II

SPECIAL MEETING ON DIRECT EXPLORATION OF THE MOON

THE APOLLO MISSIONS

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Abstract. In successfully carrying out a manned lunar landing and return, with both operational and technological objectives, the Apollo program made possible a variety of significant scientific experiments. This important milestone in the continuing quest for knowledge took the eyes, hands, and mind of man, as well as his instruments, to a new world. The activities of highest priority carried out by the astronauts, once the landing had been successfully completed, were to collect lunar material and data, emplace sophisticated experiments, and record man's impressions and observations.

In the missions ahead, scientific exploration of the Moon will be the principal goal. Unique features and sites on the Moon will be visited. New experiments, both on the lunar surface and in lunar orbit, will be carried out, as we probe the Moon's past and attempt to unravel the early history of the Earth. In so doing, we will also be establishing and defining the possibilities and limitations of man as a space explorer as we extend his domain further in space.

My purpose is to provide a broad overview of the Apollo missions. I intend to discuss briefly the Apollo 11 and 12 lunar landings, the problems we experienced with Apollo 13, and some of our future plans. I will mention the major scientific results of these missions briefly since subsequent papers will discuss these results in much greater detail.

Last summer sufficient testing on Apollo hardware had been accomplished to provide us with the confidence to attempt man's first landing on the Moon. On July 16, 1969, Apollo 11 was launched from Cape Kennedy.

After checkout in earth orbit, Apollo 11 started on its translunar trajectory. The mission proceeded as planned and as Apollo 11 swung into orbit about the Moon one of the photographs the crew made on the lunar farside is the Crater Daedelis, shown in Figure 1.

In lunar orbit, the Lunar Module separated from the Command Module and descended to the lunar surface in the Sea of Tranquility. Astronauts Armstrong and Aldrin remained on the lunar surface for about 18 h. They were outside of the spacecraft for two hours.

After takeoff, the Lunar Module ascended again to lunar orbit for a rendezvous with the Command Module in which Astronaut Collins had remained. The astronauts returned safely to Earth and began their quarantine period about which I will speak later.

On November 14, 1969, Apollo 12 was launched on the second lunar landing mission. Again, success was obtained even though the spacecraft was struck by lightning shortly after takeoff. On this mission, it was important to learn how to make a very accurate landing so that later flights can explore sites more difficult from an operational point of view but also more interesting from a scientific point of view. For these, pinpoint accuracy will be required for a successful landing. Scientifically, it was desirable for Apollo 12 to land at a different mare than Apollo 11 so that we could

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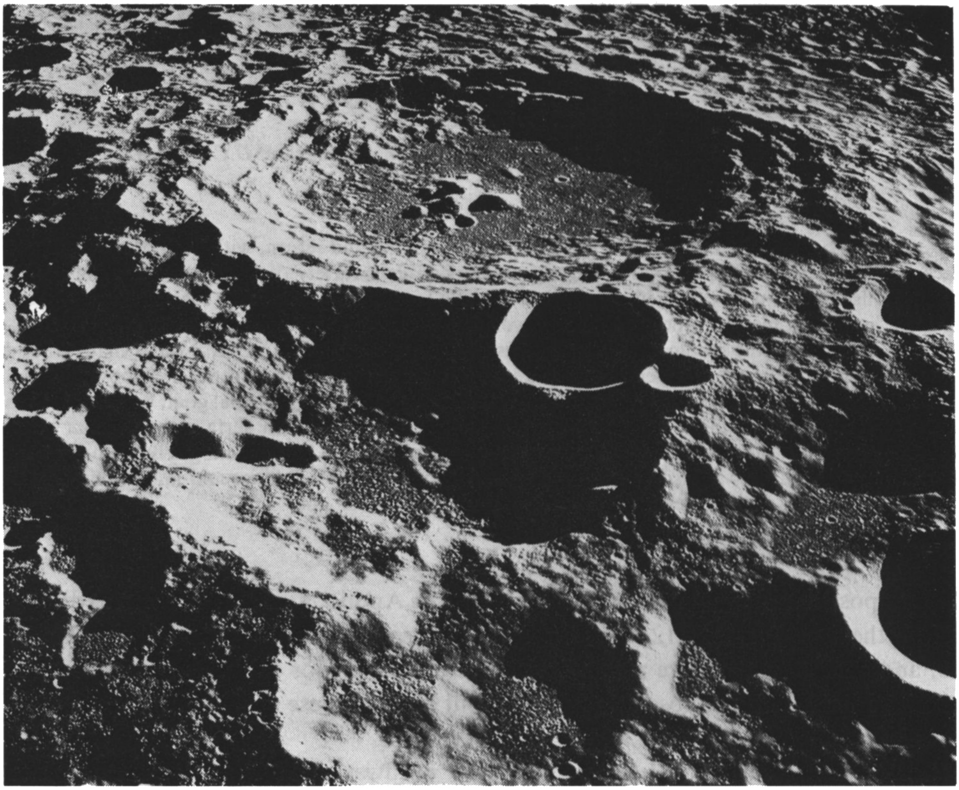

Fig. 1. Crater Daedelis.

determine the degree of similarity. With these two points in mind, we selected a site on the Ocean of Storms at which Surveyor 3 had landed in April 1967. We made changes in a number of procedures and computer programs to improve our landing point accuracy. The results are graphically portrayed by the photograph of Surveyor 3 made by the Apollo 12 crew (Figure 2). The crew inspected and photographed the Surveyor spacecraft in detail and removed and returned the camera, scoop, and other parts. These are still undergoing detailed analysis to determine the scientific and engineering changes that have occurred in the lunar environment during this precisely known period of time. Such data may be extremely important for future lunar work such as the establishment of permanent stations.

In April of this year, we were ready for Apollo 13. For this mission we selected a site in an upland region known as the Fra Mauro formation. This is thought to be material deposited when Mare Imbrium was formed, perhaps by impact of a smaller moon. In any event, it is distinctly different in appearance from the mare regions in which the previous landings have been made.

