APOLLO OVER THE MOON: A VIEW FROM ORBIT (NASA SP-362)

Chapter 1 - Introduction

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[For a high resolution picture- click here]

Objectives

[1] Photography of the lunar surface was considered an important goal of the Apollo program by the National Aeronautics and Space Administration. The important objectives of Apollo photography were (1) to gather data pertaining to the topography and specific landmarks along the approach paths to the early Apollo landing sites; (2) to obtain high-resolution photographs of the landing sites and surrounding areas to plan lunar surface exploration, and to provide a basis for extrapolating the concentrated observations at the landing sites to nearby areas; and (3) to obtain photographs suitable for regional studies of the lunar geologic environment and the processes that act upon it. Through study of the photographs and all other arrays of information gathered by the Apollo and earlier lunar programs, we may develop an understanding of the evolution of the lunar crust.

In this introductory chapter we describe how the Apollo photographic systems were selected and used; how the photographic mission plans were formulated and conducted; how part of the great mass of data is being analyzed and published; and, finally, we describe some of the scientific results.

Historically most lunar atlases have used photointerpretive techniques to discuss the possible origins of the Moon's crust and its surface features. The ideas presented in this volume also rely on photointerpretation. However, many ideas are substantiated or expanded by information obtained from the huge arrays of supporting data gathered by Earth-based and orbital sensors, from experiments deployed on the lunar surface, and from studies made of the returned samples. These ideas are still evolving. The reader will notice that in some cases the authors of captions for the photographs in this volume interpret similar features differently, or place different emphasis on the relative importance of the various processes involved in the formation of such features. These differences in interpretation reflect in large part the evolving state of lunar data analysis and demonstrate that much work remains to be done before our goal of understanding the history of the Moon is reached. One of our goals with this volume is to convey an impression of the many exciting scientific results still emerging from the study of the photographs and other data already gathered.

At the termination of the Apollo program in December 1972, nearly 20 percent of the surface of the Moon had been photographed in detail....
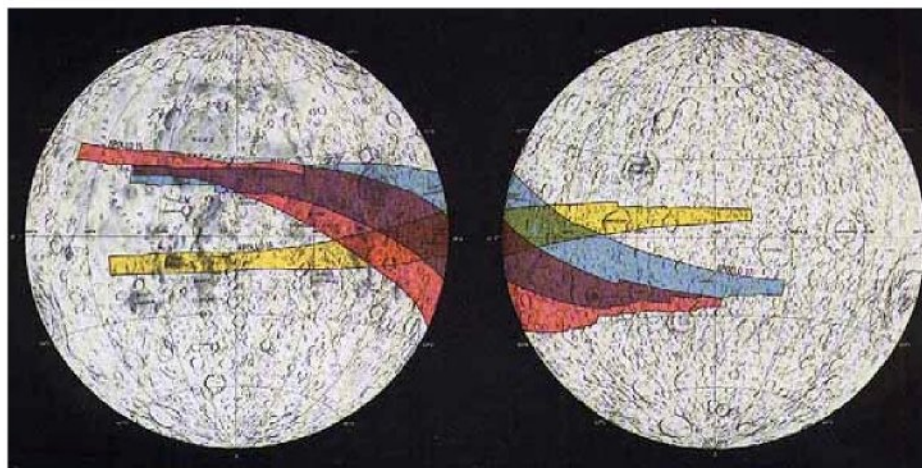
Mapping camera coverage
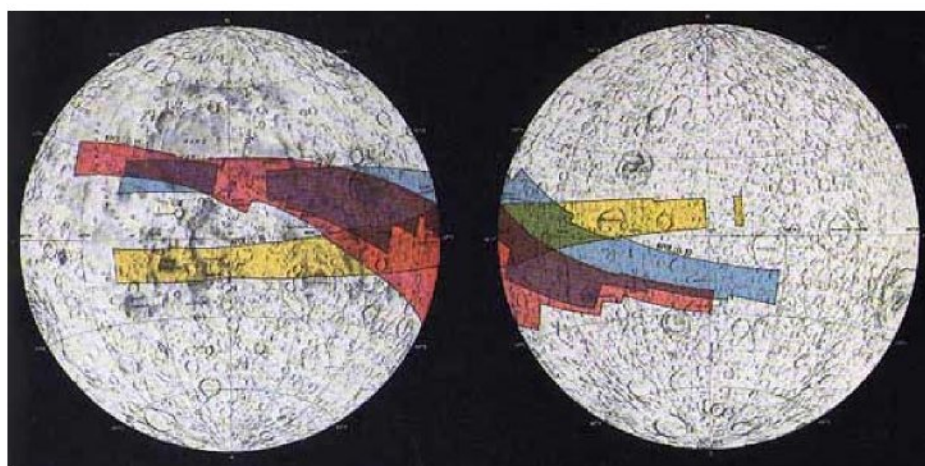
Panoramic camera coverage

[2] FIGURE 1.-Above: Mapping camera coverage obtained by the Apollo 15, 16, and 17 missions. Only areas photographed in sunlight in the vertical mode are shown. Excluded are areas photographed obliquely, those in darkness beyond the terminator, and regional scenes taken after leaving lunar orbit. Facing page: Panoramic camera coverage obtained under the same conditions. [Base map courtesy of the National Geographic Society] [Note: For both maps: Near side is on the left and the Far side is on the right. Red: Apollo 15; Yellow: Apollo 16; Blue: Apollo 17. Chris Gamble, html editor]

...from orbit by a variety of camera systems (fig. 1). A selected sample of the nearly 18 000 orbital photographs so acquired is shown in this volume. (See app. A for an index of photographs.) The tremendous success of the Apollo photographic mission must be attributed ultimately to the great dedication, enthusiasm, and ability of the members of the Apollo program. Their efforts have resulted in a great harvest of new scientific information and a consequent increase in knowledge for mankind.

Orbital Science Photographic Team

Early in the Apollo program, then directed by Lt. Gen. Sam C. Phillips, it was realized that adequate planning for the acquisition of photographs would require the participation of many individuals acting in an advisory capacity. On September 6, 1968, prior to the flight of Apollo 8, an Ad Hoc Lunar Science Working Group was convened at the Manned Spacecraft Center (now Johnson Space Center), Houston, [3] Tex. The Working Group's function was to recommend target areas of scientific interest for lunar photography. This group planned and supported the photography done on the first five lunar orbital missions (Apollos 8 and 10 through 13; Apollo 9 was an Earth orbital mission) working with the Mapping Science Branch of the Science and Applications Directorate of the Manned Spacecraft Center. Hasselblad cameras with 80- and 250-mm lenses constituted the major photographic system employed on these early flights (table 1). (App. B contains a list of lunar probes.)

On December 14, 1969, a year before Apollo 14 was launched, Dr. Rocco Petrone, Apollo Project Director, established the Apollo Orbital....

TABLE 1.- *Camera Systems Carried on Board the Command and Service Module (CSM) on Apollo Lunar Missions 8 Through 17.*

Camera	Mission								
	8	10	11	12	13	14	15	16	17
Data acquisition (Maurer)	X	X	X	X	X	X	X	X	X
70-mm EL (Hasselblad)	X	X	X	X	X	X	X	X	X
70-mm DC (Hasselblad)	X	X	X	X	X	X	X	X	X
Lunar topographic (Hycon)					X	X			
35-mm (Nikon)							X	X	X
Mapping and stellar (Fairchild)							X	X	X
Panoramic (Itek)							X	X	X

[4] ...Science Photographic Team because Apollo 14 was the first mission to include an orbital mapping camera. The purpose of the team was to provide "scientific guidance in the design, operation, and data utilization of photographic systems for Apollo program lunar orbital science." The team included a chairman and 12 members who were specialists in the fields of geology, geodesy, photogrammetry, astronomy, and space photographic instrumentation:

Frederick J. Doyle, Chairman (photogrammetry), U.S. Geological Survey

Lawrence Dunkelman (astronomy), NASA Goddard Space Flight Center

Farouk El-Baz (geology), Bellcomm, Inc.; later, the National Air and Space Museum, Smithsonian Institution

William Kaula (geodesy), Institute of Physics and Planetary Physics, University of California at Los Angeles

Leon J. Kosofsky (space photography), NASA Headquarters

Donald Light (photogrammetry), Defense Mapping Agency Topographic Center

Douglas D. Lloyd (space photography), Bellcomm, Inc.

Harold Masursky (geology), U.S. Geological Survey

Robert D. Mercer (astronomy), Dudley Observatory, Albany, N.Y.

Lawrence Schimerman (photogrammetry), Defense Mapping Agency, Aerospace Center

Helmut H. Schmid (geodesy), U.S. Environmental Science Services Administration

Ewen A. Whitaker (astronomy), Lunar and Planetary Laboratory, University of Arizona

As specified in the charter of the Apollo Orbital Science Photographic Team, its responsibilities included providing NASA with recommendations in the following areas:

(1) Equipment functional specifications:

(a) The team shall recommend functional requirement orbital photographic systems.

(b) The team shall provide technical advice during the procurement phase for photographic systems.

(c)The team shall be represented at photographic equipment ment reviews.

(2) Equipment use:

(a) The team shall participate in preparation of plans scientific use of the photographic systems and sup mission operations planning.

(b) The team shall participate in planning for coordinated, use of photographic systems to support other experiments.

(c) The team shall participate in planning for other experiments that will support photography.

(d) The team shall participate in operations planning photo graphic requirements to support Apollo lunar landing site selection.

[5] (3) Crew training: The team shall provide technical advice for and will support, as requested by the Manned Spacecraft Center, astronaut training related to photographic tasks.

(4) Real-time operations: The team shall support operations as requested by providing real- time scientific and technical advice to astronauts for photographic and related tasks.

(5) Data processing:

(a) The team shall provide technical advice in selection of film and film processing requirements to optimize postmission scientific analysis by photographic users.

(b) The team shall recommend major data reduction equipment and analysis procedures to assure that optimum scientific use is made of the photographic data obtained.

Analysis of the photographic data was carried out by a broad spectrum of scientists representing the following institutions: the U.S. Geological Survey, Bellcomm, Inc., the University of Arizona, Ames Research Center, and the Smithsonian Institution. H. Masursky directed and collated for publication the results of the studies relating to the scientific interpretation of the photographs. He and his colleagues, T. A. Mutch of Brown University and G. W. Colton, K. A. Howard, and C. A. Hodges of the U.S. Geological Survey, performed the same function for the last three Apollo missions. Many of the studies were performed as part of the later NASA-funded experiment S-222, which analyzed data after the completion of the flights.

Orbital Camera Systems

In preparation for the Apollo program of landing men on the surface of the Moon, the Lunar Orbiter project inserted five spacecraft into lunar orbit. Their cameras photographed almost all of the lunar surface (Kosofsky and El-Baz, 1970; NASA Langley Research Center, 1971). However, the nature of the camera's electronic readout system was such that it was difficult to measure positions on the lunar surface accurately from the Lunar Orbiter pictures. Another disadvantage was that little stereoscopic coverage was obtained, making three-dimensional measurements impossible. Furthermore, most Lunar Orbiter pictures were taken under low Sun angles so that few high Sun pictures showing differences in albedo were available. The Apollo photographic systems succeeded in correcting these conditions.

Two groups of cameras were used for Apollo orbital photographs: those in the command module (CM) which were handheld or mounted on brackets and operated by the astronauts, and those that were stowed in the scientific instrument module (SIM) bay in the service module (SM) and remotely operated by the astronauts from the CM. Table 1 lists the photographic systems carried on these missions, and table 2 lists their characteristics.

Hasselblad cameras, using both black-and-white film and color film, were carried on all lunar orbital flights of the Apollo program. On Apollo missions 8 through 14 the bulk of the photogeologically useful pictures acquired was taken with the Hasselblad systems. Hasselblad....

[6-7] TABLE 2.-Characteristics of Camera Systems Carried on Board the CSM on Apollo Lunar Missions 8 Through 17

Camera		Features	Film size and type	Uses
SIM bay:	Mapping (Fairchild)	Electric; 76-mm focal length lens; reseau crosses, fiducial marks, time, altitude, shutter speed, and forward motion control setting recorded on each frame.	127 mm; type 3400 Panatomic-X aerial.	To provide mapping quality photography (25- to 30-m resolution)-when used stereoscopically and in conjunction with auxiliary data, the geometry of the lunar surface can be reconstructed with a higher degree of precision than possible with earlier systems.
	Stellar (Fairchild)	Part of mapping camera system; 76-mm focal length lens; axis oriented at 96 to mapping camera axis; exposure synchronous with mapping camera exposures; reseau crosses, fiducial	35 mm; type 3401 Plus-X aerial.	To record star field at a fixed point in space relative to mapping camera axis so that orientation of the latter can be accurately determined for

		marks, time, and altitude recorded on each frame.		each mapping camera frame.
	Panoramic (Itek)	Electric; 610-mm focal length lens; optical bar design for high-resolution and image motion compensation; frame number, fiducial marks, time, mission data, velocity/height ratio, and camera-pointing attitude recorded on each frame.	127 mm; type EK 3414.	To provide strips of high-resolution (about 2-m) stereoscopic coverage for relatively large- scale topographic mapping and for detailed photogeologic analysis.
CM:	Hasselblad EL	Electric; interchangeable 80-, 105-, 250-, and 500-mm focal length lenses; 105-mm lens transmits ultraviolet (UV) wavelengths.	70 mm; color reversal films SO-121 and S0-368 Ektachrome MS; black and white films 3400 Panatomic X, 2485, S0-349 aerial, and 3414 aerial; spectroscopic film (W-sensitive) IIa- O.[a]	To document operations and maneuvers; to obtain convergent stereoscopic coverage of candidate landing sites, particularly with the 500-mm lens; to photograph preselected orbital science targets, different terrain types near the terminator, astronomical phenomena, views of the Moon after transearth injection, views of Earth, and to acquire special UV spectral photographs of the Moon and Earth. [b]
	Hasselblad DC	Electric; 80-mm focal length lens; reseau plate.	70 mm; black and white films 2485, 3400 Panatomic X, and S0-349 aerial. [a]	To obtain strips of stereoscopic coverage of the approach paths to candidate landing sites, as well as of orbital science targets. [b]
	Lunar topographic (Hycon, later Actron)	Vacuum platen and image-motion compensation; 457-mm focal-length, f/4 lens; fiducial marks, time, and shutter speed recorded on each frame.	127 mm; black and white films 3400 Panatomic X and S0-349 aerial. [a]	Primarily to obtain high-resolution coverage of the Apollo 16 candidate landing site area near Descartes on the Apollo 14 mission. Camera malfunction prevented achieving this and most other goals. [b]
	Data acquisition (Maurer)	Electric; interchangeable 5-, 10-, 18-, 75-, and 200-mm focal length lenses.	16 mm; color reversal films S0-368 Ektachrome MS, SO-168 Ektachrome EF, and S0-368 Ektachrome EF; black and white films 2845, SO-164 Panatomic X, and AEI 16. [a]	To document engineering and operational data, experiment records within the CSM maneuvers with the lunar module (LM), CM entry, and landmark tracking; to photograph general targets inside and outside the CSM; to obtain continuous sequence terrain photography. [b]
	35-mm (Nikon)	Mechanical; through-the-lens viewing and metering; 55-mm focal length lens.	35 mm; black and white film type 2485; SO-168 Ektachrome EF.[a]	To photograph, under dim light conditions, astronomical phenomena and lunar targets illuminated by Earth shine.[b]

[a] Different combinations of the films listed for the Hasselblad and data acquisition cameras were used different missions.

