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ABSTRACT

Apollo 14 landed in the Fra Mauro highlands on February 5, 1971, at latitude 3°40′24″ S., longitude 17°27′55″ W. The materials of the area are interpreted to be part of the large deposit of ejecta from the Imbrium basin and appear to be older than the materials of the maria. Because of its relatively old age, the regolith is thicker than on the typical mare, and the ages of the various surfaces within the landing site are reflected in the size-frequency distribution of rock fragments. Since lunar materials generally darken with age, their albedos serve as a general indication of the relative length of time that they have been exposed at the surface. Polarimetric properties and albedo appear to be useful signatures for comparative studies of lunar materials.

The Fra Mauro Formation at the Apollo 14 site comprises breccias that were formed by the Imbrium event and possibly other, earlier impact events. One type of breccia consists of mostly dark clasts in a lighter matrix; the other type, a mixture of light- and medium-gray clasts in a dark matrix. The origin of the breccias and the effects of exposure on the lunar surface are suggested by structures and textures of boulders photographed along the astronauts' traverse line.

INTRODUCTION

The Apollo 14 *Lunar Module* (*LM*)[1] landed on the lunar surface February 5, 1971, at lat 3°40′24″ S., long 17°27′55″ W., in the Fra Mauro region (figs. 1, 2). The landing site, 1,230 km south of the center of the Imbrium basin and 550 km south of the southern rim crest of the basin, was selected in order to study the Fra Mauro Formation, which covers large areas of the near side of the moon. This formation forms a broad belt surrounding Mare Imbrium and is believed to be material that was excavated by a large impact that formed the Imbrium basin.

The mission commander (CDR) was Adm. Alan B. Shepard, the first American astronaut, on Mercury 1, to fly into space. The LM pilot (LMP) was Capt. Edgar D. Mitchell, and the *Command Module* pilot (CMP) was Lt. Col. Stuart A. Roosa. Apollo was their first space flight. Shepard and Mitchell descended to the lunar surface, while Roosa remained in lunar orbit. In this report, the "astronaut crew" refers only to Shepard and Mitchell. Fred Haise, the Capsule Communicator (Capcom) during the periods of *Extravehicular Activity* (*EVA*), is referred to as "Fred" by the astronaut crew in the voice transcript excerpts in table 5.

All the astronauts had a period of training in basic geology before the Apollo missions. Beginning with Apollo 11, each astronaut crew received increasingly more training, not only in the fundamentals of geology but also in lunar geology and the detailed geology of the landing sites.

During the Apollo missions, an advisory team of scientists worked in the Mission Control Center at Houston in the *Science Operations Room* (*SOR*). By the time of Apollo 14 an interaction system had developed to the point where questions and suggestions from the science team could be sent to the crew at almost any time during EVA periods.

Many informal names used throughout the report were assigned to local landmarks before the missions, for ease of discussing landmarks and other features. Still others were named, usually by the astronaut crew, during the mission. For example, "Weird crater" (pl. 1) was named before the Apollo 14 mission because of the odd shape of three coalescing craters. A large boulder near Weird crater examined during the second EVA was referred to, therefore, as "Weird rock," although there appears to be nothing particularly "weird" about the rock.

The Apollo 14 LM landed about 1,100 m west of Cone crater, which is located on a ridge of the ridgy unit of the Fra Mauro Formation (pl. 1). Cone crater is a sharp-rimmed, relatively young crater approximately 370 m in diameter from which blocks were ejected as large as 15 m across derived from beneath the regolith. Sampling and description of these blocks, which the

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[1] Many of the terms and names in this report are not included in standard glossaries and dictionaries, partly because much of the jargon of space flight and space science is so new. Italicized terms are explained in the Glossary.

