



Geologic Preparation For Exploring The Moon And Planets: Using The Past As A Key To The Present

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and

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Constellation Geologic Program Development: Introduction



- The purpose of this presentation is to:
 - Document the history of the Apollo geologic training
 - Show the direction we will need to go in crew training to support crew lunar geologic exploration Constellation.
 - Show some of the activities that are being undertaken to being geology familiarization within the Constellation Program

Apollo/Constellation Geologic Training: April 2008 Workshop Report



- To understand where we've been and where we need to go in this area, the Apollo/Constellation Geologic Training Workshop was held on April 16-17, 2008, at the Lunar and Planetary Institute in Houston, Texas, sponsored by the Constellation Shuttle and Apollo Generation Expert Services (SAGES) Program and Johnson Space Center (JSC) Training.
- The purpose of the workshop was two-fold:
 - Capture the experiences and lessons learned from the Apollo era geologic trainers from NASA, the U.S. Geological Survey and academia.
 - Draft a new geologic training curriculum that would be used as part of the initial training set for the 2009 Astronaut Candidate class.
- The workshop was organized as follows:
 - The first day of the workshop consisted of presentations by Apollo trainers on the history and evolution of the training, its organization, and the lessons learned from the experience.
 - On the second day, the participants were divided into three groups, and they tackled the issues of what training needs to be developed for future lunar crew members, how that training would be organized, what field locations would be applicable, and what the sequencing of training would be.

Geologic Training for Apollo Missions



- The overarching goals for Apollo geologic field training were based on teaching the crew members to act and think like geologists in field, regardless of whether the “field” was on Earth or on the Moon.
- The training emphasis:
 - Problem solving: The geologic thought process in field
 - How do geologists think about a particular problem?
 - Developing a common language: Do you have the words that work?
 - Each technical field has its own words.
 - The crews were trained to use consistent, if not always “kosher,” terminology to communicate what they were seeing.
 - Observation skills: Can you describe what you see?
 - Again, consistency was the key, and each crew member developed his own approach.
 - Classes emphasized recognizing lunar rock types and geologic features.
 - Train the crew, capsule communicator (CAPCOM), mission operations personnel and scientists together.
 - The scientists who would be at Johnson Space Center during the mission needed to understand what the crew could and couldn’t do on the surface in order to understand as much of what the crew was experiencing as the crew understood what to do scientifically.
 - Everyone trained to a detailed, well understood set of mission objectives.
 - Conduct realistic simulated traverses, science backroom procedures and practices, and debrief activities.
 - The key was to train what the whole crew (astronauts, backroom scientists, controllers) would do when the mission was real.
 - Practice routine procedures:
 - Navigation, following the map, taking accurate, economical photographic panoramas
 - Collecting, documenting rock and soil samples
 - Description from small- to large-scale features
 - Repetition, repetition, repetition
- If we expect to be as successful in future lunar science exploration, we need to train our future lunar crews to the same level as the Apollo crews.

Geologic Training for Apollo J-Missions: Apollo 15 Example



- **General Scientific Training (includes all science training prior to mission selection and mission-specific training for Apollo 15): ≈375 hours**
- **Apollo 15-Specific Science Training (Apollo-16 and -17 had similar training)**
 - General science lectures - 80 hours
 - Principal investigator briefings - 20 hours
 - Orbital geology training - 80 hours
 - Lunar sample training - 12 hours
 - Geologic field training trips - ≈470 hours
 - Orocochia Mountains, Calif. ≈20 hours
 - Mojave Desert, Calif. ≈10 hours
 - Meteor Crater, Ariz. ≈16 hours
 - San Francisco Volcanic Field ≈20 hours
 - Suffield, Alberta, Canada ≈4 hours
 - San Juan Mountains, Colo. ≈20 hours
 - Buell Park, Ariz. ≈16 hours
 - Ely, Minn. ≈12 hours
 - Merriam Crater, Ariz. ≈16 hours
 - San Gabriel Mountains, Calif. ≈16 hours
 - Hawaiian volcanoes ≈40 hours
 - Kilbourne Hole, N.M. ≈8 hours
 - Ubehebe Craters, Calif. ≈24 hours
 - Taos, N.M. ≈20 hours
 - Coso Hills, Calif. ≈20 hours
 - Nevada Test Site, Nev. ≈16 hours
- **Total training hours: ≈1,037 hours for Apollo 15 science operations**

