VII. Apollo 12 through Apollo 17

There was little time to project what we learned from Apollo 11 into planning for Apollo 12. For the next three years, a lunar mission would be carried out every six months. The scientific community would have preferred to slow down the rate of the missions in order to have time to digest the data from one mission before samples arrived from the next. Costs, however, dictated that the launches be separated by only a few months.

Apollo 12, with Conrad, Bean, and Gordon, was launched on November 14 and landed on the Moon at a near equatorial site on the relatively young basalts of the Ocean of Storms. The exact landing was within 200 yards of the Surveyor 3 spacecraft, which had landed there in April 1967 and was the nominal target point. Building on lessons learned from Apollo 11, the Apollo 12 crew stayed on the lunar surface much longer and performed a more complex mission. Conrad and Bean made two traverses, collected several drive tube samples, dug and sampled two shallow trenches, photographed 23 panoramas, described several craters, and collected about 34 kilograms of samples, many of which were documented. In addition, they deployed a more sophisticated instrument array, including another passive seismometer and a magnetometer. Samples of the Surveyor 3 spacecraft were collected both for engineering and scientific purposes. The mission was an outstanding success. The second batch of lunar samples was on its way back to Earth weeks before detailed results from Apollo 11 were complete.

The first Lunar Science Conference was held in Houston on January 5–8, 1970. Each principal investigator was required to have a paper ready for publication at the beginning of the conference. The papers were turned in to editorial staff who were prepared to handle the publication of the results with record speed. Also, each principal investigator was required to present his or her major results in a brief oral presentation. It had been agreed that no investigator would release information about his results until this conference. Everyone would hear the results at the same time. It was the most excitement-filled scientific conference I have ever attended! Each day we learned new things and tried to fit new data into each of our personal concepts of the Moon. The results were published in a single issue of *Science*.[26]

Our laboratory at the University of Houston had done its work also, and we had one observation we believed was significant. Among the small rock fragments in the lunar soil, we found fragments of anorthosite, a generally light-colored rock composed almost entirely of calcium-rich plagioclase feldspar. We noted that this rock type was not represented among the larger rocks collected at Tranquility Base and speculated the anorthosite fragments might be broken pieces from the nearby lunar highlands. We found at the conference that three other laboratories had made the same obser-

[26]*Science*, vol. 167, no. 3918 (30 January 1970), 417–792.

vation. In addition, we concluded, "None of the glass yet examined is similar to tektite glass. This observation tends to reinforce strongly the previous conclusions of many workers that tektites do not originate from the Moon." Based on preliminary data from the Apollo 12 samples, our conclusion was challenged almost immediately.[27] I tried to ignore the paper, went on vacation, and hoped someone else would refute it. But alas, when I returned from vacation I had to write a rebuttal.[28] I consider it lucky that although our discussions of tektites, both face-to-face and in print, have been passionate, O'Keefe and I have remained good friends throughout our disagreements.

I was no longer a member of the PET. My new obligations with the university did not allow time for such work, and my ex-big boss at NASA probably would not have permitted it. I still lived in the NASA area and frequently saw many of my old friends.

During the Apollo 12 preliminary examination, a break in the biological barrier occurred in the area where the preliminary mineralogy, petrology, and geochemistry were being done. I heard the news report while driving home down the Gulf Freeway. The report listed the scientists who had been quarantined. Frondel was on the list. I pulled off the freeway, stopped at a liquor store, and bought two fifths of Canadian Club and some 7-Up, Frondel's favorite libation. I drove straight to the LRL and approached the autoclave where materials could be passed in and out of the Crew Reception Area. A technician and a guard were on duty. I knew them both. I told them I had a bag to be passed in to Professor Frondel. "What is it?" they asked. "Personal effects," I said. The technician winked his eye, and the goods were logged in as a "care" package. I later found out that another member of PET, Ross Taylor, an Australian geochemist, had hidden in the potentially contaminated area to avoid quarantine. Frondel admitted, after the fact, that being

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[27] J. A. O'Keefe, "Tektite Glass in Apollo 12 Sample," *Science*, vol. 168 (1970), 1209–1210.

[28] E. A. King, R. Martin, and W. Nance, "Tektite Glass NOT in Apollo 12 Sample," *Science*, vol. 170 (1971), 199–200.

quarantined with the Apollo 12 crew had been a memorable time and not at all unpleasant.

The basalts from Apollo 12 proved to be a little younger than the rocks from Tranquility Base, averaging about 3.3 billion years. Also, the rocks contained less ilmenite and thereby had lower titanium contents.

