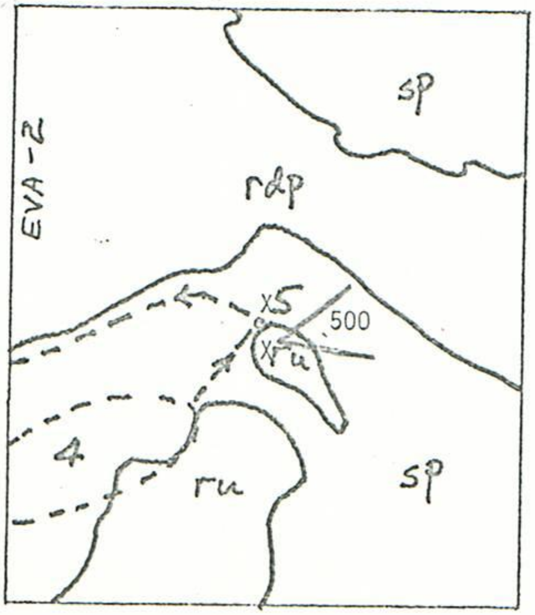
Travel 3 - 4 (:05)

LMP photos (14 frames)

Station 4 (:40)

Odometer and heading
Pan (frame ?)
Describe, sample sp, dark spots
in sp, ru in flank of
Rocky Mountain
Large block ?
Pan (frame ?)

(transfer 500 mm to Prime Crew)

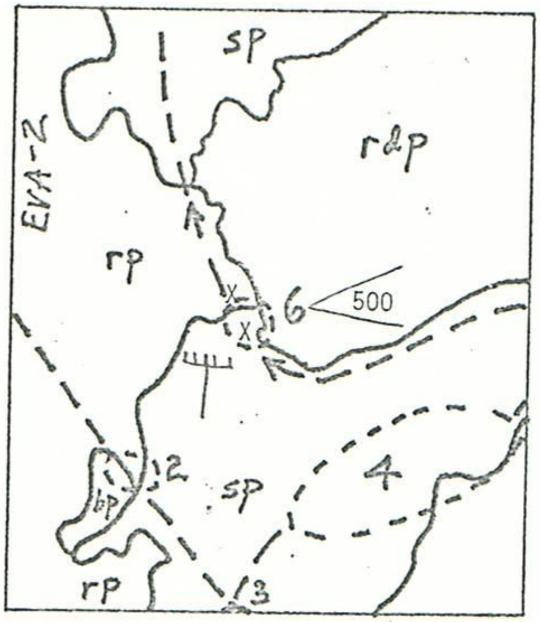


Travel 4 - 5 (:02)

LMP photos (4 frames)

Station 5 (:20)

Odometer and heading
Pan (frame ?)
Describe, sample, ru, sp
500 mm from hill crest of
Crescent and eastern
spur of Rocky Mountain
Pan (frame ?)

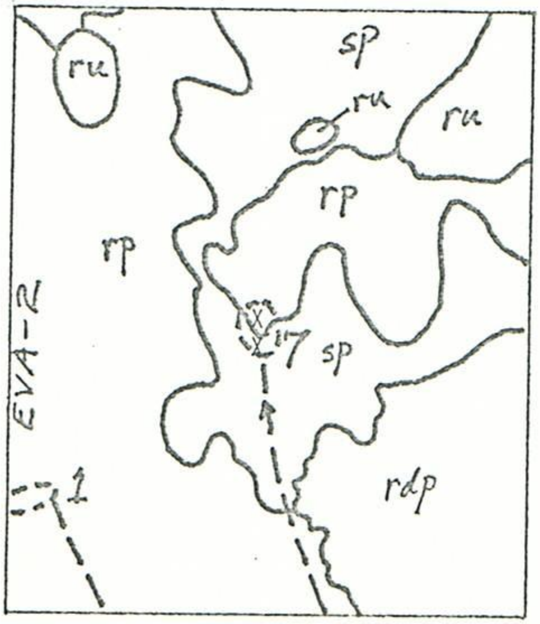


Travel 5 - 6 (:05)

LMP photos (14 frames)

Station 6 (:30)

Odometer and heading
Pan (frame ?)
Describe, sample, sp, rp, rdp
Rake
500 mm from surface of rdp of the falls, Crescent
Pan (frame ?)



Travel 6 - 7 (:05)

LMP photos (12 frames)

Station 7 (:20)

Odometer and heading
Pan (frame ?)
sp (albedo changes)
rp (compare with rp of LM area)
Samples
Pan (frame ?)

APPENDIX S: APOLLO 12 TRAINING DEBRIEFING

CLANTON Okay, well, once again these are a series of questions that you were supposed to be asked in the debriefing, but for various reasons didn't. Anyway I'll run through them. What field area that we worked with you best duplicated the moon for rock type, do you think?

CONRAD Well, I don't think you can name just one area. I think for realism the Hawaii operation was —

BEAN That was Kapoho.

CONRAD Yes, was, you know, about as realistic in that sense. There's no place we were that was like the moon, but the fact that there wasn't much in the way of other earth-things like forests and ground and creek washes and things like that that I think Hawaii was, but as far as the rock type itself I think where we went in the… where was it we saw the most crystalline rock and the olivines?

CLANTON Kilbourne Hole?

CONRAD Yeah.

BEAN I'll tell you another good place over there in Hawaii that we went. It's pretty much like the moon, too. It's not, but what we have seen in the training was that forest that had gotten all the ash from the volcano that we got to see.