[b] Specific uses and emphasis upon various uses changed somewhat from mission to mission.
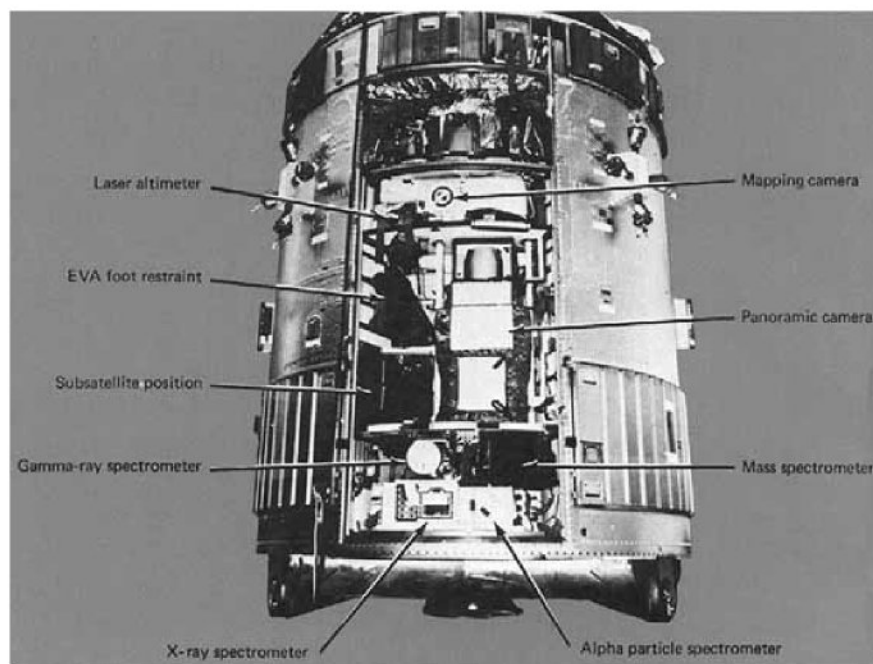
[8] FIGURE 2 [above] .-Arrangement of the equipment used for the orbital experiments conducted from the SIM bay during Apollos 15 and 16 is shown. A largely different assortment of instruments was carried on Apollo 17. The extravehicular activity (EVA) foot restraint is used by the astronaut who retrieves the exposed film from the cameras during the return of the spacecraft to Earth.

....photographs were used to study future landing sites, to perform geologic mapping, to conduct geodetic studies, to study the regional and local geology of the Moon, and to train astronauts for later lunar missions.

On Apollo missions 13 and 14, a lunar topographic camera (the Hycon camera) was carried in the CM. A very limited amount of photography was obtained with it, however, because the Apollo 13 mission was aborted before tile photographic phase was to have begun and on Apollo 14 the camera malfunctioned early in lunar orbit, just as the spacecraft approached the Apollo 16 candidate landing site in the Descartes region. The necessary photographs of the Descartes area were obtained with the Hasselblad (500-mm lens) camera by pitching the spacecraft to compensate for its forward motion in orbit so that no image smear appeared on the photographs.

On Apollos 15 to 17 the much-more-sophisticated mapping and panoramic camera systems were used. These, and other remote sensing instruments, were mounted in the SIM bay that was added to the CSM for the last three missions (fig. 2). Higher resolution and much more systematic coverage of the ground track areas traversed by the spacecraft were obtained with these cameras. Personnel from the Flight Operations Directorate, Johnson Space Center, monitored the performance of the instruments and were essential to the successful acquisition of the data.

The mapping camera system consisted of a terrain camera coupled to a stellar camera and a laser altimeter. Each exposure of the terrain camera was accompanied by a stellar camera exposure of the star field to provide a means of determining the orientation of the spacecraft in space. Simultaneously the laser altimeter recorded the height of the [9] spacecraft above the Moon's surface. At nominal orbital altitude the terrain camera was capable of resolving objects on the surface as small as 25 to 30 m on a side. The geometry of the optical system of the terrain camera permitted the metric pictures to be used for precise triangulation and cartography. Thus they can be used for three purposes: (1) to construct a geodetic network of control points for topographic mapping with both terrain and panoramic camera photographs, (2) to compile medium-scale topographic maps, and (3) to perform photogeologic interpretation.

The panoramic camera, capable of attaining l-m resolution on the surface from orbital altitude, provided high-resolution stereoscopic photographs of the surface during periods of varying Sun angle conditions. High Sun angle pictures show differences in albedo to advantage, and low Sun angle pictures delineate small and low relief features more clearly.

Detailed Camera Description and Stereograms

The Metric Camera System

The coordinated operation of the three components of the mapping camera system is illustrated schematically in figure 3. Except when in use, the mapping camera system is in a retracted position in the SIM bay. During photographic sequences the system is extended on rails to a point where the

terrain and stellar cameras have clear fields of view. The components of the system are illustrated in different degrees of detail in figures 4 through 6. The terrain camera component has a 76-mm, f/4.5 lens to cover a square frame 114 mm on a side. The shutter consists of a pair of continuously rotating disks and a capping blade. An automatic exposure device selects the correct disk speed to provide a range of exposures from I /15 to 1/240 s in duration. The film is held precisely in place by pressure against a movable glass stage plate that contains reseau marks. Fiducial marks are flashed on the film marking the optical axis at midexposure time. Simultaneously, the time of exposure, to the nearest millisecond, according to the spacecraft clock is recorded on the data block on each frame. The film magazine holds 460 m of 127-mm film-enough for 3600 frames. The terrain camera was designed to compensate for the image blur that would otherwise be present in a picture taken from a rapidly moving camera; the stage plate that controls the exposure is driven forward in the direction of flight at a velocity proportional to the ground speed of the spacecraft. The velocity over height value (v/h) is set by the astronaut from the CM. Successive frames overlap by 78 percent (fig. 3) and alternate frames by 57 percent; thus each point on the lunar surface appears on at least four successive frames. In most cases successive orbital passes provided for 60 percent sidelap.

The stellar camera exposes 35-mm film with a 76-mm f/2.8 lens. Each exposure, of 1.5-s duration, is made simultaneously with an exposure of the terrain camera. In the stellar camera the film is pressed against a glass stage plate that bears an array of 25 reseau crosses. The....
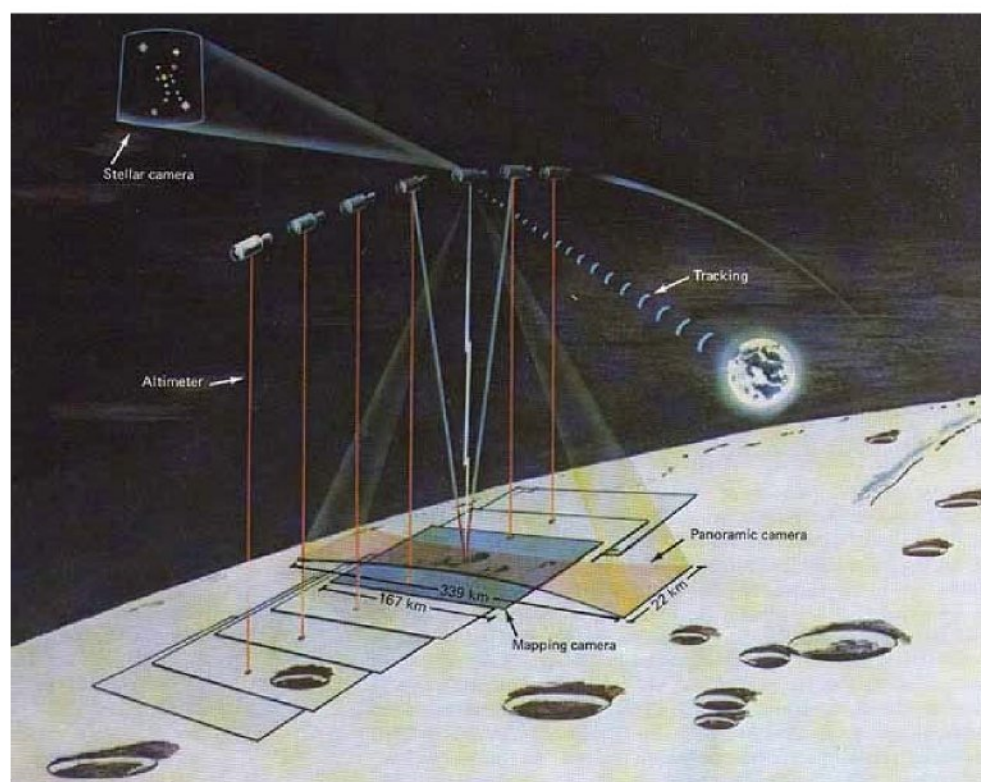
[**10**]

FIGURE 3 [above].- The mapping camera system in operation. During normal photographic operations the terrain camera automatically exposes a series of pictures of the Moon's surface. When the camera axis is perpendicular to the surface (red lines), each exposure outlines a square area (the blue parallelogram in this perspective view). The areas covered by each exposure overlap to form a continuous strip across the surface. The position of the spacecraft in orbit is recorded continuously by radiotracking stations on Earth; however, for precision photography the orientation as well as the position of the spacecraft must be known. This is accomplished with the stellar camera component, which takes a picture of part of the star field each time a terrain camera picture is taken. The stellar camera thus provides the data needed to orient the spacecraft and the terrain camera. The distance to the lunar surface is measured with the laser altimeter. At each exposure of the terrain camera, a beam of light (red lines) from the altimeter is pulsed to the surface (to the center of the area being photographed), and its time of return is recorded. Because the velocity of light is known, the distance between the spacecraft and the Moon is easily calculated. This diagram also shows the relationship in size and shape of areas covered by the terrain (blue) and panoramic (tan) cameras.-G.W.C.

[**11**] FIGURE 4
[right].- The Apollo
mapping camera
system, which

consists of a terrain or mapping camera, a stellar camera, and a laser altimeter. The three components can be located by referring to figure 5. [Photograph courtesy of the Fairchild Camera and Instrument Corporation]
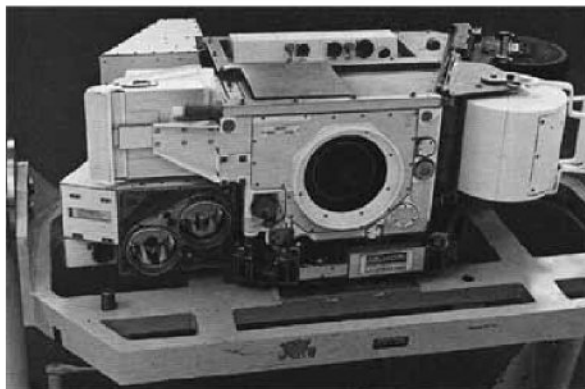
FIGURE 5 [right].- A schematic drawing showing the major components and selected parts of the mapping camera system. The angular fields of view (FOV) are given in degrees for the stellar and mapping (or terrain) camera components.
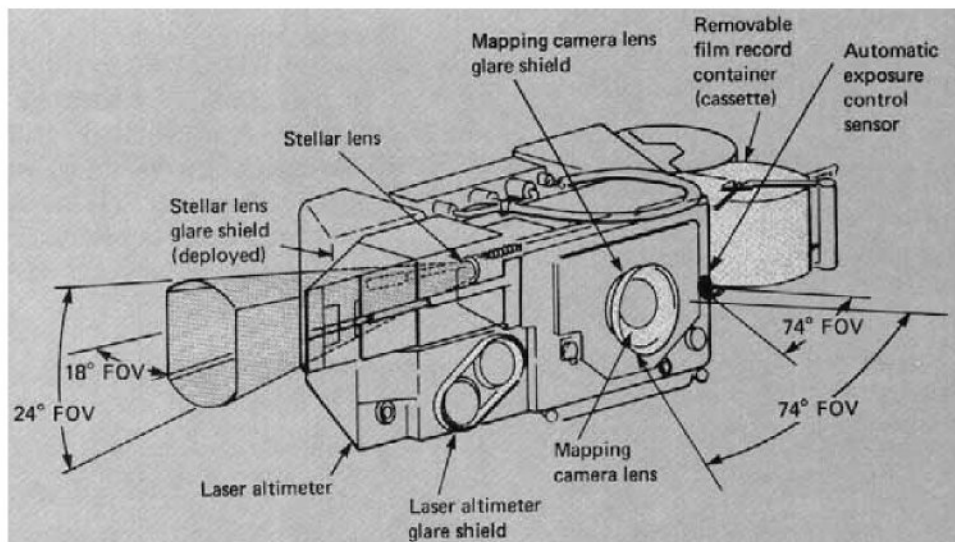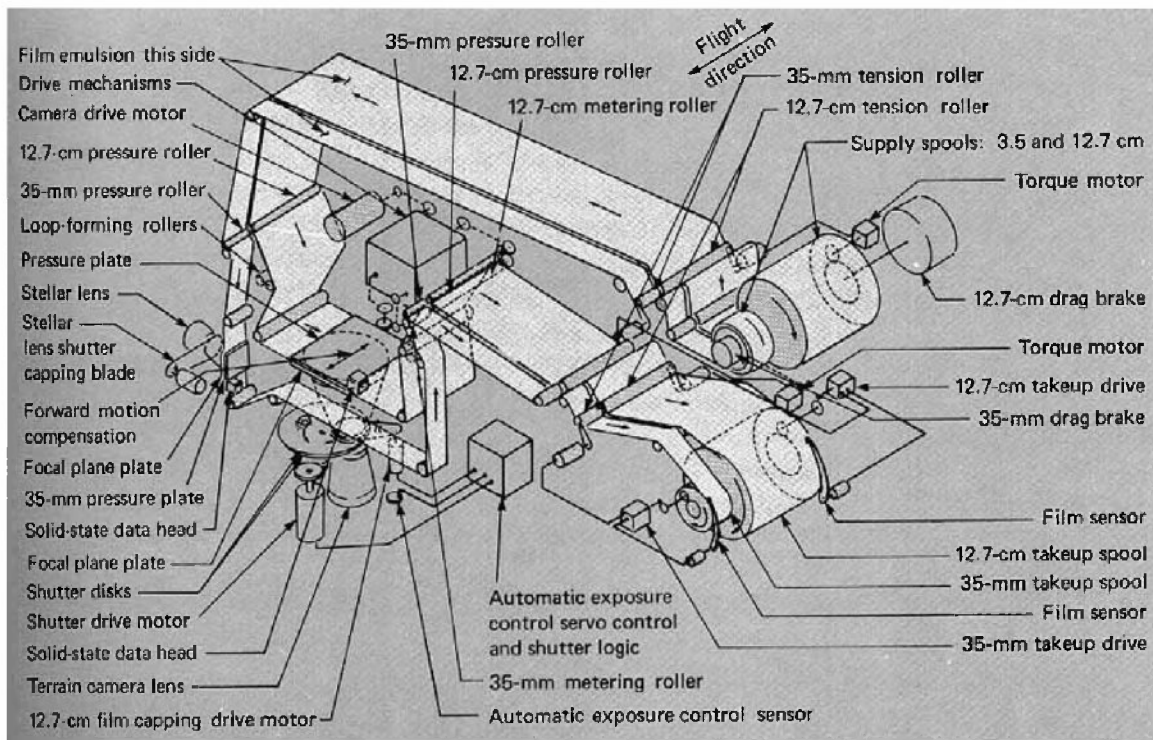
FIGURE 6 [above].- The terrain camera mechanism. (For a more complete description, see Kosofsky (1973).)