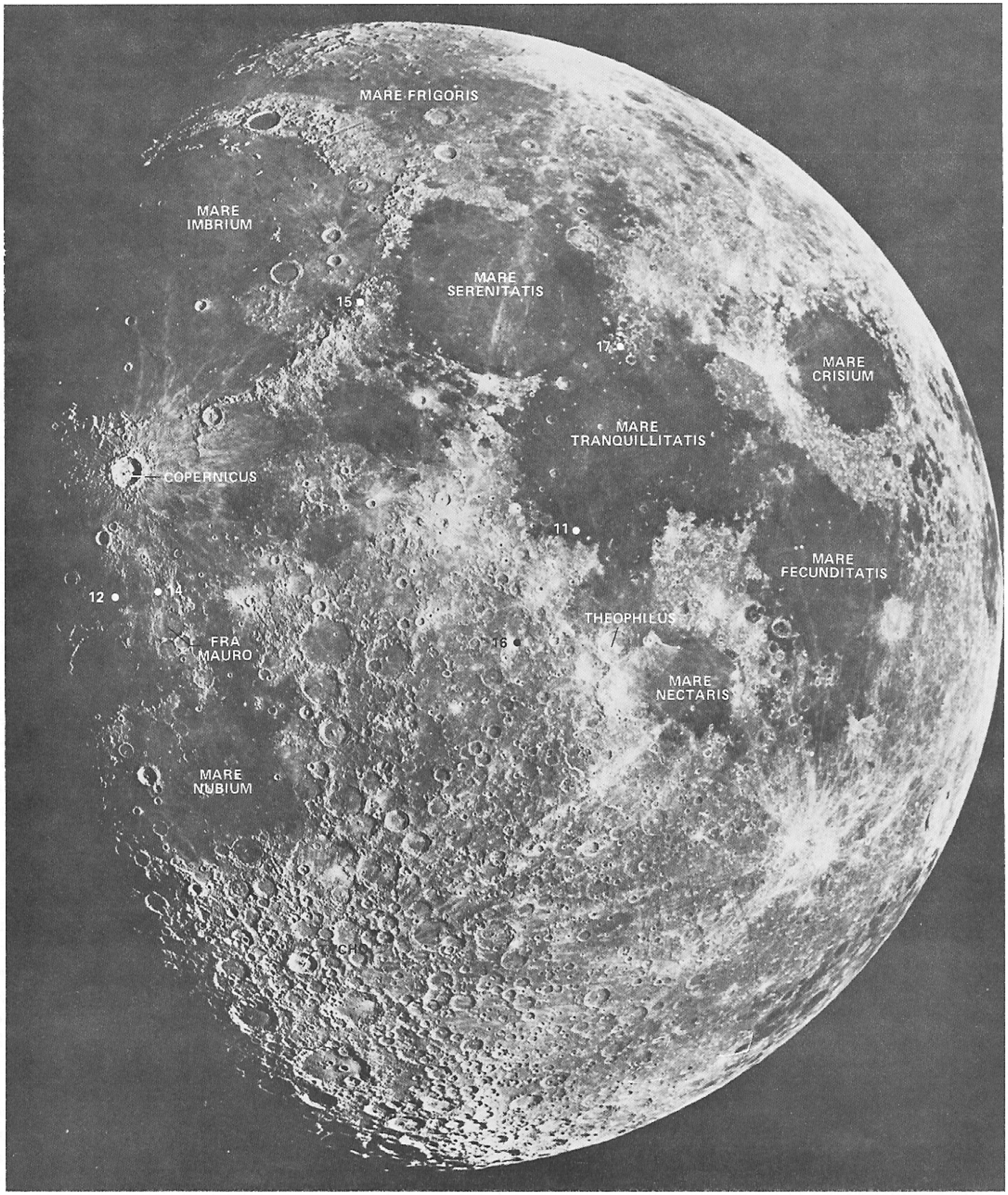

FIGURE 1.—Telescopic photograph of 9-day Moon showing Apollo 11–17 landing sites. Photograph number 113C, August 12, 1940 by J. H. Moore and J. P. Chappell. Lick Observatory 36-inch telescope. North is at top.