CLANTON Kilauea Iki

BEAN Kilauea Iki, but this was kind of in the forest. You couldn't even see where the ——

CLANTON But they were all dead trees -

BEAN That's right, and Kilauea Iki was off in the distance.

CLANTON Right, right.

BEAN We wandered around sort of under all that ash and cinders and stuff, and there were some collapsed features there and I thought that was good. In fact, now that I think about it they even had some -- down in some of those holes you can see some sort of bedrock type and layers in different colors. That place and over at Kapoho are good places.

CLANTON I guess I should have read the whole question because I had rock type, morphology, and total similarity and you seem to be talking about all three,

BEAN Well, they are certainly all linked together.

CLANTON Do you consider the tools helpful in the training exercises?

CONRAD Uh huh.

BEAN Mandatory in the training exercises.

CLANTON Okay, next question is …

BEAN That is half the problem right there, camera and the tools, you ought to have all for every training exercise.

CONRAD Yeah.

BEAN And use them, that’s how you get focus and all of that other stuff under control.

CLANTON Okay, next Question. How about cameras and mounting, particularly -- well, you didn’t get the chest packs until the very last at flagstaff.

CONRAD No, but I think that’s the way to do it. That’s the way we’re doing it now, so the next question kind of--- That seemed to be the least of our problems. I think we had derned few photos out or focus.

BEAN Two or three, next to nothing.

CLANTON Okay, next question’s kind of all inclusive, how can we improve the crew’s training?

CONRAD Well, my idea of improving the training is to continue with the way we did it and as you get more and more of the gear, like when they throw the MET in the operation and everything else, you should use them because again the more you do something, there’s no doubt about it, you don’t want a dumb-dumb up there. I’m still more convinced now that we’re back and as you do the training you should try and almost fit your timelines to it. I think now you know you’re going to go and you’re pretty sure of landing in a spot where you can go on one traverse and that traverse should be planned so if you complete it in the given time, and you’ve got more time to stay out, you should have an appendage on it, or you know, you should always know something else to do and this goes -- some guys get worried about having too much.

CLANTON Okay, we’ll come back to that in some of the other questions. Would it be to the crew’s advantage to work more or less with you during the training simulation? In particular, there were two times in your training where we more or less cut you loose and you ran the traverse that we had laid out that you planned and CAPCOM and so on set up by yourself. This was at flagstaff and also at Kapoho II. The rest of the time Laughon or I or someone else was standing close by keeping track. The question here is, is there any advantage to you operating alone? I realize there is a learning curve here but --

CONRAD I think even though we did not operate completely by ourselves, you always went along with us.

CLANTON Well, yeah.

CONRAD And I think you should because I think maybe it’s advantageous at any time no matter where you are in the training to-- if we miss some obvious things and you might not notice it either, it would be better to point it out at the time than to wait until later.

BEAR I don’t want to go back, I used to hate that.

CONRAD I think you should kind of run on the timeline and yet the other thing I was going to get to, and the reason you ought to have the gear along is that you pretty well figure out how you want your checklist put together then, and you’re really doing two things you’re learning the geology, there’s some point where we started out you get out of the classroom, right? From the time you get out of the classroom I think you don’t have enough time to learn to take pictures and everything so there’s no opportunity to go on just pure field trips that are just geology, and for another reason and that’s probably what’s coming up here right now. I don’t think anybody realized how much we did in four hours and that’s why they’re concerned now at the documentation of it because you really don’t have that kind of time when you’re up there and it’s sort of hard to realize that. You can pick up a rock and you can discuss it in five minutes, but in that five minutes on the lunar surface that rock had to go in the bag and you had to do something and you know, you sort of went along. I feel that you’ll get a better lunar surface operation in the end with more geology in it and better documented if you always do your field trips with the gear and the idea of framing up that traverse and how you do core tubes, and I'll tell you, there are a lot of things that we fumbled around on. We had the new core tubes with the pins in them. You know something --

CLANTON And you had never seen them before.

CONRAD We knew about the pins but I'll tell you something we didn't know about. We just hadn't thought about it. We'd never driven double core tubes, never, never, never, and we'd never put it together, so I took the top off the front core tube end put them together and threw the top away and Al drove the core tubes. Jeez, I had to go around and find the damn top again. We never thought of that.

BEAN That's right, I had forgotten about that.

CONRAD It wasn't anywhere spelled out, we'd never driven a double core tube, we talked an awful lot about it. We found it and we were lucky.

BEAN There we were, looking all over the moon for a little piece of metal.

CONRAD We happened to drop it next to all our gear and after he drove the core tube we took it all apart, and I said, you know, I think we need something back, but you just don't know how many little things, and it's just like the damn TV camera.

BEAN You need core tubes on those field trips.

CONRAD Yeah, and we should have had a Westinghouse engineer come down, but no, we were happy to work with that dumb block of wood [which simulated the camera] and I still think we'd have blown it, no matter what happened because we were cleared for 15 seconds into the sun. The checklist read that, you know, 15 second pan, they said, "okay, don't worry about it even if they shine it into the sun, you don't pan any longer than 15 seconds; you aren't going to burn it out" and, man, that camera didn't any more than see the first corner of the sun, it came in the top of the frame and that camera did it, right? That thing didn't look at the sun more than half a second before it blew out, you know, but we're the bad gays, and in some respect it was our fault. It was the one thing we really hadn't worked hard with; we were never sure we were going to get it and we never saw the flight camera until they put it on the MESA. Never had it in our hands until we got to the lunar surface, and I'll tell you if you don't screw with the equipment you don't know it.