About 55 h into the mission, a muffled explosion was heard by the crew. The events that followed were almost catastrophic. It was immediately obvious that the lunar

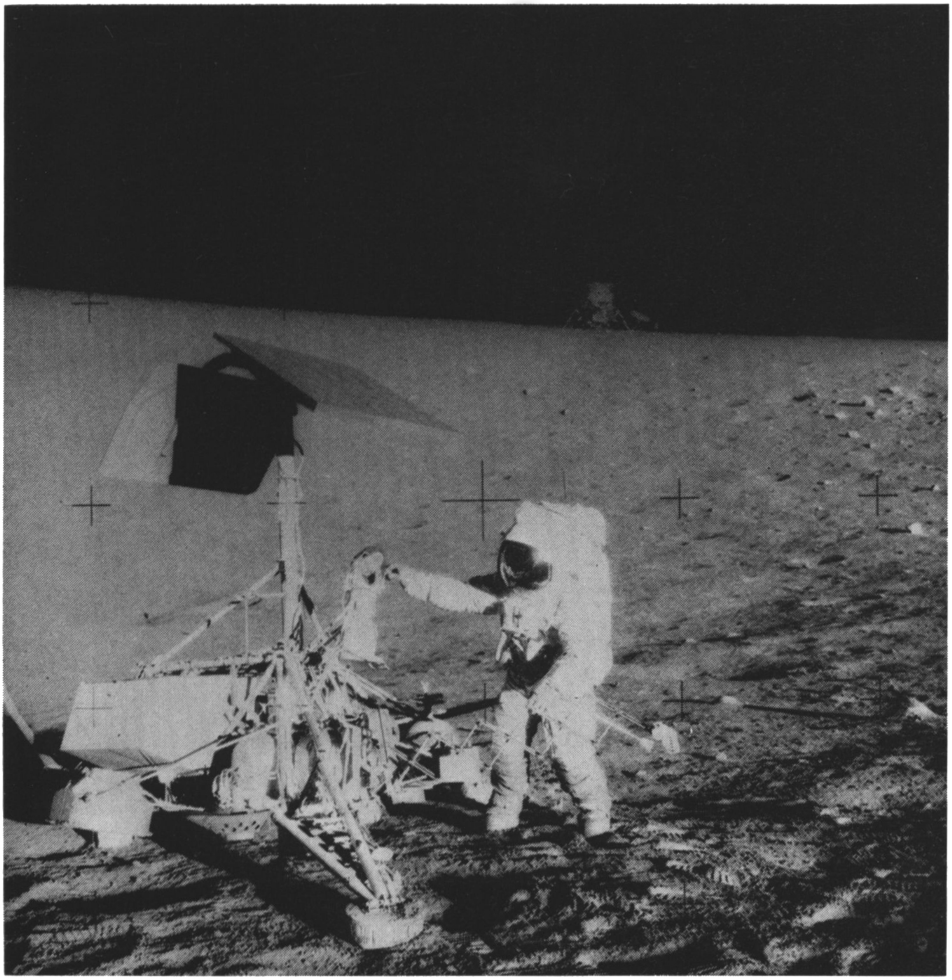

Fig. 2. Astronaut Conrad with Surveyor III

landing could not be attempted and all remaining efforts were devoted to returning the crew to Earth. It was only through outstanding work on the part of the crew, mission operations personnel, and a great many support people that the difficulties were overcome and the crew returned safely.

An extensive investigation was conducted to determine precisely what occurred. As the Lunar Module was separated from the Service Module approaching re-entry to Earth, the crew made the photograph in Figure 3. As can be seen, an entire panel is missing, and there is obvious damage to much of the equipment. The cause was the rupture of an oxygen tank. A short circuit occurred within the tank causing combustion of the teflon wire insulation. The pressure and temperature within the tank built up rapidly and the tank finally ruptured. This resulted in an explosive separation of the

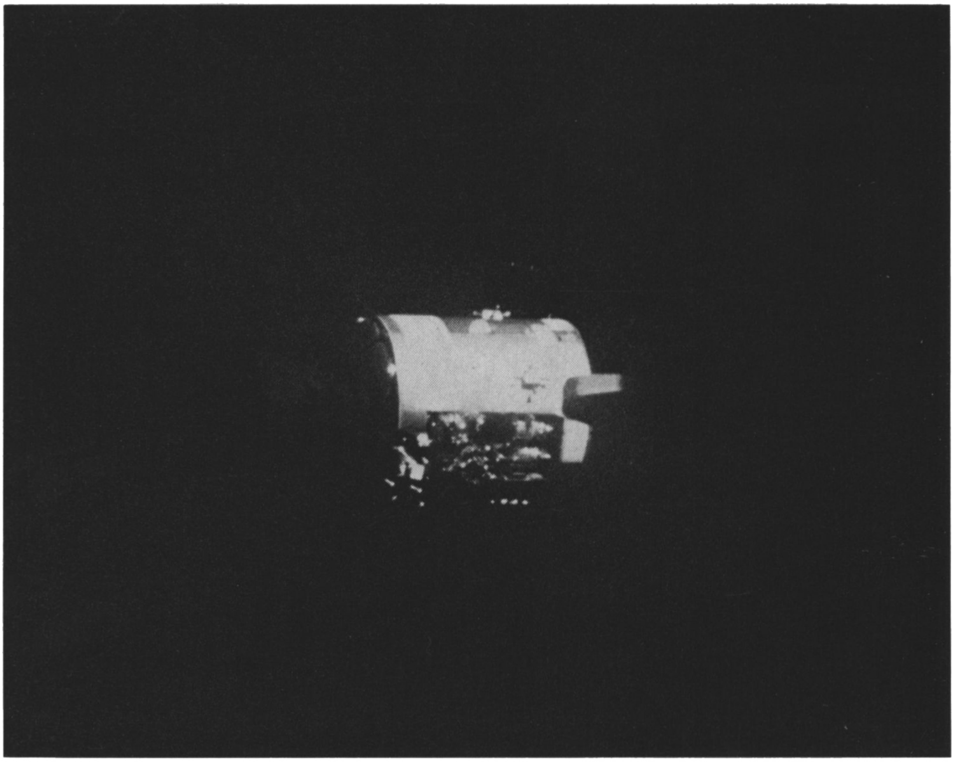

Fig. 3. Apollo 13 Service Module.

Service Module panel. Obviously, a number of corrective changes have been made for the succeeding missions.