[12] ....film is 155.4 m long, allowing 3600 exposures to be made. The stellar camera is rigidly mounted with its optical axis at an angle of 96° to that of the terrain camera. Thus the orientation of the latter (as well as of the spacecraft) can be determined from the known position of the stars recorded by the stellar camera.

The laser altimeter is alined parallel to the optical axis of the terrain camera. A ruby laser emits a very short pulse of red light at the time of each mapping camera exposure and a photomultiplier tube detects the portion of the pulse that is reflected from the Moon. Measurement of the round trip traveltime of the pulse multiplied by one-half the speed of light gives the precise altitude of the spacecraft above the Moon's surface. With the orientation and altitude of each metric photograph thus determined, the metric photographs can be tied together to create a geodetic network of control points.

The Panoramic Camera

High-resolution stereoscopic coverage of large areas of the lunar surface was provided by the panoramic camera. The camera used on the Apollo missions, a modified version of the U.S. Air Force's KA-80A "optical bar" camera, was manufactured by Itek Corp.
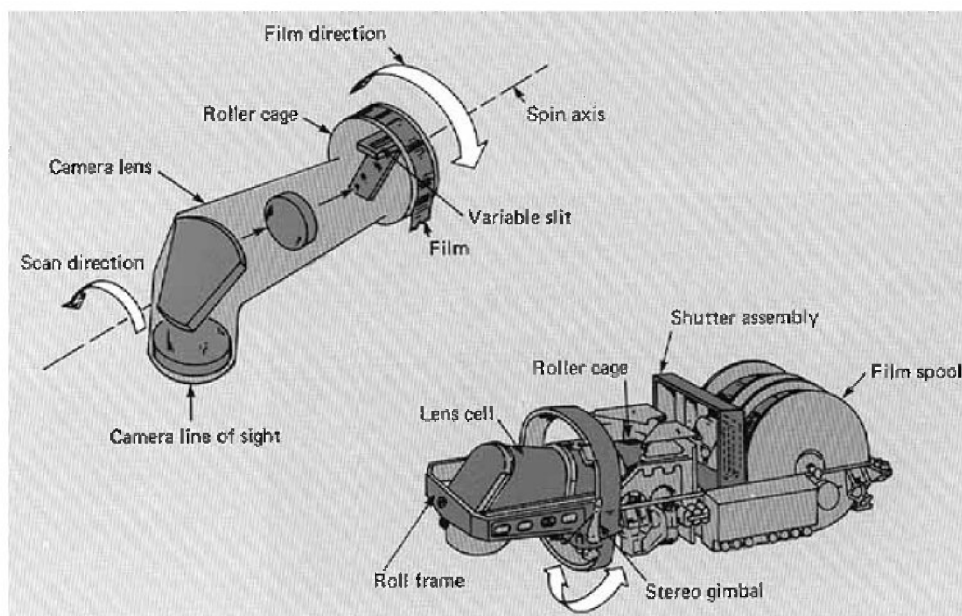
Figure 7 [above].- The panoramic camera shown diagrammatically. Left: The optical bar concept. Right: The camera mechanism with covers removed.

The panoramic camera mechanism allowed an exceptionally wide area to be covered with a narrow-angle lens. This is accomplished by [13] rotating the lens during the exposure. The 610-mm f/3.5 lens has eight lens elements and two folding mirrors. The optical bar, consisting of this optical system, an exposing slit, and a roller cage that supports the film, rotates continuously during camera operation. Film exposure starts at 54° on one side of the flight line and extends to 54° on the other side for a total scan of 108° perpendicular to the flight path. In the direction of flight, the field of view is 10.6°. The photographic exposure of the film is determined by the rate of rotation of the optical bar and the width of the slit. To prevent image smear due to the rotation of the lens, the film is pulled across the slit in the opposite direction.

The optical bar and the motor that spins it are mounted in a roll frame that is connected to the camera's main frame by a gimbal structure (fig. 7). By rocking the roll frame about this gimbal, the camera provides both stereoscopic overlap and forward motion compensation. The exposures are made with the roll frame rocked alternately 12.5° forward and 12.5° aft (fig. 8). The camera cycle rate is controlled so that the ground covered by a forward-looking photograph is covered again five frames later by an aft-looking photograph, thus providing a stereo pair. During the time (about 2 s) that each of these exposures is being made, the same gimbal mechanism "freezes" the ground image by matching the rocking motion to the angular rate at which the ground passes beneath the spacecraft. The camera's v/h sensor, which measures this rate continuously, is the pacemaker for the entire operation.
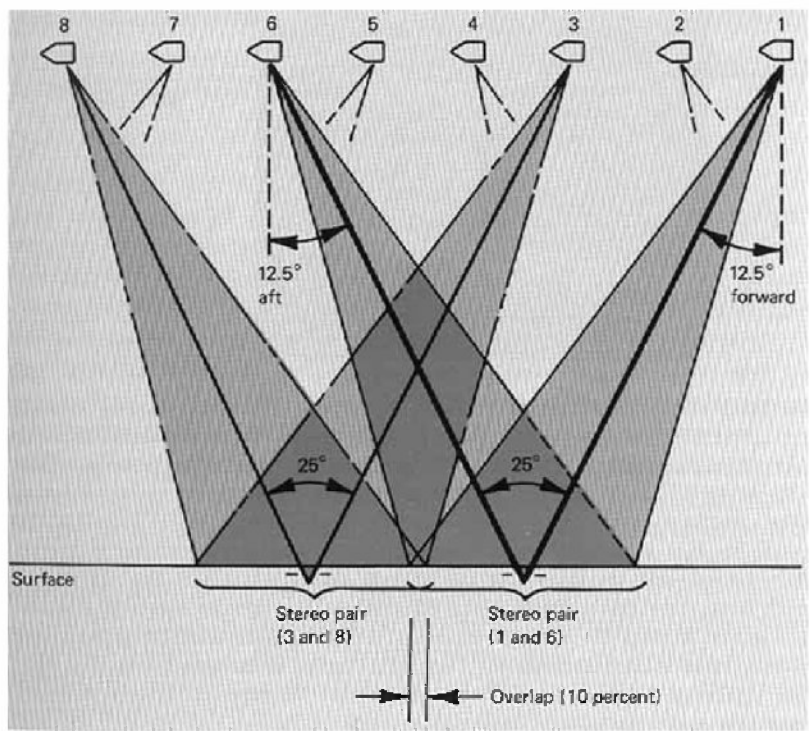
Figure 8 [above].- Diagram showing how alternate exposures of the panoramic camera are taken with the roll frame rocked forward and aft by 12.5° in each direction. The two heavy solid lines converging on a common point at an angle of 25° indicate how stereoscopic coverage is obtained with every fifth exposure. In this case it is with frames 1 and 6.

[14] The main frame of the camera holds all film handling mechanisms. The panoramic camera must move considerable lengths of film rapidly. During the 2s it takes for one exposure, 1.2 m of film must be pulled smoothly over the roller cage and across the exposure slit. This action is...
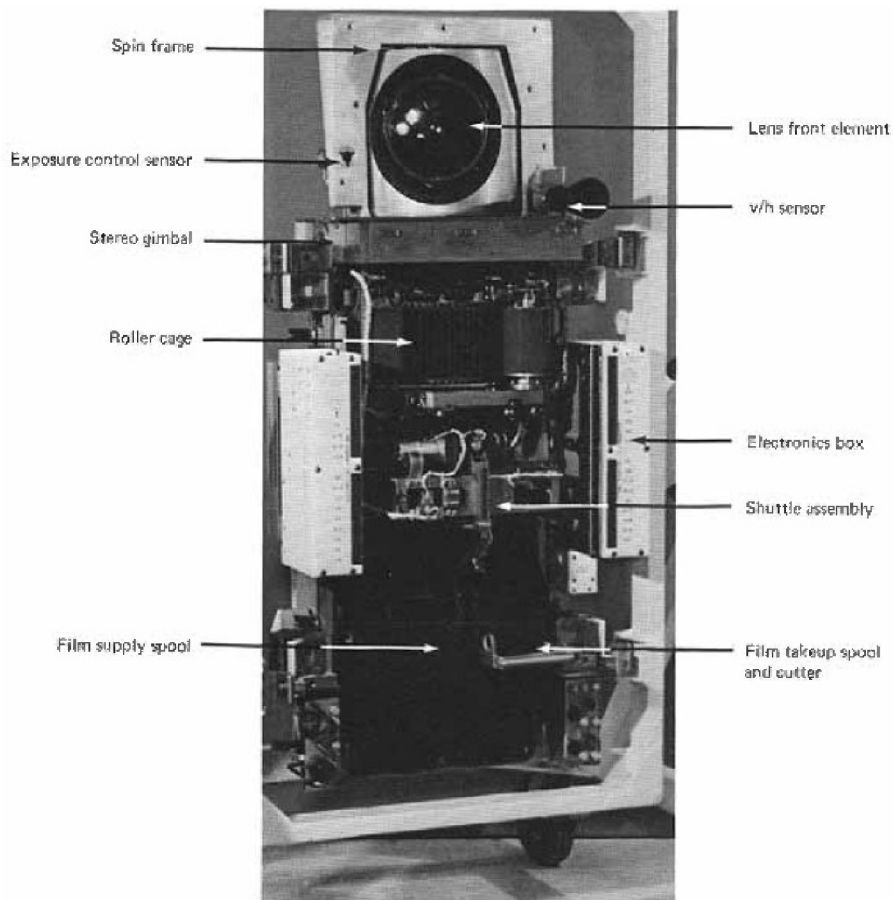
FIGURE 9.- [above] This photograph of the Apollo panoramic camera, supplied by the Itek Corp., was taken at the camera plant. The side facing the reader would face the Moon in actual operation. The covers that normally protect the film from light have been removed to show the internal mechanism. The parts that are not coated with white paint in the photograph would normally be under the covers. The half of the optical bar that includes the lens front elements is necessarily outside the covers, while the half with the roller cage and the rear elements is inside. The roller cage, which is an open drum composed of 60 small rollers, appears dark toned in the photograph. It hides the lens' rear elements. The film shuttle assembly is the silver-colored frame located between the two white-painted electronics boxes. The very dark objects at the bottom of the photograph are the large film spools. A bright metal film cutter can be seen on the takeup side.- L.J.K.

[**15**]

FIGURE 10 [above].- Astronaut Ron Evans retrieving film from the SIM bay cameras while the Apollo 17 spacecraft was returning to Earth.

...repeated every 6 s. A load of film sufficient for 1600 exposures is 2 km long and weighs 25 kg. Because the forces that would be required to start and stop such a mass of film intermittently are prohibitively large, the supply and takeup spools actually rotate continuously during camera operation. An ingenious "shuttle assembly" functions as a buffer between the continuous and the intermittent film movements. In the interval between exposures, the supply side of the shuttle accumulates enough film for the next frame while the takeup spool empties the takeup side of the shuttle.

The arrangement of the camera parts can best be studied in the accompanying photograph (fig. 9), which shows the camera as it would be seen from outside the SIM bay if the light-excluding covers were removed A more detailed description of the camera systems is given in Kosofsky (1973).

The film cassettes from both the metric and panoramic cameras were recovered by the command module pilot (CMP) on the way back to Earth (fig. 10) and stored in the CM for later processing at the Photographic Technology Laboratory, Johnson Space Center.

[16] Photographic Mission Plans and Accomplishments

Personnel from the Science and Applications Directorate and the Apollo Spacecraft Programs Office were responsible for designing the mission plans. The final plans incorporated many of the recommendations made by the Apollo Orbital Science Photographic Team.

Metric camera photography for Apollo 15 had several limiting constraints set by the instrumentation, the requirements of other SIM bay experiments, and the orbital plane of the CM. The high inclination o] the Apollo 15 orbital plane (approximately 25° from the equator; sec fig. 1) resulted in a relatively wide separation of the ground tracks of succeeding revolutions. Because 60 percent side overlap was required for pictures taken in adjacent orbits, careful planning and budgeting of the film was required.

The performance of other scientific experiments using instruments in the SIM bay prohibited concurrent use of the metric camera during some parts of the mission. Some of the experiments were conducted with the SIM bay pointed away from the Moon. During most of the time devoted to the geochemical experiments, such as the gamma ray spectrometer experiment, the SIM bay was pointed toward the lunar surface but the metric camera was retracted and the lens was covered to prevent radioactive thorium contained in the camera and laser altimeter lenses from interfering with the spectrometric measurements. During one orbit, as a test, the two instruments were run concurrently. Radiation from the lenses was less than anticipated; consequently, during the Apollo 16 mission, the two instruments were run concurrently, with only slight degradation of the spectrometric measurements.

Despite constraints such as these, all objectives of the Apollo 15 photographic plan were met, and an excellent set of vertical metric photographs was acquired. In addition, many oblique photographs looking 40° fore and aft and to the north and south of the ground tracks were obtained; although they are of limited use in making topographic maps, they are extremely useful in photogeologic studies.

The panoramic camera on Apollo 15 obtained excellent, very useful photographs, even though its operation was subject to constraints similar to those placed on the mapping camera system. Furthermore, the panoramic camera could only be run for about one-half hour (half the sunlit portion) of any given orbit because of thermal limitations on the instruments. The area of coverage was limited to the same area covered by the mapping camera system because only the latter could provide the geodetic control necessary for constructing mosaics and orthophoto maps from the panoramic camera pictures.

On the Apollo 16 mission, film budgeting was not difficult because the low angle of the orbital plane (about 9° from the equatorial plane) restricted the spacecraft to a narrow orbit belt and hence limited the width of the area that could be photographed from the vertical mode (fig. 1). The planned coverage for both systems was obtained long before the film loads were consumed. The original mission plans were to take the metric and panoramic photographs very early and very late in the orbital phase when the near-side terminator had progressed far [17] enough west to permit photographing the western limb. However, early in the orbital phase problems developed with the spacecraft orientation mechanism that forced a decision to shorten the mission time by 1 day. Although the time available for orbital photography was less than originally planned, about 90 percent of the planned photographic coverage was obtained. Only the westernmost part of the orbital tracks was not photographed.

