12

A Western Mare?
1969

ACT 2

Was magnificent Apollo 11 the end of the grand endeavor or the beginning of a grander new one? Those who thought that the safe landing and return were Apollo's only purposes and the culmination of the space race did not really care what NASA did next. Those who thought that science and exploration were worthy aims considered Apollo 11 only the opening round in the exploration of the universe.

Despite some sentiment to quit while they were ahead, NASA was already committed to at least one more act in the Moon-landing show. Originally, launches were scheduled to go off every two months between July 1969 and July 1970, meaning that Apollo 12 would have flown in September 1969 and six Apollos would have flown by July 1970. George Mueller backed off from this frenetic pace, however, and the launches would now come at four-month intervals.[1] But there was no way to change any hardware in the immediate future. The simple land-and-return mission flown by Apollo 11 was a G mission. Apollo 12 was the first of four planned (but only three flown) missions of a more advanced type (H) that had a complete integrated Apollo Lunar Surface Experiments Package (ALSEP), two EVAs, and longer stay times. The J types were the much more complex missions with major hardware alterations that ended up being called Apollos 15, 16, and 17.[2] The Apollo 12 H-1 mission was scheduled to fly in November 1969.

THE WRONG SITE

The choice of the site for the second manned landing has always pained me. In my opinion Apollo 12 wasted an opportunity that was never made up and left a gap in lunar geologic knowledge that has never been closed. For years I have comforted myself with the belief that black-hatted philistine engineers inflicted their unreasonable requirements on us enlightened white-hatted scientists. In October 1988 Farouk El-Baz told me a more complicated story.[3]

Since December 1967 the GLEP plan for early Apollo mare landings had been first to go east, then west. We had settled on five sites: two eastern alternatives in Mare Tranquillitatis (ALS 1 and ALS 2), one central site (ALS 3) in Sinus Medii, and two western alternatives in Oceanus Procellarum (ALS 4 and ALS 5). Apollo 11 had taken care of the east by landing on ALS 2. The Sinus Medii site was mainly for backup purposes. Therefore the choice seemed to be between the two Procellarum sites in the west. Engineers and scientists liked them both. The choice would be determined by launch month. Winter was best for ALS 4, which was south of the equator, and summer for ALS 5, north of the equator. November was the divide.

The Rump GLEP liked these Procellarum sites because their maria are young. We wanted a landing on a young mare to calibrate the lunar stratigraphic time scale and to learn whether lunar magmas evolved progressively. Crater counts, crater sharpness, and blockiness as seen in high-resolution Lunar Orbiter photos all clearly showed that the two western sites contain younger mare units than do the eastern and central maria. So the planners consciously or subconsciously equated "western mare" with "young mare." Mare color differences were also still a mystery worthy of investigation during this planning stage, before the Apollo 11 results were digested. Mare Tranquillitatis is an "old blue" mare. The part of Oceanus Procellarum that included the two potential Apollo 12 landing sites is a "young, slightly less blue" mare. The maria in between, including Sinus Medii and as far west as 25° west longitude, are relatively "red" in color and intermediate in age. Unfortunately, the actual landing site fell in this intermediate zone.

Understandably, NASA managers cared more about the performance of their rockets and spacecraft than about mare colors or ages. They were not sure originally whether Apollo could land at a predefined point as opposed to a general dispersion ellipse. The selenographers were unable to locate visible points on the surface exactly. Lunar gravity deflects a spacecraft's path in unpredictable ways. The engineers began to gain confidence, however, when tracking of the Lunar Orbiters began to pinpoint the mascons and other blips in the lunar gravity field. In 1968 the Rump GLEP therefore picked small "relocated" (R)[4] points of scientific interest in the Sinus Medii and southern Procellarum sites. A point landing next to an already landed Surveyor spacecraft would be even more dramatic, so we added to the list, as 6R,[5] the far-west Surveyor 1 landing site in Oceanus Procellarum inside the Flamsteed ring. The Flamsteed site not only provided a sitting Surveyor but also was favored by geologists because of its large expanses of unequivocally young (Eratosthenian) mare material. Farouk El-Baz, Hal Masursky, and I even moved it ahead of the other Procellarum sites (ALS 4 and ALS 5) as our choice for the second landing.

The other successful Surveyor that might receive an early visitor was Surveyor 3, Surveyor 5 being too near Tranquillity Base and Surveyor 7 being outside the early Apollo zone. While carefully screening the Lunar Orbiter 3 photos in the spring of 1967, the terrain analysts had concluded that the landing site of Surveyor 3, called Orbiter site 3P-9, had "little potential as an Apollo landing site" because of excessive roughness.[6] Ewen Whitaker later located the downed Surveyor exactly by means of the images taken on the surface by its own cameras.[7] It sits 370 km south of the crater Copernicus, on or near one of that crater's bright rays (3.0° S, 23.4° W).[8] In about January 1969 the Surveyor 3 site became ALS 7 and began to be considered for an Apollo landing.