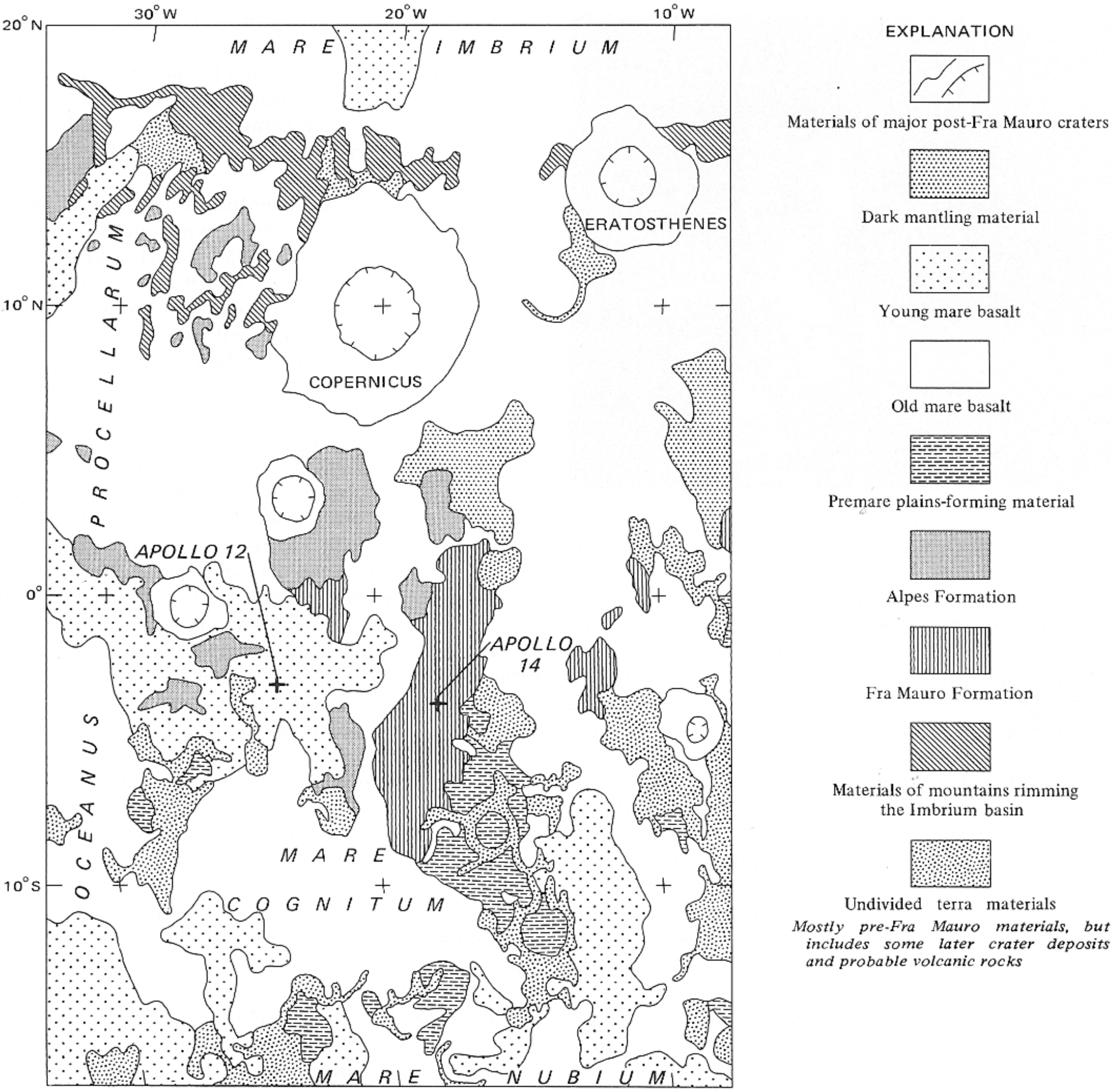

FIGURE 2.—Regional geologic map of the Apollo 12 and 14 landing sites. Adapted from Wilhelms and McCauley (1971).

pre-mission mapping (Eggleton and Offield, 1970) indicated would be unambiguous representatives of the Fra Mauro Formation, was a primary objective of the mission. The landing took place on a smooth terrain unit that was identified in pre-mission *Lunar Orbiter* and *Apollo orbital photographs*. Sampling and description of this unit was another major objective that was completed. The smooth unit, originally thought to be either highlands volcanic material or a smooth facies of the Fra Mauro Formation that was ponded in low areas between the ridges of the ridgy unit (Eggleton and Offield, 1970), was determined to be underlain by breccias similar to those of the ridgy unit.