The orbital attitude of the Apollo 17 spacecraft was similar (about 20° from the equatorial plane) to that of Apollo 15; because much of the ground track area had previously been photographed by the earlier mission (fig. 1), the 60 percent overlap requirement was waived. In some areas previously photographed during the Apollo 15 mission, photographs were obtained when the Sun angle was different from that of the earlier photographs; additional information was supplied in this way.

Apollo 17 carried several new orbital experiments including the infrared scanning radiometer, the UV spectrometer, and the lunar sounder experiments. Some of these required special spacecraft attitudes and freedom from interference, thereby reducing the amount of time available for using the SIM bay camera systems. However, modifications made in the photographic plan to accommodate these experiments on this and earlier missions proved worthwhile because the results of the experiments have proved useful in supporting photogeologic interpretations.

The panoramic camera was used to extend the Apollo 15 photographic coverage and to fill gaps in both the Apollo 15 and 16 belts.

Cartographic Mapping Products

When the Apollo program ended with the successful completion of mission 17, nearly 10 000 metric and 4800 panoramic photographs had been acquired. Controlled orthophotomaps at a scale of 1:250 000 (fig. 11) are being made from the metric photos; the panoramic camera photographs are being used to make large-scale maps at 1:50 000 and 1:10 000 scale for particular areas of scientific interest (fig. 12). The basic data analysis scheme for converting the raw photographs into finished map products is described in Appendix C (Doyle, 1972). The production of these maps is a massive undertaking and will take many years to complete.

Copies of individual Apollo photographs may be ordered from-

National Space Science Data Center
Goddard Space Flight Center

Greenbelt, Md. 20771

Orthophotomaps and other cartographic products may be obtained from-

Lunar and Planetary Programs Office
National Aeronautics and Space Administration
Washington, D.C. 20546
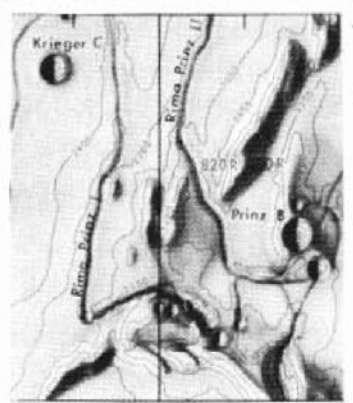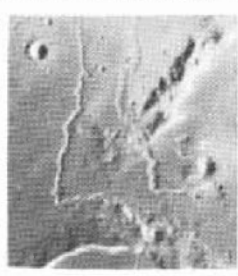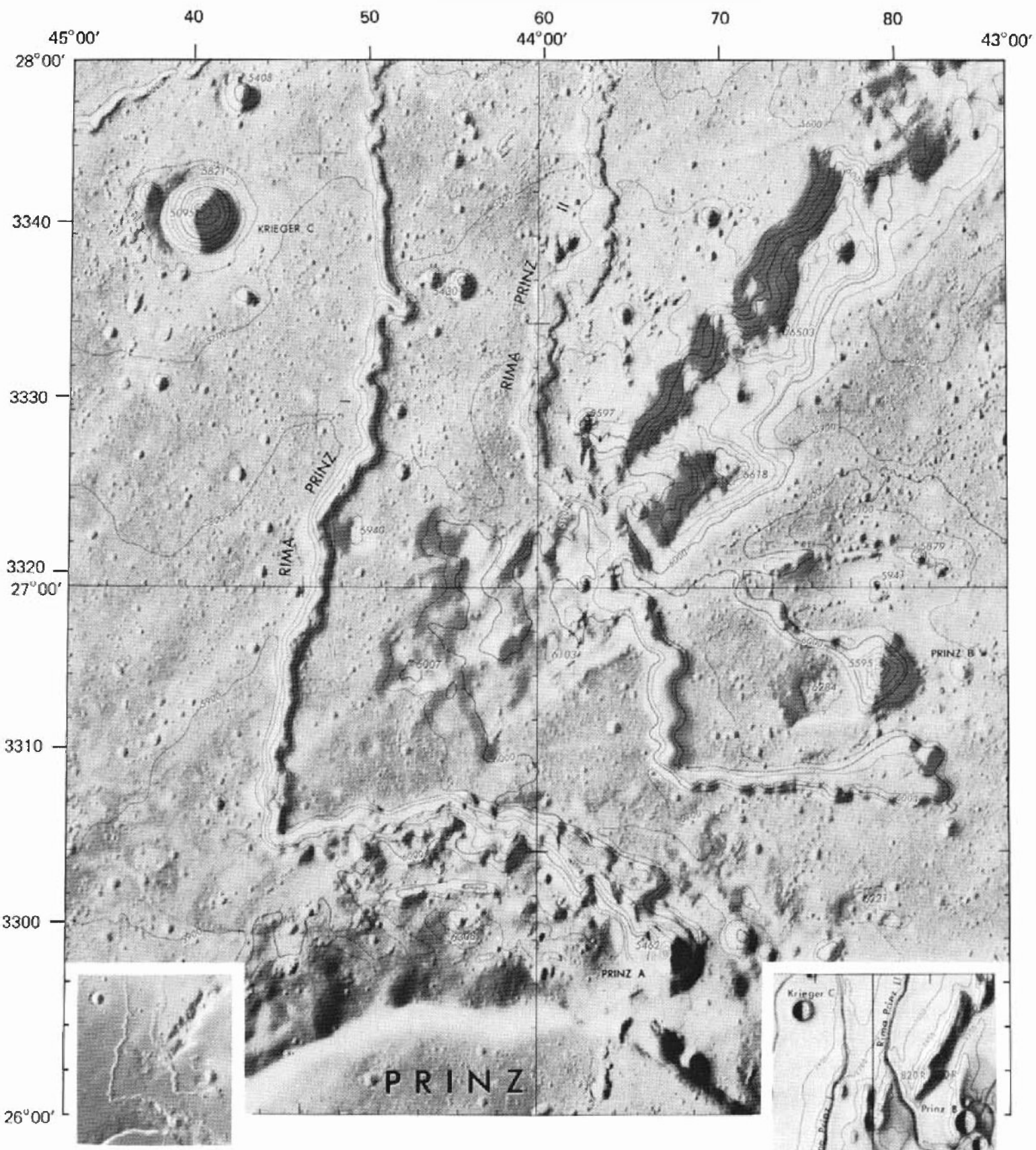
Original scale 1:250 000

| 5 | 0 | 5 | 10 | 15 | 20 | 25 | 30 km |

Contour interval: 100 m
Supplementary contours at 50-m intervals

[**18**] Contour interval: 100 m

Transverse Mercator Projection

Supplementary contours at 50-m intervals.

The Apollo 15 datum was established by photogrammetric triangulation based on the Apollo 15 mission ephemeris dated December 1971.

Map and contour elevations are derived from radius vectors from the mass center of the Moon as referred to an arbitrary zero vertical datum of 1 730 000 m; for example, the map elevation of a point with a radius vector length of 1 735 000 m is derived by subtracting 1 730 000 m to obtain 5200 m.

[**19**] FIGURE 11 [above].- An example of the detailed topographic portrayal made possible by mapping camera photographs. The sample area shown is part (about one-fifth) of Lunar Orthophoto Map sheet LTO39A3(250), prepared by the Defense Mapping Agency Topographic Center, Washington, D.C., and published in 1973. The rilles are Rima Prinz I and II in northern Oceanus Procellarum. Topographic contour lines (lines of equal elevation) in red are superposed on an orthophotograph version of mapping camera frame AS15-2474 enlarged to the scale of the map. For comparison (or contrast) that portion of the frame corresponding in area to the sample map is shown in the lower left corner. At the lower right is the same area as it appeared on Lunar Aeronautical Chart (LAC) 39, which was one sheet of the earliest series of detailed cartographic maps of the Moon showing surface relief. Compiled entirely from photographs taken through Earth-based telescopes and from direct telescopic observations, it was published in 1963 by the U.S. Air Force Aeronautical Chart and Information Center, St. Louis, Mo.-G.W.C.
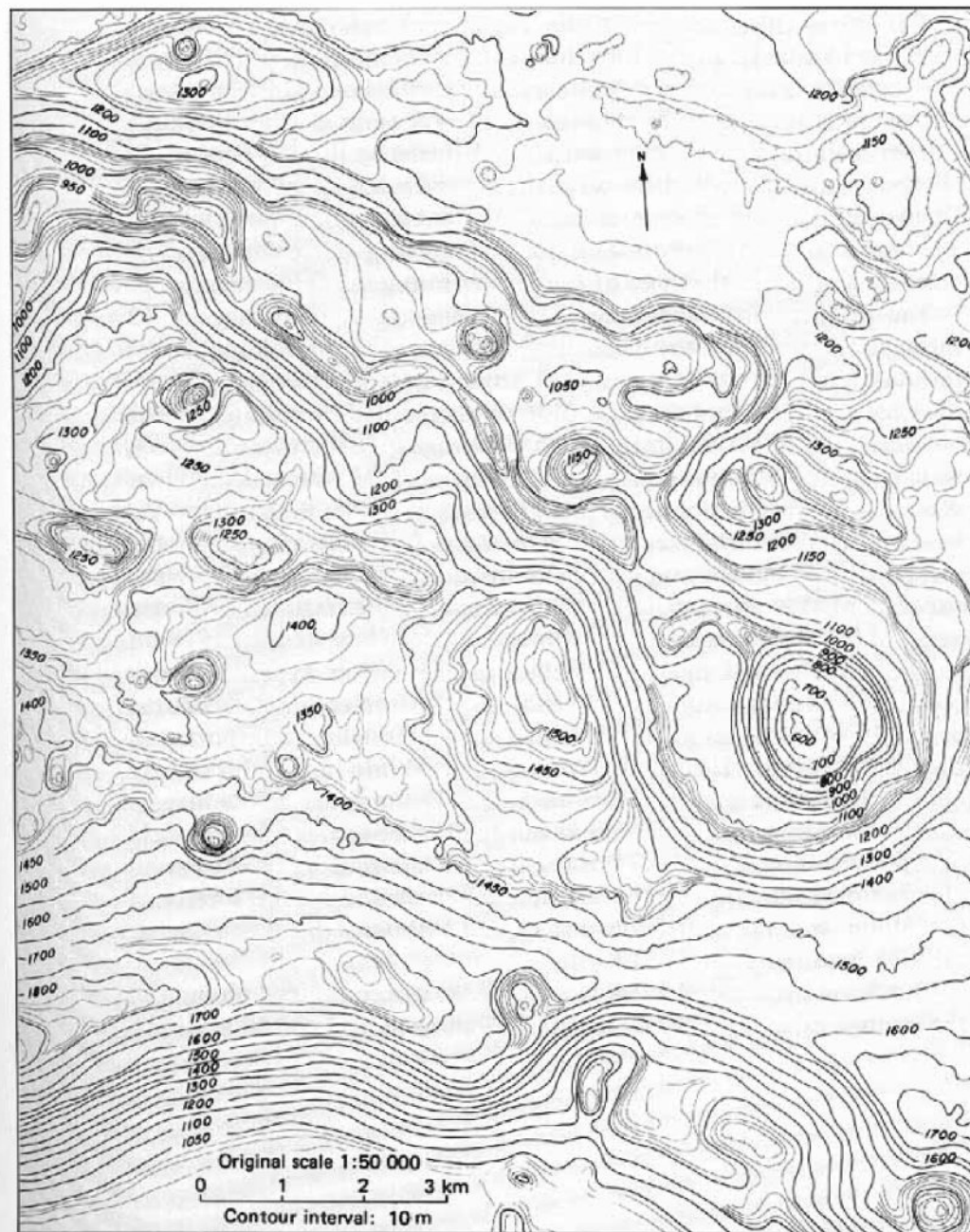
FIGURE 12 [above] .-Another example of the versatility of photographs taken of the lunar surface from orbital altitudes. This topographic contour map was compiled by photogrammetric methods from two Apollo 15 panoramic camera frames. It shows a small area around the head of Rima Prinz I, one of the rilles covered in the preceding map (fig. 11). It was prepared in Flagstaff, Ariz., in support of a geologic study of rilles and their origin. It will not be published separately, hence, many of the stylistics of a map prepared for publication are lacking. Nevertheless, it is a fine example of what can be "seen" in panoramic camera pictures taken, in this case, at an altitude of 119 km.-G.W.C.

Selected Orbital Experiments

[20] In this section we discuss only those orbital experiments that collected data relevant to photointerpretation. All of the instruments used for these experiments were transported in the SIM bay.

The gamma ray spectrometer (GRS) experiment aboard Apollos 15 to 16 detected gamma rays produced by the radioactive decay of materials on the lunar surface; areal variations in the intensity of gamma radiation make it possible to map the distribution of rock types along the ground tracks. The detector, which was mounted on a boom, contains a crystal that responds to an incident gamma ray by emitting a pulse of light. The light-pulse is converted by a photomultiplier tube into an electrical signal the strength of which is proportional to the energy of the gamma ray. The electrical signal is then processed and sent to Earth over the radio telemetry channel. Signals from other charged particles are canceled in the electronics processing so that

only the gamma rays signals are returned to Earth.

The X-ray fluorescence (XFE) experiment was used on Apollo missions 15 and 16 to measure the chemical composition of the Moon. The sunlit portion of the Moon is constantly bombarded by solar X-rays. It is the secondary fluorescent X-rays emitted from the lunar surface material that are detected and measured by this experiment. In particular, the characteristic wavelengths and energies of magnesium, aluminum, and silicon were detected. Variation of the ratios of Mg/Si and Al/Si are extremely useful for determining the chemical composition and hence the type of rock constituting the surface materials.

The bistatic radar experiment, conducted on Apollo missions 13 through 16, measured the electromagnetic and structural properties of the outer few meters of the Moon's crust. Radio signals emitted from the CSM were reflected from the Moon and recorded by radiotelescopes on Earth. As the CSM orbited, the impinging beam of radiowaves, which covered a 10-km-square area of the surface, scanned the lunar disk. The characteristics of the areas so measured were then interpreted in terms of dielectric properties, size of the fragments composing the surface debris, and the magnitude and frequency of sloping surface. The experiment thus provides a means of measuring the small-scale "roughness" of the lunar surface.

The particles and fields subsatellite magnetometer experiment was conducted during Apollos 15 and 16. Instrumentation consisted primarily of a magnetometer mounted on a subsatellite transported in the CSM SIM bay. The subsatellite was inserted into lunar orbit shortly before the CSM began its return to Earth. The purpose of the magnetometer was to record variations in time and space of the magnetic field at Apollo orbital altitudes. The resulting data are being used to complement data obtained by the magnetometers placed on the surface of the Moon and the magnetometer carried onboard the much higher orbiting Explorer 35.