That is where matters rested while Apollo 9 tested the LM in Earth orbit in early March 1969, and its backup crew of Charles ("Pete") Conrad, Jr. (b. 1930), Alan Lavern Bean (b. 1932), and Richard Francis Gordon, Jr. (b. 1929), was announced as the prime Apollo 12 crew on 10 April. Apollo 10 had not yet tested the LM in lunar orbit, so Apollo 12's mission was still not entirely certain; Conrad and Bean were primed to be the first landing crew in case Apollo 11 had not been able to land. Mission commander Pete Conrad (Geminis 5 and 11) was highly regarded by his peers[9] and was the LM specialist among them.[10] LM pilot Al Bean had backed Gemini 10 and Apollo 9 but, like all future LMPs (Haise, Mitchell, Irwin, Duke, and Schmitt), had not yet actually flown in space. CMP Dick Gordon had flown with Conrad in Gemini 11. Their backups were the future Apollo 15 crew of Dave Scott, Jim Irwin, and Al Worden. The support crew was Gerald Carr, Paul Weitz, and scientist-astronaut Edward Gibson, none of whom would fly an Apollo but all of whom would fly on Skylab.[11]

After Apollo 10 flew and Apollo 11 was about to, the planning for Apollo 12 became serious. The minutes of a critical ASSB meeting on 3 June 1969 record that Noel Hinners of Bellcomm and Hal Masursky of the USGS presented the Rump GLEP's low opinion of ALS 7 and preference for ALS 4 or ALS 5. General Phillips, the chairman of the ASSB and the Apollo program director, recommended that both the Surveyor 1 (ALS 6) and Surveyor 3 (ALS 7) sites be dropped from consideration for Apollo 12. The ASSB asked the Rump GLEP to provide R points in ALS 5, and Newell Trask responded with nine alternatives on 19 June 1969.

At the same meeting Masursky proposed the Fra Mauro Formation or the upland plains in the ancient crater Hipparchus for Apollo 12. General Phillips did not reject this leap into the terrae, but it was too bold for MSC. Worried about low N numbers and inadequate photographic coverage (which was not true for Hipparchus), they rejected Fra Mauro and Hipparchus on 12 June 1969.

In contrast, the Surveyor 3 site (ALS 7) was leading a charmed life. Ben Milwitzky, the Surveyor program manager, had presented a long list of reasons why a Surveyor site should be visited by an Apollo. Changes since the landing could be observed, pieces of the craft could be brought back to analyze the effects of the lunar environment, and the original remote analyses of the rocks and the site could be checked against reality. The unfavorable Lunar Orbiter screening evaluation of the Surveyor 3 site was ignored despite MSC's obsessive concern for safety. Owen Maynard of MSC, always a leading Apollo planner and an ASSB member, claimed that MSC was not ready to land at any relocated site but could accommodate the Surveyor 3 site. Jack Sevier, GLEP's longtime companion at site-selection discussions, was another who favored it. Lou Wade of MSC's Mapping Sciences Branch liked it because an orbiting command module passing over it could easily obtain *bootstrap* photography (obtained by Apollos for Apollos) of the Fra Mauro and Davy sites that were being considered for Apollos 13 and 15. By the time of an ASSB meeting on 10 July 1969, NASA Headquarters had approved consideration of the Surveyor 3 site for the second landing. The main reason lies in the following fateful though somewhat ambiguous line from the minutes of that meeting: "It was generally agreed that on the second mission we would not be ready to give up recycle and that either [ALS 3] or S-III [ALS 7] would be included as a prime target." Launch recycling was still a decisive factor in landing-site selection despite the decreasing concern about it and the astronauts' objections to having to train for backup sites. ALS 5 was available if a launch to the Surveyor 3 site had to be recycled. Unfortunately, there were no backup sites west of the Surveyor 1 site, and the other Procellarum sites and Sinus Medii did not contain a Surveyor except the lost Surveyors 2 and 4.

The minutes of the ASSB meetings do not reveal the additional reason for ALS 7's acceptance that I recently learned from Farouk. One of the ASSB members, possibly General Phillips, said that there was no hope in hell of ever landing inside Copernicus because Congress would kill the Apollo program when the mission crashed. Farouk pointed to the Copernicus ray that passes through the Surveyor 3 site as another way of sampling Copernicus material and thereby determining the crater's age and its target material's composition. Masursky, having presented the case for one of the western Procellarum sites, now jumped up and enthusiastically supported Farouk. Farouk did not know that others of us in the Rump GLEP thought the mare units at Surveyor 3 were older and less distinctive than the more westerly units. The communication channels among everybody involved were wide open in those days and we were all at hair-trigger readiness to answer any call to action. I am afraid that the intervening 20 years have erased the tracks of exactly how this misunderstanding arose.

