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Apollo Lifts Off
1967–1969

SANTA CRUZ (AUGUST 1967)

Project Apollo was at once the driving force behind the lunar geologic program, the focus of geologically based forecasts about lunar terrains and rock types, the emotional culmination of many careers, and the source of massive new data that would propel and redirect post-Apollo investigations. The history already recounted in this book led up to it, and the post-Apollo period that is still continuing has been spent digesting its results. Apollo involved hundreds of thousands of people in a concerted U.S. effort that touched much of the rest of the world as well.

While armies of engineers tackled the never-ending challenge of building and rebuilding new rockets and spacecraft, platoons of scientists were assembling their wish lists of objectives for Apollo and its hoped-for successors. In 1967 most questions about the surface and subsurface had been carefully formulated but remained unanswered to general satisfaction. How and when did craters, basins, maria, and special features form? What are the Moon's bulk composition and internal structure, and do they vary laterally and vertically? How hot was and is the Moon's interior? Are the elevations of the various parts of the crust determined by their masses, or is isostatic balance being prevented by a rigid crust, as Urey thought, or internal convection, as Keith Runcorn thought?[1] Does the Moon have a magnetic field, and did it in the past? How numerous and how large were the projectiles that have rained down from the cosmos since the formation of the Solar System? For the astrophysicists, the lunar regolith awaited with its unequaled record of ancient cosmic and solar radiation. Also still at issue was the amount of water and other volatiles on the Moon, as was, in many minds, the possibility of past lunar life or present organics. Finally came the biggest question of all: How and when did the Moon originate? The goals boiled down to establishing the chemical and physical character of the Moon to learn its origin and the roots of its present condition.

Within the available time and budget, this ambitious scientific quest would have to be effected at a few points from which maximum portions of the surface and interior could be probed. The process of selecting sites for the landings involved engineers, operations specialists, and scientists in a complex give-and-take that I have begun to describe. The Iowa City summer conference in 1962 began the planning process and assembled the first teams of interested participants. The Woods Hole and Falmouth conferences in 1965 had established the general scientific goals of lunar exploration.[2] Early in his term at MSC Wilmot Hess initiated the next step by convening the third NASA summer study on the beautiful new campus of the University of California at Santa Cruz between 31 July and 13 August 1967, right in the middle of the Lunar Orbiter 5 mission. My commitment to Orbiter put me in the SFOF at JPL, giving me a perfect record of missing summer studies, but I think I can reconstruct what happened at Santa Cruz well enough to describe its role in our history. The 150 conferees were told to let their imaginations soar.[3] They did, and they were due for a letdown from the gaudy heights they had contemplated.

They were chartered to consider the specifics of the AAP program, a term that at this juncture meant all manned flights after the first few landings. AAP would last at least five years after the flag was first planted on the Moon. Now was the time to specify what science to do, in what sequence to do it, and what experiments and hardware to do it with.

Visiting a few spots on Earth — say, an ocean and a sea of desert sand — would teach precious little about our planet as a whole. Good lunar science would similarly require more mobility and longer stays than those envisioned for the early land, salute, and leave missions. NASA and the scientists wanted to know how much mobility and how long. Mobility might be achieved by a roving vehicle, possibly the massive and versatile MOLAB (*mobile lunar laboratory*) but more likely the scaled-down version known as the *local scientific survey module* (LSSM) that could be used with or without a human crew ("dual mode"). The planners addressed both single-launch missions, which they still hoped would be only the first of the AAP series, and the dual-launch missions that had been discussed in optimistic 1965 at Falmouth, whereby Saturn 5s or Saturns plus Titans would land robotic vehicles containing the LSSMs and other supplies in advance of two-week manned missions. Houston could then summon a MOLAB or LSSM like an obedient canine Rover toward a newly landed crew. After the astronauts departed, the LSSMs could either plug into a shelter for recharging and await the next crew or continue to traverse hundreds of kilometers under remote control from Earth, transmitting stereoscopic television pictures and geochemical and geophysical data, and even collecting samples for the next human mission to take home. A seriously considered alternative was the Buck Rogers machine called the *lunar flying unit* (LFU) or *lunar flying vehicle* (LFV) that would enable astronauts to examine vertical stacks of rock layers as terrestrial geologists do on foot. The orbital surveys with human pilots were also still planned. Advanced unmanned landers (block 2 Surveyors) and orbiters would supplement the manned missions.

The 28-member geology working group at Santa Cruz (the largest of eight groups, four geoscience and four nongeoscience) was cochaired by Gene Shoemaker and Al Chidester. Shoemaker had long been spread too thin, and a year earlier had given up his administrative duties in Astrogeology to an acting branch chief (Max Troyer) and a number of administrative assistants who dealt with fiscal and organizational realities. Santa Cruz also promised to provide a good learning experience for Chidester, who, as chief of the manned-investigations group in Flagstaff, seemed destined to expand his role in human lunar exploration. Chidester also seemed destined to rise higher on the Survey organizational chart. At the time of the conference, USGS Chief Geologist Harold James[4] officially split the six-year-old Branch of Astrogeology into two branches corresponding to the scientific and mission-oriented subdivisions that already existed. Scientific studies that entailed looking down on the Moon's surface from above went to the Branch of Astrogeologic Studies, with Hal Masursky as its chief (Hal was on both the geology and the geodesy/cartography groups at Santa Cruz). Preparations for Apollo and any other mission-related geology done on the surface of a moon or planet were gathered in a new branch with the appropriate though grammatically ambiguous name Surface Planetary Exploration (SPE). The work of Astrogeologic Studies was conducted in Menlo Park, Flagstaff, and Washington, D.C., while SPE operated entirely in Flagstaff. Chidester was to be SPE's chief, fulfilling a lifelong ambition to be a Survey branch chief; or so he thought. Shortly afterward there appeared in Flagstaff, without forewarning, one Arnold Leslie Brokaw (1911–1990), a man with no previous connection with the lunar program but who was to be SPE's branch chief. Hal James had sent the gruff Brokaw, an American Indian, to remind the free-wheeling Flagstaff office that they were part of the United States Geological Survey and to find out what they were up to. Chidester, no longer so amiable, was kicked upstairs to the position of deputy assistant chief geologist for astrogeology, nominally the coordinator of both branches and Brokaw's boss. The wound never healed.

At Santa Cruz the geology group devised a hypothetical program that included three early Apollo missions, more than a dozen AAP manned missions, and a number of robotic or mixed missions.[5] Reasonably, they foresaw the first landing site as the much-photographed Sinus Medii. The second was to be in a western Mare Fecunditatis site that had interested Lunar Orbiter planners and screeners.[6] The third was on a very young "blue" mare north of the crater Flamsteed, next to the Surveyor 1 spacecraft that had landed in June 1966. This would have been a superb early Apollo site. Chapter 12 tells why it did not become one.

The geology group also continued the planning that eight of its members had begun at Falmouth by compiling an elaborate list of tasks for the field geologist–astronaut.[7] In AAP this well-trained scientist would explore the Moon's rocks and regolith much as he would on Earth, except that such routine chores as location and data recording would be automated. He would have access to a wide variety of geologic tools ranging from simple hammers to elaborate spectrometers and petrographic microscopes. He would be supported, or possibly closely controlled, by a well-equipped team of quick-thinking scientists and assistants in a scientific data center back at the home planet. These had been Gene Shoemaker's visions since before NASA was founded, and they had become the visions of many other geoscientists on and off the working groups. Some of the visions would become reality and some would not.