BEAN That's right.

CLANTON Well, okay, we actually ran you two times operating alone. This was when we cut you out at --

CONRAD Well, I think we should operate alone like you're talking about, except you, if you're on the field trip, should go along. You've been over the ground and you're sort of sitting there as a monitor and -- but the only difference is I think you should stop us at some point and we'll just break the time if you're doing it and say, okay, you guys missed this right here, because that's pure geology, then you pick it back up again. The other thing is, we were doing the same thing up there that we were doing on the moon if you stop and think about it. We're not 100 percent trained geologists. You guys have been over that ground for a long period of tine and you were pretty damned familiar with what was there and you knew that you wanted us to find, but you've got to take two guys and stick them up there, even the trained geologists, and realize in four hours -- I mean, let me put it to you this way, if you had gone out there in Hawaii with us without having been there I'm not 100 percent sure you would have seen all the things either...

CLANTON That's true, that's true.

CONRAD . . . as a trained geologist. So I was just trying to make that point and I think you should go along with the guys. You spent the time on it.

CLANTON Yeah, well, the only concern here and the reason I keep beating the same dead horse is we were concerned about how much you felt like you were leaning on us when Bob and I were standing there or walking through with you, because if something came up we were there to answer the question. If, like at flagstaff and Kapoho II, we had you cut loose there for a couple of hours on your own, I was wondering if there was enough -- did you feel like you were alone?

CONRAD Yeah, we felt like we were alone. I'm not 100 percent sure that even when you do the mission sim that you couldn't, if you have good com, you couldn't call break if the crew wants to have a discussion that's not pertinent to the sim time. I mean I'd be willing to do that, and again we were beginning to get rushed at the end. It's that same old -- I'll tell you, you know what's going to happen too. It ain't going to improve on 6 months centers. I'll tell you why it's not going to improve on 6 months centers, because the simulator time is not available anymore and the guys are going to wind up getting rushed at the end as sure as I'm standing here. They are closing down one of the CMS's; the guys are only going to be able to get three days a week of LMS time. There's not going to be any Saturdays or Sundays and there has got to be a certain amount of time to update the simulators and we ain't buying ourselves one thing new from what we had on two months centers when it comes to training the crew, except they might have more time to work on the geology of the thing.

BEAN That will be good.

CONRAD But I'm wondering whether they will or they won't. You don't realize how many Saturdays we worked on things like that. It's not going to be available any more.

BEAN But there will be some for geology.

CONRAD Well, I hope so.

BEAN I'll tell you one thing I didn't like about the training. I didn't like for us to go out and -- I think a hard part of the training is the -- that you don't want to do too much of the little sim [simulation] parts that we did because they're hard and they take a lot out. I don't know why, but I noticed that if we did one that when we did the second one we did a lot worse, when we did the third one we were really sorry and our heart wasn't in it. Also, we did those late in the day and we weren't too good. I think what you ought to do is schedule them so the guys have maybe 30 minutes or so of just looking at something to kind of get warmed up and then they do a sim, and then if they're going to spend the rest of the morning they do something else, so they are spread out.

CONRAD You don't want to keep doing them.

CLANTON It takes quite a bit out of you.

BEAN It does, but I don't know why. I know when we ran that second one in the afternoon over there in Kapoho my heart wasn't in that.

CLANTON Well, the next question I guess. It's what do you think about the field trip sequence? Should it be different?

BEAN Say that again.

CLANTON The field trip sequence.

BEAN I think you ought to do and do all that stuff over and over again.

CLANTON Well, pardon me, by sequence I meant you started out -- well, we did the Quitmans first, and then we went to Kilbourne Hole, and then West Texas, and on like this.

BEAN Let me put it this way, do you want to run the same sequence for each lunar lunar flight anyhow?

CLANTON No, but one of the things, for instance, in West Texas., there in Big Bend area, there was a rock type in there with rather subtle contacts, if you recall that part of the training.

CONRAD Yeah.

BEAN Do all of it like that.

CLANTON Well, I guess the question --

BEAN If you are asking should we do the gross stuff and then the subtle stuff, I say forget the gross stuff, it isn't there on the moon. Do all subtle stuff. I think all the gross operation we did in geology was useless. We never saw any.

CLANTON Okay.

CONRAD Yeah, but hold the phone now. When these guys get up into the mountain areas they are going to see gross geology.

BEAN Think so?

CONRAD Sure, I'll tell you what they're going to be doing. They're going to, besides sample selection, they are going to probably be taking photography of large features that they can't get to completely and they're going to be looking for synclines and anticlines and shelves, and is that the kind of thing you are talking about?

BEAN Not really. I'm talking about like I think Uel was talking about there, for instance crystalline rocks and --

CLANTON Well, for instance, the flow contacts we worked around in Hawaii.

BEAN I think they'll be there. You are not going to see them. You're going to see a slight difference in textures and --

CONRAD I agree with what you're saying but I think -- my point is I think depending on where a particular lunar flight is going to go, they may be expecting to do more gross geology and by nature a photographic and equipment, a photographic and talking about features, suppose you land at the bottom of Copernicus and you drive up to some cliff, you know, a shear wall that's going up there. They're going to be interested in gross features.

BEAN Well, they are going to have to go out to West Texas or somewhere --

CONRAD What I'm saying is I think each one of these lunar flights is going to have to get the best high res photography of where they are going to go and get an idea of the kind of terrain they are going on. For instance, I think we're going to know after awhile, after a couple more of these things, whether -- they're going to know -- they're going to send flights into known volcanic regions. All right, now I think we were probably in a volcanic region and didn't realize it. I think basically underneath what we were on was probably all lava flow.