ALS 7 was confirmed as the Apollo 12 landing site when all went well with Apollo 11, and it was announced as such during the general elation shortly after Armstrong, Aldrin, and Collins returned to Earth. I was in Germany and did not know the results of the dealings. When I heard the site number announced, I thought there must have been some mistake in the transmission. But it was true. Achieving a point landing had become more crucial than ever because of Apollo 11's substantial miss of its landing point.[12] The presence of a Surveyor, the availability of the more westerly backups, and the Copernicus ray had sealed the deal.[13]

Conrad and Bean would be the first crew to do more than land, grab some rocks and pictures, and return. Thus they received more mission-specific training than the Apollo 11 crew, though much less than later crews would get. They simulated their lunar fieldwork on such appropriate grounds as an artificial crater field near Flagstaff (Cinder Lake) and the diverse volcanic terrain of Hawaii, and were briefed repeatedly by Gordon Swann, Al Chidester, and Thor Karlstrom of the field geology team. By all reports they seemed interested in the geologic aspects of their mission.

On 8 September 1969 the stage was set for the encore as Apollo 12's Saturn 5 inched on the crawler to Launch Complex 39A and as the designer of the launch complex and director of launch operations, Rocco Petrone, prepared to replace General Phillips as Apollo program director. George Mueller was also planning to leave NASA, as were scientists Wilmot Hess, Elbert King, and Don Wise.[14] A different cast was assembling for the next act, if there was going to be one.

AT THE SNOWMAN

The target of Apollo 12 was known as the Ocean of Storms to the astronauts and MSC, who preferred the English names of lunar features. The scientists called it Oceanus Procellarum. Whatever the language, the name seems to have influenced the launch conditions on Earth; at 1622 GMT (11:22 A.M. EST) on 14 November 1969, Apollo 12 took off in a thunderstorm and was struck by lightning twice in the first minute of its ascent. The Saturn 5 stack and its trail of ionized exhaust gases had acted like a giant lightning rod. After some anxious moments, flight director Gerald Griffen gave Apollo 12 clearance to continue.[15]

Apollo 12 included some impressive technological advances.[16] Its trajectory was a hybrid that began with free return until the CSM extracted the LM during translunar coast, and then continued in a nonreturn trajectory correctable by the LM engine even if the CSM engine malfunctioned (stay tuned for chapter 13). After the LM separated from the CSM in lunar orbit, precise tracking and descent-engine burns placed it right on target. When the LM pitched over so Conrad could see the target, he saw that he was heading right for the familiar crater configuration of five 50–200 m craters called the Snowman. He flew the LM around like a helicopter over the 200-m Surveyor crater, the Snowman's body, to find a smooth landing spot, and landed in a cloud of dust at 0654 GMT on 19 November 1969. Conrad and Bean could not locate themselves accurately by looking out the LM windows, but about four hours after the landing Dick Gordon spotted the shadow of the LM with his sextant from the command module *Yankee Clipper* (Conrad was one of the few Northeasterners among the astronauts).

Upon stepping off the LM ladder, nine minutes short of five hours after landing, the short and witty Conrad delivered with a "Whoopie!" his preplanned statement, "Man, that may have been a small one for Neil, but that's a long one for me." A minute later he looked around, and there was the Surveyor within easy walking distance, only about 160 m from the LM. Any American, Russian, or anyone else who wasn't impressed should have been.

About 15 m from the LM Conrad collected the black-looking contingency sample with six scoop motions and such comments as "whee" and "oops" and stowed it aboard the LM. Then Bean emerged. Unfortunately, one of his first acts was to point the color television camera at the Sun, ruining it and losing the TV audience back home. But they would have moved out of TV range anyway, and for scientific purposes we have a permanent record in the form of hundreds of frames taken with 70-mm film by the specially designed Hasselblad cameras used on all missions. Many other frames were shot with a 16-mm movie (officially, "sequence") camera that could be exposed frame by frame and was used during flight and from the LM windows on the ground. One Hasselblad skipped some pictures, though, and one magazine of "undocking and couple other mundane things" (Conrad's description) was accidentally left on the Moon.

The next and longest part of this first EVA was devoted to erecting the ALSEP, which Bean carried 130 m from the LM's dangerous takeoff rocket in two packages balanced at the ends of a carrying pole like the weights of a barbell.[17] Scientists laid great importance on the ALSEP for Apollo 12 and subsequent missions. The only instruments set up by Apollo 11 had been the passive seismometer, the Swiss solar wind collector, and the LR^3; and the seismometer lost its radio link with Earth after only 21 days. The ALSEPs consisted of a central station connected to a variable number and type of instruments (five on Apollo 12) by a radial starburst of cables. The central station integrated the signals from each instrument and transmitted them in computerese back to Earth. Everything except international-orange instructions was painted white to reflect the fierce unblocked sunlight. But during the long lunar night there would be no Sun to power the ALSEP, so it carried its own power source—a highly radioactive generator fueled by plutonium, which was hot enough to melt a spacesuit but which the astronauts nevertheless had to carry with the barbell and deploy.[18] The connecting cables were supposed to lie flat so as not to be tripped over, a dreaded possibility that happened anyway on Apollo 16.