I will turn now to a brief look at the science results of these missions. Astronauts Armstrong and Aldrin returned 20 kg of lunar material. In addition, they deployed several experiments on the surface, among which was a seismometer powered by solar cells. For 21 d this instrument provided information on man-made and natural seismic events. Furthermore, a laser reflector was deployed; it is an array of very precise corner reflectors from which laser beams from the Earth can be reflected to measure Earth-Moon distances with extreme precision. The ranging from the McDonald Observatory in Texas is obtaining a precision of about 15 cm. This improved knowledge of the changes in the lunar distance opens the possibility of increasing our knowledge of the Earth, the Moon, and the solar system in some very fundamental ways. It is important to note that this reflector – and we plan several others on later missions – is available for all scientists of the world to use. A third experiment on Apollo 11 is the solar wind composition collector. This is aluminum foil exposed to the Sun while the astronauts were on the surface, then returned and analyzed for trapped lighter elements of the solar wind. This is an experiment of Dr Johannes Geiss of Switzerland.

Fig. 4. Apollo 12 Science Station.

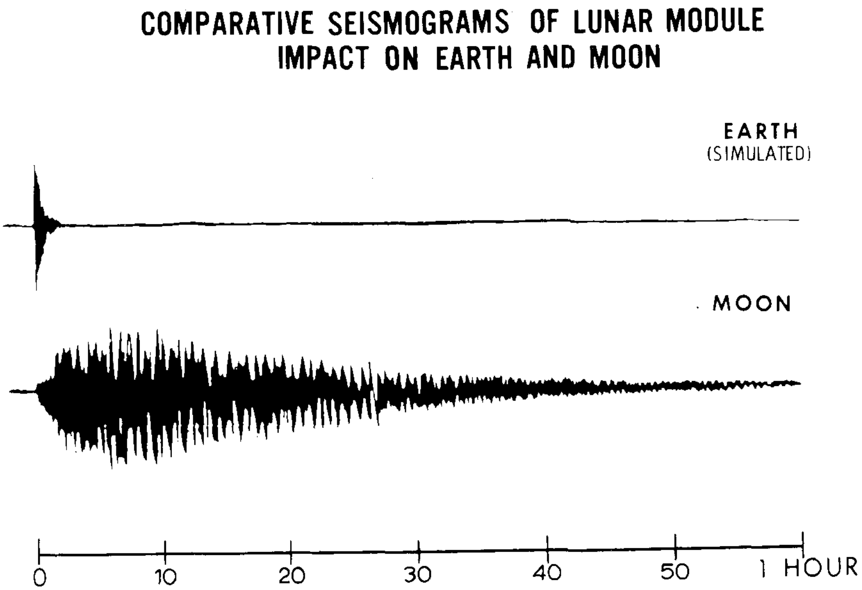

Fig. 5. LM Impact – Earth/Moon.

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For Apollo 12, a more complicated science station was carried (Figure 4). Instruments included a seismometer, a magnetometer, a solar wind spectrometer, an atmosphere detector, and an ion detector. The science station is powered by a nuclear generator. At this time, it is still functioning well after more than 9 m. In addition, another solar wind composition collector was deployed.

One of the intriguing scientific results is the seismic data. To better understand this

Fig. 6. Crater Tycho.

information, as well as for operational reasons, we deliberately impacted the Lunar Module of Apollo 12 after the crew left it. On the Apollo 13 mission, we deliberately impacted the spent third stage of the Saturn V rocket on the lunar surface.

The energy of the Lunar Module striking the Moon was equivalent to approximately one ton of TNT. Figure 5 compares the resultant seismic signals on the Earth and on the Moon from such an explosion. As can be seen, signals were received at the seismo-

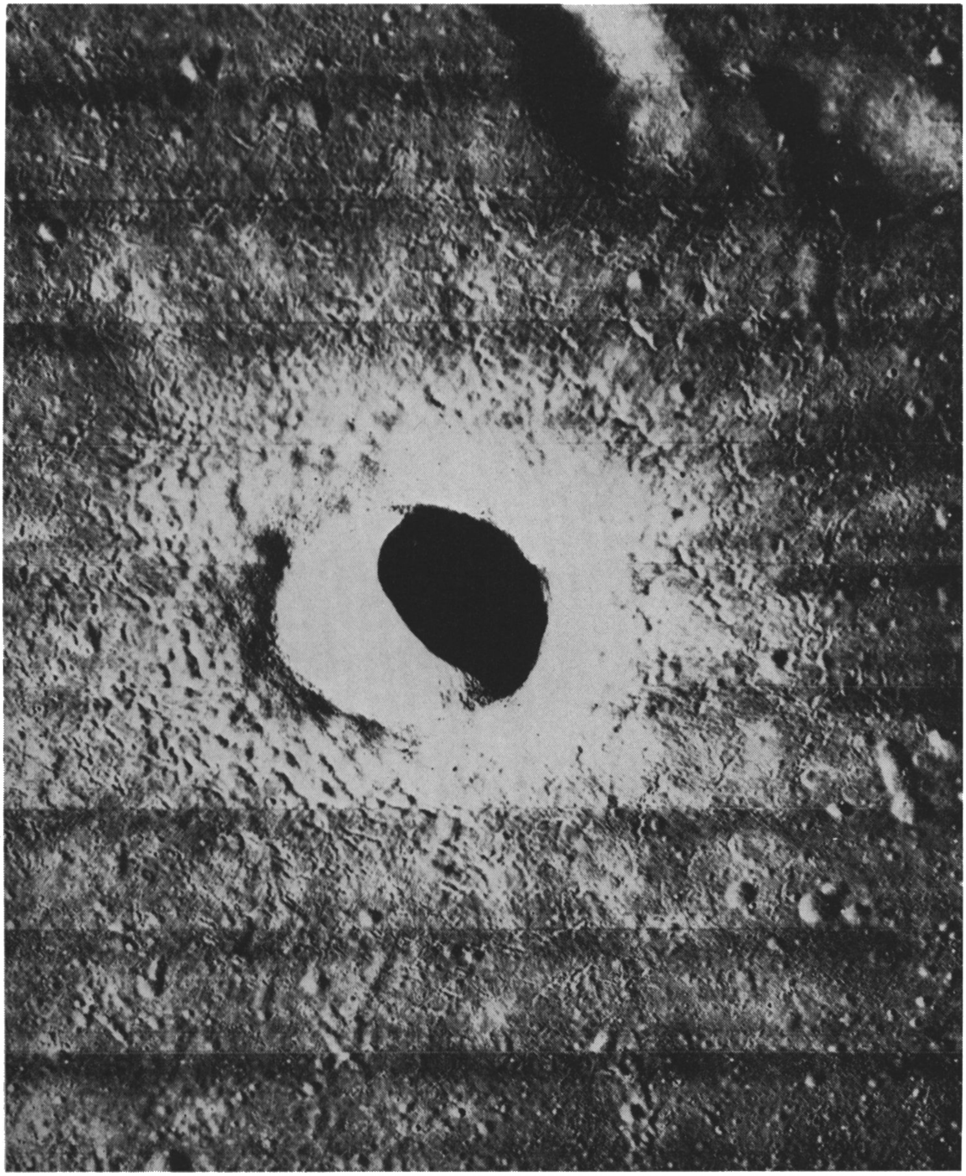

Fig. 7. Crater Mösting.