Apollo Science Training Conditions and Hardware: Field Geology Training



Apollo 17 crew conducting shirtsleeve geologic training in the Central Nevada Volcanic Field, using Portable Life Support System volumetric simulators, sunglasses to mimic colors seen through the A7LB EVVA (extravehicular visor assembly), and cameras mounted and operated identically to the flight models.

Use of Mission Simulations in Apollo Surface Operations Training



Science backroom, Sudbury impact structure, Ontario, Canada

Lessons Learned: Conduct of Geologic Training



- The lead field trainer must be an enthusiastic, charismatic, experienced, good teacher.
 - Each lead field trainer (e.g., Bill Muehlberger, Lee Silver) instilled in the crew members the excitement and enthusiasm for being a field geologist.
 - This excitement, in turn, flowed from the mission commander into the entire program.
 - The crew members became, in effect, stakeholders in achieving science program objectives.
 - The science return of the J-missions, in turn, was based on the enthusiasm each commander brought to the whole mission team.
- The training must proceed, whether in the classroom or in the field, in a manner similar to a graduate seminar.
 - Open discussion with questions encouraged
 - Apollo crews had a strong “BS” filter and were not afraid to challenge the instructors; future lunar crews should be no different, and the instructors should be comfortable with that.
- The success of each mission was based, in part, on a consistent team of trainers, crew members and flight control personnel working together.
 - In particular, each mission had several key NASA and United States Geological Survey (USGS) geologists that supervised the training for a specific crew and stayed with the mission from the beginning of training until splashdown.

Lessons Learned: Conduct of Geologic Training



- It took a *minimum* of two years for each group of associated geologists, astronauts and flight controllers to become a team and learn the background and procedures.
 - This includes all the field training (roughly one field trip per month) and various types of simulations.
 - Each activity built teamwork, developed trust between different groups of participants, and developed working relationships that were critical for mission success.
 - Repetitive procedures training taught the crew to work with a highly subscribed timeline, requiring high efficiency and focus on objectives.
- Although the Earth is not the Moon (and vice-versa), there are many relevant sites where terrestrial geology mimics lunar geology and should be included in any future training curriculum (e.g., large impact structures, basaltic volcanic terranes).
 - Although some training and testing can be done at “artificial” facilities (e.g., rock piles at Johnson Space Center and Kennedy Space Center, the vast majority of geologic training has to be done in the field, where the rocks are.
- Each field trip must be organized around the same basic elements:
 - Up-front training objectives
 - A chain of command where one person is in overall charge of the training and the operational decisions associated with the training
 - Detailed logistical and science planning before the field trip takes place
 - Consultation with, and participation of, local experts
 - Pre-trip reconnaissance with all the participating trainers to minimize training and logistical hiccups
 - Sufficient on-site support for all training equipment used, such as communications equipment

Lessons Learned: Conduct of Geologic Training



- Various simulations were the key to the conduct of mission science operations.
 - They trained not only the crew members, but the flight controllers and the science backroom personnel.
 - They developed and exercised contingencies, and equally important, developed the working relationships between team members that was critical for mission success.
- The Science Planning Panel was a critical aspect of all Apollo science mission activities, including training.
 - It must represent all phases of the mission and meet monthly in order to maintain momentum.
 - The future Science Planning Panel chair must be a nationally recognized individual who has the respect and confidence of the science community.
 - Without that level of respect, the science can founder on “my (science) (experiment) (site) is better than yours” arguments.
 - All science training must flow from the science program that originates within the Science Planning Panel.
- The crew members who participated enjoyed the training, particularly when compared with other training experienced.
 - The biggest issue was that the time on the lunar surface in the early Apollo missions (Apollos 11, 12 and 14) did not allow sufficient time to put into practice the skills the crew members had worked so hard to acquire.
 - Although this was less of an issue for the later missions, the surface crew occasionally had to be creative to get the time to use their skills.