Every last detail of the ALSEP had been thought about and tinkered with in the four years since the Falmouth summer study where its basic objectives had been sketched out. The scientist-experimenters had their long wish list, and the geo-scientists and sky scientists each made their claims. They constantly had to make deals with the engineers, who were always trying to carve off another few ounces of weight and figure out how to stow the thing in the LM and unload it again on the Moon. The astronauts spent long hours practicing its deployment. In the middle of the fray were the "human-factors engineers," whose elaborate efforts to make the ALSEP and the hand tools easy to use were described trenchantly and with relish at the time by Henry Cooper.[19] The human-factors engineers came up with the barbell, a "universal handling tool" to compensate for the astronauts' inability to bend over, and detailed time lines for the dangerous job of loading the fuel into the radioisotope thermoelectric generator and the intricate job of deploying the ALSEP—the details of which the astronauts could accept or ignore as they saw fit when they got to the Snowman crater cluster. The engineers invented and redesigned everything from the wheel to the bolt many times over and were stopped by only one tool, the geologic hammer. After many attempts to do something to this simple but highly versatile device, such as setting the head and handle out of line, the one the astronauts took to the Moon looks pretty much like the one you can buy in any hardware store.[20] Versatile indeed; Bean used it on the Moon to try to fix the TV camera and today uses it to create texture in his paintings of lunar scenes.

The main function of the ALSEP was to study the Moon's interior, so it included a seismometer. The Apollo 12 seismometer was passive; that is, it did not initiate moonquakes but just sat there on a stool under its insulating Mylar blanket waiting for them to happen. Just as the boundaries between Earth's crust, mantle, and core had been detected by the way they affect waves from earthquakes, so similar boundaries would be detected on the Moon—if it had any, and if it had any moonquakes.

The method for probing the interior employed by the other Apollo 12 ALSEP geoscience instrument was a little more indirect. Geophysicists at the NASA Ames Research Center, including longtime lunar investigator Charles Sonett, developed a three-arm magnetometer to measure three vector components of the Moon's magnetic field. Planets that have any magnetic field at all have a nearly steady part originating in their interiors and a fluctuating part caused by electromagnetic waves from the Sun. The experimenters planned to compare the surface measurements of both kinds of field with those obtained from orbiting spacecraft, especially Explorer 35, a lunar sky science mission also run by Ames that was launched into a high lunar orbit (800 by 7,700 km) in July 1967 and continued to return data until February 1972. Mainly what the geophysicists wanted to learn from the magnetism was whether the Moon has an iron core, at that time widely presumed to be the most likely source of any magnetic field. Luna 2, Luna 10, and Explorer 35 had all suggested that the Moon today has no overall dipole field like the one that affects compasses on Earth. However, the Apollo 11 samples showed something peculiar: a record of a substantial past field or fields in the form of a permanent natural magnetism of some of the rock samples — a *remanent* magnetism (not that this finding influenced the choice of instruments for the Apollo 12 ALSEP). Also, the difference in the fluctuating field on the surface and in space would provide a measure of the Moon's electrical properties, from which, the experimenters claimed, they could measure the Moon's temperature.

The other three instruments that unfolded expansively when they emerged from the deceptively small carrying boxes were devoted to sky science. First was a solar wind spectrometer from JPL, which did not analyze the solar wind's composition — the Swiss flag did that — but only its energy, density, direction of travel, and fluctuations. The idea was to see if it was deflected or otherwise affected by interactions with the Moon, effects that Explorer 35 data suggested would be subtle if they existed at all. Second was a suprathermal ion detector, also called the lunar ionosphere detector, from Rice University. It was housed in a legged box 20 cm high that sat on a spiderweb-like screen that was supposed to compensate for any fearsome magnetic or electrical emanations from the Moon. Its purpose was to detect solar ionization of gases from a number of sources, including lunar volcanism, the LM exhaust, and the astronauts' life-support system. Attached to it by a cable was a small cold cathode gage from the University of Texas and MSC to measure the amount (not composition) of the natural lunar atmosphere and the atmosphere given off by the astronauts' life-support system. The life-support system proved to be much more gaseous than the Moon.