The launch of Apollo 13 on April 11, 1970, signaled the start of a lunar mission that nearly ended in disaster. An explosion in a fuel cell on board the Service Module seriously crippled the life support systems of the spacecraft en route to the Moon. The crew had to travel outbound around the Moon and head back to Earth. The condition of the cabin atmosphere was critical. With carbon dioxide building up in the spacecraft atmosphere and little oxygen left, only superb engineering analyses on the ground and a crudely taped-together pair of lithium hydroxide canisters on board to absorb some of the carbon dioxide from the cabin atmosphere would enable Lovell, Swigert, and Haise to make it back alive. It was a very close call.

When the Apollo 14 crew was announced on August 6, 1969, almost everyone expected Gordon Cooper to be named mission commander. Instead, Shepard was picked for the mission commander assignment. Shepard had never been a member of an Apollo back-up crew, as was customary for previous prime crew members. Cooper resigned from NASA less than a year later.

I asked my dean at the University of Houston for funds to host a cocktail party and reception for the lunar sample investigators at the Apollo 12 Lunar Science Conference. He agreed. We held the affair in the Rice Hotel in downtown Houston. It was a huge success, attended by the mayor of Houston and a number of other academic and political dignitaries. One noteworthy attendee was Russian academician A. P. Vinogradov, who was accompanied by an interpreter. Vinogradov had been invited to present a report on the preliminary results from the highly successful unmanned Luna 16 mission. Luna 16 brought back 101 grams of sample from Mare Fecunditatis (Figure 1, page 25) in September 1970. Vinogradov made an interesting presentation at the conference and was a charming guest. We noted that both Vinogradov and his interpreter drank only orange juice, contrary to Russian tradition. We later heard that the interpreter was missing and was presumed to have defected, at least temporarily, but I never found out.

The next Apollo lunar landing occurred on the Fra Mauro Formation approximately 181 kilometers from the Apollo 12 landing site. Ed Mitchell manned the LM, together with Al Shepard, and Stu Roosa was the CSM pilot. From lunar orbital imagery, the Fra Mauro Formation was interpreted to be ejecta from the huge Imbrian Basin; therefore, it was believed to contain much older rocks than the Apollo 11 or Apollo 12 landing sites. The possibility existed of collecting some rocks from deep within the Moon that had been excavated by the Imbrian impact. This was a rougher landing site, but NASA felt confident it was a suitable site from an operational standpoint.

The crew of Shepard and Mitchell made two long traverses from the LM, one of these approximately a kilometer away to the rim deposits of Cone Crater. They were aided by a new rickshaw-like device called the modularized equipment transporter (MET), which could be used to carry samples and collection equipment. They collected approximately 43 kilograms of samples, deployed a complex suite of lunar surface experiments, conducted active surface experiments, and made numerous observations. In addition, Roosa photographed surface features of interest from lunar orbit, including the candidate Apollo 16 landing site. Many of the surface samples were well-documented and were included within the numerous surface photographs. Shepard made his famous lunar golf shot, which prompted a variety of reactions. The samples proved to be quite different from the previously collected mare samples. Most of the large samples were breccias. Only two of the rocks greater than 50 grams in weight were crystalline igneous rocks, and a big dispute arose that one of these, rock 14310, might be crystallized impact melt rather than a standard, garden-variety igneous rock.

Compositions of the rocks were distinctly different from the basalts of Apollo 11 and Apollo 12, containing less titanium, more alumina, and less iron, on the average. Their crystallization ages averaged about 3.9 billion years, the probable age of the Imbrian event. Included in the Apollo 14 breccias were nearly spherical objects with textures that looked very much like meteoritic chondrules, except that they were of lunar origin.[29] These lunar chondrules were abundant in some samples. Together with my co-workers, I quickly prepared a paper for publication on this finding and sent it off to a major journal.

Urey was again visiting the Lunar and Planetary Institute, so while the paper was "in press," I called and made an appointment to see him. I took a slide projector and some slides of the lunar chondrules. It seemed like a small courtesy to extend to a man who had spent much of his lifetime trying to understand complex scientific issues. Urey was fascinated. We reviewed each slide several times and discussed many matters related to chondrules. We wondered what the occurrence of lunar chondrules might mean, if anything, in terms of the origins of meteoritic chondrules. Our discussion still has not been fully resolved, though most researchers now agree that at least some meteoritic chondrules are produced by impact-related processes.

In the haste and physical exhaustion of the EVAs on Apollo 14, along with confusion over which rocks were in which weigh bags, the localities from which some of the large rocks were collected have not been positively established. However, a big lunar rock is a valuable resource even if its exact field context is unknown. It was the largest and most varied suite of rock samples returned from the Moon at that time.

The automated Russian spacecraft, Luna 20, landed on the Moon in Mare Fecunditatis in February 1972. This mission also was successful in returning a small sample from a locality about five degrees latitude north of the Luna 16 landing site.

[29]For example, see E. A. King, M. F. Carman, and J. C. Butler, "Chondrules in Apollo 14 Samples: Implications for the Origin of Chondritic Meteorities," *Science*, vol. 175 (1972), 59–60.