The S-band transponder (SBT) experiment was conducted on the last three missions, and gravity field observations were made on all missions.

[21] The transponder was used to measure areal variations in the Moon's near-side gravitational field by recording very slight changes in the velocity of the orbiting CSM, subsatellite, and the LM. Changes in the gravitational field are caused by differences in density of the rocks. The experiment thus provides data for mapping the density of the rocks composing the upper part of the lunar crust. Radio signals transmitted to the three orbiting spacecraft components from Earth were multiplied by a constant (for electronic reasons) and then retransmitted to Earth. The difference in frequency between the transmitted and returned signals is a function of the velocity of the spacecraft.

The Apollo lunar sounder (ALSE) experiment was conducted only on Apollo 17. It used radar techniques to "see" into the Moon to depths as great as 1 1/2 km. The sounder was designed for three primary modes of operation: the sounding mode detected and mapped subsurface features, and the profiling and imaging modes provided quantitative metric and topographic data as well as albedo measurements. Three frequencies of radiowaves were transmitted to the Moon from antennas mounted on the SM. Some of the waves were reflected by the lunar surface while others penetrated to various depths depending upon the type of material encountered. Those that penetrated the Moon were reflected by layers of rock within the Moon. The reflected component of the radiowaves was detected by the spacecraft antennas, delivered to the receiver, amplified and converted to light signals, and recorded optically on photographic film. The character of the reflected waves furnishes information about the nature of subsurface layers, and their return times tell the depth of the reflecting layers.

The infrared scanning radiometer (ISR) on board Apollo 17 was used to measure the emission of heat from the Moon's surface. A sensitive thermometer was mounted at the focus of a telescope. Light from a small area (about 2 km^2) of the Moon's surface enters the telescope through a mirror that oscillates back and forth to scan the surface of the ground track. After passing through various components of the instrument to a detector, the radiant energy of the light beam is changed into an electrical signal. This electrical signal is related to the temperature of the spot that is viewed by the telescope at any instant in time. The thermal properties so measured can then be correlated with known geographic and geologic features.

Scientific Results

Interpretation of the photographic products of the Apollo missions, augmented by the array of data obtained from the geochemical and other orbital experiments, has given rise to many new ideas about the configuration and origin of the lunar crust. The evolution of the Moon's crust is diagramed in figure 13 to show the temporal relationship of the major processes that affected the upper part of the crust.

One of the notable returns from the Apollo program is the radiometric dating of returned samples showing their great antiquity. This information is proof that the lunar surface we see is very old-...

Geologic periods

Billions of years before present

Significant events

Copernican

0

◄ Crater South Ray

1

◄ Crater Copernicus

Eratosthenian

2

3

Mare

Imbrian

Basins

Light plains

◄ Youngest returned mare samples

Nectarian

4

Craters

◄ Orientale basin
◄ Imbrium basin
◄ Nectaris basin

Pre-Nectarian

Formation of lunar crust

◄ Oldest returned lunar sample
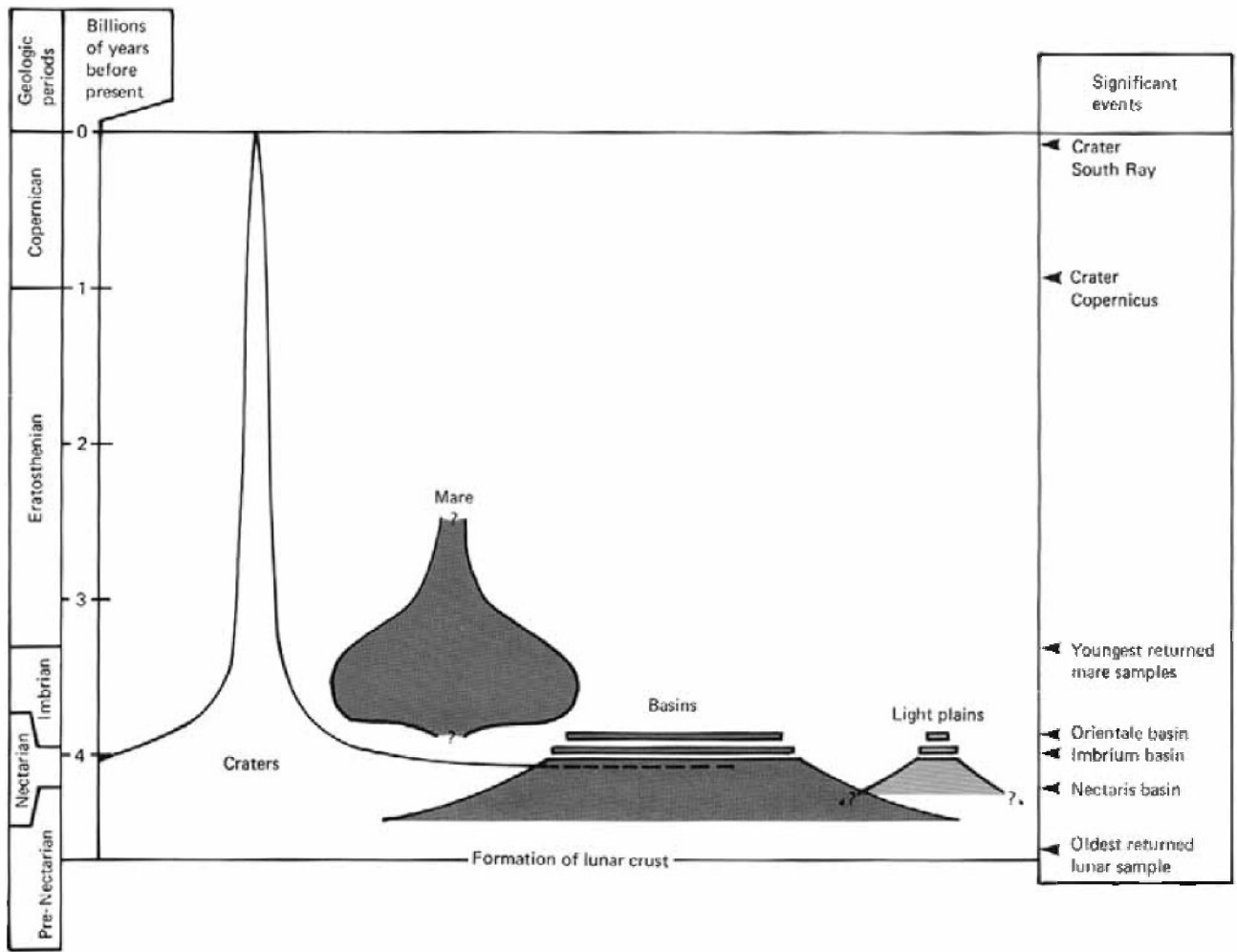
[22] FIGURE 13 [above].- This diagram, conceived by D. E. Wilhelms, graphically summarizes the sequence in which the major rock types of the lunar surface accumulated. Time scales are shown on the left, and the position in time of representative events and of selected returned lunar samples is shown on the right. The horizontal scale has no time connotation. The areas covered on this diagram by each of the four types of deposit are roughly proportional to their present areal extent on the surface of the Moon. Craters probably began to form and crater deposits began to accumulate as soon as the crust had solidified about 4.6 billion years ago. However, the early part of the record is hidden, and the rate at which they formed is unknown. At the end of Nectarian time or the beginning of Imbrian time, about 4 billion years ago, the rate at which craters formed began to decrease abruptly. It has continued to decrease, but much less rapidly, to the present. Mare materials had a very different history. The oldest mare materials to be recognized among the returned samples or on the basis of photogeologic mapping are early Imbrian in age. They apparently postdate, although by little, the formation of the Imbrium basin. The bulk of the mare material accumulated during the Imbrian period, but photogeologic studies (including crater-counting methods) indicate that some is at least as young as Eratosthenian. All basin and light plains deposits are ancient-apparently none being younger than early Imbrian in age.-G.W.C.

[23]...much older than the surface of Earth, which has been so degraded and changed by dynamic forces that primary crustal material is now largely unrecognizable. The lunar samples, therefore, provide a clue to the possible composition of original rocks on Earth. Information from the returned samples can also be extrapolated to date rocks underlying the lunar surface far from the landing site areas. In this way a new understanding of the general history of the Moon is emerging.

The mare areas of the near side of the Moon appear to be 2 to 5 km below mean lunar radius; the far side appears to be as much as 5 km above mean radius. Basaltic lava flows (the "maria") fill most of the low-lying basins on the near side (fig. 14); thicker, low density rocks underlie the high-standing ("terra") regions found on both near and far sides. The marked difference between the dark lowland regions (maria) and the bright highland regions (terrae) was first noted by Galileo in 1609. The results from several of the Apollo orbital experiments have confirmed their essential difference (fig. 15). Laser altimetry and gravity tracking results have defined marked differences in elevation. Variations in Al/Si and Mg/Si ratios obtained from the X-ray fluorescence experiment have confirmed the chemical difference between the two terrain types and strongly indicate that there has been little lateral surface transport of material from the highlands to the low-lying mare basins (Adler et al., 1974). Variations in gamma activity determined by gamma ray spectrometry have also documented this essential difference.

Recent estimates of the thickness of the lunar crust based on orbital laser altimetry, S-band tracking data, and surface seismic information indicate the existence of 20 km of basalt overlying 20 km of anorthositic material-crust-under eastern Oceanus Procellarum, 5 km of crust under some of the circular mare basins, 48 km under the near-side highlands, and 74 km of crust under the far-side highlands (Kaula et al., 1974). Variation in thickness of

the lunar crust may have been caused by early chemical differentiation of the crust soon after the Moon was locked to Earth by gravitational attraction.

Orbital and surface magnetometer measurements (Coleman et al., 1972*a,b,c*) correlate closely with the gamma ray highs and lows. The deflection of the solar wind observed over some limb areas by the subsatellite magnetometer are thought to be caused by regions of high magnetization in that part of the Moon.

Tracking of the spacecraft as they respond to gravity has shown that craters up to 100 km in diameter are deficient in mass; that is, they constitute gravity lows. On the near side, mare- filled craters more than 150 km in diameter have positive gravity anomalies (Sjogren, Wimberly, and Wollenhaupt, 1974). The anomalies are probably caused by the dense basaltic lava flows that fill the craters and the underlying denser materials in the lower part of the crust that were thrust upward by the impact.

Basaltic lava flows occupy irregular mare areas, such as the very large one recognized as Oceanus Procellarum, as well as the many circular multiringed structures 150 km or more in diameter that are thought to have originated as impact basins (fig. 14). Among the best examples of...

Near side / Far side
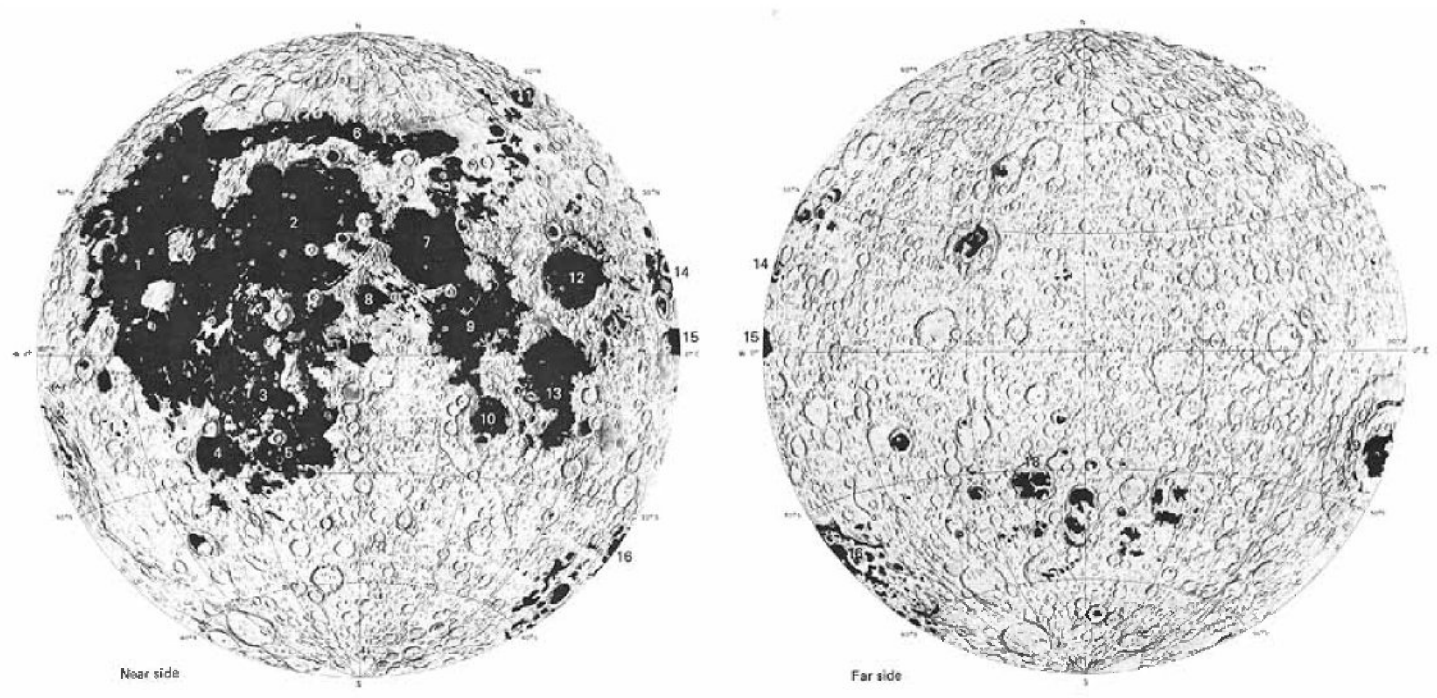
[24] FIGURE 14 [above].- This highly simplified geologic map distinguishes between the two major types of lunar terrain. Mare areas are shown in black, and terra or highland areas are shown without overprint as they appear on "The Earth's Moon" [courtesy of the National Geographic Society]. The unequal distribution of mare materials is shown to advantage on this equal area projection. Also clearly evident is the tendency of mare materials to be concentrated within the margins of large multiringed circular basins. The Serenitatis (7), Crisium (12), Moscoviense (17), Ingenii (18), and Orientale (19) Maria are especially good examples. The broad irregular expanse of mare material known as Oceanus Procellarum is another type of occurrence.- G.W.C.