Rocky geoscience also got something out of the first EVA. Conrad had collected the contingency sample, which weighed 1.9 kg (on Earth) and included four rocks and a lot of soil fines. After the ALSEP was in place, both astronauts collected selected samples. *Selected* indicates a stage of care in collection one step up from the grab samples variously called contingency (taken immediately during the first EVA), bulk (the Apollo 11 term), or desperation (the unofficial term). Conrad and Bean "selected" one sample near the largest accessible crater, the 400-m Middle Crescent (not part of the Snowman), and another at one of two peculiar mounds north of the 140-m Head crater. They inferred, probably correctly, that the mounds consist of ejecta from a crater. The selected samples added almost 15 kg to Apollo 12's running total. At the end of the four-hour EVA, near the LM, the astronauts also collected a core tube sample. Such samples were a legacy of the late Hoover Mackin, whose involvement in planning lunar geologic fieldwork had begun before the 1965 Falmouth conference and continued until his death in August 1968. The Falmouth report had included Mackin's recommended inclusion of tubes that could be driven or augured into the soil, could retain samples even of loose material, and could be attached end to end. These "Hoov Tubes" were 46 cm long and could be doubled or tripled in length if they could be pounded in that far. Apollo 11 had returned two single-core samples, and Apollo 12 eventually got two singles and one double.

The plan for the second EVA, called the geology traverse, was reviewed and updated while Conrad and Bean were in the LM between EVAs. During a weekend review session at the Cape with Swann, Chidester, and Karlstrom before the launch, the crew had requested that names and colors be added to the site maps they would carry along. This was done at the last minute, and the maps were smuggled on board four days before launch, to the annoyance of rival MSC geologists. Not knowing in advance the exact landing point, the geology team had plotted four sets of possible traverses to reach desired stations. Now that the landing point was known, they simply adjusted the traverse to reach the same stations.

Scientists and engineers in "back rooms" carefully watched everything that went on during all missions. A room in the Mapping Sciences building contained Farouk El-Baz, Hal Masursky, and various other orbital scientists like John Dietrich of MSC and Ewen Whitaker of LPL at various times, Wilhelms having bugged out after Apollo 10 because of my dislike for mission operations. The field geology team occupied a science-support room in the Mission Control building and were available to offer suggestions to the crews. Other back rooms monitored the launch vehicle (after Marshall in Huntsville handed it off), the CSM, the LM, the life-support systems, and so forth. At one time Eugene Shoemaker had wanted himself or other geologists to direct astronauts' activities in detail while watching their activities by television, but no mission was run this way. All back-room denizens passed their questions or comments to an experiments officer, who passed them on to the capcom, who passed them on to the astronauts. Only astronauts could speak to astronauts, reminding one of the Lodges, Cabots, and God in Boston. Capcom Edward Gibson, a Caltech Ph.D.

in engineering, passed on the geologists' thoughts in pleasingly geological terminology during the Apollo 12 EVAS. Conrad and Bean enthusiastically welcomed the instruction to roll a rock down a crater wall to test the ALSEP seismometer, remarking that they had been well trained for that sort of thing on their geology field trips. Bench and Sharp craters were to be the main sampling sites. Trenching with the hope of sampling the Copernicus ray was also planned.

The second EVA began 16 1/2 hours after the first and had as its main purpose the collection of the documented sample. Apollo 11 had little time for documentation, a type of lunar fieldwork that had long been planned and would characterize all future missions. Photographs were supposed to be taken of each rock before it was picked up and of its former resting place after it had been picked up. A gnomon was set in the field of view for scale, local vertical, and orientation relative to the Sun. The samples were identified by being placed in prenumbered Teflon bags (13 in the case of Apollo 12) or identifiable tote bags that might also carry other miscellaneous things. This procedure was the product of years of meditation about how to exploit these fleeting visits. The documented sample needed enough data for the reconstruction of the site's geology in relative leisure back on Earth.

The documented sample added 17.6 kg of otherworldly material, including 21 rocks, a double-core tube, and two vacuum-sealed containers supposed to hold a gas sample and an environmental sample in which lunar material was sealed in with the Moon's own atmosphere. Now there was a grand total of 34.3 kg, only 12 kg more than Apollo 11 got, despite the two EVAS and almost four times longer on the surface; the takeoff weight was still limited. Apollo 12 also got more rocks but less fine soil than did Apollo 11, and returned pieces of the newly tanned Surveyor for assessment of the changes inflicted by the lunar environment in the 30 months it had been sitting there (it got dusty and irradiated but was not hit by primary microimpacts).[21] Last, Bean quickly fired off 15 frames for Gold's stereoscopic close-up camera. In his report Gold added the nice phrase "precision molding" to express the exactness with which the soil could reproduce a bootprint even at the detail seen by his cameras. He also expressed surprise that so many dust-free rocks were visible, then worked this observation into his dust-transport theory by suggesting that the transport mechanism was efficient enough to clean off the rocks.