BEAN Oh, yeah. That's what all the rocks were. How they got up so shallow is a good question.

CONRAD But I think when they land in -- it really doesn't look to me like Jim [Lovell on Apollo 13] is going to a place, I'm probably wrong, I guess he is -- the kind of terrain he's going to be on, it doesn't look to me a hell of a lot different. What's underneath it is different and, therefore, the rock types may be different, but gross feature-wise, other than having more hills and things like that, he is not going to notice a hell of a lot of difference in the lunar surface. They may be different rocks. Don't get me wrong, but I agree with what you're saying. But when a guy lands in the bottom of one of these craters and gets in a rover and tools off somewhere; he is going to be more interested in getting over crevices or --

BEAN That's a good point. When they get the rovers, then they are going to have more gross geology. They are going to get in that SOB, and roll along and they are not going to see any subtle features.

CONRAD Al is absolutely right. As far as gross features went, there were none that you could tell by looking with the eye and that's the reason; there's no real differentiation in gross geology around there. I am sure it was there.

BEAN We just didn't drive far enough. We just covered a little bitty ole area. Maybe if we had driven over to that big crater two miles in that direction we might have come to the world's greatest contact.

CONRAD Yeah.

BEAN Because the places we always go to study were always near the contact. You could always take a guy and set him out in the middle of West Texas, and if there are no contacts, even if he is the world's greatest geologist, if there are no contacts there.

CONRAD But I tell you one thing, that is one of the reasons that I like that one last thing we did in Hawaii, because just to the naked eye it all looked the same.

BEAN Yeah, that was good.

CONRAD It all looked the same up there too. It wasn't until we noticed that we sank in deeper or whatever.

BEAN The subtle things.

CONRAD Surveyor Crater was the firmest ground we walked on, you know, which was a real switch because everybody said that that was going to be softest. And it turned out to be just the other way around. We sank in the least, and it was the firmest in the side of that crater. Now as far as telling with your naked eye, everything looks the same; you had to pick a rock up and put it up right in front of your face plate before you saw it. You knew it had crystalline structure but as far as seeing green …

CLANTON Seeing any detail?

CONRAD Yeah, and colors, and there were different colors. You had to flat put it right up to your face. If it was just laying down there five feet away from you, looking with your naked eye through that visor, everything was brown; I mean just different shades of brown depending on whether you were looking up sun or looking down sun.

CLANTON Could you notice any textural differences particularly?

COTTBAD Well, the places we did, we comment on it. We mentioned the textural difference out at Sharp Crater but we noticed that first from looking at the foot tracks and then we just realized that it looked like finer material and we were sinking in deeper. The other textural difference that we noticed that Al discussed quite a bit, we got into an area where it looked like it had been rained on.

CLANTON Yeah, little hills and depressions, CONRAD Yeah.

CLANTON Okay, let's continue on. Do you recall any area or stop that we made during the field trips we might cut for the future people? This one is loaded particularly. Do you feel that we made any stops that were really of no benefit?

CONRAD No, and I don't feel that way after the trip either. I think there were things that we did … there were many things we did that we never used up there because we never came across similar material. But you don't know that and I think that it is up to you guys to take the morphology of 11 and 12 and say, all right, here is a couple of areas you guys went into and now what we have down here maybe you can find a better place around the Earth to do that. I tell you it's just like that field out there in West Texas. You are pretty pressed to figure out that something looks different, other than texture.

CLANTON Okay, this is in Big Bend.

CONRAD Yeah.

CLANTON Where all the rocks were brown with desert varnish.

CONRAD About the only difference is in the texture. Now I knew damn well they were not going to be the same, but I would almost bet that we brought a lot of the same rock type. But apparently there are quite a few differences. We got into this question the other day when I was talking to the Lunar Science Board; they said, "what were you primarily looking for? Did you bring back everything that looked different and ignore the normal, or what?" We said, "no we went to the preplanned places and looked for the things that they wanted us to look for and anything else that we saw that was different. But we didn't ignore what we thought was common either. We sampled what we thought was common at that particular place and anything that looked different." Again, I almost, when you talk to those guys they almost get involved in the forest and the trees argument. You know, you are up there and you have so many hours and it is a real trade off; there wasn't one place up there where we stopped that we couldn't have stayed for the whole EVA, within a 50, or 100, or 200 foot area and worked it a lot harder and more efficiently, We had a traverse to go over and we had six stops to make and anything in route that struck our eyes sort of thing. You have a timeline to keep and I sometimes have the impression I'm waiting for the Jack Schmitt types to get up there, because if he is not careful he is going to get himself bogged down and not use his time right up there. You only get that one crack at it; it is a compromise, what the hell do you do? I think one of the funniest things to me, I think the guys flat goofed. We talked about the mounds in the first EVA; we picked it up in the selected example and the selected sample other than just a few photographs that we took. Those guys had 12 hours to think about those mounds and they never asked us to go back there and take a documented sample. Now we got them stereo photos in color and we picked up one or two pieces which we threw in a selected sample and there was no way of telling which ones they were until you came back and tried to compare them. They have been tearing their hair out over those God damn mounds ever since then. Now, that isn't our fault. I even thought about it, you know, but I had a lot of other things on my mind, too. I thought it was kind of peculiar when they gave us the traverse that we didn't go back there.

CLANTON Well, I guess like everything else, doing it for the first time there are going to have to be a few new....

