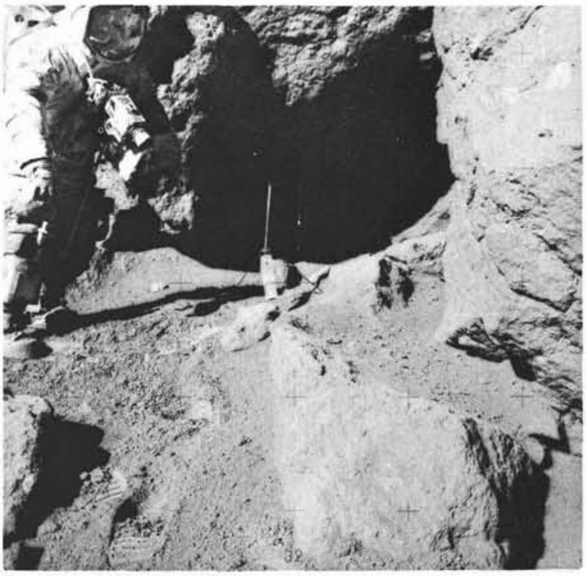

FRONTISPIECE. The tripod-like object just outside the shaded area is the gnomon and photogrammetric chart assembly which is used as a photographic reference to establish local vertical Sun angle, scale, and lunar color. The gnomon is one of the Apollo Lunar Geology Hand Tools. The author took this photo (December 13, 1972) of Astronaut Eugene A. Cernan standing near an overhanging rock during the third Apollo lunar surface extravehicular activity (EVA) at the Taurus-Littrow landing site.

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The Measure of the Moon

The detailed geometry and orientations at sample localities were obtained largely through roughly horizontal stereophoto pairs using a special gnomon for Sun-line and vertical control.

THE COMBINED efforts of geologists and photogrammetrists have been the major contributions to establishing the geometric context of the data from the Apollo program. For the most part we applied the techniques of classical photogrammetry to the problems of modern exploration. The problems were also classical. We needed to establish the cartographic positions of data points (at widely varying scales) relative to each other and relative to the whole moon. We needed the detailed geometry of large- and small-scale features, and the positions and orientations of samples relative to this geometry, and relative to the Sun and space.

We required the topography, slopes, and inertial positions of the landing sites for the safe and precise attainment of our science objectives. Finally, and perhaps most importantly, we needed the fundamental constraints on our evolution models for the Moon, which photogrammetry provides, such as the relations between the center of mass and the center of figure of that planet.

To tackle such problems our techniques

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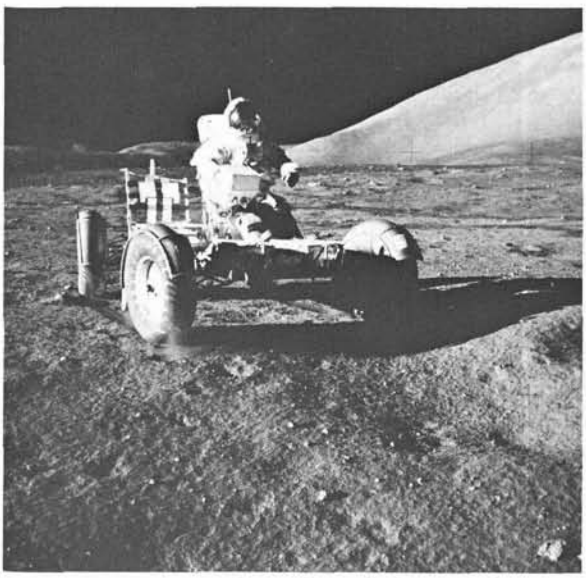
ranged from the simple to the sophisticated. We used simple photographic panoramas and three-point *resection* for much of our lunar surface position control. Perspective (Canadian) grids were used in situations lacking planimetric control, but with eventual base control provided by metric photographs from orbit.

The detailed geometry and orientations at sample localities were obtained largely through roughly horizontal stereoscopic pairs of photographs using a special gnomon (Frontispiece) for Sun-line and vertical control, for scale and for photometric calibration. *Reseau* marks provide geometric control of the film. In most instances analytical plotters were mandatory in the analysis of what are almost random sets of photographs. For some unusual photographic combinations measurements were accomplished by special point-by-point analytical programs.