The geologic voice transcript of the EVAS includes relatively little geologic commentary besides the necessary words describing the sampling activity. The astronauts' reserve resulted partly from their fear of misusing scientific terms. There had been a few minor misuses on Apollo 11, such as Buzz Aldrin's harmless mention of biotite. For this reason, and because of personality differences from Aldrin and Armstrong, Conrad and Bean intermixed such terms as "funny rock," "goody," and "jabber-do" with "microbreccia" and "secondary crater." They also used terms from their NASA mineralogy courses when they said they couldn't see rock colors and had to go by "texture, fracture, and luster" to distinguish rocks. They reported blocky, clotted, and powdery soft ejecta. They said they could see in shadows while on the surface but not while looking out the LM windows. They noted that in general the soil felt "queasy" when stepped on but held firm and was barely compressible, although it differed slightly in different places: soft near Sharp and inside other craters, firm near the LM, firmest near Halo and Surveyor craters. They understood the principles of geologic units and stratigraphy, and reported that these differences in footing were about the only clues to different units; few sharp contacts were discernible.

When they had time to do what Shoemaker thought humans should do on the Moon, they produced important results. The digging of a trench at Head crater was accompanied by the following conversation:

Bean:	Where Pete digs up — sure enough, right underneath the surface, you find some much lighter gray — boy, I don't exactly know what at this point, and you can look around now and see several places where we've walked. If the same thing's occurred, we never have seen this at all — boy, that's going to make a good picture, Pete. Never seen this at all on the area we were before. Hey, that looks nice.
Capcom:	Roger, Al. We copy that; you think it could be the Sun angle?
Bean:	Listen. No, not at all. This is definitely a change to a light gray as you go down, and the deeper Pete goes — he's down about 4 inches now — it still remains this light gray. This soil must be of a different makeup than that we were on outside the crater, because we have to —
Conrad:	Say, this is different than around the spacecraft, because we've kicked up all kinds of stuff around the spacecraft and it's all the same color.

So they were observing an unusual, distinctive layer of possible importance. Could this be the Copernicus ray visible on telescopic and orbital photographs? I am told that Aaron Waters in the geology back room thought so, jumping up and shouting, "That's it!" Later the astronauts found more light material when they kicked up the surface. In a few places they found light gray material on the surface. Here were observations best made by humans on the spot.

This second and last EVA lasted 10 minutes short of four hours and took the astronauts half a kilometer away from the LM over a traverse totaling 1,450 m. The time was limited by their backpack life-support systems, and they said they would have no problem moving and working longer if they had time; the most strain was on their hands, from carrying and manipulating tools. They were greatly inhibited by the inability to bend over, and this made the tools seem less ideal than they had seemed in training.

After leaving the surface and rendezvousing with and reentering the CSM, they jettisoned the ascent stage of the LM to perform a further scientific experiment. This expensive but now expended projectile struck the surface at a low angle 76 km east-southeast of the ALSEP at 1.67 km per second, in the range of natural secondary impacts, setting off reverberations that lasted almost an hour. The Earth would not respond this way to a single shock, and all sorts of explanations were offered at the time: long-lasting landslides, secondary impacts raining down from the impact, a cloud of propellant gases from the LM, or collapse of fine "fairy castle" surface material (this despite the firm footing at the Snowman), but most likely it was due to novel physical properties of the lunar crust. The experimenters hoped to resolve the issue by the impact of the Apollo 13 S-4B.

A high-priority item in orbit was the bootstrap photography.[22] High-resolution pictures were needed of the all-important Fra Mauro site, the target of Apollo 13. Before Conrad and Bean descended to the surface, the site was photographed at the same 7° Sun illumination that Apollo 13 would encounter on landing and then at higher Sun angles as the terminator moved inexorably westward. Other important photographic sites high on the list for future landings but previously not well photographed were Descartes and Davy Rille. A third item of interest was the high-floor "delta-rim" crater Lalande. And as was customary, the crew shot some oblique "targets of opportunity" partly for science but mainly for their beauty.

While Conrad and Bean were on the ground, Dick Gordon in the CSM had performed a multispectral experiment with a four-camera array that was supposed to extend to fine scale the considerable information that Earth-based remote sensing in different wavelengths can provide (recall Whitaker's color boundaries from the Ranger era). A few color differences were seen, but the experiment could not even pick out the contact between the mare and the terra. Nor were the orbital visual observations very helpful.[23] For example, several areas were seen that "seemed to indicate that the lunar surface has been involved in some volcanic action." The old days of selenology were still making themselves felt; the faithful Moon watchers back on Earth had seen another transient phenomenon in Alphonsus, but Gordon saw nothing unusual from his closer vantage point.