CONRAD Well, that's the name of the game.

CLINTON Yeah, they are going to have to specify a little clearer what and when.

CONRAD If they didn't learn something from what we did, technique-wise, also and they don't, you know, improve Jim Lovell's EVA's then they are not doing their end of the job.

CLANTON Right.

CONRAD God knows how many hours we all just argued over how to do things and we were trying to express our point of view in what we thought some of the problems would be. I could go back there tomorrow and do that traverse six times better than we did, and so could you if you went out to Big Bend again.

CLANTON Yeah, that's typical. The learning curve is pretty steep the first time you go through. Then it begins to flatten. You begin to open your eyes there after the second one or so.

CLANTON Okay, in Hawaii, for instance, we had Jack Schmitt set up as the Science Support Room. Do you think that was adequate? We need more people, or do we pull in one or two people and run the back room?

CONRAD Well, I'm not sure I'm qualified to say. I would guess what you ought to do is ask the guys that ran the back room on 12 if they were satisfied with the ---

CLANTON This is mainly from a point of Capcom coming to you and asking some of the questions as you go through.

CONRAD I'll be real truthful with you. If I was going to do it again, I think what I'd like to do, at least on one of those things, not Flagstaff, but one of the others, I'd like to see the principal guys out of the back room and the flight director on that EVA and the CAPCOM of that EVA, all parked up on the side of the hill and run their operation with the crew down below. So that they can get a little discussion back and forth and they, themselves, are a little bit ironed out as about how these questions are going to work.

CLANTON Well, for instance, there at Kapoho, that first morning exercise, we had the backup crew, Schmitt and everybody else sitting up on top of the hill. Is that, something like that, is that what you have in mind?

CONRAD Yes, I think that was good. All I'm saying is I think you ought to add two more people. You ought to have the Flight Director. The flight director is the real buffer. If somebody really wants to get to the crew, they have to go through him and he's got to understand the problem and also he's the guy that has got to buttress the Kraft, Slayton, Lovell people who try to shut that sort of stuff off.

CLANTON That's a good point.

CONRAD Yes. Now, you know, we had Jerry pretty well tuned to being favorable now. I don't really know what the guys in the back room felt. I don't know whether they thought they got what they should have gotten or whether they thought they should have had more.

CLANTON Well, I guess the question here is loaded specifically toward you all. Did you feel the back room bugging you during the little sim exercise we ran was adequate for what happened on the moon?

CONRAD Yes. Well, I think they should. And I think that's not only for the crew, I think that's for the whole benefit of the total operation.

CLANTON Okay. New question comes along and says, "When you stepped out on the moon you may have felt some inadequacy, some gap, left out in your geology training. What areas might we stress more for each future flight?"

CONRAD I didn't feel that way. I certainly didn't. I don't think I made any comments that way, did I?

CLANTON No, but at least as a geologist, sometimes when I'm pulled into an area that I'm not familiar with, I think “Gee, maybe I should have listened a little more at this class or that class or something like this. And I was just wondering

CONRAD No, I felt quite the other way. I felt that we had adequate training to do this job. The one thing … Again, the only thing that I felt was, that traverse was just about to the limit of what we could have done in the time line, you know, and realize that each place didn’t get completely the attention that it could have gotten. And so, if you want to analyze something, maybe what you really ought to do is take the information that comes back from each thing that we did and take that voice transcript and see how much time it took to do each one of those and that would more adequately help the preplanning of the next traverse out there for the type of operation that you want to do. The other thing it would do, it gives you a little insight into anything new that’s coning up to sort of … if you cam think how long it took us to do things on the ground I used to really snicker when Ed Gibson would say, “Oh, yes. Well, you collected three samples per 15 minutes,” or something like that, but it was some number more like it takes one minute to collect one sample or something like that, and take all the photographs. I don’t think that ... I don’t think it worked out quite that way. I think the time worked out to be longer than that. I think you ought to crank that into your planning, you got to crank that into your field trips and then when guys are doing, like they got this big core drill and everything, if it takes 10 minutes to do it down here on earth and everything’s going all right, you probably ought to add five for the drill, five minutes. Something isn’t going to go quite the way it’s supposed to. Or you’re just -- the fact that you’re in the 1/6 g and you’re not practicing in a 1 g, weighing 300 pounds, may or may not add time to it. That kind of thing, I think, would be useful in planning a walking traverse. You’ve got to integrate in things like the MET. What this meant -- that’s another thing right there -- every God darned piece on that METS has got to he tied down or it’s going to fall off, you know. I’m not completely convinced...

CLINTON That’s the way to go?

CONRAD …that‘s the way to go. Because any time you want to stop and take a sample, I don’t know how efficient you are around the METS. See, that’s another thing. And another thing to me -- catching a random sample is one thing. If you’ve got all this gear, even when you’re carrying something, you ought to be able to collect a single sample and take photographs of it, if you’re in route, without taking anything off the METS. But the next thing that tells me is, you really ought to plan more time at one stop because you wind up being more efficient. You ought to just say, “Okay, I’m going to take so much time from here to here and what I really ought to do is set up my gear and cover some radius in here.” And then pack it all up and go on. Because if you start taking off something just to drive one core tube or, you know, and I really thought that one out. I don’t know that much about the METS but I do know that everything is going to have to be tied down and you better be able to get it on and off real efficiently. And that sort of thing is time wasting. Any time you take something off and collect and put it back on and move on, if you had collected five samples in the same spot, you’re more efficient. So ---

CLANTON That’s why we tried to push early in the game, “Don’t drop in one pea-sized rock at a collection site, fill up the hag!”