Geologic Training Curriculum Development



- The geologic training curriculum development proceeded from several specific initial points.
 - The overall science objectives that drove training in a particular area
 - These were based on work done by the NASA Advisory Council (NAC) and the Lunar Exploration Advisory Group (LEAG)
 - The skill set needed to be trained, both in the classroom and the field
 - The field locations where each area of training was best conducted
- The NAC objectives were used in a formal systems engineering approach; that is, they were used to tie the training curriculum firmly to satisfying science problems that have been identified as being critical to lunar exploration
 - e.g., mGEO2 - Determine the composition and evolution of the lunar crust and mantle to constrain the origin of the Moon and other planetary bodies.
- Each matrix was designed to flow to the different levels of skills from a given NAC objective down to a series of field areas that could be visited to develop the scientific skill sets of lunar crew members.
- The matrices drive out the critical skills that must be taught to each lunar crew for them to be capable of tackling the particular NAC objective.

Geologic Training Matrices

mGEO2



| NAC Objective | High-Level Problem Definition | Intermediate-level Knowledge/Skill Requirements | Detailed Knowledge/Skill Requirements | Potential Field Training Locations |
|---|---|---|--|--|
| <p>mGEO-2: Determine the composition and evolution of the lunar crust and mantle to constrain the origin of the Moon and other planetary bodies</p> | <p>Sampling volcanic rocks and impact breccias, and observation of geologic relationships in lunar crater/basin central peaks, walls and ejecta blankets to understand 1) deep planetary composition; 2) processes of planetary formation that can be understood from the Moon, and 3) the pre-Nectaran geochemical and thermal evolution of the Moon</p> | <p>Field mapping of volcanic and plutonic igneous rocks, including anorthosites, ultra-mafic rocks and basalts, impact breccias, impact melts, and pyroclastic vents and eruption products</p> | <p>Sampling protocols (including identification and description of rock textures, mineral phases, glass coatings and impact effects, and sample documentation) for volcanic rocks, including pyroclastic materials, and plutonic rocks, including anorthosites, ultra-mafic rocks and impact breccias from large basins <i>[Note: sample study set should include returned lunar samples]</i></p> | <p>Mauna Loa, Mauna Kea, HI; SP Mountain, other San Francisco Volcanic Field localities, AZ; Sudbury Crater, Ontario, Canada; Manicouagan Crater, Quebec, Canada; Ries Crater, Germany; Kilbourne Hole, NM and other kimberlites and explosive diatremes; Cerro Hueco, Springerville Volcanic Field, AZ; Capulin Mountain, NM; Medicine Lake Volcano, CA; Rio Grande Rift volcanoes, NM; San Gabriel anorthosite, CA; Marcy anorthosite complex, Adirondack Mountains, NY; Rainy Lake anorthosite complex, Ontario, Canada; Stillwater Complex, MT; Labrador anorthosite bodies, Labrador, Canada; Thetford Mines area, Quebec, Canada; locations where faulting has exposed deep-seated materials; study of returned lunar samples in the JSC Curatorial Facility</p> |
| | <p>Using laboratory techniques to augment field understanding of geologic processes and for planning subsequent field operations</p> | <p>Use of a variety of geochemical and petrographic techniques (e.g., XRF, IR, petrographic analysis, trace element data, isotopic composition) for understanding chemical composition and evolution of crustal rocks</p> | <p>Field operations - i.e., basic field geology training, including field geologic mapping; stratigraphic measurement and description; sampling protocols and sample description; use of geographic data sets (maps, air/orbital photographs, remote sensing data sets); planning future field operations on the basis of data collected in the field and laboratory</p> | |
| | | | <p>Lab operations, specifically oriented to operations that would take place on the lunar surface, to include hand specimen (description identification and description of rock textures, mineral phases, glass coatings and impact effects), sample processing procedures (splitting, bagging for return, etc.), and analytical techniques that will be available in the Habitat (e.g., SEM/Energy Dispersive Spectrometry) <i>[Note: sample study set should include returned lunar samples]</i></p> | |