After the SPS sent the three astronauts on the transearth coast toward home, Conrad and Bean had time to reflect on what they had seen and to answer questions from the back room. During their 31 1/2 hours on the Moon, compared with 21 1/2 for Apollo 11, they perceived a warming of the surface color from gray to brownish because of the increasing elevation of the Sun. They thought that even a trained geologist would have trouble doing fieldwork on the Moon because all one could see was big rocks and little rocks scattered around on the regolith. Lunar bedrock was as hidden from view as in a densely vegetated area of Earth. Thus one should just collect different samples and document them, and not try to geologize. People back home on the ground could do that. At one point while still on the surface, Conrad had expressed this by saying, "They'll baloney about it all day long in the LRL. The name of the game is to get the business done." And as Bean expressed it:

> You know where we talked to Al Chidester and the guys, before we went, about the main objectives of the geology wasn't to go out and grab a few rocks and take some pictures, but to try to understand the morphology and the stratigraphy and what-have-you of the vicinity you were in. Look around and try to use your head along these lines. Well, I'll tell you, there was less than 10 times I stood in spots, including in the LM both times we were back in, and said "Okay now, Bean, . . . is it possible to look out there and try and determine where this came from, which is first, which is second and all that?" And except for deciding which craters looked newer than others, which we knew from ground observations, I was not able to see any special little clues like we were, for example, over Hawaii . . . [or] out at Meteor Crater.

Still, they made the good stratigraphic observation that Block crater had penetrated a thin cover of soil in Surveyor crater to reexcavate that crater's rocky wall. But the Moon is a hard place to do fieldwork, partly because "the whole area has been acted on by these meteoroids or something else" (Bean) and partly because the investigators were aliens who had to bring their environment with them and hurry home.

They tended to collect the unusual, as did most other crews. But by emphasizing the much greater effect Sun illumination has on color on the Moon than on Earth, they sounded a warning about trusting the eye to select similar and dissimilar rocks for collection. A rock that appears distinctive viewed from one angle might appear run-of-the-mill when viewed from another. Such reflections lead to the unanswered question of whether the Apollo collections are typical of their collection sites.

The sport of rock rolling continued to serve a scientific function during the transearth-coast debriefing. Could frequent rock rolling cause that peculiar long-lasting seismic signal? The astronauts' answer: Most rocks looked like they had not moved for a long, long time.

A DIFFERENT MARE (1970)

Yankee Clipper splashed down near Samoa on 24 November, and LSPET pounced on the samples the next day. The crew went into quarantine, and Robin Brett went in with them for the last 12 days after one of the gloves with which he was handling rocks in the LRL sprang a leak. Fortunately, if the convicts got tired of watching the cockroaches crawl in and out under the airtight biological barrier, they could go outside for a breath of fresh air through the trailer that was pulled up behind the quarantined rooms.

Unfortunately, no USGS professional paper or other complete, corrected summary of the mission was ever published. Shoemaker had turned much of his attention to his chairmanship of the Division of Geological Sciences at Caltech, which he had assumed in January 1969, and no one else picked up the task. At least USGS geology team members Bob Sutton and Gerry Schaber, both of whom had joined the Branch of Astrogeology in Flagstaff in 1965, pinpointed the original lunar location and orientation of the rock samples.[24] Robert Leeds Sutton (1929–1982) continued this vital documentation function for every Apollo mission and is universally credited with preserving a record of the geologic fieldwork on the Moon that could not otherwise have been reconstructed.

Some of the results of the analyses were available for presentation at the first Rock Fest in January 1970, although a number of these preliminary results unsurprisingly proved erroneous. A diverse group of samples containing the same low abundance of volatile elements but less titanium than those from Apollo 11 appeared in the returned rock boxes and bags.[25] LSPET quickly noted that only 2 of the 34 rock-size samples (pieces larger than 4 cm across) were breccias, compared with about half of the Apollo 11 rocks. Shoemaker's geology team shrewdly attributed this large number of crystalline igneous rocks to their collection from the rims of the Snowman craters, which probably excavated solid bedrock from beneath the thin regolith at the site (1–3 m) and were too young to have accumulated much new regolith themselves.[26] Impact shock had consolidated parts of the thicker (up to 6 m) regolith at Tranquillity Base into rocklike breccias which, after ejection, had taken their place among the crystalline rocks on the regolith's surface. The fine material from Apollo 12 also showed other indications that the regolith here was less mature, including less glass and solar wind material. Gold, of course, denied the presence of bedrock at shallow depth.[27]

The crystalline rocks are mare basalts — as Conrad and Bean realized while still on the Moon — which are generally coarser and much more diverse in texture and mineral abundances than those collected by Apollo 11. As all geologists hoped, they are younger than those from Apollo 11, and in fact are the youngest mare basalts or Moon rocks of any type collected in abundance by any Apollo. The *Apollo 12 Preliminary Science Report* published in the middle of 1970 stated their age as 1.7–2.7 aeons, although later analyses showed that it is actually 3.2 aeons. In accord with this relative youth, the general region of the landing site has a lower density of craters larger than a few hundred meters than does the Apollo 11 mare—one and a half to three times fewer. As most of the Rump GLEP feared, however, the absolute age of 3.2 aeons is hard to correlate exactly with the relative age of the mare because the stratigraphy at and near the landing site is complex. The Snowman and other clustered craters give an old appearance to the site, but most are too small to help in dating because they are within the steady-state size range in which as many old craters are obliterated as new ones are formed.