CONRAD Yes. That’s a damn good point. I think we tried to fill the bag. I tell you, though, that’s another thing, there’s a big argument going on now. Some people are saying we brought back samples that were all too big. Shit.

CLANTON You bring back ---

CONRAD You better bring back what you see that looks to you like it ought to he brought back and forget the god damn size because you might not find the right size. It’s hard for you, really. You go out, I’ll tell you, there’s just not that many samples laying around up there, at least in the areas that we were in. You take a good look at those photographs up there and there just aren’t a lot of rocks laying around that are that big. It’s really funny. And then you get to a place where there --well, let's say, there are a lot laying around. More than likely, they're all the same thing. Not necessarily, but if you look at them up there, they look pretty much the same, so you fill the bag with two or three and do the best you can.

CLANTON Comment about the light. Was the low sun angle of such a problem during EVA that we should include it in some of the exercises?

CONRAD You can see perfectly adequately up there. I don't consider that a problem.

CLANTON Good. What difference, if any, did you notice between the rock appearance on the moon and in the LRL when you looked at them? Is there any way we can ---

CONRAD They were either in rock boxes or inside the surveyor bag and we brought that surveyor bag in and put it all together and tied it up; we never took it apart until we got in the MQF. We looked at them in the MQF and they looked brown to me in the MQF. Not quite the same brown, but you know, you could see crystalline structure in those sort of things in those big rocks. But most of them were pretty covered with dirt. I didn't see them in the LRL. I took those same rocks out in the LRL and gave them to them the first day we were there and that's the last I ever saw or them.

CLANTON Well, the question here was loaded primarily ---

CONRAD Speaking of that, it turns out, looking at these surveyor parts, we sand blasted that son-of-a-gun when we went by. It's pretty well proven. With the LM.

CLANTON And that's probably where the brown coating...

CONRAD It may very well have been.

CLANTON Well, this one was primarily trying to find out if you had noticed a lot of difference between what you saw on the moon and what you saw, hand specimen, back in the LRL that would be worth our while to try to specifically do something during the field trip to duplicate this.

CONRAD I've got to stick with my original premise and that is that the best that you can do up there is size, color, and texture. Really. I mean like crystal size and the texture of the rock, color of the rock, with the general description that it's like a granite or those sort of things. Again, I mean we'd be standing out there, there's a couple of times we'd be standing out there and Al would start motoring on and, damn, we had things to do and I just had to tell him to put the rock away and let's go. Because I just, you don't have the time to do that. It's just not going to get the job done.

CLANTON Did you recognize the major rock types when you picked them up on the noon? I realize you didn't recognize you picked up the microbreccias but...

CONRAD The two microbreccias we never looked at. They were picked up in the contingency sample. I deliberately picked those rocks up. Because --

CLANTON For size or because they looked different?

CONRAD Not because they looked different. They were the rocks that were handiest in the area that we were collecting from, and they wanted both rocks and dirt in the contingency sample. I picked up 3/4 of a bag of dirt and looked around and about five feet away was this nice broken up rock with a bunch of chips and I went over and got those chips and those are the microbreccias. They just had to be the first ones right out in front of where I was standing to collect the sample. There's not that many rocks laying around up there. It's kind of funny, but there are and there aren't. The kind of things you want, there's a lot of stuff this big laying around or bigger, but when you start talking about -- it's really funny. You either get something that^{1}s really small or something that's that big. Isn't a hell of a lot of rocks around that are that big.

CLANTON They don’t fit the bag.

CONRAD That’s right.

CLANTON Well, I guess when we wrote this one up we were thinking, for instance, when you picked up the very coarse grained one and Al talked about it a little hit, you obviously recognized that here’s one we have not seen before and here’s a unique specimen.

CONRAD Yeah, I talked about one. The one that was so rich in the olivine it looked Coca Cola bottle green to me. We could see those big green crystals in there. But that is holding it right up here and looking at it. You don’t see that down on the ground.

CLANTON That’s bad.

CONRAD That’s why I say, what you see down on the ground is that the texture of that rock and the shape of it makes it look different from something else right along side it. So you go ahead and you pick it up. Now, Al’s got another good point. If you pick a rock up, you are not about to throw it away.

CLANTON That’s right. You’ve done all the work at that point, you might as well include it. Okay. I think you’ve already answered this one. It says, “Would a more formalized geology simulation be of any benefit, following the mission time line closer, boxing samples and so on like this,” You already commented that . . . follow the time line as closely as possible.

CONRAD Yes. I think that -- I think for these walking EVA’s, it’s probably not completely worth the effort. You may not have to make a terrain. Al suggested that they build Flagstaff for every landing area, you can’t do that. But I think you could lay out the traverse physical-distance-wise. Now you may have to not follow the time line to do that. You’ve got to figure out, I can move four feet per second, so if I’m going to go from this block to this one, you can shorten it up. You can just delay. You know, go from one area, you could maybe put the sampling areas together and not make the legs the proper distance and just kill the time there that you’d be going from one place to another by critiquing the last little session you did right there in real time. There are other ways of doing that.