The Santa Cruz conference came a little too soon to examine the Lunar Orbiter 5 photographs, but the conferees knew what Orbiter 5's targets were and had studied them on the recently acquired Orbiter 4 photos. They devised one plan that called for two men to spend three days exploring the central peak and floor of Copernicus. Except for the suggested use of the LFU, this was similar to a mission considered for Copernicus until nearly the end of the Apollo program. Field studies of astroblemes on Earth were showing that peaks bring up material from strata beneath the crater floor, and Orbiter 2's Picture of the Century had shown a ledge in the Copernicus peak that could be an outcrop of such a layer. Most people still thought they saw a variety of volcanic features on the crater floor.

The planners also concocted more fantastic missions. Perennial water-ice at one of the Moon's poles would welcome parched travelers after a long journey. An all-out, week-long, dual-launch mission would attack the crater Alphonsus, whose many and diverse features had attracted the longing gazes of planners ever since the days of Kozyrev and Ranger 9 and would continue attracting them until the landing site for Apollo 17 was finally chosen. After the astronauts had finished this complex mission and gone home, the LSSM would crawl out and head 750 km across the rugged central highland "backbone" of the Moon toward Sabine and Ritter, the twin putative calderas photographed by Ranger 8 and Lunar Orbiter 5.

A dual-launch six-day dream mission was sketched for the special-feature and transient-phenomena heaven around the young impact crater Aristarchus and the adjacent Cobra Head and Schröter's Valley. This complex area remained in contention for a landing mission for a few more years, but it had to be dropped because it remained outside Apollo's accessibility envelope even after the envelope was expanded. After the astronauts departed, the LSSM would crawl to two more special features: first, the volcanic Marius Hills, "only" 500 km away, and then Hadley Rille, 1,500 km away! (To explain these illusions, perhaps we should recall that summer 1967 was the Summer of Love, and the flower children in the Haight-Ashbury district of San Francisco 60 miles up the road were also resisting reality.) As a one-launch manned mission, however, the Marius site remained a leading contender for an Apollo landing until the final choice for the final mission. It is crossed by sinuous rilles, was thought likely to have coughed up deep samples, probably would furnish samples of volcanics more silicic than basalt, and therefore would show how lunar magmatic differentiation worked.

One of the most persistent AAP sites during later site deliberations was the string of closely spaced craters known as Davy Rille (Rima Davy). Another of Shoemaker's pre–Space Age interests was influencing the Apollo era. The diatremes of the Colorado Plateau had erupted some rocks (*xenoliths,* "foreign stones") from great depth. Davy's linearity suggested that the structural control was also deep-seated, so it should furnish material from deep within the Moon. The same important goal of examining deep material was thought attainable at Rima Hyginus. Copernicus brought up the deep materials mechanically, and Davy or Hyginus brought or were still bringing (!) them up volcanically. Davy was not an Orbiter 5 site, but it remained near the top of all Apollo site lists until it was dropped for the complex reasons given in chapter 15.

The geology group's report reveals the fine hand of Hal Masursky in the ample space it devotes to floor-uplift craters, a type of special feature whose cause he had adopted three years earlier.[8] Besides Sabine and Ritter, for which the group wanted more photographs, the margin of Mare Serenitatis boasts the conspicuous Posidonius. The floor of this Copernicus-size crater is not only shallow but tilted and incised by a tightly meandering sinuous rille. Most other boundary zones between lunar maria and their enclosing impact basins also contain craters with shallow, undoubtedly uplifted floors. Here I have to get something off my conscience. Maurice Grolier soon noticed this preferential location of high-floor craters and wanted to write a paper about it. I advised him not to bother, because "everybody knows that." Later, of course, others wrote the papers Maurice had wanted to write and got the credit.

Finally, an elaborate four-launch investigation of the Imbrium basin and mare would end up at the Apennine Mountains and Hadley Rille. Remnants of this grand plan, alone among the geology group's proposals for AAP, were actually implemented (see chapter 15).

After almost two weeks of this intensive hopeful planning, reality in the shape of former navy captain W. T. O'Bryant arrived from NASA Headquarters. There had been a slight change in plans. NASA had tentatively decided to cut off the Saturn 5 production line after 15 of the monsters had been produced.[9] There would be no glorious dual launches to the Moon, nor any Mars Voyager mission with a Saturn 5, as James Webb had proposed.[10] There would be a maximum of 10 manned lunar landings, and all would be based on Apollo hardware. Oh.

Robert Gilruth and George Low had felt for at least a year that follow-on lunar missions without new development of flight systems made little sense, but there was no money and little interest in developing such hardware for the Moon. Apollo proper would now take the part earmarked for the Moon, and the rest would go to Earth-orbital missions.[11] Funding in general was getting tighter after its peak in 1966. The Vietnam War and the Great Society were taking their toll on lunar and planetary exploration before it got properly under way. After late 1967 all lunar landings were called not AAP but Apollo.

Nevertheless, NASA continued to fund astrogeologists, especially an SPE group coordinated by George Ulrich, to plan AAP or post-AAP dream missions, including traverses hundreds of kilometers long for the dual-mode rover. For example, Ulrich followed up a discussion by the Santa Cruz geology group and designed a massive attack on Mare Orientale (meaning then the mare and the basin).[12] Planning continued for two and a half more years after Santa Cruz, sometimes in informal venues. I have a memo from Farouk El-Baz dated 12 December 1968 containing plans for a lunar rover in the dual mode. A handwritten note attached by Farouk says that (1) "some nuts messed up a lunar chart during a beer break," (2) Masursky wanted to include the report in the *Congressional Record,* and (3) I owe him (Farouk) a drink for taking the unrewarding task of compiling the plan off my hands. Unrewarding indeed; the handwriting was on the wall of the Santa Cruz conference rooms way back in the Summer of Love.

GLEP (DECEMBER 1967)

Toward the end of the Santa Cruz conference, Wilmot Hess crafted conference attendees into another important committee whose deliberations affected the rest of the history told in this book, the Group for Lunar Exploration Planning (GLEP). GLEP's responsibility was to translate general scientific objectives into recommendations for specific landing sites for specific Apollo and AAP missions, a process that did not progress as far at Santa Cruz as Hess had hoped.[13]

To begin this process Hess convened a working group of 19 scientists and cognizant NASA experts in Washington, D.C., in the 17th Avenue offices of Bellcomm on 8–9 December 1967, four months after Santa Cruz had set up the problem and Orbiter 5 had supplied the data. Chairman Hess's charter to the group was to review the scientific merit for a lunar landing of all the well-photographed lunar sites. Hess plus 11 other conferees constituted a site-selection subgroup, which, displaying once again his mastery of English, Farouk El-Baz dubbed the "Rump GLEP." Our Bellcomm host was represented by El-Baz, secretary of the Rump GLEP, and his immediate boss, Noel William Hinners (b. 1935), its chairman. During the next five years, geologist-geochemist-geophysicist Hinners became the final voice of the scientists deliberating about site selection. Don Beattie of NASA Headquarters, John Dietrich of MSC (who prepared the minutes), and Hal Masursky and myself of the USGS were the other geologists in attendance who earlier had helped choose the Orbiter 5 sites that we were now reviewing. John Adams, a pioneer in lunar remote sensing, and Jim Burke, one of the scapegoats of the Ranger misfortunes five years earlier, represented JPL. Jack Schmitt, wearing his astronaut hat, presented (in absentia, I believe) MSC's current view on how crews would operate during an AAP mission. Geophysics was represented by Gene Simmons (b. 1929) of MIT, who served as MSC's chief scientist from 1969 to 1971. The chairman of the Santa Cruz geochemistry group, the knowledgeable but abrasive and volatile Paul Werner Gast (1930–1973) of the Lamont Geological Observatory of Columbia University, was heard from often both during the meeting and throughout the Apollo era, as we shall see.