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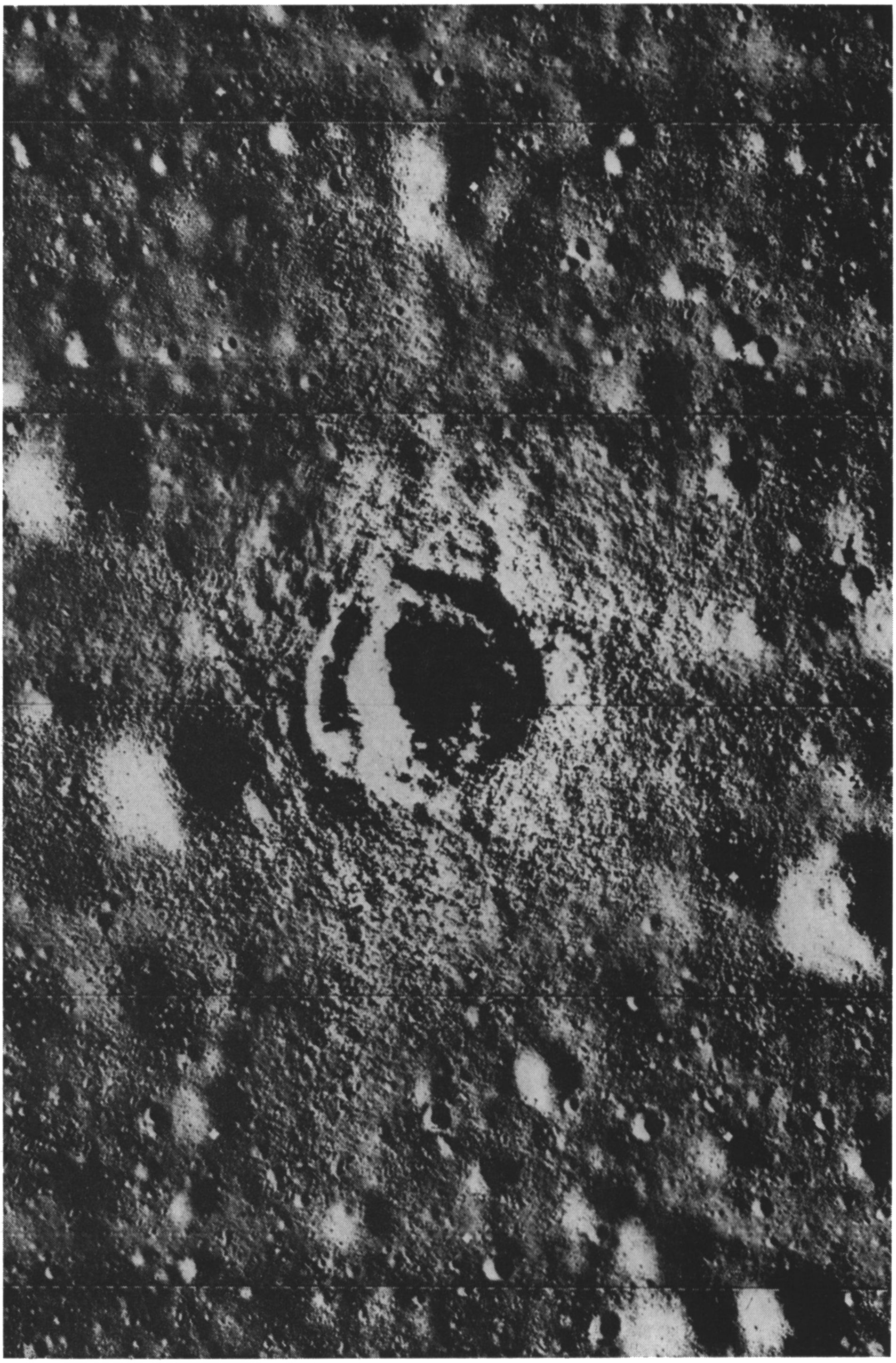

Fig. 8. Unnamed Crater.

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meter for one hour. The Saturn stage impact represents roughly ten times greater energy than the Lunar Module. At that occasion the seismic signals were received for more than four hours. It is difficult to hypothesize a lunar interior that would result in such signals.

We have known for hundreds of years that the Moon is covered by craters of all sizes at the resolution that could be seen. We conjectured that when we finally reached