On April 28, 1971, NASA announced that the Interagency Committee would no longer require either crew or sample quarantine on future lunar missions. All test results in search of lunar pathogens had been negative. This announcement was welcome relief. The Service Module propulsion system had proven so reliable that NASA could relax the free return trajectory constraint, meaning the crews could visit sites at higher latitudes out of the bow-tie zone. Apollo 15 landed near Hadley Rille at a latitude of approximately 26 degrees north on July 30, 1971 (Figure 1, page 25). The prime objectives of this mission were to sample the rocks of the great Apennine Front, Hadley Rille, and the mare material of Palus Putredinis on the eastern edge of the Imbrian Basin. The Apennine Front was believed to contain ancient rocks uplifted by the Imbrian event. Hadley Rille was targeted for exploration in order to understand the disputed origin of the lunar sinuous rilles. The mare material was simply the smoothest place to land, but might offer basalts of different age or petrologic type. Mt. Hadley towered above the landing site by about four kilometers. All of the sampling objectives were within reach of the Lunar Roving Vehicle (LRV), which was first used on this mission (Photo 57). The LRV was carried to the

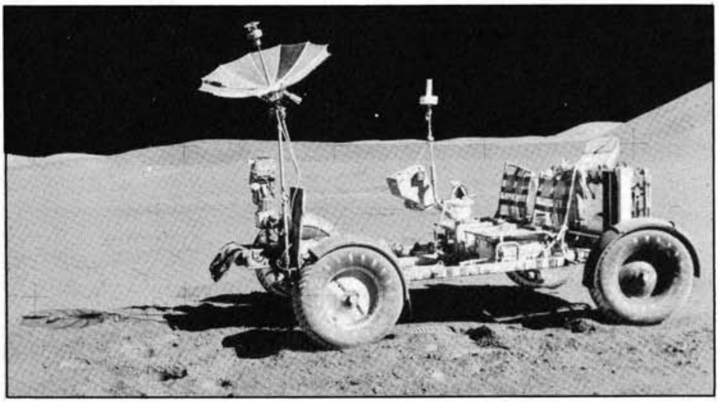

Photo 57. Portrait of the Lunar Roving Vehicle (LRV) at the Apollo 15 landing site, view looking north. The LRV carries communications, imaging, and sample collection equipment. (NASA photograph AS15-88-11901)

moon folded up in a portion of the LM descent stage. It weighed 462 pounds and could carry a payload of more than 1,000 pounds, including two astronauts. By terrestrial standards, the vehicle was a tired Jeep with a half gallon of gas, but this two-man, battery-powered vehicle with all its sampling, imaging, and communications gear made possible a much greater radius of surface exploration than was previously possible.

Scott and Irwin spent 18.5 hours of surface EVA. They collected 77 kilograms of samples, many of which were documented, deployed a complex experiments array, and took more than 1,150 photographs. An important part of the scientific data on this mission came from experiments on the orbiting CSM, piloted by Al Worden. In particular, the orbiting gamma-ray spectrometer and X-ray fluorescence experiment enabled us to extend compositional information from the rocks at the landing sites to much larger areas of the Moon.

The mare basalts from Apollo 15 proved to be almost uniform in composition, showing little range in magnesium, iron, and titanium values. The ages of the basalts were mostly around 3.3 billion years, while the ages of the Apennine Front materials tended to be about 3.9 billion years. Anorthosites were abundant in the Apennine Front samples. During a surface traverse, a peculiar green rock was noticed by the crew. This proved to be made of green glass spherules and fragments of probable volcanic origin. Green glass was a common component of the soil on the Apennine Front. Impact melt rocks also were common.

While returning to the LM to recharge his life support system, Scott said that he had a seat belt problem and stopped the LRV. A few minutes later he said it was okay and continued on. When asked about the supposed problem during the technical debriefing, Scott admitted he had noticed a rock he should collect and had used the seat belt story as an excuse to stop. Scott doubted that mission control would have allowed the stop at that point in the traverse. All in all, the Apollo 15 mission was one of the best. The crew collected a large and marvelously varied suite of rocks.

The Apollo 16 landing site (Figure 1, page 25) was selected because it was interpreted from photogeology to be composed predominantly of highlands volcanic units. This interpretation turned out to be false. Nonetheless, this was the only landing in classic lunar highlands and was of great interest for that reason alone. The Caley and Descartes Formations, which were prime exploration targets of this mission, proved to be impact-emplaced ejecta units. Shock metamorphosed materials and impact glasses were abundant in the samples. I had agreed to edit a proceedings volume from the third Lunar Science Conference,[30] but these Apollo 16 samples were already on their way back to Earth before the volume went to press.