At the time of the meeting George Mueller was setting up at NASA Headquarters an Apollo Lunar Exploration Office headed by Lee Scherer and chartered to oversee both the flight systems and the scientific aspects of lunar exploration.[14] Don Wise, who had been heard from in 1962 at Iowa City, went on leave from peaceful Franklin and Marshall College to enter the maelstrom as chief scientist and deputy director of Scherer's office. Don Beattie served as manager of the Apollo surface experiments for Scherer.

Captain O'Bryant presented a still-optimistic though avowedly tentative plan for 10 missions lasting through fiscal year 1975. The manned orbital survey succumbed to the success of the Lunar Orbiters and the likelihood that orbiting Apollos could accomplish what the Orbiters had left undone. Anyway, no one had ever made a convincing case for the need for a man in orbit beyond establishing a "presence" in space. A machine could turn switches on and off just as well.

I remember thinking that we were doing something important and influential in Bellcomm's comfortable, distinctly nongovernmental meeting room. We constructed a shopping list of sites and objectives previously suggested at Santa

Cruz and back home at the USGS, Bellcomm, and MSC. The geologists tried to identify spots that would investigate all four dimensions — two representing large surface areas, the third probing the depths of the Moon, and the fourth looking back in time. The geophysicists pursued similar aims by recommending widely separated points for their probes of the interior and their determinations of present and past heat flow and magnetism. Since the Orbiter 5 targets were picked by the same criteria, it is not surprising that most of them remained on GLEP's list of 36 potential Apollo and AAP landing sites. A few non–Orbiter 5 sites also appeared on the list, most notably Davy Rille and a peculiar hilly and furrowed deposit near the crater Descartes that keeps appearing in the history of lunar exploration.[15]

Subsequently, the labor of detailed juggling of the sites fell to the Rump GLEP. Though site selection was not part of Bellcomm's original charter, they continued as the focus of the planning because they saw the whole picture and because, more than incidentally, Noel Hinners and Farouk El-Baz took an interest in the subject. John R. ("Jack") Sevier represented MSC and fed the realities of spaceflight operation into our deliberations. The Rump GLEP met many times during the subsequent years and submitted its recommendations to the full GLEP, usually at meetings at MSC chaired by Hess or his successor, Anthony J. Calio. The lists that the Rump GLEP and GLEP extracted from the December 1967 list in 1968, 1969, and 1970 usually included 10 sites in the continuing hope for at least 10 missions. Complexity of the sites was considered in assigning them to early or late missions; some vigorous contenders for early missions were later dropped from the list because they were too simple for the later missions. Hinners, El-Baz, Masursky, Wise, or other members of GLEP (never I) would then present the decisions to the Apollo Site Selection Board (ASSB) for definitive rulings. The ASSB then passed the recommendations up to George Mueller or his successor, Dale Myers, who always accepted them. By this route the sites where six Apollo lunar modules would set down on the Moon's rocky surface were selected.

ONWARD AND UPWARD (NOVEMBER 1967 – OCTOBER 1968)

If pessimists could read the handwriting on the wall, optimists could go to the Cape and absorb the air of confidence and excitement that still prevailed in late 1967.[16]

The testing that had been interrupted by the Apollo 1 fire resumed with a mighty roar on 9 November 1967, three months after Santa Cruz and two days after the Surveyor 6 launch. Nobody knows what Apollos 2 and 3 were, but

Apollo 4 was the first launch of all three stages of the awesome Saturn 5 stack and accordingly was numbered AS-501.[17] After two orbits the command module was shot upward 18,000 km into space and then powerdived back into the atmosphere at 40,000 km per hour. It was recovered in a condition that showed that its crew would have survived. Nearly everything else also worked beautifully, and the United States was back on the road to the Moon.

Shortly before this test, old Langley hand Owen Maynard in George Low's office at MSC had devised an alphabetic series of letters symbolizing the mission types NASA contemplated. Apollo 4 was an A mission, and the first manned landing was the G mission. Later, we will have many occasions to refer to the designations H and J that were added to the series after Apollo 9 flew.[18] The complete manned orbital survey that was not flown was the I mission.

The B mission's purpose was for a Saturn IB to place a lunar module and an updated Moon-ready (block 2) command module in low Earth orbit. In January 1968, the month Surveyor 7 landed and Orbiter 5 was crashed into the Moon, Apollo 5 (AS-204) so successfully testfired the LM in space that further unmanned tests of this procedure were deemed unnecessary. Nevertheless, structural problems were found in the LM, and it became the pacing item in Apollo hardware development.[19]

Korolev died two years before Apollo 5, but the USSR apparently was still planning to land cosmonauts on the Moon. After the last flights of the American Lunar Orbiters and their own Luna 10, 11, and 12 orbiters, the Soviets returned to flybys. At least 5 Zonds, and possibly as many as 10, were assigned for this purpose.[20] Kosmos 146, Kosmos 154, and an unnumbered Zond, all with the Moon as their apparent objective, had been launched in March, April, and November 1967, respectively. They failed to leave (Kosmos) or to achieve (Zond) Earth orbit. The first to be assigned a number was Zond 4, which was launched away from the Moon on 2 March 1968.[21] In the same month American spy satellites photographed the rollout of a giant new Soviet booster called G-1 in the West and N-1 in the East.[22] On 27 March 1968 the Soviets lost their first space hero when Yuri Gagarin crashed in his jet trainer, immediately becoming the object of almost religious worship among the populace and cosmonauts alike.

A second unmanned A-mission test of the Saturn 5 stack was conducted by AS-502, Apollo 6, on 4 April 1968 (the day Martin Luther King, Jr., was assassinated). As an afterthought, Apollo 6 also provided the first purely scientific—that is, nonengineering—data from an Apollo as it photographed the Earth from orbit with excellent clarity and color fidelity.[23] All three stages of the Apollo 6 Saturn 5 performed shakily—literally; the effect was called "pogo," as in pogo stick. Although von Braun's team in Huntsville quickly brainstormed and corrected the problems, the launch vehicle for any early manned mission would have to be a Saturn 1B, not a much more powerful Saturn 5.

This Saturn 1B (AS-205) boosted the first manned Apollo, the C-type Apollo 7, whose task was to orbit Earth for at least as many days as would be required for a flight to the Moon and back. Between 11 and 22 October 1968 the Apollo 1 backup crew of Mercury astronaut Wally Schirra and third-group astronauts Donn Eisele and Walt Cunningham spent 260 long hours in the cramped and smelly command module. Schirra's (1988) memoirs paint a rosier picture of the ordeal than Cunningham's (1977), as one might predict from their respective personalities, but clearly all three astronauts were bored and miserable during most of the flight, suffering from colds and the bad food. Nevertheless, Apollo 7 fulfilled its mission as the critical SPS engine of the command and service module was successfully refired eight times and the crew and the command module got back to Earth in good shape.