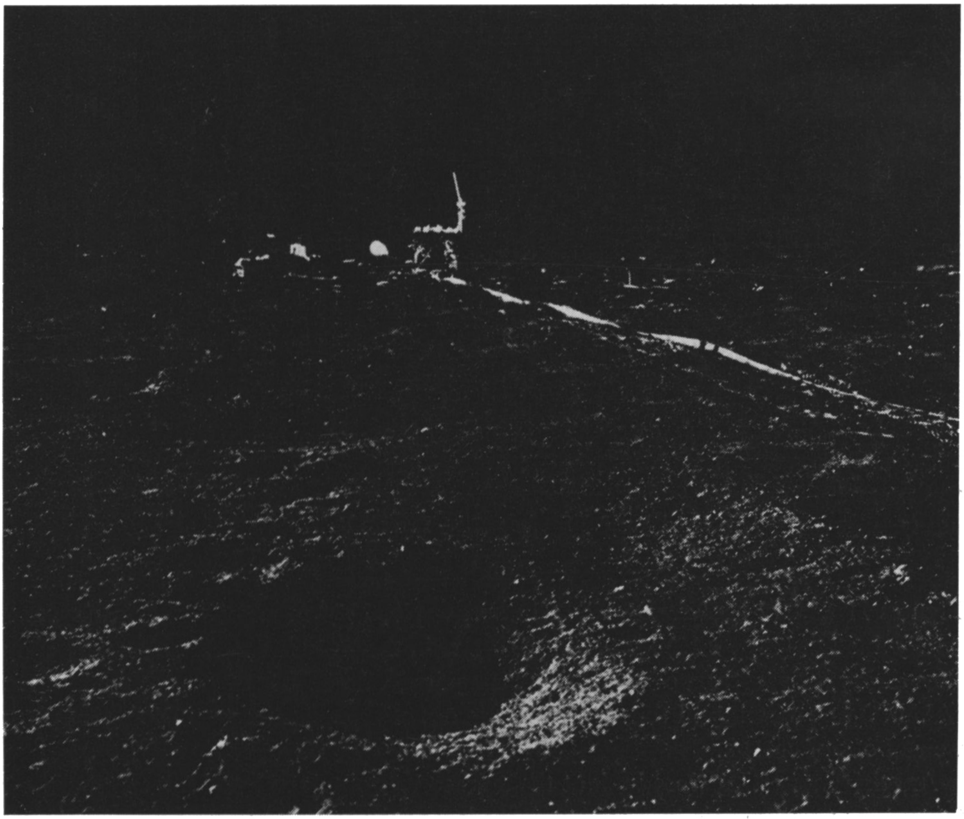

Fig. 9. Apollo 12 Landing Site – Craters in Foreground.

the Moon, we would find more and more craters of smaller and smaller size. Since lunar craters is a subject of some interest to this session of the IAU, I thought it might be of interest to quickly run through a family of craters to illustrate this. First (Figure 6) is a massive crater, Tycho, almost 10^5 m in diameter. Next (Figure 7) is Mösting C, several thousand meters in diameter. Figure 8 is a crater 200 m across which is below the size that we had been able to see prior to the existence of lunar spacecraft. The next of the series (Figure 9) are several one-meter size craters in the Apollo 12 landing site. Figure 10 of a returned rock shows craters in the 1 mm range.

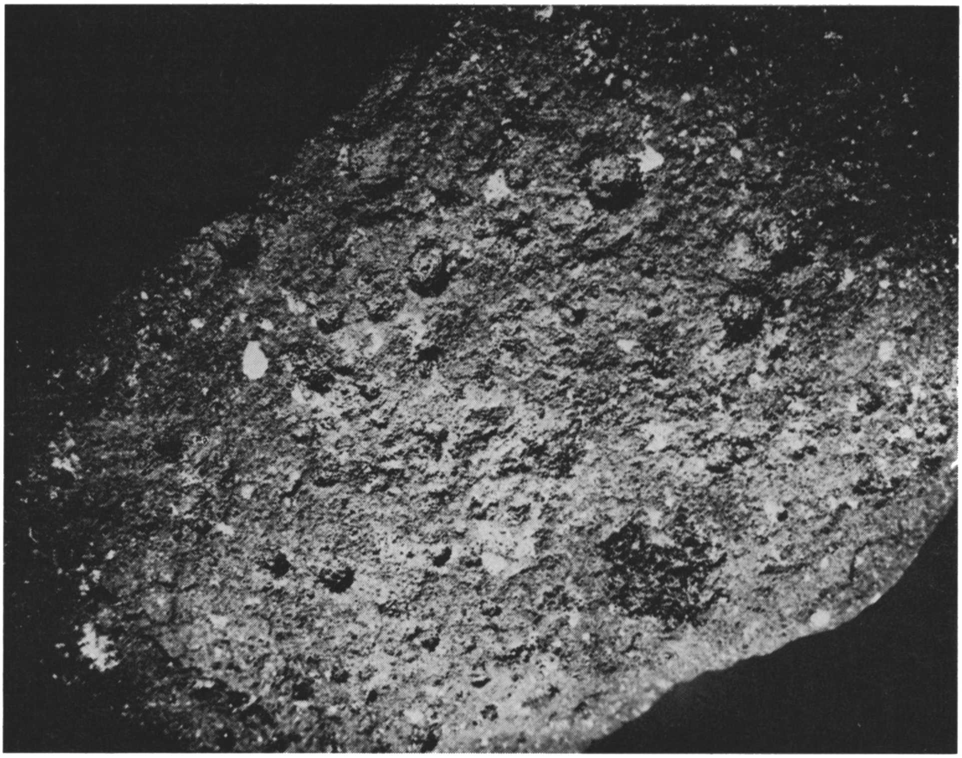

Fig. 10. Surface Pits – Breccia Rock.

Figures 11 and 12 show craters in a lunar sample, 10^{-4} m and 10^{-5} m in size, and finally another (Figure 13) lunar sample crater in the 10^{-6} m range. This total family runs through a spectrum of 11 orders of magnitude. Just think of the problems of the IAU in future meetings! I think you will run out of names of important people before we run out of craters.

Another interesting close look at the surface was obtained by a stereo camera. By this means we were able to obtain a close view of the surface in an undisturbed state.

We have a very extensive scientific program for analyzing the returned lunar samples. You will hear later some of the details of this program. One of the concerns that has required special care is that of possible contamination of the Earth's biosphere. We established a quarantine program that we considered to be prudent. The astronauts were kept in quarantine for 21 d after leaving the lunar surface. No adverse effects were noted. A large number of biological specimens were placed in contact with the lunar soil and studied carefully to insure that there were no adverse results prior to release of the samples to investigators for detailed analysis. The crew was placed in the Mobile Quarantine Facility immediately upon recovery and returned to the recovery ship. This facility was moved by ship and air directly to the Lunar Receiving Laboratory in Houston.

The lunar samples were treated equally carefully. They were moved in their sealed containers, and were not opened until they were behind the double quarantine barrier in the Lunar Receiving Laboratory. Then they were moved into the vacuum chamber. Inside the chamber the box was opened. The rocks vary considerably in appearance.