Legend:
1 Oceanus Procellarum
2 Mare Imbrium
3 Mare Cognitum
4 Mare Humorum
5 Mare Nubium
6 Mare Frigoris
7 Mare Serenitatis
8 Mare Vaporum
9 Mare Tranquillitatis
10 Mare Nectaris
11 Mare Humboldtianum
12 Mare Crisium
13 Mare Fecunditatis
14 Mare Marginis
15 Mare Smythii
16 Mare Australe
17 Mare Moscoviense
18 Mare Ingenii
19 Mare Orientale
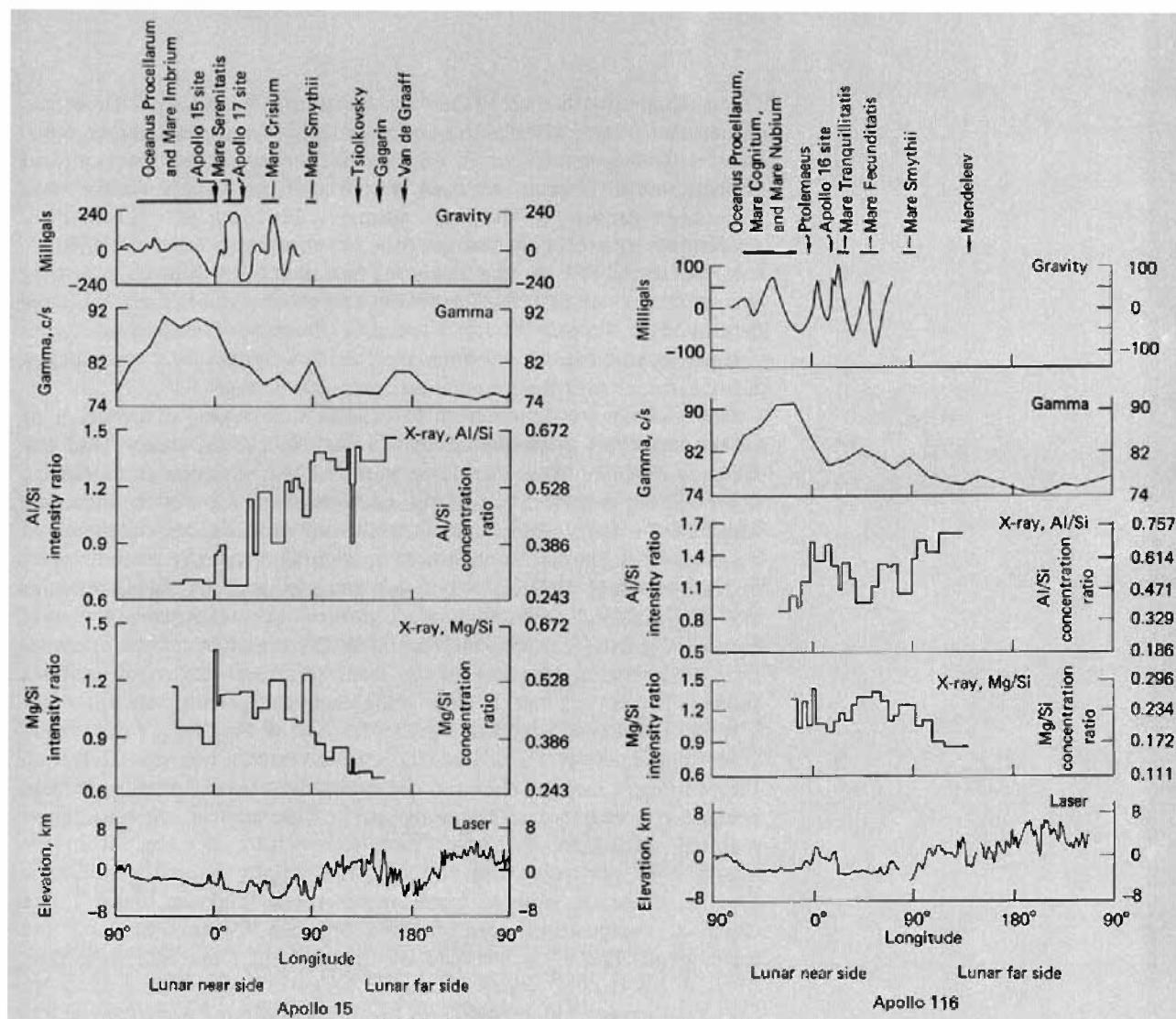
[25] FIGURE 15 [above] .- Curves showing correlations of some physical and chemical properties recorded by elected remote sensing instruments carried in the SIM bay with topographic and geologic features. Left: Representative sensing curves plotted from data recorded along some of the Apollo 15 ground tracks. Right: The same types of data but along some of the Apollo 16 ground tracks. For purposes of location, selected geographic features are shown at the top of the graphs and degrees of longitude along the bottom. These curves show many interesting relations including (1) the positive gravity anomalies (concentrations of mass or "mascons") marking the circular mare basins, (2) the high gamma radiation from the border between Oceanus Procellarum and Mare Imbrium, (3) the inverse relationship between rations of Al/Si and Mg/Si, (4) the systematic change in these ratios from maria to terrae, and (5) the differences in elevation between mare areas (low) and terra areas (high). Another significant observation is that the east limb of the Moon near Mare Smythii is much lower in elevation than other areas along the Apollo 15 and 16 ground tracks. In fact, the mare areas on the front side decrease in elevation from the west limb at Oceanus Procellarum to the east limb at Mare Smythii.

[26]...impact basins with mare filling are Imbrium, Crisium, and Orientale. Other multiringed circular basins of probable impact origin are, however, devoid or nearly devoid of mare fill. Structural, geochemical, and topographic differences between the circular and irregular mare areas have been proven by the laser altimeter, lunar sounder, gamma ray spectrometer, and X- ray fluorescence experiments, as well as by photointerpretation. The circular maria are bounded by striking cliff-forming arcuate segments of crustal blocks while the irregular maria have low serrate edges. Positive gravity anomalies ("mascons") delineated by the S-band transponder experiment are associated with the impact basins but are absent over the irregular areas.

There are many hypotheses to explain the varying distribution of crustal materials documented by the Apollo orbital sensors and the samples returned from the lunar surface. The variation in thickness, composition, and elevation of the mare and terra regions, the increased gamma ray activity observed in the midfront and far sides, the increased magnetic and gamma ray measurements obtained over some limb areas, and the essential differences between irregular and circular mare basins and the highland areas all imply a controlling mechanism. A theory based on mantle convection (the internal circulation of hot material) gives a possible explanation for the observed sensor data and describes a possible controlling mechanism for the chemical, geophysical, and topographic variations. Very early in tile history of the Moon's formation, when it was very hot and fluid, the mantle material was separated from the primordial melt by chemical differentiation. Lower density material became concentrated in the upper part of the mantle, whereas denser material settled in the lower part. Convection currents within the mantle then partially stripped the lighter weight material from' some areas to

cause the marked variation in crustal thickness, density, and chemical composition now observed between the present terra and mare areas. The areas stripped of lighter weight material were then flooded by basalts, which presently lie on a greatly thinned crust. Localized areas of increased concentrations in gamma ray and magnetic activity were caused by internal circulation and concentration of materials with higher magnetic and gamma ray properties. The mantle convection theory, however, is still being debated. True understanding of the development of the lunar crust may require years of additional study.

The mechanics of impact cratering have been studied intensively with the aid of the Apollo data. Craters ranging in size from the giant basins hundreds of kilometers across (like the Imbrium basin), to the smallest craters visible in orbital photographs (1 m in diameter), to microcraters on the surface of minute glass spheres contained in the returned lunar soil samples have been studied.

Crater ejecta material has been studied and classified into two groups: ballistic ejecta that is thrown out to form linear or curved patterns of rays and clusters of secondary craters on the Moon's surface, and fine-grained fluidized ejecta that locally blankets the lunar surface and forms patterned flows extending downrange from the primary [27] impact crater. The continuous ejecta blanket is apparently emplaced by base surge flow on the surface surrounding the crater. A striking example of surface patterns created by ejecta flow and its interaction with the local topography is found near the far-side crater King (fig. 159).

The continued bombardment of the lunar surface by meteoroids and secondary impact material has formed a regolith on the surface composed of breccia fragments and unconsolidated fragmental debris. The thickness and age of the regolith vary systematically. In general, thickness estimates based on crater shape agree well with estimates based on bistatic radar measurements.

A variety of features has been investigated and recognized as being of volcanic origin. Other terrain features have been more equivocally classified as possibly volcanic in origin. A succession of lava flows has been mapped in the Imbrium basin. Dark halo craters have been studied extensively and divided into two classes: The round, smooth-sided craters with no visible blocks in the crater walls are believed to be volcanic, and the dark halo material is thought to be composed of very fine-grained volcanic ejecta. Dark halo craters having irregular outlines may be impact craters from which darker material was exhumed at the time of impact. Lines or chains of craters have also been classified into two groups: volcanic crater chains (Hyginus Rille and Davy crater chain) and secondary impact crater chains extending radially from large craters (such as Copernicus, Kepler, and Aristarchus) and formed by ballistic ejecta from the large craters.

<div align="center">

Acknowledgments

</div>

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APOLLO OVER THE MOON: A VIEW FROM ORBIT (NASA SP-362)

Appendix A Photographic Data

Figure number	Frame number	Altitude, km	Sun elevation, deg	Camera Tilt,deg	Camera Azimuth, deg.	Camera system [a]	Lens focal length, mm	Film type	Frame type [b]
Introduction									
10	AS17-152-23391	-	-	-	-	M	80	S0-368	FF
Regional views									
17	AS16-3021	-	-	-	-	M	76.2	S0-368	FF
18	AS17-3153	-	-	Vertical	-	P	610	3414	FF
19	AS16-0729	116	15	40	358	M	76.2	3400	FF
20	AS17-150-22959	117	18	57	199	H	80	S0-368	FF
21	AS15-2503	113	15	40	185	M	76.2	3400	FF
22	AS17-2871	113	56	62	292	P	610	3414	FF
23	AS11-37-5437	-	Low	62	-	H	80	SO-168	FF
24	AS16-0566	113	25	25	269	M	76.2	3400	FF
25	AS16-2478	119	28	40	174	M	76.2	3400	FF
26	AS16-2518	124	36	Vertical	-	M	76.2	3400	FF
27	AS17-0940	110	24	40	3	M	76.2	3400	FF
28	AS17-0953	105	6	40	357	M	76.2	3400	FF
29	AS15-1537	106	31	40	5	M	76.2	3400	PF
30	AS15-93-12602	108	19	60	180	H	80	S0-368	FF
31	AS15-2618	105	4	40	180	M	76.2	3400	FF
The Terrae									
33	AS17-155-23702	115	8	61	3	H	80	2485	FF
34	AS17-0274	191	43	Vertical	-	M	76.2	3400	PF-M
	AS17-0278	200	39	Vertical	-	M	76.2	3400	PF-M
	AS17-0281	206	35	Vertical	-	M	76.2	3400	PF-M
	AS17-0286	217	29	Vertical	-	M	76.2	3400	PF-M
	AS17-0289	224	26	Vertical	-	M	76.2	3400	PF-M
	AS17-0293	232	21	Vertical	-	M	76.2	3400	PF-M
	AS17-0294	234	20	Vertical	-	M	76.2	3400	PF-M
35	AS17-1674	104	9	40	177	M	76.2	3400	FF
36	AS17-1817	106	18	Vertical	-	M	76.2	3400	FF-M
	AS17-1819	105	15	Vertical	-	M	76.2	3400	PF-M
37	AS17-2433	114	28	40	183	M	76.2	3400	FF
38	AS17-1825	103	7	Vertical	-	M	76.2	3400	FF
	AS17-1828	103	4	Vertical	-	M	76.2	3400	PF-M
39	AS15-9297	106	39	Aft	-	P	610	3414	PF
40	AS17-136-20694	On surface	16	-	-	H	60	3401	FF
41	AS17-144-22129	On surface	28	-	-	H	500	3401	PF

Figure number	Frame number	Altitude, km	Sun elevation, deg	Camera		Camera system [a]	Lens focal length, mm	Film type	Frame type [b]
				Tilt,deg	Azimuth, deg.				
42	AS15-9804	107	32	Aft	-	P	610	3414	PF
43	AS15-90-12187	On surface	30	-	-	H	60	3401	PF-S
	AS15-90-12209	On surface	31	-	-	H	60	3401	PF-S
44	AS16-1420	113	2	40	2	M	76.2	3400	FF
45	AS16-0700	114	24	40	180	M	76.2	3400	FF
46	AS16-0974	115	28	Vertical	-	M	76.2	3400	PF-S
	AS16-0976	114	26	Vertical	-	M	76.2	3400	PF-S
47	AS16-124-19829	308	3	50	275	H	250	2485	FF-M
	AS16-124-19830	309	3	45	275	H	250	2485	FF-M
	AS16-124-19831	308	3	50	275	H	250	2485	FF-M
48	AS16-1411	114	15	40	360	M	76.2	3400	FF
49	AS16-0982	113	19	Vertical	-	M	76.2	3400	FF
50	AS17-0304	254	9	Vertical	-	M	76.2	3400	PF
51	AS16-1646	118	52	Vertical	-	M	76.2	3400	PF-S
	AS16-1648	118	49	Vertical	-	M	76.2	3400	PF-S
52	AS17-2302	114	19	Aft	-	P	610	3414	PF
53	AS16-0708	112	13	40	180	M	76.2	3400	FF
54	AS16-0989	112	10	Vertical	-	M	76.2	3400	FF
55	AS16-2965	123	45	Vertical	-	M	76.2	3400	PF
56	AS16-0875	117	29	Vertical	-	M	76.2	3400	FF
The Maria									
58	AS17-0448	113	12	Vertical	-	M	76.2	3400	PF-M
	AS17-0449	112	10	Vertical	-	M	76.2	3400	PF-M
	AS17-0452	111	7	Vertical	-	M	76.2	3400	PF-M
	AS17-0604	110	5	Vertical	-	M	76.2	3400	PF-M
	AS17-0805	108	8	Vertical	-	M	76.2	3400	PF-M
	AS17-0808	107	4	Vertical	-	M	76.2	3400	PF-M
59	AS17-150-23069	108	20	28	176	H	80	S0-368	FF
60	AS15-1115	111	52	Vertical	-	M	76.2	3400	PF
63	AS17-2102	116	24	Vertical	-	M	76.2	3400	PF-S
	AS17-2103	116	26	Vertical	-	M	76.2	3400	PF-S
64	AS15-1145	103	17	Vertical	-	M	76.2	3400	FF
	AS15-0424	99	2	Vertical	-	M	76.2	3400	FF
65	AS15-1701	100	4	Vertical	-	M	76.2	3400	PF-M
	AS15-2295	115	1	Vertical	-	M	76.2	3400	PF-M
66	AS15-1556	110	4	40	355	M	76.2	3400	FF
67	AS15-1010	99	3	Vertical	-	M	76.2	3400	FF
68	AS16-2836	124	9	Vertical	-	M	76.2	3400	PF-M
	AS16-2839	124	6	Vertical	-	M	76.2	3400	PF-M
69	AS16-120-19244	120	13	Vertical	-	H	250	S0-368	PF
70	AS14-78-10375	-	2.0	-	-	H	80	S0-2485	PF-M
	AS14-78-10376	-	1.5	-	-	H	80	S0-2485	PF-M
	AS14-78-10377	-	.5	-	-	H	80	S0-2485	FF-M
	AS14-78-10378	-	0	Vertical	-	H	80	S0-2485	PF-M