Geologic Training Matrix Development: Astronaut Candidate Geologic Training



- Training of the next generation of lunar explorers needs to proceed “in depth,” starting with the Astronaut Candidates’ first-year training.
 - The first-year training is intended to give new crew members an introductory level exposure to geology that will emphasize both learning the basic tenets of geology in a classroom setting and the conduct of field observations in a number of geologic settings.
 - The goal of this training is to prepare crew members for more intensive, field-based training that will take place in the years following the Astronaut Candidate year through specific mission training as part of a lunar surface crew.
- The general consensus of the geologist developing this plan is that the field is the best trainer, so field activities should be the main focus.
 - However, field training proceeds more efficiently when based on a foundation of basic classroom activity.
 - Consequently, both areas are considered important.
- What follows is an outline of the basic training flow for Astronaut Candidate classes, tied directly to the NAC objectives for lunar science.

Meteorite Impact Classroom:Field Training Flow (mGEO2, mGEO6, mGEO7, mGEO8)



CLASSROOM TRAINING SUBJECT

CLASSROOM ACTIVITY

FIELD ACTIVITY

Using impact breccias for understanding deep planetary composition, processes

Field mapping of impact breccias and melts

Basic geology training on meteorite impact, including:

- Impact processes, including event timelines, shock effects, cratering mechanics
- Field relationships, including field mapping and description of impact craters
- Field discrimination of impact breccias, primary impact melts
- Field mapping of ejecta blankets, secondary craters
- Hand specimen identification and field description

Estimate eight hours lecture, eight hour lab exercises

Field work with impact craters, including field relations, field hand specimen identification and description, protocols to discriminate and systematically sample melts, ejecta blankets

“Field work” in the Lunar Sample Curatorial Facility and Johnson Space Center B31, working with lunar breccia samples to understand physical and chemical properties

Laboratory Analysis Classroom:Field Training Flow (mGEO2, mGEO12, mGEO13, mGEO14, mGEO16)



CLASSROOM TRAINING SUBJECT

CLASSROOM ACTIVITY

FIELD ACTIVITY

Using lab techniques to augment field understanding of geologic processes

Use of a variety of geochemical and petrographic techniques (e.g., X-ray fluorescence, infrared, petrographic analysis, trace element data, isotopic composition) for understanding chemical composition and evolution of crustal rocks

Basic sample analysis and processing familiarization for activities that are likely to take place on the lunar surface, including:

- Hand specimen description
- Sample processing procedures (splitting, bagging for return, etc.)
- Scanning electron microscope/energy dispersive spectrometry (EDS)

Estimate four hours lecture, eight hours lab exercises per crew member

“Field work” in the Lunar Sample Curatorial Facility and B31, learning about the variety of methods for characterizing the chemistry of samples (note - the kinds of analytical capabilities we will have on the lunar surface should be our focus, but going one layer deeper to develop an understanding about why certain things might be done on the Moon will be useful)

Astronaut Candidate Training Flow



- The proposed Astronaut Candidate curriculum involves a combination of classroom training and field activities, each intended to complement the other.
- As defined on the following slide, the proposed training flow is as follows:
 - Initial training in Apollo science operations and science results
 - This is intended to give an initial exposure to the geologic exploration done on Apollo and will be based on some basic overview of Apollo, followed by hands-on "field" activity in the lunar curatorial facility, looking at lunar samples returned from Apollo.
 - Part of this training will be classroom discussion sessions with Apollo crew members to give the class a feel for what the crew members experienced on Apollo.
 - First field operation
 - This will be a two- to three-day exercise in a geologically relevant terrain, similar to exercises conducted in fiscal year 2008 with Constellation personnel in Arizona and Hawaii.
 - Teams of two crew members will be paired with a professional geologist and will conduct a several-day field investigation of the site.
 - The purpose of the activity will be to expose the students to "real-time" geologic thinking in a field setting as well as the thought process associated with testing geologic hypotheses through field work.
 - Dedicated classroom work
 - This will include a follow-on debrief of the initial field trip, but will build on the field experience through more formal classroom and individual training in geology and geophysics.
 - Some local field activities will be conducted as part of this, but the emphasis will be on preparation for the next field activity.
 - Second field operation
 - This will be a week-long activity patterned after the geologic field trip to the Taos plateau taken by Astronaut Candidate classes since 1978.
 - However, this will include individual field exercises as well as a group geophysical investigation, with follow-on data reduction and debriefing back at Johnson Space Center.