On 26 October 1968, four days after Apollo 7 splashed down, the Soviets showed they were also back in the manned-spaceflight business when they launched Soyuz 3 to attempt a Gemini-like rendezvous with the unmanned Soyuz 2. The two craft closed to within a meter but did not or could not dock.[24]

An ominous changing of the guard occurred in Washington at the same time. James Webb, a giant of the Apollo program[25] who had hammered NASA's refractory organization into shape and threaded the precarious path between NASA's desires and fiscal reality, abruptly announced his resignation effective 6 October 1968, his sixty-second birthday. He would not be in office when NASA reached the only goal it ever had clearly in sight before or since. Webb has not said publicly why he retired. One explanation is that he knew he would not be retained by either presidential candidate (Hubert Humphrey or Richard Nixon), so he got out before having to deal with Apollo 8.[26] A recurring rumor is that his departure was precipitated by the man who brought him into NASA, Lyndon Johnson. One account has Webb talking casually with lame-duck president Johnson about an eventual retirement, and Johnson eagerly marching him immediately to tell the reporters.[27] Another is that he threatened to resign unless Johnson restored some budget cuts, and Johnson refused.[28] What is certain is that Webb correctly foresaw an uncertain future for NASA in the light of shrinking budgets and a lack of direction from the administration, Congress, and NASA itself.

APOLLO 8 (DECEMBER 1968)

Thoughts about the uncertain future also made their way into the media at this time. But that was nothing new, and I think most people saw 1968 and 1969 as a time of hopeful progress in space. Five Apollo missions at two-month spacings had been planned for 1969. After the Apollo 7 mission, only the LM among all the components remained to be checked. Commander Frank Borman (b. 1928), command module pilot (CMP) Michael Collins (b. 1930), and lunar module pilot (LMP) William Alison Anders (b. 1933) had been training for more than a year to test the LM in very high Earth orbit, the E mission. Originally, Collins had been the LMP and Anders the CMP. As a space rookie, however, Anders was not allowed to remain in a command module alone when the other two went off in the LM. Therefore Collins became CMP and remained in this specialty for the rest of his NASA career. If not for this he might have been the Apollo 11 LMP and landed on the Moon instead of Buzz Aldrin.[29]

Two hitches developed. First, Collins had to undergo a critical operation on his neck vertebrae in July 1968 and was replaced by his backup, Jim Lovell, thus reuniting the Gemini 7 crew of Borman and Lovell. Lovell also had flown in Gemini 12 with Aldrin. Second, no LM was ready for Anders to fly (not that the LMP actually piloted the LM anyway).[30]

Time was a-wasting and people were wondering if the testing would ever end. The alphabetical A–G series of steps was being checked off painfully slowly.[31] There was another driving factor: in early August 1968 the CIA informed NASA that the Soviets seemed to be planning a manned lunar flyby for late 1968.[32] So it happened that NASA ended the supercaution that had prevailed during the year and a half since the fire. Why not let the next test of the Saturn 5 be manned? George Low then said out loud what he had been thinking for at least a month: why not extend the next mission *really* high to a 380,000-km apogee — around the Moon? Earlier in the year MSC had toyed with the idea of doing this with the E mission and calling it E prime (E′), but since no LM would be carried (except a $10 million dummy), the mission was in the C category and was designated C′. Surprisingly, nobody except the usual critics of the manned program could think of any objections, and it was agreed that if Apollo 7 worked well, Apollo 8 would fly the C′ mission and burst the bonds of Earth. The idea looked increasingly good when, in September, the Soviet Zond 5 became the first spacecraft to fulfill the Zond lunar mission plan by passing around the Moon, the first Soviet spacecraft to splash down on water (the Indian Ocean), and the first spacecraft from any nation to carry living organisms to the Moon and to return lunar photographs on film. When Apollo 7 (and Soyuz 3) came through in October, the final decision that Apollo 8 would go to the Moon was made by NASA acting administrator Thomas Paine within a week and formally announced on 12 November 1968. The original goal of Project Apollo before Kennedy's redirection would be fulfilled amazingly soon. But the Soviets were not far behind.[33] Zond 6 took stereoscopic photographs of the Moon and performed the sophisticated velocityreducing stunt of skipping off the atmosphere above the Southern Hemisphere and then landing in the usual Soviet recovery zone in Central Asia.[34]

Apollo 8's main purposes were, of course, to test the spacecraft systems and flight operations and to beat the Russians. But like everybody else, lunar geologists wanted to squeeze every possible drop out of the grand opportunity. Just as Gerard Kuiper promoted visual observations with the telescope, so those of us supporting Apollo science hoped that human observers could perceive subtle coloring and shadings that could not be recorded on film. The manned-space-flight faction in NASA was also eager to prove the value of man in space, often sarcastically capitalized by proponents of unmanned exploration as Man in Space.

Apollo 8 would also be the first U.S. craft to bring actual photographic film back to Earth from the Moon. A science advisory team chaired by James Sasser, chief of MSC's Mapping Sciences Branch and Apollo 8 project scientist, was set up to prepare a program of photography and visual observations, as well as Earth-orbital and astronomical studies. Specific targets to be photographed were picked by a lunar science working group that included Jack Schmitt, John O'Keefe, radar expert G. Len Tyler from Stanford University, and most of the Orbiter 5 gang (Bryson, Dietrich, and Whitaker), including me as chairman and Farouk El-Baz in his customary organizing role. Also as customary, Jack Sevier of MSC was there as chairman of the lunar operations working group to tell us what the mission could and could not do. JPL was proposing to drop hard-landing probes from the CSM, so Jim Burke was there to consider the targets' engineering properties. The targets were printed on the flight charts but were called "targets of opportunity" because they would be photographed only when time and other duties permitted. Of course, our list included many of our old friends, the special features. There were *delta-rim* craters, Jack Schmitt's term referring to the smooth rim profiles of shallow-floored craters like Sabine and Ritter that lack the steep inner walls and gentler outer flank that characterize impact craters. There were short, gentle furrows centered in mounds, the usual assortment of dark and bright "domes," and all sorts of crater interior features such as "bulbous peaks" and "fractured tumescent floors." Sinuous rilles look somewhat like rivers, yet no deposits like those at the ends of rivers had ever been seen at their ends, so these were to be looked for. There was also a lot of meat-and-potatoes geology such as impact craters and maria. Also, each potential Apollo landing site was to be shot with a 250-mm lens, as were the landed Surveyors. There was an effort to fill in areas around Mare Crisium that had been foggily photographed by Lunar Orbiter 4. Sasser's branch also identified landmarks that would be located accurately to improve the knowledge necessary for navigation preparatory to landings; positions on the far side were known to be off by a scandalous 10°, or 300 km.

We took every opportunity to brief the astronauts in visual observing. We even shuttled to the Cape shortly before launch to make sure they absorbed every last drop of our vast knowledge. Jack Schmitt was the scientific guru of the astronauts and the interface between them and us. On one occasion, in the last week of November 1968, Hal Masursky and I visited the spartan crew quarters at the Cape and gave a last crash course. Bill Anders was to do most of the scientific photographing and observing, so he was the astronaut who worked with us most closely. He 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. I don't remember what I talked about but I know Hal dragged out his old favorite, the *base surge,* a terrestrial term for surface flows started by clouds of debris that descend through the atmosphere over their source. Hal had come across the concept during a coffee break with volcanologists at Menlo Park some years before and clung to it in these last precious moments before launch, despite its inapplicability to the airless Moon. Another memory of this visit is a meal with the astronauts and others in their dining room. The door opened and someone announced, "Gentlemen, Mr. Arthur Godfrey." Instinctively, everyone stood up, as if entertainer Arthur Godfrey could hold a candle to Frank Borman, Jim Lovell, Bill Anders, and their backup crew of Neil Armstrong, Buzz Aldrin, and Fred Haise. One night Anders drove us out to a point near launch pad 39A. The Saturn 5 that would take him to the Moon was poised there in the glow of floodlights, stunning in its isolated grandeur.