Figure number	Frame number	Altitude, km	Sun elevation, deg	Camera Tilt,deg	Camera Azimuth, deg.	Camera system [a]	Lens focal length, mm	Film type	Frame type [b]
71	AS15-98-13361	99	5	30	180	H	250	2485	FF
72	AS15-2487	106	7	Vertical	-	M	76.2	3400	PF
73	AS15-2399	119	61	Vertical	-	M	76.2	3400	PF-S
	AS15-2401	119	63	Vertical	-	M	76.2	3400	PF-S
74	AS17-0939	111	25	40	4	M	76.2	3400	FF
75	AS17-2313	113	14	Forward	-	P	610	3414	PF
76	AS17-2313	113	14	Forward	-	P	610	3414	PF
77	AS17-2313	113	14	Forward	-	P	610	3414	PF
78	AS15-9298	106	37	Forward	-	P	610	3414	PF
79	AS17-2313	113	14	Forward	-	P	610	3414	PF
80	AS17-2309	113	15	Forward	-	P	610	3414	PF-S
	AS17-2314	113	15	Aft	-	P	610	3414	PF-S
81	AS17-2309	113	15	Forward	-	P	610	3414	PF
82	AS15-9361	102	19	Aft	-	P	610	3414	PF
83	AS17-3075	117	23	Forward	-	P	610	3414	PF
84	AS17-1913	118	20	Forward	-	P	610	3414	PF
85	AS17-1676	100	30	Forward	-	P	610	3414	PF
86	AS16-5452	123	17	Forward	-	P	610	3414	PF
87	AS16-4970	107	20	Forward	-	P	610	3414	PF
88	AS16-120-19237	115	11	53	215	H	250	S0-368	FF
	AS16-120-19237	115	11	53	215	H	250	S0-368	FF, PF
89	AS15-0344	108	12	Forward	-	P	610	3414	PF
90	AS17-2317	112	12	Forward	-	P	610	3414	PF
91	AS16-2824	124	24	Vertical	-	M	76.2	3400	FF
92	AS16-5428	124	27	Forward	-	P	610	3414	PF-S
	AS16-5433	124	27	Aft	-	P	610	3414	PF-S
93	AS17-3114	113	71	Aft	-	P	610	3414	PF
94	AS16-5425	123	29	Aft	-	P	610	3414	PF
95	AS17-2224	121	47	Aft	-	P	610	3414	PF
Craters									
97	AS15-0293	117	17	Vertical	-	M	76.2	3400	FF
98	AS17-150-23102	124	34	46	166	H	250	S0-368	FF
99	AS15-0102	82	34	Vertical	-	M	76.2	3400	FF
100	AS15-8936	81	34	Forward	-	P	610	3414	PF
101	AS15-8937	82	33	Aft	-	P	610	3414	PF
102	AS15-9348	102	21	Forward	-	P	610	3414	PF
103	AS16-4136	119	14	Aft	-	P	610	3414	PF
104	AS16-4136	119	14	Aft	-	P	610	3414	PF
105	AS16-4558	112	17	Forward	-	P	610	3414	PF
107	AS17-1764	95	56	Forward	-	P	610	3414	PF-S
	AS17-1769	95	56	Aft	-	P	610	3414	PF-S
108	AS15-9721	119	55	Forward	-	P	610	3414	PF

| Figure number | Frame number | Altitude, | Sun elevation, | Camera | | | | | |

Figure number	Frame number	Altitude, km	Sun elevation, deg	Tilt,deg	Azimuth, deg.	Camera system [a]	Lens focal length, mm	Film type	Frame type [b]
109	AS15-9301	106	37	Aft	-	P	610	3414	PF
110	AS16-121-19407	115	47	65	315	H	250	S0-368	FF
111	AS16-4511	115	34	Aft	-	P	610	3414	PF
112	AS15-9337	104	26	Aft	-	P	610	3414	PF
113	AS15-9254	109	50	Forward	-	P	610	3414	PF
114	AS17-2744	112	48	Forward	-	P	610	3414	PF
115	AS15-2405	120	67	Vertical	-	M	76.2	3400	FF
	AS16-4469	118	48	Aft	-	P	610	3414	PF-S
	AS16-4471	118	47	Aft	-	P	610	3414	PF-S
116	AS15-0018	120	94	Forward	-	P	610	3414	PF
117	AS15-9287	107	41	Aft	-	P	610	3414	PF
118	AS16-4559	112	18	Aft	-	P	610	3414	PF
119	AS16-4502	115	35	Forward	-	P	610	3414	PF
120	AS16-5444	144	20	Forward	-	P	610	3414	PF
121	AS16-5444	144	20	Forward	-	P	610	3414	PF
122	AS16-5430	124	25	Forward	-	P	610	3414	PF
123	AS16-4658	116	18	Forward	-	P	610	3414	PF
124	AS17-2120	116	4	Vertical	-	M	76.2	3400	PF

Figure number	Frame number	Altitude, km	Sun elevation, deg	Camera		Camera system [a]	Lens focal length, mm	Film type	Frame type [b]
				Tilt,deg	Azimuth, deg.				
125	AS17-2444	118	13	40	177	M	76.2	3400	FF
126	AS17-2291	114	5	Vertical	-	M	76.2	3400	FF
127	AS17-3093	117	18	Vertical	-	P	610	3414	PF
128	AS16-4653	116	22	Aft	-	P	610	3414	PF
129	AS16-4653	116	22	Aft	-	P	610	3414	PF
130	AS16-1973	116	15	Vertical	-	M	76.2	3400	FF
132	AS16-1671	116	22	Vertical	-	M	610	3414	PF
133	AS16-1276	113	15	Vertical	-	M	76.2	3400	FF
134	AS17-149-22838	125	63	57	320	H	250	S0-368	FF
135	AS17-2321	112	11	Forward	-	P	610	3414	PF
136	AS16-4530	114	26	Forward	-	P	610	3414	PF
137	AS17-3103	118	14	Vertical	-	P	610	3414	PF-M
	AS17-3105	118	13	Vertical	-	P	610	3414	PF-M
	AS17-3107	118	13	Vertical	-	P	610	3414	PF-M
138	AS17-2922	118	15	Vertical	-	M	76.2	3400	PF
139	AS15-0274	112	34	Forward	-	P	610	3414	PF
140	AS14-70-9671	-	17	Vertical	-	H	80	3400	FF
141	AS14-72-9975	-	34	50	330	H	500	S0-368	FF
142	AS17-3062	117	28	Aft	-	P	610	3414	PF
143	AS15-9866	117	75	Forward	-	P	610	3414	PF
144	AS15-9874	117	73	Forward	-	P	610	3414	PF
145	AS15-9328	104	27	Forward	-	P	610	3414	PF

Figure number	Frame number	Altitude, km	Sun elevation, deg	Tilt,deg	Azimuth, deg.	Camera system [a]	Lens focal length, mm	Film type	Frame type [b]
146	AS17-3081	117	22	Vertical	-	P	610	3414	PF
147	AS17-2265	117	31	Forward	-	P	610	3414	PF
148	AS17-2006	116	30	Vertical	-	M	76.2	3400	PF-S
	AS17-2007	116	31	Vertical	-	M	76.2	3400	PF-S
	AS17-2773	114	19	Forward	-	P	610	3414	PF
149	AS16-122-19580	-		-	270	H	250	S0-368	FF
150	AS16-120-19268	98	14	65	245	H	250	S0-368	FF
151	AS16-4998	109	29	Forward	-	P	610	3414	PF
152	AS16-5000	109	30	Forward	-	P	610	3414	PF
153	AS16-4996	108	25	Forward	-	P	610	3414	PF
154	AS10-30-4349	-	-	-	-	H	250	3400	FF
155	AS16-120-19266	98	13	65	255	H	250	S0-368	FF
156	AS16-5000	109	30	Forward	-	P	610	3414	PF
158	AS16-5000	109	30	Forward	-	P	610	3414	PF
159	AS16-1578	113	35	Vertical	-	M	610	3414	PF
160	AS16-1579	113	36	Vertical	-	M	610	3414	PF
161	AS16-120-19231	114	42	20	260	H	250	S0-368	FF
162	AS16-5006	109	32	Forward	-	P	610	3414	PF
163	AS16-4815	112	33	Forward	-	P	610	3414	PF
164	AS17-151-23260	114	53	64	180	H	250	S0-368	FF

Figure number	Frame number	Altitude, km	Sun elevation, deg	Camera Tilt,deg	Camera Azimuth, deg.	Camera system [a]	Lens focal length, mm	Film type	Frame type [b]
165	AS15-0326	109	18	Forward	-	P	610	3414	PF
166	AS16-0692	115	35	40	176	M	76.2	3400	FF
167	AS16-0154	112	25	Vertical	-	M	76.2	3400	PF
168	AS16-4531	114	27	Aft	-	P	610	3414	PF
169	AS16-0532	120	71	25	267	M	76.2	3400	FF
170	AS15-0757	119	27	25	270	M	76.2	3400	FF
172	AS15-1030	117	21	Vertical	-	M	76.2	3400	FF
173	AS15-9591	115	17	Forward	-	P	610	3414	PF
174	AS15-9596	115	17	Aft	-	P	610	3414	PF
175	AS17-2608	113	18	Vertical	-	M	76.2	3400	FF
176	AS15-0892	119	31	Vertical	-	M	76.2	3400	PF-S
	AS15-0893	119	32	Vertical	-	M	76.2	3400	PF-S
178	AS17-0341	121	22	Vertical	-	M	76.2	3400	FF
179	AS15-1541	105	26	40	5	M	76.2	3400	FF
180	AS15-2510	115	27	40	205	M	76.2	3400	FF
181	AS16-120-19295	123	6	55	180	H	250	S0-368	FF
182	AS16-2995	123	4	Vertical	-	M	76.2	3400	FF
183	AS16-0839	112	16	40	359	M	76.2	3400	FF
Rilles									
185	AS15-2611	107	15	40	180	M	76.2	3400	FF
186	AS15-0341	108	16	Aft	-	P	610	3414	PF
187	AS15-0342	108	13	Forward	-	P	610	3414	PF

Figure number	Frame number	Altitude, km	Sun elevation, deg	Camera Tilt,deg	Camera Azimuth, deg.	Camera system [a]	Lens focal length, mm	Film type	Frame type [b]
188	AS15-0332	108	16	Forward	-	P	610	3414	PF
190	AS15-9309	106	34	Aft	-	P	610	3414	PF
191	AS15-2606	109	21	40	185	M	76.2	3400	FF
192	AS15-2083	102	9	Vertical	-	M	76.2	3400	PF
193	AS15-0321	109	21	Aft	-	P	610	3414	PF
194	AS15-0320	109	20	Forward	-	P	610	3414	PF
195	AS15-88-11982	114	4	65	280	H	60	SO-168	FF
196	AS15-0349	108	12	Aft	-	P	610	3414	PF
197	AS15-93-12725	109	19	20	0	H	250	S0-368	FF
198	AS17-3128	119	6	Vertical	-	P	610	3414	PF
199	AS15-2076	104	17	Vertical	-	M	76.2	3400	PF
200	AS15-1702	100	3	Vertical	-	M	76.2	3400	FF
201	AS17-23717	114	1	32	352	H	250	2485	PF-M
	AS17-23718	114	1	27	355	H	250	2485	PF-M
202	AS15-1135	106	28	Vertical	-	M	76.2	3400	FF
203	AS15-85-11451	On surface	20	-	-	H	60	3401	FF
204	AS15-11720	12	11	15	260	H	60	SO-168	FF
205	AS15-9432	103	23	Aft	-	P	610	3414	PF
206	AS15-9816	107	42	Aft	-	P	610	3414	PF
207	AS15-91-12366	311	23	35	315	H	250	S0-368	PF
209	AS8-13-2225	-	12	-	South	H	80	3400	FF

Figure number	Frame number	Altitude, km	Sun elevation, deg	Camera Tilt,deg	Camera Azimuth, deg.	Camera system [a]	Lens focal length, mm	Film type	Frame type [b]
210	AS15-93-12641	115	27	60	180	H	80	S0-368	FF
211	AS16-2478	116	83	40	173	M	76.2	3400	FF
216	AS16-4656	110	12	Aft	-	P	610	3414	PF
217	AS10-31-4645	-	Medium	-	-	H	250	3400	FF
218	AS15-9368	101	15	Forward	-	P	610	3414	PF
219	AS15-13345	101	4	55	305	H	250	2485	FF
220	AS17-2313	113	14	Forward	-	P	610	3414	PF
221	AS17-2313	113	14	Forward	-	P	610	3414	PF
Unusual features									
223	AS15-9350	102	20	Forward	-	P	610	3414	PF
	AS15-9355	102	20	Aft	-	P	610	3414	PF-S
224	AS15-9299	106	38	Aft	-	P	610	3414	PF
225	AS15-0244	114	44	Forward	-	P	610	3414	PF
226	AS15-9361	102	19	Aft	-	P	610	3414	PF
227	AS15-9361	102	19	Aft	-	P	610	3414	PF
228	AS17-3125	119	7	Vertical	-	P	610	3414	PF
229	AS16-5410	123	32	Forward	-	P	610	3414	PF
230	AS15-2627	110	12	Vertical	-	M	76.2	3400	FF
231	AS15-9960	117	16	Forward	-	P	610	3414	PF
232	AS17-1672	105	12	40	178	M	76.2	3400	PF
233	AS15-0176	117	65	Forward	-	P	610	3414	PF-S
	AS15-0181	117	65	Aft	-	P	610	3414	PF-S
235	AS15-9358	102	18	Forward	-	P	610	3414	PF

236	AS17-1931	120	27	Forward	-	P	610	3414	PF
237	AS16-4151	120	21	Forward	-	P	610	3414	PF
238	AS15-8893	91	19	Aft	-	P	610	3414	PF
239	AS15-8910	87	26	Forward	-	P	610	3414	PF
240	AS 15-8928	83	32	Forward	-	P	610	3414	PF
241	AS17-2334	111	8	Aft	-	P	610	3414	PF
242	AS17-2335	111	6	Forward	-	P	610	3414	PF
243	AS17-3067	117	25	Forward	-	P	610	3414	PF
244	AS17-2318	113	14	Aft	-	P	610	3414	PF
245	AS16-4525	114	23	Aft	-	P	610	3414	PF
246	AS16-5429	124	28	Aft	-	P	610	3414	PF
247	AS16-5587	-	-	Aft	-	P	610	3414	PF
Epilog									
248	AS11-44-6665	-	-	-	-	H	250	S0-368	FF
249	AS17-148-22725	-	-	-	-	H	80	S0-368	FF

[a] H = Hasselblad; M = metric; P = panoramic.

[b] FF = full frame; PF = partial frame; FF-M = full frame-mosaic; PF-M = partial frame mosaic; PF S = partial frame-stereogram.