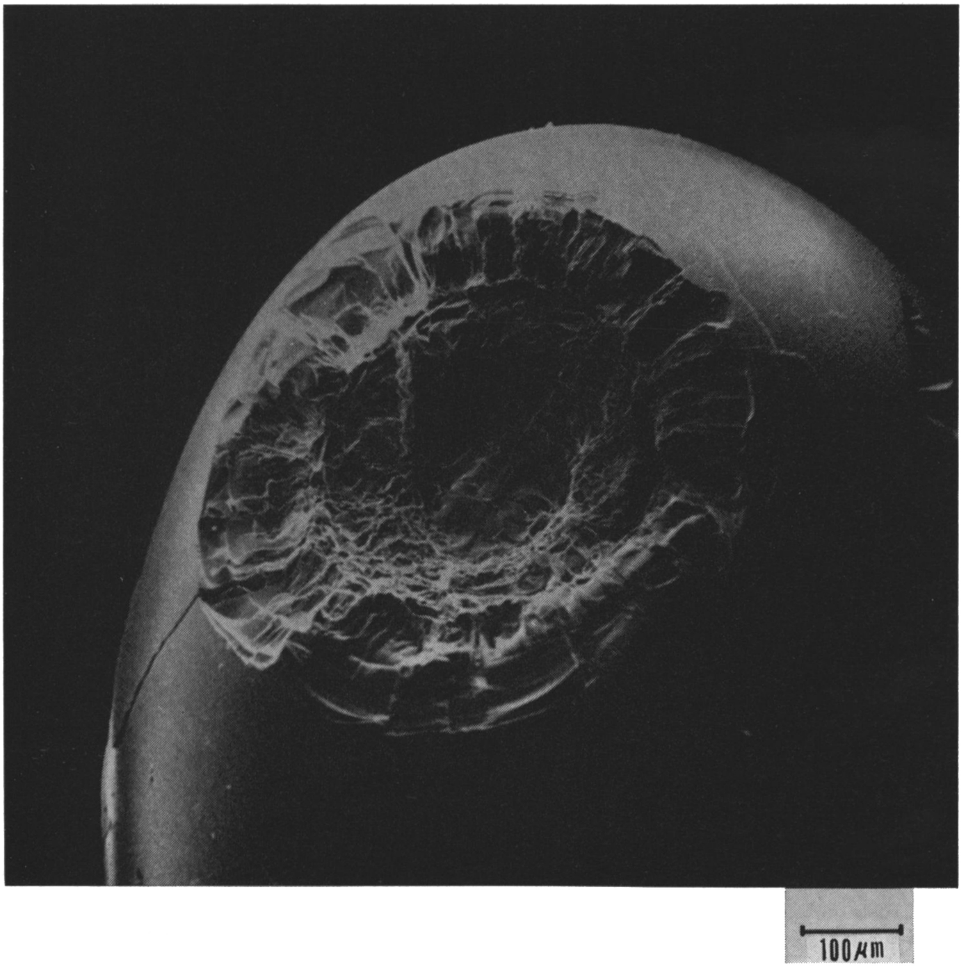

Fig. 11. Lunar Sample – 5×10^{-4}.

Figure 14 shows a typical crystalline rock formed from the high temperature melt. Figure 15 is a breccia made up of mechanically bonded varying types of materials. Figure 16 shows some of the interesting glass beads that are found in the lunar soil.

The lunar sample operations in the Laboratory proceeded as follows. After the containers were opened in a vacuum or in a nitrogen atmosphere, they were subjected to a preliminary scientific examination. Simultaneously, biological testing was undertaken. The samples were retained in vacuum or nitrogen, depending upon the type of

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later analysis to be conducted. The many investigators were then sent samples in a form most suitable for their investigations. Some were provided whole rocks; others thin sections; still others mineral separates.

A large number of cultures, animal and plant specimens were exposed. No deleterious

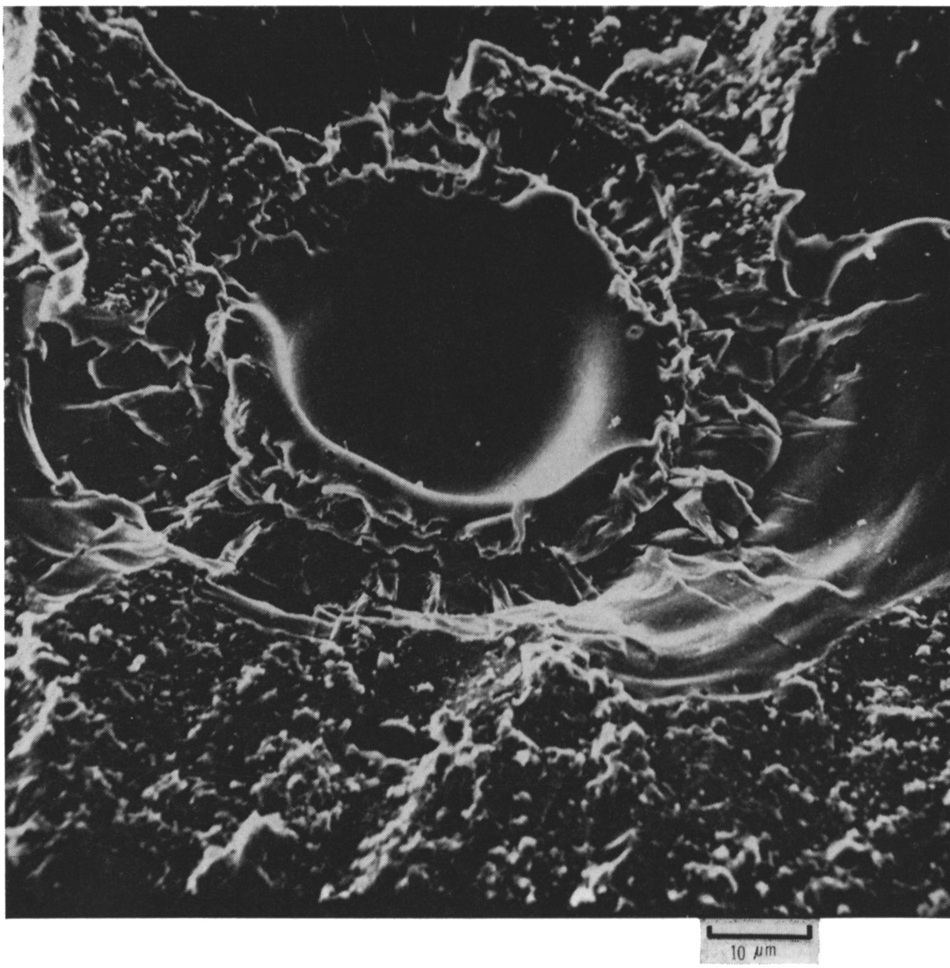

Fig. 12. Lunar Sample – 4×10^{-5}.

effects were noted of any on these. An interesting and unexpected result was obtained during the botanical testing. It was found that some of the simple plants thrived when a small quantity of lunar soil was added. This effect on the liverwort plant is graphically illustrated in Figure 17. This result is not fully understood, and considerably more investigations are underway.