The Apollo 16 crew performed very well. We were particularly proud of "Black Bart," a nickname earned by John Young for his favorite cowboy hat that he wore on geology field trips.

As the date for the Apollo 17 launch neared, I decided to go to the Cape for the event. It was the last lunar landing mission, the last big Apollo Saturn V configuration, a spectacular night launch, and Cernan and Schmitt would be LM crew. It all seemed to mean that I should be there. Before, I had always been too busy to get away to the Cape, but this time I was going to take the time. I couldn't find a motel room closer than Orlando, but I managed to get a confirmed rental car reservation. As the evening of December 7 approached, I stopped to get a bottle of champagne, some beer, and a big sandwich for later and drove to the Cape. I had a pass for the VIP viewing area, but the bleachers were full and didn't look very comfortable. I staked out a good-looking patch of grass and waited for "t=0" to arrive. The countdown went well in the early stages, and everyone was very upbeat. Many of the lunar sample principal investigators were there. We had a very pleasant visit, cracked jokes, and waited for the big rocket to go. There were a couple of "holds" near launch time, during which we drank all the beer and champagne. The big moment finally arrived, and the ignition and

[30] E. A. King, ed., Proceedings of the Third Lunar Science Conference, Vol. I, Mineralogy and Petrology, *Geochimica et Cosmochimica Acta, Supplement* 3 (1972).

lift-off were truly spectacular. Air pressure and sound waves from the rocket drowned out everything and buffeted us with energy. Although low clouds had hung above for most of the evening, the sky had few clouds at launch, and we could see the rocket at 85 miles down range. I could also see the first-stage cut-off and second-stage ignition. Cernan, Evans, and Schmitt were on their way to the Moon! I was on my way back to Orlando. The highway was like a big parking lot. It took four hours to get to my motel. I flew to Houston the next morning.

Apollo 17 landed in the Valley of Taurus-Littrow, approximately latitude 20 degrees and 10 minutes north and longitude 30 degrees and 46 minutes east (Figure 1, page 25). Cernan had done extremely well in the geology training course. Schmitt was a Harvard Ph.D., so it was not surprising that the mission was extremely productive scientifically. Five separate large-scale stratigraphic units were sampled, the crew made excellent surface observations, a large instrument array was deployed, and a huge suite of samples (approximately 110 kilograms) was collected during 22 hours of EVA on the lunar surface. The LRV worked very well, covering over 35 kilometers. As in previous missions, many photographs and special samples were taken, and the CSM also had a full suite of orbital experiments. At one stop, the crew recognized the now famous "orange soil," which proved to be glass of probable volcanic origin.

By now, seeing astronauts on the lunar surface had become commonplace. The major TV networks did not even offer live coverage of all the EVAs, but we had it in Houston. The local educational channel, whose facilities were on the University of Houston campus, arranged to cover the EVAs in real time. I acted as "science host" and described events to our viewers, interviewed various local NASA scientists and some principal investigators for lunar surface experiments, and gathered a panel of students who commented on various aspects of the mission. It was a lot of fun, and we received a number of favorable comments about our coverage, even though it wasn't as "slick" as national network coverage.

Suddenly, the flights of the Apollo program were over. NASA decided to cancel Apollo Missions 18, 19, and 20, even though hardware existed and plans had been made. The decision allowed NASA to commit the hardware to Earth-orbital flights that might lead to a new large-scale program.

Scientific work on the lunar samples continued in high gear for 10 years and, as a matter of fact, continues to this day, although at a slower rate. Some of the lunar surface experiments, such as the net of passive seismometers deployed by the Apollo missions, continued to function and provide valuable data long after the landings were over. The lunar seismic data told us the Moon has a small core that is partially molten. Scientific papers about the Moon, lunar samples, and other closely related topics from Apollo now fill a shelf of books about eight feet long! Apollo missions produced an information explosion about the Moon in particular and planetary science in general.[31] We had made six highly successful manned lunar landings and sample returns on one side, the visible face, of the Moon. We had achieved the goal set by President Kennedy, and no new major goals in manned planetary exploration had been established. The United States planned no further lunar exploration.

There is a mistaken idea that the cost of the Apollo missions should all be charged to science. This is simply not true. Many factors led to the decision to go to the Moon: development of advanced technologies, competition with the Russians, stimulation of the national economy, and diversion of attention from the Bay of Pigs fiasco. Science was barely mentioned in the fine print. We got a lot of scientific data from the Apollo program, but only through the immense efforts of a few individuals against a batallion of bureaucrats. If the chief emphasis of the Apollo program had been on science, the missions would have been performed rather differently.

[31]For example, see S. R. Taylor, "Planetary Science: A Lunar Perspective," *Lunar and Planetary Institute* (Houston, 1982). For detailed technical papers on lunar sample results, see the individual proceedings of the now numerous Lunar Science Conferences.