APOLLO OVER THE MOON: A VIEW FROM ORBIT (NASA SP-362)

Appendix B

Lunar Probes, Attempted and Successful

Name	Country	Launch Date	Vehicle	Remarks
Thor-Able I (Pioneer)	U.S.A.[a]	Aug. 17,1958	Thor-Able	1st attempt to probe Moon: failed.
Pioneer 1	U.S.A.	Oct. 11, 1958	Thor-Able	Failed to reach Moon; sent 43 hr of data.
Pioneer 2	U.S.A.	Nov. 8, 1958	Thor-Able	Failed to reach Moon.
Pioneer 3	U.S.A.	Dec. 6, 1958	Juno II	Failed to reach Moon; provided radiation data.
Luna I	U.S.S.R.	Jan. 2, 1959	A-1	Passed within 6000 km of the Moon; went into solar orbit.
Pioneer 4	U.S.A.	Mar. 3, 1959	Juno II	Passed within 60 000 km of the Moon; went into solar orbit.
Luna 2	U.S.S.R.	Sept. 12, 1959	A-1	1st probe to impact on Moon.
Luna 3	U.S.S.R.	Oct. 4, 1959	A-1	1st probe to photograph Moon's far side.
Atlas-Able 4 (Pioneer (P-3))	U.S.A.	Nov. 26, 1959	Atlas-Able	Failed to reach Moon.
Atlas-Able SA (Pioneer (P-30))	U.S.A.	Sept. 25, 1960	Atlas-Able	Failed to reach Moon.
Atlas-Able SB (Pioneer (P-3))	U.S.A.	Dec. 15, 1960	Atlas-Able	Failed to reach Moon.
Ranger 3	U.S.A.	Jan. 26, 1962	Atlas-Agena B	Missed Moon by 36 800 km; ended in solar orbit.
Ranger 4	U.S.A.	Apr. 23,1962	Atlas-Agena B	Impacted on Moon, but cameras and experiments did not operate.
Ranger 5	U.S.A.	Oct. 18, 1962	Atlas-Agena B	Missed Moon by 725 km; ended in solar orbit.
No name	U.S.S.R.	Jan. 4, 1963	A-2-e	Probable lunar probe; failed.
Luna 4	U.S.S.R.	Apr. 2, 1963	A-2-e	Attempted soft landing; missed Moon by 8500 km; went into barycentric orbit.
Ranger 6	U.S.A.	Jan. 30, 1964	Atlas-Agena B	Impacted on Moon; TV system did not function during approach.
Ranger 7	U.S.A.	July 28,1964	Atlas-Agena B	1st successful Ranger mission; impacted on Moon after taking 4308 pictures of lunar surface during approach.
Ranger8	U.S.A.	Feb. 17, 1965	Atlas-Agena B	Impacted on Moon after returning 7137 closeup pictures.
Kosmos 60	U.S.S.R.	Mar. 12, 1965	A-2-e	Probable lunar probe: failed.

Name	Country	Launch date	Vehicle	Remarks
Ranger 9	U.S.A.	Mar. 21,196	Atlas-Agena B	Impacted in crater Alphonsus after returning 5814 pictures.
Luna 5	U.S.S.R.	May 9, 1965	A-2-e	Attempted soft landing by U.S.S.R.: impacted on Moon.
Luna 6	U.S.S.R.	June 8, 1965	A-2-e	Attempted soft landing: missed Moon by 161 000 km and went into solar orbit.
Zond 3	U.S.S.R.	July 18, 1965	A-2-e	Transmitted 25 pictures of lunar far side taken dunng lunar flyby; went into solar orbit.

app.b

Luna 7	U.S.S.R.	Oct. 4, 1965	A-2-e	Attempted soft landing: impacted on Moon.
Luna 8	U.S.S.R.	Dec. 3, 1965	A-2-e	Attempted soft landing: impacted on Moon.
Luna 9	U.S.S.R.	Jan. 31, 1966	A-2-e	1st successful soft landing by U. S. S. R.; returned 27 pictures of lunar surface in 3 days.
Kosmos III	U.S.S.R.	Mar. 1, 1966	A-2-e	Suspected lunar probe: failed.
Luna 10	U.S.S.R.	Mar. 31, 1966	A-2-e	Achieved lunar orbit; transmitted physical measurements for nearly 2 months.
Surveyor 1	U.S.A.	May 30, 1966	Atlas-Centaur	Successful soft landing; transmitted 1 1 237 pictures of lunar surface.
Explorer 33	U.S.A.	July 1, 1966	Thrust-augmented Delta (TAD)	Attempted lunar orbit not achieved; in barycentric orbit.
Lunar Orbiter I	U.S.A.	Aug. 10, 1966	Atlas-Agena D	Successful orbital photographic mission; photographed Moon until Aug. 29, 1966; impacted on Moon Oct. 29,1966.
Luna II	U.S.S.R.	Aug. 24,1966	A-2-e	Achieved lunar orbit; transmitted data until Oct. 1, 1966.
Surveyor 2	U.S.A.	Sept. 20, 1966	Atlas-Centaur	Attempted soft landing; impacted southeast of Crater Copernicus.
Luna 12	U.S.S.R.	Oct. 22, 1966	A-2-e	Achieved lunar orbit; transmitted lunar pictures and data.
Lunar Orbiter 2	U.S.A.	Nov. 6, 1966	Atlas-Agena D	After transmitting 422 pictures from orbit, impacted on the Moon.
Luna 13	U.S.S.R.	Dec. 21,1966	A-2-e	Successful soft landing; transmitted pictures and soil density data.
Lunar Orbiter 3	U.S.A.	Feb. 4, 1967	Atlas-Agena D	After transmitting 307 pictures from orbit, impacted on the Moon.
Surveyor 3	U.S.A.	Apr. 17,1967	Atlas-Centaur	Successful soft landing; transmitted 6315 pictures and soils data.
Lunar Orbiter 4	U.S.A.	May 4, 1967	Atlas-Agena D	Photographed all of near side; after returning 326 pictures from orbit, impacted on the Moon.
Surveyor 4	U.S.A.	July 14,1967	Atlas-Centaur	Impacted on the Moon; experiments did not function.

Name	Country	Launch Date	Vehicle	Remarks
Explorer 35	U.S.A.	July 19,1967	TAD	In lunar orbit; measures Earth's magnetic tail every 29.5 days.
Lunar Orbiter 5	U.S.A.	Aug. 1,1967	Atlas-Agena D	Last of the highly successful Orbiter missions; impacted on the Moon after completing photographic coverage of far side.
Surveyor 5	U.S.A.	Sept. 8,1967	Atlas-Centaur	Successful soft landing; transmitted 18 006 pictures and chemical analysis of soil.
Surveyor 6	U.S.A.	Nov. 7, 1967	Atlas-Centaur	Successful soft landing; transmitted 30 065 pictures and chemical and mechanical soil studies; performed first rocket takeoff on Moon.
Surveyor 7	U.S.A.	Jan. 7, 1968	Atlas-Centaur	Successful soft landing; transmitted 21 274 pictures and chemical analysis of soil.
Zond 4	U.S.S.R.	Mar. 2, 1968	D-1-e	Launched into undisclosed trajectory from initial parking orbit probable precursor to manned lunar mission.
Apollo 6	U.S.A.	Apr. 4 ,1968	Saturn V	Failed to reach Moon.
Luna I4	U.S.S.R.	Apr. 7, 1968	A-2-e	In lunar orbit; measuring lunar gravity field and Earth-Moon mass relationship.
Zond 5	U.S.S.R.	Sept. 15, 1968	D-1-e	1st circumlunar mission after which spacecraft returned to Earth; recovered from Indian Ocean

Name	Country	Launch Date	Vehicle	Remarks
				Sept. 21 1968.
Zond 6	U.S.S.R.	Nov. 10, 1968	D-1-e	2d unmanned circumlunar mission; spacecraft recovered in U.S.S.R.
Apollo 8	U.S.A.	Dec. 21, 1968	Saturn V	1st manned circumlunar flight; 10 orbits completed; first mission in which true photographs taken from lunar orbit were returned to Earth (Astronauts Borman Lovell and Anders).
Apollo 10	U.S.A.	May 18, 1969	Saturn V	LM detached from the CM and piloted to within 14.9 km of the Moon and returned to the CM; first color TV from space (Astronauts Stafford Young and Cernan).
Luna 15	U.S.S.R.	July 13, 1969	D-1-e	After completing 52 orbits impacted on Moon.
Apollo 11	U.S.A.	July 16, 1969	Saturn V	1st manned lunar landing July 20 1969 western Mare Tranquillitatus; 21.6 hr spent on the Moon; first samples of lunar rocks returned to Earth (Astronauts Armstrong Aldrin and Collins).

Name	Country	Launch Date	Vehicle	Remarks
Zond 7	U.S.S.R.	Aug. 8,1969	D-l-e	3d successful unmanned circumlunar flight; spacecraft recovered in U. S. S. R.
Apollo 12	U.S.A.	Nov. 14,1969	Saturn V	2d manned lunar landing Nov. 19, 1969, eastern Oceanus Procellarum; 31.6 hr on the Moon (Astronauts Conrad, Bean, and Gordon).
Apollo 13	U.S.A.	Apr. 11, 1970	Saturn V	Attempted manned landing mission aborted 56 hr after launch; returned after crossing the far side of the Moon (Astronauts Lovell, Swigert, and Haise).
Luna 16	U.S.S.R.	Sept. 12, 1970	D-l-e	Unmanned lander arrived in Mare Fecunditatis Sept. 20, 1970; 1st unmanned mission to return lunar samples to Earth.
Zond 8	U.S.S.R.	Sept. 20,1970	D-1-e	Circled Moon; recovered Oct. 27, 1970.
Luna 17	U.S.S.R.	Nov. 10,1970	D-l-e	2d unmanned lander arrived in western Mare Imbrium Nov. 17, 1970; automated roving vehicle Lunokhod I traveled 10.54 km, took more than 20 000 pictures, and conducted experiments during 11 lunar days.
Apollo 14	U.S.A.	Jan. 31, 1971	Saturn V	3d successful manned landing Feb. 5, 1971, Fra Mauro site in eastern Oceanus Procellarum (Astronauts Shepard, Mitchell, and Roosa).
Apollo 15	U.S.A.	July 26, 1971	Saturn V	4th manned landing July 30, 1971, Apennine-Hadley site in eastern Mare Imbrium; first manned lunar roving vehicle; SIM permitted larger number of scientific experiments and more sophisticated photography to be conducted from orbit.
Luna 18	U.S.S.R.	Sept. 2, 1971	D-l-e	Impacted on Moon after 54 orbits.
Luna 19	U.S.S.R.	Sept. 28, 1971	D-l-e	Lunar orbital photographic mission; completed more than 4000 orbits; filmed selected areas; still in orbit.
Luna 20	U.S.S.R.	Feb. 14,1972	D-l-e	Achieved soft landing Feb. 21, 1972, in northeastern Mare Fecunditatis; returned to Earth Feb. 25, 1972, with lunar samples.
Apollo 16	U.S.A.	Apr. 16,1972	Saturn V	5th manned landing, Apr. 21, 1972, Descartes region of Central Highlands (Astronauts Young, Duke, and Mattingly).

Name	Country	Date	Vehicle	Remarks
				6th and last manned lunar landing of the Apollo

Apollo 17	U.S.A.	Dec. 7, 1972	Saturn V	Program, Taurus-Littrow region; 79 hr on the lunar surface; 113 kg of rock samples returned to Earth (Astronauts Cernan, Schmitt, and Evans).
Luna 21	U.S.S.R.	Jan. 8, 1973	D-l-e	Achieved successful soft landing in crater Le Monnier; automated roving vehicle Lunokhod 2 traveled 37 km and conducted many experiments during 5 lunar days.
Explorer 49	U.S.A.	June 10, 1973	Thorad Delta	Radio astronomy from far side of Moon.
Luna 22	U.S.S.R.	May 29, 1974	D-l-e	Lunar orbital mission; obtained photographs and other data; ran out of attitude control gas Sept. 2, 1975; last communication Nov. 6, 1975.
Luna 23	U.S.S.R.	Oct. 28, 1974	D-l-e	Achieved successful soft landing on Mare Crisium; sampling prevented by damage to rock drill; conducted restricted research until Nov. 9, 1975.
Luna 24	U.S.S.R.	Aug. 9, 1976	D-l-e	Achieved successful soft landing in Mare Crisium; complete core sample from depth of 2 m returned to Earth on Aug. 22, 1976.

a This project was directed by the Advanced Research Projects Agency and launched by the U.S. Air Force. All subsequent U.S. lunar projects were directed by the National Aeronautics and Space Administration.

APOLLO OVER THE MOON: A VIEW FROM ORBIT (NASA SP-362)

Appendix C

Basic Data Analysis

Scheme for Preparation of Lunar Maps*

(1) Identification of star images on the stellar photographs, measurement of their image coordinates, and computation of the orientation of the camera in the right ascension and declination Earth-centered stellar coordinate system

(2) Computation of the orientation of the mapping camera in the stellar coordinate system by using the precalibrated relationship between the stellar and mapping cameras

(3) Transfer of the orientation of the mapping camera from the Earth-centered stellar coordinate system to the Moon-centered geographic system-this transformation involves the ephemeris and physical librations of the Moon

(4) Selection of lunar-surface points (approximately 30 per frame) on the mapping camera photographs and identification of them on all overlapping frames on which they appear

(5) Measurement of the coordinates of the selected points and correction of the points for film deformation, lens distortion, and displacement of the focal plane reseau

(6) Triangulation of groups of photographs-this computation includes the measured image coordinates, the attitudes obtained with the stellar camera, the laser altimeter data, a state vector obtained from the tracking data, and a gravity model [a]

(7) Assembly of the triangulated groups into a single adjusted network-the output of this computer program will be a geometrically homogeneous set of coordinate values for all selected points on the lunar surface, plus the position and orientation of each photograph in the same Moon-centered coordinate system [a]

(8) Preparation of small-scale maps from the mapping camera photographs

(9) Transformation of the panoramic photographs into equivalent vertical photographs for interpretation and mapping

(10) Preparation of large-scale maps from the panoramic photographs

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*From Doyle (1972).

[a] The procedure in steps 6 and 7 was not actually followed because errors in the spacecraft tracking data proved to be much larger (up to 1.5 km) than those in the photogrammetric measurements (about 30 m).

In the control solution performed by the Defense Mapping Agency Aerospace Center, each orbital pass was

triangulated separately using spacecraft tracking data as constraints. Pass 44 on Apollo 15 gave the best fit between photogrammetry and tracking data. It was adopted as the fundamental control, and all other passes were subsequently adjusted to ht.

In the control solution performed by the U.S. Geological Survey, the entire photogrammetric network was computed in a single simultaneous solution without tracking data constraints. This network was subsequently adjusted to the tracking data from pass 44 on Apollo 15.