We welcome proposals from scientists throughout the world for analysis of the lunar samples. At the present time, samples are being supplied to 193 investigation teams in 17 countries of the world. We have recently issued another announcement soliciting proposals for analysis of material from later missions. Many have been received and are currently being evaluated.

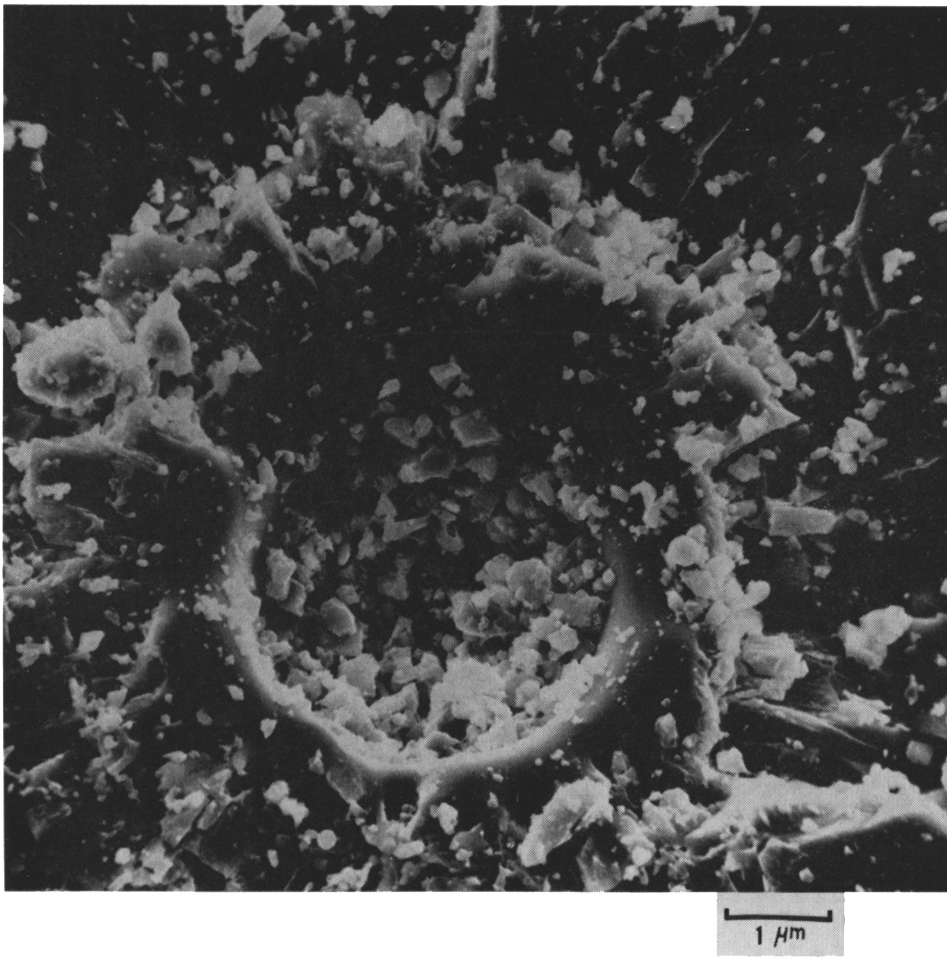

Fig. 13. Lunar Sample – 3×10^{-6}.

Let me summarize the more important scientific results obtained from our first two landing missions, although, of course, much work is still going on. We now know that parts of the Moon are at least four and one-half billion years old. We know that if the Moon was once part of the Earth, it must have split off very early in its history. We have found considerable variation in the composition of the lunar material between the sites of Apollo 11 and 12, even though they both appeared to be very similar terrain. Our analyses have uncovered several minerals never before seen. Evidence shows that rocks crystallized at a very high temperature. They are low in the volatiles and high in the refractories. The lunar surface has been continuously modified but at a very slow rate. Thus far, we have not found any indisputable evidence of water, organic compounds, or lunar life.

On Apollo 12 we found an unexpected lunar magnetic field. We do not know how widespread it may be. From remnant magnetization in the rocks, the ancient magnetic field must have been stronger than at present. This may infer that the Moon was once

Fig. 14. Apollo 11 Crystalline Rock.

much closer to the Earth than it is now. Natural seismic events on the Moon are few and weak compared to the Earth, but the seismic transmissions through the Moon are considerably different than we find on the Earth. Our analyses show much evidence of Sun's activity recorded in the lunar material. Finally, I think we can state positively that man can function very effectively as a scientific explorer on another planet. We are very pleased with the relative ease in which the crews have been able to adapt to the lunar environment and to perform the many tasks which they were assigned.

I would like to say a few words about the future. Apollo 14 is being targeted for the same Fra Mauro region as Apollo 13. Although a great deal was learned on Apollo 11 and 12, the remaining Apollo missions will be increasingly effective. Figure 18 is a plot of several parameters of Apollo 11 and 12 and what we anticipate for Apollo 14. There is a significant increase in the capabilities of each mission. Most of this is due to learning and increase in confidence.

Fig. 15. Apollo 12 Breccia.

Starting with Apollo 16, we are making some hardware changes that will result in very significant improvements and capabilities. The landed payload will be increased by over 100%. We anticipate at least three excursions to the lunar surface, with the total man-hours exploring the surface increased from 18 to 40. The range and efficiency of surface operations will be greatly improved by modified space suits and life support systems, and by use of a small roving vehicle. Finally, we will be in orbit around the moon for a longer period of time, and are adding to the Service Module a number of orbital experiments for remote sensing of the lunar surface.

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For the remaining Apollo missions, the landing sites are under continual review. We will ensure that the limited number of missions are placed in the most important scientific areas. Various candidate sites are under consideration for the remaining missions. These include areas in the highlands, in apparently fresh volcanic regions, near the mysterious rilles, and in the bottom of deep craters. There are more prime candidate sites than we have missions to send, so we are proceeding very carefully in the selection. In addition to scientific considerations, there are various operational constraints. For example, it seems doubtful that we will ever consider the risk operationally acceptable for landing near the crater Tycho. A key scientific objective at a site near the central peaks of the crater Copernicus would be to bring back samples from the central peaks which would represent material rebounded from deep beneath the lunar surface when this impact crater was formed. A landing site near the Hadley Rille, which extends some 100 km, would provide data on the rille itself and the contact between the mare and the Apennine mountains. Other factors that must be considered in the selection of future sites are networks established by the geophysical station. Network considerations are particularly important with the seismometers but also with the magnetometers and the laser reflectors.