Our most modern approach to lunar photogrammetry came from orbit. The introduction into lunar orbit operations of precision metric and panorama cameras and laser altimeters provided the photographs and data through which we can now solve many of our local and lunar-wide control problems.

The details of all of these efforts are best left to the experts; I am merely one of hundreds of consumers of their contributions. Through these and the contributions of all scientists and engineers involved in Apollo, we have in our hands, if not yet in our minds, a first-order understanding of another planet, our Moon. In the remainder of this presentation I wish to review that understanding by means of an orbital tour of the Moon.

I shall try to outline the pattern of our present understanding of the evolutionary sequence through which this sister planet of ours has passed over the last four and one-half billion years. Understanding, however, is a transient thing and even today alternative explanations exist for the phenomena we have observed. On the other hand, the sequence to which I shall refer is consistent with most, if not all, of our present knowledge. This interpretive sequence gives a framework for future investigation, including a new look at our Earth through the corrective vision of the Moon.



Astronaut Cernan makes a short checkout of the Lunar Roving Vehicle during the early part of the first Apollo 17 EVA. This view of the *stripped down* Rover is prior to loadup. Equipment later loaded on the Rover included the ground controlled television assembly, the lunar antenna, aft tool pallet, and lunar tools and scientific gear. Cernan is the Apollo 17 commander, and the picture was taken by the author while Astronaut Ronald E. Evans remained with the Command and Service Modules in lunar orbit. The mountain in the right background is the east end of South Massif.

APOLLO REQUIRED a Newtonian match between the explorers' sunrise and the Moon's sunset. Sunset on the far side of the Moon was not always so starkly tranquil as it is now. About 4.6 billion years ago, when the Moon was approximately its present size, the Sun probably set on a glowing, seething sea of molten rock. Storms of debris still swept its surface, mixing, quenching, outgasing, and remelting a primitive melted shell while inside the shell the crust of the Moon was gradually taking form.

By about 4.4 billion years ago the Moon's crust must have looked not unlike the highland areas we see today, although still hot and violently changing in appearance as the debris storms continued their declining, though still dominant, ways. This cratered and pulverized outer crust is composed largely of plagioclase feldspar, a mineral rich in calcium and aluminum, although other minerals and elements are also present.

As the residue of creation was consumed by Earth and Moon alike, the debris storms decreased in frequency, although not without occasional unusually massive reminders of the past. Sometime prior to about 4.1 or 4.2 billion years ago, large basins, such as the Ingenii, began to form by major impact events at a time when they could not be obliterated by more numerous smaller collisions.

DURING THIS same time the Moon's interior, through the accumulation of the heat of radioactive decay, gradually reached temperatures by which it could begin to influence the character of the surface regions. First, a hot core of a liquid solution of sulphur and iron appears to have accumulated, and in this core a remarkable and still little understood phenomenon occurred: an electric dynamo probably came into existence, began to perpetuate itself, and produced a magnetic dipole field about 1/25th of that presently associated with the Earth. Although the dipole field has disappeared, the magnetic anomalies persist to the present.

The second event generated by the Moon's interior processes was the apparent eruption on the surface of light-colored materials composed largely of the pulverized remnents of the ancient crust. These light-colored feldspar rich materials appeared to have partially filled all the great basins that then existed, such as Gagarin. Their irruption may have been driven by the melting and upward migration of the materials, rich in radioactive and gaseous components, that were left over after the crystallization of the Moon's melted shell.

As the last of the large basins were created about 3.9 billion years ago, the final major internally generated episode of evolution took place. This chapter tells of the flooding of all the great basins on the front side of the Moon by vast, now frozen, oceans of dark basalt. Only the very deepest of basins on the far side, such as Tsiolkovsky, were

The author, Scientist-Astronaut and lunar module pilot, is photographed seated in the Lunar Roving Vehicle at Station 9 (Van Serg Crater) during the third EVA. The photograph was taken by Astronaut Cernan, commander; he and the author had descended in the Lunar Module *Challenger* to explore the lunar surface.

affected by the formation of the maria, although to some degree all portions of the outer crust must have been permeated up to a general mare *sea-level.*

THIS TREMENDOUS upwelling and extrusion of molten rock was probably triggered by heat from radioactive elements and, in this instance, portions of the Moon's deep inner crust or even deeper outer mantle melted.