Proposed Geologic Training Addition to 2009 Astronaut Candidate Training Flow



| GENERIC ASTRONAUT CANDIDATE TRAINING w/ GEOSCIENCE TRAINING | | | | | | | | | | | | | | | | | | | | | | |
|---|--------|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|--------|-----|-----|-----|-----|-----|-----|-----|--------|-----|
| | Year 1 | | | | | | | | | | | | Year 2 | | | | | | | | Year 3 | |
| | MAY | JUN | JUL | AUG | SEP | OCT | NOV | DEC | JAN | FEB | MAR | APR | MAY | JUN | JUL | AUG | SEP | OCT | NOV | DEC | JAN | FEB |
| NASA PUBLIC ANNOUNCEMENT | █ | | | | | | | | | | | | | | | | | | | | | |
| WATER SURVIVAL TRAINING AT NAS PENSACOLA | | █ | | | | | | | | | | | | | | | | | | | | |
| BASIC AIRCRAFT FLIGHT TRAINING AT NAS PENSACOLA | | | █ | | | | | | | | | | | | | | | | | | | |
| CLASS REPORT DATE | | | | █ | | | | | | | | | | | | | | | | | | |
| LAND SURVIVAL TRAINING | | | | █ | | | | | | | | | | | | | | | | | | |
| NASA AIRCRAFT FLIGHT TRAINING | | | | | █ | | | | | | | | | | | | | | | | | |
| PROFICIENCY FLYING | | | | | | █ | █ | █ | █ | █ | █ | █ | █ | █ | █ | █ | █ | █ | █ | █ | █ | █ |
| NASA FAMILIARIZATION | | | | | █ | █ | █ | █ | █ | █ | █ | █ | █ | █ | █ | █ | █ | █ | █ | █ | █ | █ |
| RUSSIAN LANGUAGE TRAINING | | | | | | | | | | █ | █ | █ | █ | █ | █ | █ | █ | █ | █ | █ | █ | █ |
| SPACE STATION SYSTEMS TRAINING | | | | | | | | | | | | | █ | █ | █ | █ | █ | █ | █ | █ | █ | █ |
| CLASSROOM TRAINING | | | | | | █ | █ | █ | █ | █ | █ | █ | █ | █ | █ | █ | █ | █ | █ | █ | █ | █ |
| ENRICHMENT | | | | | | █ | █ | █ | █ | █ | █ | █ | █ | █ | █ | █ | █ | █ | █ | █ | █ | █ |
| EXPLORATION FIELD TRAINING | | | | | | | | | | | | | | █ | █ | █ | █ | █ | █ | █ | █ | █ |
| GEOLGY/GEOPHYSICAL FIELD TRAINING | | | | | 1 | | | | | 2 | | | 3 | 3 | 4 | 4 | | | | | | |
| NATIONAL OUTDOOR LEADERSHIP SCHOOL (NOLS) | | | | | | | | | | | | | | | | | █ | █ | █ | █ | █ | █ |
| SCUBA CERTIFICATION | | | | | | | | | | | | | | | | | | | | █ | █ | █ |
| MEDIA & PUBLIC APPEARANCE TRAINING | █ | | | █ | | | | | | | | | | | | | | | | | █ | █ |
| END OF ASCAN TRAINING | | | | | | | | | | | | | | | | | | | | | | █ |

1. Initial training on Apollo surface activities, including time in Johnson Space Center Curatorial Facility and presentations by Apollo crew members
2. First field trip - "blind" trip to Warford Ranch Volcanic Field, Gila Bend, Arizona [similar to the February 2008 geologic familiarization trip]
3. Preparation for Taos trip - ≈20 hours geophysics training/preparation, ≈20 hours basic geologic training preparation
4. Taos field trip - One-week field trip (including geologic and geophysics field exercises) and ≈20 hours follow-on training/debrief at Johnson Space Center