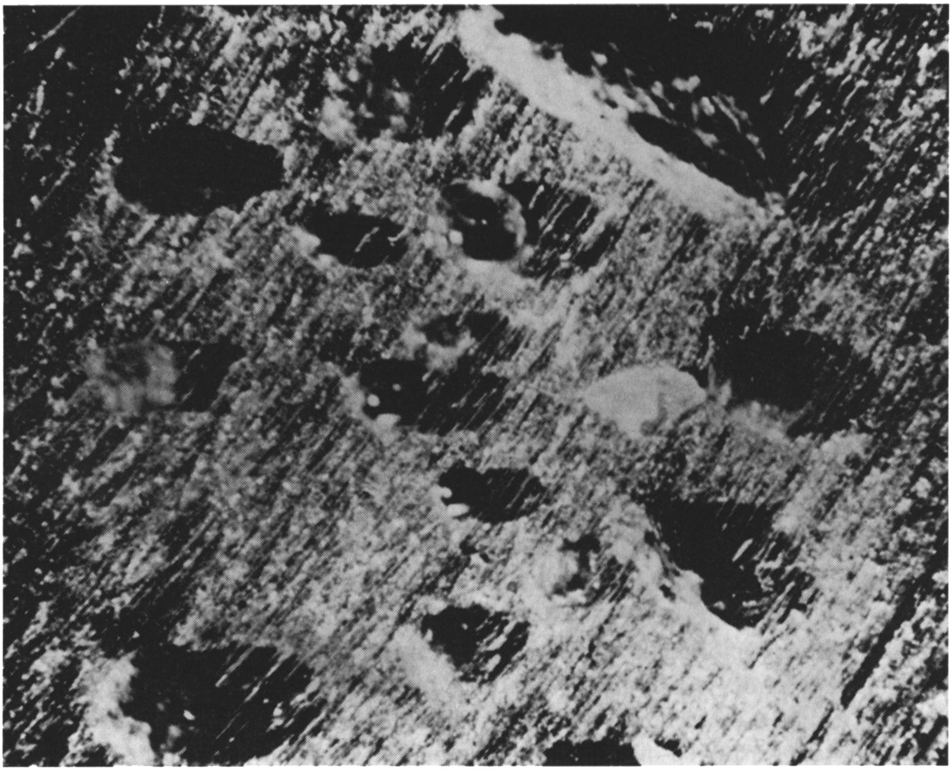

Fig. 16. Glass Beads on Lunar Sample.

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This has been a very broad overview of the Apollo missions and our progress and plans for lunar exploration. We feel we are making substantial progress in unravelling some of the mysteries of man's nearest neighbor.

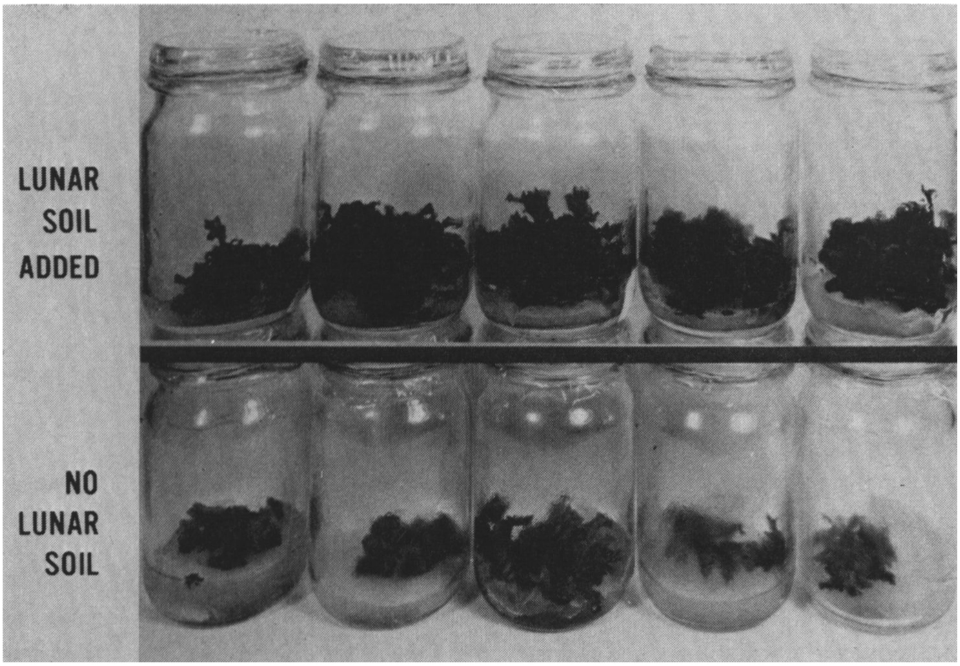

Fig. 17. Soil Effect on Plant Life

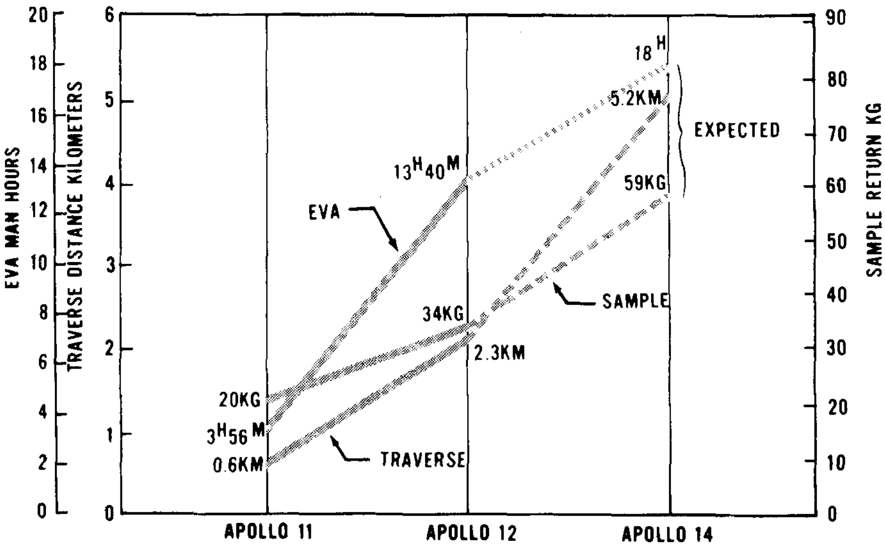

Fig. 18. Mission Science Growth.

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