Variations in the internal composition of the Moon caused the period of mare flooding not only to span the time from 3.8 to about 3.2 billion years ago, but also to cause profound chemical differences in the character of the basalts that were produced as this time passed.

Then a relative quiet settled forever on the surface of the Moon. When the waves and currents on the maria had finally been arrested, the Moon's appearance differed only slightly from that of today.

The storms of debris had decreased and disappeared; the last huge basin had been formed, and the seas of basalt were finally quiet. Only an occasional stony or cometary traveler of our solar system collided violently with the surface, only local volcanic fields developed over unusually high heat sources, only isolated stresses fractured the hardened lunar crust and changed ever so slightly the face of the Moon. Some of these changes, (such as unusual swirls of unknown character—the swirls of Marginus—a large ridge system with associated volcanic fields, evidence of global stresses) suggest that beneath the crust major chapters of history were being recorded. Possibly the Moon's interior reached a thermal state where great slow connection cells were formed. These cells may have wrinkled, stretched and broken portions of our aging Moon as heat and some new materials reached the surface. But, as cooling progressed, even the phenomenal dynamo and magnetic field of the core ceased to function.

Now, except for faint rumblings and occasional sharp ringings as reminders of the past, the storied Moon has completed the record of its tale. The next book is being written by Man as he begins to peruse the library of the planets.

APOLLO 8 finally and irrevocably broke the bonds of biological evolution that had thus far bound our species. For the men of Apollo living out our exploration on the ground, this was *The Mission;* Apollo 11 was our job, but Apollo was our spirit, our daring, and our imagination. With it we, and all mankind, evolved into the universe, never to be satisfied with only the beauties and comforts of Earth. Paradoxically, we also found enhanced awareness and appreciation of those beauties and comforts we were now so willing to leave behind.

As we progressed toward our historical goal of a lunar landing (the Smythii Mare), Apollo 10 provided the final technological verification that we were ready. While showing the world an orderly progression of engineering and orbital procedures, the mission emphasized how ordinary, but then how extraordinary, the new breed of explorers were to be.

The far horizon of Mare Tranquillitatis holds a unique place in the annals of Man. Even though we speak personally in so special a way about Apollo 8, the event that history will remember as having changed the course of that same history was the landing of Apollo 11. The returns of that mission will span the history of science, the history of *men,* and the history of *Man.* Science finally had real and factual insight into the temporal dimensions, if not all of the actualities, of the evolution of our sister planet and its Sun. Men finally had seen their first truly spacefaring Nation and saw that it carried the traditions of freedom as super-cargo. And Man saw himself as a creature of the Universe.

THEN THE relatively unheralded work of exploration began and progressed. Apollo 16, in finding that we were not yet ready to understand the earliest chapters of lunar history recorded in the Descartes Highlands, also found that the major central events of that history were apparently compressed in time far more than we had been prepared to imagine. There appeared to be indications that the formation of the youngest major lunar basins, the irruption of light-colored plains materials and the earliest extrusions of mare basalts took place over about 200 million years of time around 4 billion years ago.

After the heady findings and conclusions following the landing at Tranquillity Base, Apollo 12 returned precision to lunar navigation and obvious complexity to lunar science. The structure of the hardened upper few meters of lunar surface became clearly a complex history book in its own right; also representatives were uncovered of heretofore unexpected rocks rich in potassium, rare-earth elements and phosphorous, elements thought to be present only in trace amounts on the lunar surface; and the range in age and character of the mare basalts began to unfold.

The author is photographed working beside a huge boulder at Station 6 (base of North Massif) during the third Apollo 17 EVA. The front portion of the Lunar Roving Vehicle is visible on the left.