Post-Graduate Field Training



- The proposed Astronaut Candidate curriculum is intended as an introduction, not as an end point.
- We envision that upon completion of the initial training year, crew members will receive additional training in several phases:
- Phase 1
 - This phase is intended to cover the period between completion of the initial training year and assignment to a lunar crew.
 - It is intended to build on the initial training, emphasizing more field training, with concomitant classroom training to augment field operations.
 - Training trips will be held once per year at some location pulled from the list developed during this exercise.
 - Field operations will include a mix of “show-and-tell” training at specific field locations (e.g., an outcrop of impact breccia that shows textural and genetic relationships), along with field mapping or geophysical exercises where crew members are paired 1:1 with a professional field geologist
- Phase 2
 - This phase covers the time between assignment to a lunar crew and flight.
 - Based on the overwhelming input from the Apollo trainers, this phase will be patterned after the Apollo J-mission field training, with intensive field training, leading up to joint integration simulations during the last months of training prior to flight.
 - The localities for this phase will be driven but the lunar program in extent at the time, but this phase is expected to include localities from the lists developed by this group.

Constellation Geologic Field Operations Familiarization Trips



- In order to familiarize Constellation Program engineers, flight controllers and managers as to the nature of geologic field operations, we have begun a program of field excursions to teach them geology, in the field, under the tutelage of experienced field geologists
- The underlying theme behind these trips is to lay to rest a number of myths and misconceptions behind geologic field work
- Each trip, which has included activities in southern Arizona and at Kilauea Volcano, have the following objectives:
 - Understand the conduct of geologic field mapping in a lunar-like field setting
 - Understand the vertical and horizontal relationships between rock units
 - Experience geologic field operations, including the need move through the terrain, and the need to see and get up close and personal with the rocks
 - Acquire data from visual examination of rock samples
 - Develop the geologic context necessary for intelligent sample selection
 - Understand the iterative process of field data collection, hypothesis testing and geologic model development that takes place during a multi-day geologic field problem



1972-1974 Lava Flows from Mauna Iki, Chain-of-Craters Road, Kilauea Caldera

Constellation Geologic Field Operations Familiarization Trips



- The format of the each field trip has been:
 - Three person teams, with 2 students paired with 1 field geologist instructor
 - The first night, each geologist-student team meets to go over the existing data on the field area, and to work out objectives for the first field day
 - The first field day, each team will executes their plan, conducting field mapping, sampling and attempting to complete the day's objectives
 - The evening of the first field day, each team post-mortems the day's results and works out the next day's plan based on the results from the first day's field work
 - The second field day, each team will continues to execute their field plan
 - The evening of the second field day, the combined group will debrief the entire exercise, looking at areas where the operation can be improved for the next group of students
 - The evening debriefs and planning sessions will be critical to the training; each student should plan on attending the entire field session in order to get the full benefit of the exercise



Sentinel Volcanic Field, AZ

Constellation Field Geology Training: Open Issues



- Two critical issues will dominate this discussion: identifying the trainers, and funding the training budget for post-graduate training.
- Identifying the trainers
 - During the Apollo Program, the training was managed by a combination of United States Geological Survey and NASA-JSC scientists, all of whom had significant field geology experience, measuring in years to decades.
 - In the intervening years, those organizations have evolved to where they no longer have significant complements of field geologists with the background we would expect to do this training.
 - The bulk of that experience today lies in the academic community; it is this source we must tap into for our instructor base.
 - The open question is the mechanism under which we will retain these individuals.
- Funding the training
 - Apollo had what amounted to an almost unlimited budget for everything, so the significant costs of geologic training were considered part of the cost of going to the Moon.
 - Constellation's budgets will be constrained and may not support the costs of sending crew members into the field for the necessary training.
 - The present Astronaut Candidate training program will pick up the funding for the initial year of training proposed in this curriculum, but it remains an open question as to how we will fund the years of post-graduate training and the mission-specific training we believe will be necessary to prepare the next generation of lunar geologic explorers.