CLANTON Well, we backed .up

CONRAD See, by the time you do Flagstaff, you ought to have your cuff checklist. I’ll tell you, we really use that thing; we wouldn’t have got a couple of places we got in a hurry, where we didn’t use it we didn’t do one or two things completely right. It’s interesting, no matter how many times you do something, you get up there and I’m sure, like anything else, if I went back there again on Apollo 13, I could do a much better job than Apollo 13 is going to do. And a much better job than we did, in their landing area. If I could have come back here and go through the debriefing, turned around and kept my hand in it, and turned around and gone back up there. But we just don’t have that luxury. Same way if you sent the geologists up. You ought to go up every two weeks so, just like being on a two-week geology trip to some place. Like you do hand specimen geology. You get interested in an area and you go out there and what the hell do you do when you’re a geologist? You stay in that area. You normally don’t say, well, it’s so big by so big, and my experience tells me I can cover that in two weeks to do this kind of an operation, and if it takes you ten days, you come home. If it takes you three weeks, you stay three weeks, unless you’re on a budget or something.

CLANTON Another one that we thought about here. “Would the simulation exercise be any better if we give you a brief tour of the area to duplicate what you saw in the first EVA?” The thought here was, the way we typically worked the simulations, it was kind of an aborted job where we took a description portion of EVA 1, you never really saw the ground, till you got out and started working EVA 2. And we had kicked around the idea, for instance, if while we were in Hawaii, maybe before you work the Kapoho I or Kapoho II, if we'd come down there for an hour the day before and let you walk through it, would it be any better?

CONRAD Well, in the area that we were in, you couldn't see that much out in front of you. And we never, we weren't anywhere near the ground we covered in the second EVA when we did the first one.

CLANTON That's a good point.

CONRAD And except for sitting up in the LM and looking out with your eyeglass, the ground was flat enough up there that things like Bench Crater, we could find that out the front window with the eyeglass, but all you could -- you would have to stare at the area for a while and after a while you figure out that there was a crater out there, by golly. It was the spyglass. I was using the monocular when we first saw the mounds before we ever got out. And there was that thing sitting out there, looking with the monocular, then you could look and see it with your naked eye. It's weird. The photographs show that. You'll look and you'll just see more and more craters come in.

CLANTON Okay. So a brief tour in the area before we run EVA doesn't buy you much, you think.

CONRAD I don't think so.

CLANTON Okay. What difference in tool use in the way of sample bagging and other things was noticed on the moon over our training on Earth.

CONRAD I really think those sample bags ought to be bigger.

CLANTON Well, the point here was, did you suddenly notice on the moon whenever you were picking up a rock or trenching or something like this, there was a completely different feeling or different body position or motion that you went into?

CONRAD No, I didn't. One thing that didn't work was the two holders on the side of the Dixie cup. We never did get that kind of operation.

CLANTON That's flying on 13.

CONRAD I mean we never used more than one at a time, we never stopped, and while I was taking a couple of pictures, Al took two out and put them in the sides and we just had all these things handy. It just never worked out that way. Again, it's funny. Just like when we were out there in Big Bend and you were talking about all the different rock types that we found that were all brown varnished. We were never, the dust is such that you're never in an area where there's, well, maybe there's two percent rock coverage, And Al …

CLANTON That's right.

CONRAD There just weren't five different kinds or rocks laying right here in a row that we wanted to pick up, so we just said, okay, here, we're going to get six samples out of this area. Usually it was one or two at the most. Or we'd put the tools down and go look for something. Like at Bench Crater, when we walked around it. We went over there deliberately to find rock out of the bottom of the crater. And then we found a couple of interesting phenomena. We found one rock that was just absolutely level with dust. It either cracked from thermal heating or it had been hit by some very low velocity thing and it was in about five segments. There was an interesting item, we screwed around with that thing for a while. Trying to get pictures of it and get a piece of it out. But the other reason we went over there was there was an outcrop sticking out of the side which we thought had come up from the bottom. I was going to try to break a piece off of it or find a piece from it. These are the rocks that are so much different. And there's no pictures of them. The reason there aren't any pictures is because down the side of the wall, the wall was getting steeper and steeper and I'd get over there and I didn't have the opportunity to take pictures of them. I was getting out where I didn't like to be. I was trying to get the samples. I got the samples, but not the pictures. I showed them where they came from. And they're in the pans. So I think we recovered from that point of view. I don't know what they can do by blowing up those pans. I doubt if they can identify a rock from the pan. At least they know where it cane from.

CLANTON Fortunately, I think we finally convinced Flagstaff to change your photo procedure. We had beautiful coverage of Hawaii with 13. Their modified photo technique which was two generations different from what we taught you was not working. So we finally had a big meeting and convinced them that if the commander would shoot three, two before and one after, essentially from the came position at five feet, that this would nail everything down. The problem that we were getting into this technique that they were using, the tying photo that tells you what's missing is shot from a different location and a completely different geometry than you've ever seen before. This is the second generation modification which was proposed for 13. And you could, sometimes, you could tell what was missing, a good part of the time you couldn't. I think the technique we have now…

CONRAD Say, that would be slicker than glass. A guy goes over and takes two for stereo, reaches in there with his tongs and picks up the rock, and then steps back and takes one more and you have got it wired. That makes each guy a collector, which would be a hell of a lot more efficient. That's too bad.

CLANTON Well, it took quite a bit.

CONRAD It's pretty straightforward, now that I've been there. Hind sight is always 20-20 or better. Okay.

CLANTON The last one was kind of a recommendation that sounded good three months ago whenever you got back, but it's a little bit late now and the question was, "What changes do you recommend in sampling techniques, camera technique, and tool designs?"