Exactly at the long-preplanned time of 1251 GMT (7:51 A.M. Cape time) on 21 December 1968 the three stages of that Saturn thundered off with a full set of Apollo hardware and men (except a real LM) and, after an hour-and-a-quarter stay in a "parking orbit" around Earth, the S-4B third stage fired a second time for five minutes and sent the first humans off to the Moon. The person who communicated directly with astronauts in space was always another astronaut, still called the *capcom* as in the Mercury days when he was the *cap*sule *com*municator. Mike Collins drew the capcom job for the first part of the Apollo 8 mission and had the honor of radioing the historic understated message: "All right, you are go for TLI." Translunar injection occurred over Hawaii before dawn, and people on the ground could easily see the streak of the S-4B.

Amazingly, the astronauts did not see their destination for the next three days, except for slivers glimpsed by Lovell with his navigational telescope. Some 69 hours after launch the fallback plan of a single loop behind the Moon was abandoned and the go was given for orbital insertion. The SPS fired and the astronauts looked out the windows for their first view of the Moon and saw: nothing, less than nothing, total blackness. Such was humankind's first view of the Moon at close range. They knew they were looking at a double shadow, sunlight and earthlight both blocked by the invisible Moon. Then, at the exact predicted instant, the sunlit limb flashed into view. After 36 minutes behind the Moon Apollo 8 emerged from radio shadow, to the relief of Mission Control at MSC, in the right place to continue orbiting. So Borman, Lovell, and Anders spent Christmas 1968 away from home.

After two elliptical orbits, Apollo 8 was placed in a near-circular 110.6-by-112.4-km orbit inclined 12° to the Moon's equator. In accord with the usual NASA practice, derived from aviation, MSC and the astronauts described the altitude as 60 nautical miles, which is about 70 *statute* miles. The crew's descriptions of the Moon reflected the contrast with the "Good Earth" of this "misshapen golf ball" looking like "pumice," "a battlefield," "a sandbox torn up by children," "plaster of Paris," or a "volleyball game played on a dirty beach." The beach analogy got a lot of attention, possibly because of their stomping grounds at Cocoa Beach, Florida. In accord with one premission prediction, they reported the color of the Moon in touristic terms as various shades of gray, perhaps with a brownish cast "like dirty beach sand." The far-side terrae appeared texturally soft and monotonously colored, except for small bright spots and rays marking "new" craters that appeared in great numbers under high Sun illuminations. The rayed craters appeared as if made by a "pickax striking concrete." The maria offered greater contrasts in color and topography. But the general impression obtained from the astronauts' reports during the mission was that the Moon was desolate, lonely, drab, colorless, bleak, and forbidding. They were homesick and missed their cheerful Christmas hearths.

Astronomers and bartenders had long known that the sharp increase in the Moon's brightness on the night of a full moon has peculiar effects. Space scientists had succeeded in impressing the Apollo engineers with this aspect of the mysterious Moon, adding to their already long list of worries the one that astronauts coming in to land with the Sun behind them might be so dazzled by moonlight that they would not see surface features. From their orbital altitudes the Apollo 8 crew did see the predicted bright *Heiligenschein* (saint's halo) around the shadowless point opposite the Sun, but reassuringly could detect surface detail within 5° of this *zero-phase* point. They could also see considerable detail on Sun-facing slopes that were washed out on Lunar Orbiter photographs, in shadows that were completely black on photographs, and in earthshine. Some of the fear of the unknown subsided. The crew's comments were listened to with rapt attention by the science working groups in the first of many back-room science support centers, which had been set up at the instigation of Wilmot Hess and Jim Sasser in a small building (226) in the eastern corner of MSC. Our duties included taking phone calls from the Moonwatch amateurs about lunar transient phenomena. Mostly we sat, listened, and watched television of the mission, though we "reacted enthusiastically to all requests," as Farouk put it.

Anders (mostly) also shot as many of the "targets of opportunity" as possible with hand-held Hasselblad cameras equipped with a variety of films and lenses being tested for lunar application. But as the mission wore on, the astronauts wore out and scrubbed the scientific activities planned for the last three revolutions around the Moon. However, they completed the planned 10 revolutions and 20 hours in orbit. Then, at about 1:00 A.M. on Christmas Day Houston time, the faithful SPS fired a fourth time and sent the weary crew coasting toward home.

The press had made much out of the possibility that the command module might hit Earth's atmosphere at too steep an angle and burn up, or at too shallow an angle and skip back into space forever; there was only a 2° "window" (5.4°–7.4°) between these equally undesirable ways of creating a "crew loss situation." But the TEI burn was right on the mark, and after discarding the service module over China, the command module reentered squarely in the window (6.4°) at about 39,300 km per hour, damn fast but only 700 km per hour faster than the velocity with which they had left Earth orbit. At 5:51 A.M. Hawaii time (1651 GMT) on 27 December 1968, the three space travelers splashed down in the Pacific after six days and three hours in space. The "Greatest Voyage since Columbus" entered the history books.

Borman, Lovell, and Anders were named Men of the Year in the 3 January 1969 issue of *Time,* and on that and the following day they held a scientific debriefing in Houston. Anders said the photography plan was satisfactory and that he could quickly identify and shoot a target once it came into view unless it was too near the horizon. Lighting was not a problem in spotting targets. However, the ambitious photographic and observational program was only partly implemented because of the novel situation, astronaut overwork and fatigue, dirt and condensation on the windows, and the general unsuitability of the command module for scientific observing. During the flight Borman had compared it to a submarine, and during the debriefing Anders said that "flying a CSM is like driving a car by sighting through a hole in the floorboard" or "like driving through a scenic park in a Sherman tank." One window was opaque and another had "purplish stripes as if wiped by a service-station attendant with an oily rag," though the camera saw through it better than the naked eye could. The windows pointed in too many different directions and things were always floating around in the cabin. At best, the stars looked like they do on a smoggy night in Houston. Depth perception was difficult and they discovered that relief on the real Moon pops into reverse—craters become mountains and mountains become holes—just as it does to an inexperienced eye viewing lunar photographs. Recording observations on tape was difficult, and on paper, impossible. The light meter was separate from the camera and useless. In a refrain that was beginning to be heard way back then, Anders sarcastically said, "If we can't build a good one, buy one from the Japanese."

Anders made a number of useful and colorful comments about the targets of opportunity, but he stated the unavoidable problem that always plagues even the best visual observations: "The eye can see more than the camera but cannot record it." But verbal descriptions cannot be checked without a supporting photograph. He enthusiastically described a field of grooves that looked like "grass raking" that we savants never did figure out. Despite the difficulties, many scientific as well as technological firsts were achieved which paved the way for future missions.[35] Stereoscopic strips of one-third of the Moon's circumference (longitude 165° W, westward to 70° E) taken automatically with a bracket-mounted Hasselblad during two of the circular orbits showed how the Moon's appearance varies under changing lighting at high resolutions and helped locate far-side points accurately. One unplanned shot included mountains of what turned out to be the Moon's, or at least the far side's, largest basin, although it was not yet recognized by geologists while we were laboring on the postmission report.[36] Early in the transearth coast the astronauts also obtained useful photographs of the whole disk of the Moon similar to those obtained from Earth, but with a new perspective.