Another technique for dating lunar maria that became a centerpiece of USGS lunar stratigraphic analysis emerged in 1970 in time to help date the site. At Caltech Gene Shoemaker had nurtured a number of geniuses destined to help take planetary geology into a new and more sophisticated era in the 1970s and 1980s. Among these was Laurence Albert Soderblom (b. 1944), who considers himself a geophysicist but who can do anything, including administer anarchistic USGS branches (he was astrogeology branch chief between 1979 and 1983). Shoemaker suggested that Larry develop a rapid technique for dating single lunar craters based on quantification of Newell Trask's classification scheme. In 1970 Larry completed his Ph.D. dissertation on the subject, published a summary as a journal paper, and joined the Branch of Astrogeologic Studies in Flagstaff.[28] Shortly afterward he collaborated with another Caltech student in elaborating on the idea, which depends on determining the erosion of crater slopes, and applying it to two color and compositional units at the Apollo 12 site.[29] Over the next half decade the method was applied systematically by an even earlier young hire, Joseph Michael Boyce (b. 1945), who entered on duty in Flagstaff in February 1969 as a lowly technician. The world of planetary geology knows Larry's technique as the D_L method and knows Joe even better as its current source of NASA funding. Joe departed Flagstaff for NASA Headquarters in 1977, slimmed down, replaced his Arizona grubbies with good three-piece suits, and served at first as deputy to Steve Dwornik from the Surveyor program office. Joe displayed an unexpected taste for life near the Potomac and now runs the Planetary Geology and Geophysics Program for NASA. He illustrates very well an old Survey adage, "Be nice to your field assistant because someday he may be your boss." I hope I was nice to Joe; he certainly has been nice to me. I am sorry I cannot devote more space to him and Larry, but they are too young to fit into this narrative of the first round of lunar exploration.

For the Apollo 12 site the bottom line is that its basalts are younger than those from Tranquillity Base by an ample half aeon — 500 million years. Thus ended once and for all the speculations that all lunar maria are the product of a single event. They were not the simultaneous product of an impact, as Urey thought. They did not all spread out over the Moon from the Imbrium impact, as Gilbert and Baldwin originally thought; nor were they "released" by Imbrium, as Kuiper thought. They were not melted and sucked out of the interior when the Moon was captured by the Earth, as a number of catastrophe-minded scientists and amateurs have imagined. They formed piecemeal over hundreds of millions of years when small pockets in the interior built up heat to the point of melting part of the Moon's mantle. So the Moon was really neither cold nor hot while the maria were being created. Its interior was hot in spots but lukewarm overall. The diversity in compositions of the basalts also shows that the Moon's interior is not uniform in composition but is intricately structured like all other well-known bodies of rock.[30]

The light gray, 450-g trench sample (12033) may have provided a date that everyone wanted to know, the age of Copernicus. Three geochronologic methods give about the same result, averaging about 810 million years.[31] Many lunar scientists, including me, hope very much that this date is correct. We need it desperately to get any sort of handle on the times of events in the last three aeons of lunar history. The relatively old absolute age and uncertain relative age of the Apollo 12 basalts are better than nothing, but they are of little help in dating craters and other geologic units that formed during the vast span of time that has elapsed since those lavas first saw the light of day.

No human exploration of a small spot on the Moon could fail to reap a scientific harvest, and Apollo 12 did indeed reap one. But consider the harvest if it had gone to Surveyor 1 in the Flamsteed ring. Instead of an absolute age obtained from amidst a patchwork of mare units "about" at the Imbrian-Eratosthenian boundary we would have had one squarely in the Eratosthenian that could have been correlated by good crater counts with extensive flows all over the maria. The young half of lunar history would be much better understood. The volume of basalt extruded before and after the Flamsteed mare could have been determined, so much of the guesswork about the duration of lunar volcanism would have been removed. The composition of the returned basalts could have been matched without question with a telescopic spectral class, although admittedly a "blue" class not very different from that of the Apollo 11 mare. Pieces of a Surveyor exposed to space for 41 months instead of 30 would have been returned. The age of Copernicus could not have been estimated, but the present estimate is uncertain anyway; and if the ray samples had not been collected there might have been a landing in Copernicus (see chapters 15 and 16).

The ALSEP would have been spaced farther from the next one (Apollo 14's), giving a better spread for the seismic network and the farthest-west station on the Moon. Frustrating to me is that the backup requirement disappeared when NASA realized they could either launch a day early and wait in lunar orbit or land a day late and tolerate a higher Sun angle. If only they had worked this out a little sooner. . . .

So I think that one of the six precious opportunities to explore the Moon in person, while not really wasted, was not exploited to the utmost, either. Others have said the same for one reason or another about each of the later landing missions that *did* go where GLEP recommended. The complaint about the next one, however, does not concern the choice of the ultimate landing site: Apollo was to be released from the maria to explore the most important geologic building block of the near side of the Moon.