CONRAD We pretty well talked to them about that. I guess they chose to ignore most of it. I gave them an idea of how to put that tool carrier on the PLSS back, which made it easy to get it on and off without modifying the existing tool carrier. One of the other things that may be an advantage in the METS and that's that you can never get anything out of the bottom of that blasted tool carrier without two guys. You always have to have one guy hold it up; you can't bend over to get down in the bag. And you have occasion to put things in there; the shovel and you got core tubes, things like that. We wasted a little time having to trot over and hold it up for the other guy and things like that.

CLANTON Well, we have the camera techniques pretty well beat out and the tool designs. I think that's about it.

CONRAD I think what you just mentioned to me sounded real reasonable on the camera stuff. I guess they have redesigned the trenching tools to make them longer. I think you can dig as deep with that thing as you need to until you run into firm ground. In other words, if the dust is essentially the same diameter; things just aren't that packed up there, down two or three feet. The gravity just doesn't pack it. There's nothing else that packed it, like rain water. So I think you could dig down a pretty reasonable distance as long as the tool is long enough. You can brace yourself with it fairly well.

CLANTON Well, that current job they've got, the fox-hole tool, has about a five foot handle the way it's put together.

CONRAD That's good. I'll bet they can get down a couple of feet with that one.

CLANTON How about the flying dirt when you pick it up?

CONRAD Well, you just got to be careful. If you come up fast with the shovel and stop, it just keeps on going.

CLANTON Just like on the KC-135?

CONRAD It does the same thing on the airplane.

CLANTON All right. Nice to know, because I can recall several people looking at the film on the airplane and they said, “No, that will not happen on the moon because that’s aircraft-induced motion.

CONRAD You can just take that old baby and just keep going on up here and stop and a string of dirt will go straight up in the air and come back down again.

CLANTON On top of Bean’s head?

CONRAD Yeah, all in slow motion.

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34. Lecture topics in stellar and galactic astronomy course given 13 Oct., 1966 through 21 Feb., 1967

35. Science lectures Oct. 2, 1967 through Feb. 18, 1968. Names of lecturers, dates, times, topics.

36. Academic training for Oct. 2, 1966 through Feb. 28, 1967. Times, subjects, lecturers.

37. Daily calendar for academic planning guide, Oct. 2, 1967 through Feb. 28, 1968

38. Bioscience training schedule, Feb. 5-21, 1968. Topics, lecturers, times.

39. Calendar of Dave McKay for 1968.

40. Apollo 11 training calendar for Apr 20-May 24, 1969

41. Apollo 12 training calendar for Apr 20-May 24, 1969

42. Apollo Crew Training

43. Proposed Bioscience training for Apollo crews dated Oct. 26, 1967.

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2. Maps and traverses with critique for A-15 field trip to San Francisco Peaks, July 15-17, 1970

3. Maps and traverses with sample data for A-15, San Juan Mtns, August 26-28, 1970

4. Maps and Traverses for A-16 field trip to Colorado Plateau, Moses Rock, September, 1-2, 1970

5. Schedule, maps, and traverses for A-15 field trip to Buell Park, September 17-18, 1970

6. Schedule and maps for A-15 field trip to Northern Minnesota field trip, October 7-9, 1970

7. Schedule and evaluation of A-15 GROVER traverse at Merriam Crater, November 3, 1970

8. Maps and critique for A-15 field trip to San Gabriel Mountains, November 19-20, 1970

9. Maps, photos and traverses for A-16 field trip to San Gabriel Mountains, November 21-22, 1970

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11. Schedule, maps, and traverses for A-15 field trip to Kilbourne Hole, January 18, 1971
12. Schedule, maps, and traverses for A-16 field trip to Kilbourne Hole, January 19-20, 1971
13. Maps and traverses for A-15 field trip to Ubehebe Craters, February 10-12, 1971
14. Schedule, maps and traverses for A-15 field trip to Rio Grande gorge at Taos, March 11-12, 1971
15. Maps for A-16 field trip to Verde River Valley, April 26-27, 1971
16. Schedule, maps, traverses, and critique for A-15 field trip to Coso Hills, April 28-30, 1971
17. Geologic Guide, schedule, maps, and traverses for A-15 Field Trip to Nevada Test Site, May 20-21, 1971
18. Maps, photos, and traverses for A-16 field trip to Capulin, May 24-25, 1971
19. Geologic Guide, schedule, maps, and traverses for final A-15 field trip to Flagstaff and Coconino Point, June 25, 1971
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24. Geologic Guide for A-16 field trip to China Lake-Coso Hills, Nov. 16-18, 1971
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26. Cuff check list for A-16 field trip to Boulder City, Nev., Jan. 22-28., 1972
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13. ABSTRACT *(Maximum 200 words)*

Following President Kennedy's initiation of Project Apollo, NASA underwent substantial changes in personnel, organization, and programs and faced a major question: what to do on the Moon after landing. Once a decision that science activities, particularly geoscience, should be pursued, considerable debate ensued over how to accomplish this. Questions arose over instruments and tools required, samples and photos to be returned, landing site selection, and crew composition. Answers to these questions required major efforts for planning traverses on the Moon and training the astronauts in the extensive procedures necessary in low gravity to use tools, set up instruments, take adequate photos, collect and document samples, and provide proper descriptions. In addition to astronauts on the surface, an astronaut in lunar orbit managed additional instruments, photography and verbal descriptions. Training for these activities averaged nearly one hundred hours per month for over a year for each crew. There were many problems as the training progressed: adjusting groups and backgrounds of the training personnel for the best combination of personalities and skills, overcoming logistical troubles, revising awkward procedures, determining optimum means of communications between all involved groups, and devising contingency procedures for real-time problems. By the last mission these problems were overcome.

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