Probably the most important achievement of Apollo 8, however, was neither scientific nor technical. The world needed a new perspective at the end of 1968. The incredible events of that historic year started appropriately at the February lunar new year, called Tet in Vietnamese. The Tet offensive of the Viet Cong and North Vietnamese was not supposed to be possible according to the official line of U.S. political and military leaders, and when it occurred, the "credibility gap" (as official lying was called then) was evident for all to see. One result was the second shocker of the year, President Johnson's announcement on 31 March that he would not run for reelection. Five days later came the assassination of Martin Luther King, Jr., and on 6 June that of Robert F. Kennedy. France suffered major student riots in May, and the Chicago police savagely attacked antiwar demonstrators and bystanders during the Democratic party's convention in August. Also in August (the 21st), the Soviet army invaded Czechoslovakia, shelving the liberalization movement called Prague Spring for another 21 years and, incidentally, abruptly ending the International Geological Congress in Prague, whose attendees included Dale Jackson, Elbert King, and Elliot Morris. In Mexico City in October, hundreds of people died in riots and two American black athletes held up clenched fists while receiving their medals during the Olympic Games. In November Richard Nixon was elected president.[37]

Then, in December, humans for the first time were able to stand off in space and look back on our home through the eyes of Apollo 8. What the astronauts, scientists, and citizens saw was the unique beauty and fragility of Spaceship Earth—another small and self-dependent capsule adrift in a hostile cosmos otherwise unsuited for human life.

WHY TRANQUILLITY?

The scientific debriefing was followed five days later, on 9 January 1969, by the returning heroes' first public news conference. When asked his theories of crater origin, Borman replied by saying, "There are an awful lot of holes on the Moon—enough holes to support both theories." Then he sprang the first surprise of the day, that he had performed his last spaceflight, renouncing a chance to make the first lunar landing, and would become second in command to Alan Shepard in the astronaut office.

The second surprise was the introduction of a new crew of astronauts. Neil Alden Armstrong and Edwin Eugene Aldrin, who had been living in the crew quarters as the Apollo 8 backups, were named to the prime crew for Apollo 11. The years-long suspense appeared to be over. Here were the men who were going to be the first to land on the Moon, unless Apollo 10 itself landed or suffered some serious setback that affected Apollo 11. Deke Slayton's words to them were, "You're it." Armstrong was generally considered supremely competent despite trouble with Gemini 8 in March 1966 and a narrow escape from a landing simulator in May 1968. Aldrin held a Ph.D. in orbital mechanics from MIT and had long seemed to us geology instructors a likely candidate for an important mission. The new importance of Apollo 11 meant that Fred Haise was bumped as CMP by the more experienced Mike Collins. Apollo 11 thus got a whole crew born in 1930, the same year as one-third of the Apollo astronauts and also me,[38] a coincidence that tellingly brings home to me the rapidity of time's flight. Lovell, Anders, and Haise were the backups. John Swigert, Ronald Evans, William Pogue, and Thomas Kenneth Mattingly constituted a support crew to perform such time-consuming administrative functions as keeping track of changes in the flight plan and working out procedures in the simulators.[39]

Nor was the competition inactive in January 1969. The Soviets launched another unnumbered Zond and the manned Soyuzes 4 and 5, which rendezvoused and docked in orbit. The Zonds were modified Soyuz craft much larger than needed for simple robotic photography and large enough to carry at least one man and his life support to the Moon.[40] They carried living creatures to test the lunar environment. Zond 6's reentry trajectory was surely designed for human safety. The Soviets were indeed trying to be first on the Moon. In the *glas-*

nost' era of November 1989, they took a group of American aeronautics professors into a room and showed them the Soviet lunar lander.[41]

NASA had boldly gambled that the manned spaceflight system would take astronauts to the Moon without further shilly-shallying and had won its gamble. But the LM was still untested. This was a task of Apollo 9, which was flown in Earth orbit for 10 long days by astronauts Jim McDivitt, Dave Scott, and a spacesick Russell ("Rusty") Schweickart between 3 and 13 March 1969. Among other things, this D mission tested the critical rendezvous and docking maneuvers of the LM and CSM in space. Rusty bravely EVA-ed despite his discomfort, constituting for a time a third spacecraft with the radio call sign *Red Rover.*[42]

Need for an E mission had been removed by the success of the C, C′, and D missions, so both the F and the G missions moved to the figurative flight line. Tom Stafford, Gene Cernan, and John Young had been together as the backups for Apollo 7 and had been named for Apollo 10 in November 1968, before it was entirely certain what kind of mission they would fly. Gordon Cooper, Donn Eisele, and Edgar Mitchell were their backups, and Joe Engle, Jim Irwin, and Charlie Duke were the support crew. Now, after the success of Apollos 8 and 9, they knew they would go to the Moon and dip low over its surface but would not land. They also knew that Apollo 11 would be the land-and-return G mission and that it was probably headed for Mare Tranquillitatis, the Sea of Tranquillity.

Why did Tranquillity Base become a worldwide household name, and not, say, Fertility Base or Central (Medii) Base? Not primarily for scientific reasons, of course. For the first one or two landings, MSC favored eastern sites over western so that a flight could be recycled to more westerly targets and still begin in the originally scheduled month even if a launch had to be postponed. But the primary target site could not be too far east, either. A landing in Mare Fecunditatis would be unfavorable for tracking from Earth, fuel consumption, and a possible nighttime splashdown on return to Earth. Scratch the Fertility Base that had appealed to some of us Lunar Orbiter site selectors and had figured at Santa Cruz among the first three possible landing sites.

Mare Tranquillitatis, the next mare to the west, contained several of those telescopically visible dark spots that had been prime targets for all five Lunar Orbiters. Two of them became the easternmost survivors from the early Apollo list. Because of its position, the more easterly site was officially called Apollo Landing Site (ALS) 1.[43] ALS 1 was the less dark of the two Tranquillitatis sites, and those of us who pondered it vacillated between calling it mare or terra. Because of the accelerated checkoff of the alphabetical mission sequence, it was assigned to Apollo 8 as a sham landing site in order to cram more kinds of simulation into that mission. Jim Lovell looked down on it and said it looked like mare to him, and also that it looked like one of the geologic training areas he had seen, the Pinacate volcanic field in northern Mexico. It seems to be covered by a smooth material that softens large craters and obliterates medium-sized ones while preserving small young ones. Mike Carr and I devoted many man-hours to mapping and remapping the cursed place and trying to figure out what the smooth material was.[44] This being 1969, we concluded that it was a thin, young ashflow tuff deposit à la O'Keefe that was not typical of the maria because of its moderately high albedo and blanketing property. But Bill Quaide and Verne Oberbeck at the NASA Ames Research Center, who did not participate directly in the site deliberations, showed from an analysis of crater morphology that the smoothness results from a relatively thick regolith.[45] A terra substrate probably explains the high albedo, and the thick regolith explains the softness of the large craters.

The other Tranquillitatis site was known by a number of names, depending on which spaceflight was devoting attention to it.[46] Chapter 9 introduced it as Lunar Orbiter Mission A candidate site A-3, and now it was officially called Apollo Landing Site 2. Ranger 8 ended its photographic mission only 68 km to the north-northeast, and Surveyor 5 sat down successfully only 25 km to the northwest. ALS 2 afforded a two-day recycle to the next candidate site, the much-photographed ALS 3 in Sinus Medii in the center of the near side, which was included in the astronauts' preflight preparation. In turn, the northern site in Oceanus Procellarum at the western end of the Apollo zone, ALS 5, was the backup if even Sinus Medii could not be reached in the designated launch month. ALS 4 would not become advantageous until December or January.