To the west of the Mare Cognitum landing site of Apollo 12 and south of the Crater Copernicus, we targeted the Apollo 13 mission. Instead of the insight into the intensity and timing of the event that formed the Imbrium Basin, we received new insight into ourselves. The courage of the crew and resourcefulness of the controllers of that mission, following the explosive destruction of the service module, gave history's most graphic and human example of Man's potential in the face of extreme adversity.

Apollo 14 picked up Apollo's torch of exploration at Fra Mauro. The mission told us that not only did the Imbrium event occur barely 100 million years before the oldest major basalt extrusions, but also that such massive collisions transferred much more heat energy into the planet's surface than we had previously surmised.

The Apollo 15 mission to Hadley Rille at the foot of the lunar Apennine Mountains introduced a new scale to lunar exploration. We began to look at the whole planet through the eyes of cameras and electronics. On the Moon's surface we reached beyond our earlier hopes and began to rove and observe the wide variety of features available for investigation. The varied samples and observations in the vicinity of Hadley Rille and the mountain ring of Imbrium propelled our knowledge of lunar time and processes back past the 4-billion-year barrier we had seemed to see on previous missions.

Of equal importance was the realization, by ourselves and by millions of people around the world, that there existed sheer beauty and majesty in views of nature previously outside human experience.

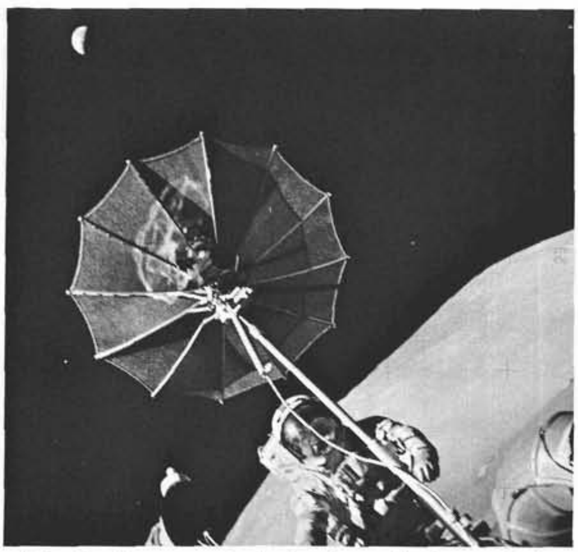
Near the coast of the great frozen sea of Serenitatis, Apollo 17 visited the valley of Taurus-Littrow. The unique scientific character of this valley helps to mitigate the sadness that, with our visit, the Apollo explorations ended. If this end had to be, it would have been difficult to find a better locality to synthesize and expand our ideas on the Evolution of the Moon.

It now appears that at Taurus-Littrow we have looked and sampled the ancient lunar record ranging *back* from the extrusion of mare basalts, through the formation of the Serenitatis Mountain ring and thence back onto materials which may reflect the very origins of the lunar crust itself. Also, we have found and are studying materials and processes that range *forward* from the formation of the earliest mare basalt surface, through 3.8 billion years of modification of that surface, including the addition of mantles which may be the culmination of processes active within the deep interior of the Moon.

The author is photographed standing next to a huge, split lunar boulder during the third Apollo 17 EVA at the Taurus-Littrow landing site.

For all of our Apollo missions we left the Moon before the lunar sunrise had progressed into the vast regions of the lunar west; Mare Procellarum, where the young mysterious features of that region's central ridge system still await the crew of a mission diverted after Apollo 13; Mare Orientale, whose stark alpine rings have been viewed closely by Man only in the subdued blue light of the Earth. The promise of the story in these regions has diminished, but seemingly watches for the progression of sunrises and the landing craft of another generation of explorers.

A TOUR OF the Moon both begins and ends with a setting Earth; a reminder that knowledge for knowledge's sake is tremendously interesting and exciting to many men and essential, in the long run, to all men. However, without at least a temporary focus, knowledge can degenerate and be lost even to the future. The focus of our lunar knowledge is the planet Earth.



The Earth appears in the far distant background above the hi-gain antenna of the Lunar Roving Vehicle in this photo taken by the author. Astronaut Cernan stands beside the Rover.