ALS 2 suited scientists very well, and GLEP went on record saying so in April 1969. We felt that ALS 1 was too exotic, though possibly interesting. For the first mission we wanted a more typical mare like the one in ALS 2. Here are many large subdued craters (500–700 m diameter), fewer small distinct craters than in the western maria, and relatively few blocks — ideal terrain for the first landing. That terrain smoothness indicates a relatively old age among maria had been shown by the Surveyor analysts and now was confirmed by an elegant scheme relating crater morphology to surface age being devised in Menlo Park by Newell Trask.[47] Maurice Grolier incorporated the idea in his geologic maps of ALS 2,[48] which were assigned to him because he had prepared the green horror with the original telescopic analysis of the place.

Mare colors were still puzzling and therefore interesting, so the scientists and the media made much of the "blueness" of ALS 2. Kuiper had thought that the colors might be related to oxidation state or age, but he knew he was only guessing. Tom McCord and Torrence Johnson, in an early phase of their career-long study of telescopic spectra in the visual and near infrared, found that color was not related to age and predicted that it was probably due to composition and mineralogy of the surface materials.[49] Beyond that, they offered no guesses about the meaning of the blue color.

As usual for the early Apollo missions, however, science did not determine ALS 2's future use. Since ALS 1 was the sham target for Apollo 8, Jack Schmitt suggested to Tom Stafford that the Apollo 10 launch be delayed a day so that ALS 2 could be the sham target for Apollo 10.[50] Jack then shopped the idea around MSC (the unstructured way progress was often made at MSC in those days). George Low and flight operations director Chris Kraft were bothered by the trouble the change would cause; however, recovery engineer Jerry Hammack realized that the change would assure a daytime splashdown. Finally, General Phillips overrode all the negative arguments and had new computations made for a one-day launch delay. Stafford, Cernan, and Young would see what ALS 2 looked like close up in good lighting.[51]

APOLLO 10 (MAY 1969)

Five months after the flight of Apollo 8 and two and a half months after Apollo 9 tested rendezvous procedures in Earth orbit, on 18 May 1969, Saturn 505 sent Tom Stafford, Gene Cernan, and John Young on the next probe of lunar space. Coming only two months before Apollo 11, their mission, the F type, was an earnest test of all spacecraft components — including the LM — and of all operations except actual landing. While Apollo 10 was on the way to the Moon, the historic Saturn 506 was creeping slowly toward Launch Complex 39A.

Apollo 10's mission included undocking the LM from the CSM and dropping Stafford and Cernan to the seemingly mountain-clipping altitude of 14.5 km above the Moon's surface. A sudden lurch of the LM elicited from Cernan the fearsome words "son of a bitch!" that seem to be the Apollo 10 highlight in most people's memories. Stafford quickly picked out ALS 2 in southwestern Mare Tranquillitatis and said it looked like the desert in California around Blythe.[52] He also said that the up-range (eastern) end of the target ellipse looked smooth but that the downrange part did not, adding, "If you don't have the hover time, you're going to have to shove off."[53] Tracking the spacecraft during this low approach led to improved knowledge of the Moon's gravity; Apollo 8 had been perturbed in unpredicted ways by the mascons, and that had to stop. The Apollo 10 astronauts reported a greater washout of surface detail near zero phase than seen by Borman, Anders, and Lovell, perhaps because of the lower orbit. ALS 1, ALS 2, and ALS 3 did not escape their cameras, although the movie camera chose to malfunction over ALS 2. Like Apollo 8, they shot stereoscopic strips and our targets of opportunity, including some at higher resolutions made possible by the low altitude. Apollo 10 lasted two Earth days longer than Apollo 8 and benefited from the experience of the Men of the Year in budgeting time, anticipating how much they could and could not do, and maneuvering the spacecraft.

Stafford, Cernan, and Young were, of course, also fully aware of the momentous technological, scientific, and political achievement they were rehearsing. NASA brass and back-room scientists alike had noted the tone of morose homesickness in Apollo 8's comments and had responded to the effect, "Oh, pardon us for making you go to the *Moon* at Christmas." Apollo 10 would adopt a tone more appropriate for a lunar program that was absorbing a considerable slice of taxpayers' money. Now, the Moon was not a gray, dead landscape or a dirty beach but was warmed by browns in the maria and tans in the terrae. Spectrally "reddish" Mare Serenitatis was a light brown or tan, spectrally "blue" Mare Tranquillitatis a dark, or chocolate, brown. But there was no time for the photo analyzers to report the observations made by Apollo 10 in the same detail as we had those of Apollo 8.[54] Stafford and Cernan's report made MSC comfortable enough with ALS 2 to remove the need for ALS 1, which was a little too far east anyway.

Apollo 10 was bracketed in April and June by two unnumbered Lunas of the rover or sample-return types that failed to reach Earth orbit.[55] In June or July 1969 a cataclysmic explosion apparently destroyed a Soviet G-1 booster on the launching pad, and the expert ground crews along with it.[56] No Soviet cosmonauts would land on the Moon.

A PAUSE TO TAKE STOCK

Whether or not a two-nation space race was still on in late 1968, the United States was engaged in an all-out effort to meet the deadline that had been set by a president now five years beneath an eternal flame in Arlington National Cemetery. New efforts were wrung from thousands of space engineers. Hundreds of petrologists, geochemists, geochronologists, geophysicists, and geologists joined in the study of lunar geoscience in preparation for receipt of rocks from the Moon.

They had survived a close call. In August 1968 George Low and Robert Gilruth's managers at MSC recommended deleting the geology investigation and most or all of the experiment package.[57] General Phillips, though not Gilruth, wanted one of the astronauts to stay in the LM, as had been the plan until the mid-1960s. The idea was just to get there, grab some Moon rock, and get back alive.

This was understandable, of course, but the scientists, led by Wilmot Hess, fought to preserve the scientific content of the first landing mission.[58] The result was a compromise in the running battle between science and mission operations. Most of the experiment package was indeed deleted, and the number of excursions from the spacecraft was reduced from the two that the geologists wanted to only one. But both landed astronauts would be able to sample and examine the surface geologically and might receive a few pearls of wisdom cautiously forwarded from support rooms in the Mission Control building.

The hub of the sample examination would be MSC's Lunar Receiving Laboratory (LRL), whose curator since September 1967 was Elbert King and whose director, also chief of the Lunar and Earth Science Division at MSC, was weak-eyed physicist Persa R. Bell from the Atomic Energy Commission's Oak Ridge National Laboratory.[59] When he established GLEP in 1967, Wilmot Hess also created and chaired two teams to be sure everyone qualified and interested got a piece of the Moon.[60] The Lunar Sample Preliminary Examination Team (LSPET), as its name implies, would do the actual work of subjecting the samples to their first scrutiny on arrival from the Moon.[61] How to select and allocate samples for analysis would be decided by the Lunar Sample Analysis Planning Team (LSAPT).[62]

Still another attempt to bridge the gap between flight operations and science took place, deliberately, outside MSC's gates.[63] In 1967 Administrator Webb had requested funding for a science institute based on the LRL, and on 1 March 1968 President Johnson personally visited MSC and announced the creation of the Lunar Science Institute (LSI).[64] LSI was formally established in October 1968 and opened in March 1969 in an attractive former mansion set in snake-infested land next to MSC. Bill Rubey, a USGS geologist from 1924 to 1960, who in 1956 had encouraged Shoemaker's efforts to start a USGS lunar program, acted as LSI's interim director by commuting part time from his professorship at UCLA. LSI's stated purpose was to facilitate the access of non-NASA scientists to the lunar data. Actually, it was widely regarded at the time as an institute in search of a mission.

The forthcoming first manned landing called for assessments of the current models of the Moon's geology. In simple terms, as expressed in newspapers at the time, science wanted to know the following: What is the Moon made of? Is it hot, warm, cool, or cold? Is it partly wet or completely dry beneath the surface? (Even many scientists still thought that sinuous rilles might be cut by water.) And, of course, how did it form?

The problems were described in more detail by two geologically slanted synoptic reviews of the knowledge gained in the Space Age's first decade. The first, by Brown University geology professor Thomas ("Tim") Andrew Mutch (1931–

1980), was in book form.[65] As both a philosopher and a practitioner of the science of stratigraphy, Tim had become interested in the way his favorite science was being applied to the Moon. He took sabbatical leave from Brown during the academic year beginning in September 1966 and spent it with USGS lunar geologists in Flagstaff and Menlo Park. We did not have to help this master of the letter and spirit of stratigraphy understand how stratigraphic principles could be applied to the Moon, but we did provide him with the facts and interpretations we had been accumulating for five years, and we thoroughly reviewed and criticized several drafts of his manuscript. His classic book is one reminder what a great loss lunar and planetary studies suffered when Tim, then at NASA Headquarters, fell to his death while climbing in the Himalayas in October 1980. Another reminder is the current prominence of Brown University in planetary geology, which in 1969 began to sprout from Tim's plantings in the form of two students whose names are known to anyone familiar with planetary geology. One was hired for Bellcomm in 1968 (on Tim's recommendation) by Farouk El-Baz, who had been promoted to supervisor, and by Dennis James and Noel Hinners. Thus entered on the scene the superproductive (actually hyperactive) James William Head III (b. 1941), who as Tim's successor at Brown has sent dozens of well-equipped students into the world of moons and planets. The other, Ronald Stephen Saunders (b. 1940), is now the Magellan project scientist at JPL. I was on Steve's Ph.D. committee and, along with Jack McCauley, tried to get him to join the USGS in 1970, but Smogville beckoned more alluringly.

The second pre-Apollo summary, I say with all due modesty, was also a classic of its type. Jack McCauley and I were asked by our NASA contract monitor, Bob Bryson, to revise, update, and quickly publish the geologic map of the region 32° N–32° S that Newell Trask, Jim Keith, and I had compiled in 1965. We started the task shortly after Orbiter 4 photographs became available in September 1967 and somewhere along the line expanded the area to include the entire coverage of the 44 1:1,000,000 LACs, compiling the mapping that had been done at that scale. Or at least that's what we said we did so as not to offend the 42 other geologists who had toiled so long and hard on the 1:1,000,000-scale telescopic maps. Actually, we remapped the whole area from scratch and presented our own interpretations. In a supplementary pamphlet we explained the principles of lunar geologic mapping and gave the status of the 1:1,000,000 mapping. Preparation of the map and pamphlet occupied about three man-years and three calendar years — more than Bryson had intended. We worked at first in our separate offices in Flagstaff (Jack) and Menlo Park (me), then in closer concert after September 1968 when Jack moved to Menlo Park. Jack "compiled" the area west of Copernicus and I did the area east of Copernicus. Jack wrote most of the text, to which we gave the final edit in San Francisco's Balboa Café, still in its pre-yuppie incarnation as a fishermen's hangout. Although it was published after the Apollo 12 mission (in November or December 1970), the map is a record of interpretations of near-side geologic units circa 1969.[66] Our results were also portrayed in journal articles on lunar provinces and a series of paleogeologic reconstructions executed by space artist Don Davis, whom I hired when he was still a high school student — before even asking his name — when he came into the Menlo Park office one day in November 1968 with a beautiful painting of the Moon under his arm.[67]

Tim's book and the near-side map agreed on a list of general conclusions about the Moon that had evolved during the decade of the 1960s:

1. The Moon is heterogeneous and has had an active and diverse history (meaning it is non-Ureyan).
2. Both impact and volcanism have played important roles in its evolution (it is not Greenish).
3. The regolith formed in all periods in proportion to the impact rate (so is not Goldish).
4. The long rays of large Copernican craters are made up of secondary ejecta and demonstrate the great energy required to form them, an energy available only from cosmic impacts (not any internal gas releases or the like — not Spurrish).
5. The maria filled their basins a considerable amount of time after the basins formed; thus the maria and basins are not genetically related, as so many early observers thought.
6. The basins, their multiple rings, and their ejecta are the dominant structures of the Moon and control the surface distribution of most other materials and structures. Their size and range of influence prove their impact origin.
7. Basins and craters form a continuous series of impact features. Some physical law or property of the target causes craters larger than about 20 km to have central peaks, and those more than 250 or 300 km (basins) to have two or more rings.
8. Many craters smaller than 20 km are the secondaries of larger primary craters or of basins.[68]
9. An unknown, possibly considerable, number of small craters with irregular shapes or arranged in chains and clusters are endogenic.
10. Endogenic origin cannot be excluded for larger craters with smooth ("delta") rims or nondiagnostic features. That is, the absence of sharp

features diagnostic of origin may result either from a moonwide process of degradation or from an original lack due to a passive (caldera) origin.

11. The depth to the mare-producing layer varies between the mare "province" and the nonmare "province," which includes the southern near side and most of the far side.

The sharp-eyed reader will have caught a few cases of slightly misplaced emphasis in the above list, although it remains mostly valid today. But consider the following less fortunate elements of the 1969 model. Each of them contains some truth, but not in the sense that was meant.

12. Hybrid craters originally formed by impact but then modified by volcanism are common.
13. There are two main suites of volcanic rock: dark and light. Within both suites, morphologic expression, presumably dependent on magma viscosity, ranges from passive (plains and mantles) to positive (domes, cones, and plateaus).
14. The majority of lunar volcanism (mare and terra plains) is of a fluid type that seeks depressions, probably the lowest depressions available at the time of extrusion. This kind of volcanism seems to have been general and is expressed wherever depressions are available.
15. The light plains are mostly Imbrian in age but older than the dark plains (maria); but some, mostly in craters, formed after the maria.
16. Terra (light-colored) volcanics of positive relief are concentrated near mare basins of intermediate (middle and late pre-Imbrian) age. A few of the very freshest occurrences are near the Imbrium basin. The positive-relief features predate the nearby terra plains (for example, the Cayley Formation).
17. The only known mare (dark-colored) volcanics of positive relief (for example, the Marius Hills) formed after the mare plains.

The reference in item 16 is to the "hilly and furrowed materials" identified by Jack and me as an important class of lunar materials, which we colored fiery red on the map. Although we recognized the dominance of lunar basins in lunar geology—in fact stressed it—we thought their relation to radial sculpture and the hypothesized volcanic deposits was indirect: the impacts induced faulting and controlled volcanic extrusion.

Jack and I devoted little attention to the boring maria, tentatively accepting the dark = young equation. Tim was a little troubled by this and presented alternative models for mare-basalt emplacement, one of which showed the central units of Mare Serenitatis as younger than the peripheral dark band.[69] A few years later that alternative would win.

Tim had his endogenic pitfall too. Like so many earlier investigators, he considered not only the sculpture but also many nonradial lineations to be tectonic faults. Assigned along with Steve Saunders to a "leftover" quadrangle in the southern highlands, he made the most of it and developed a scheme of block faulting of large regions.[70] The Earth had again spoken to a geologist.

The studies of lunar geology in the 1960s had produced a model of the origin and evolution of lunar features that was ready for testing. Impact origins were winning in the endogenic-exogenic controversy but had not yet prevailed. The ultimate test would come in fragments from the Moon itself.