Two EVA's, each about 5 hours long, were completed. Most of the first EVA was devoted to deploying the *Apollo Lunar Surface Experiments Package* (*ALSEP*). En route to deploying the ALSEP, the crew traveled westward over the smooth unit. The round-trip distance covered on this EVA was approximately 550 m (pl. 2). In addition to deploying the ALSEP, the

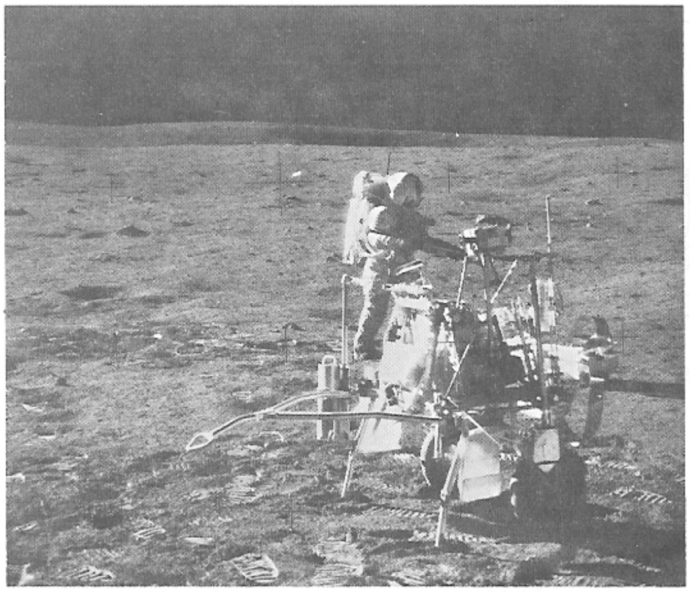

FIGURE 3.—Astronaut Shepard and the MET at station A. Old Nameless is crater on horizon. View southeast. (NASA photograph AS14-68-9404.)

crew collected 16 rock samples larger than 20 g for which locations have been determined (pl. 2): 14 in the *comprehensive sample* and 2 *football-size rocks*.

During the second EVA (pl. 2), the crew walked a round-trip distance of approximately 2,900 m. Heading eastward from the LM, they crossed the smooth and ridgy units (Ifs, Ifr), the apron unit (Ca), and the continuous ejecta blanket of Cone crater, and came within 20 m of the crater rim crest (pl. 1). They collected 30 rock samples larger than 20 g at points whose locations have been determined (pl. 2). One additional rock sample (14309) is from an unknown location. The *modularized equipment transporter* (MET) (Fig. 3) was used to transport the samples and collection tools.

The location of samples was established by relating returned samples to the *documented sample bags*, lunar-surface photographs, and Apollo 14 crew descriptions that pertain to the given samples. Lunar orientations of rock samples were also determined from lunar-surface photographs. Locations and orientations are established with various degrees of confidence; for some samples both are accurately known, for others neither.

A summary of sample documentation (table 5) cross-references all samples in sequence by traverse station, with lunar-surface documentary photographs, the status of determining sample location and orientation, brief megascopic sample descriptions, and comments by the astronaut crew at the time of sample collection.

Locations are known for all but 1 of the 47 rock samples that weigh more than 20 g, for all four *drive tubes*, and for all separately bagged soil samples. Fines and rock chips which represent residues from *weigh bags* are, for the most part, not tied to specific stations. Exceptions to this are the weigh bags used for the *bulk sample* (No. 1028), the comprehensive samples (Nos. 1027 and 1039), and samples from station H (No. 1038) (pl. 2).

Precise locations and orientations of 12 rock samples at the time of collection are known from lunar surface photographs (Nos. 14047, 14051, 14301, 14304, 14305, 14306, 14312, 14313, 14315, 14318, 14319, and 14321). The locations of other samples are known from the comments by the crew, but without photographs, the orientation of the samples when they were collected cannot be reconstructed. The approximate history of exposure of a rock sample can be determined from a study of rounding and pitting by micrometeorite bombardment, dust coatings, and glass coatings. Hörz, Morrison, and Hartung (1972) did this for samples 14053, 14055, 14066, 14073, 14301, 14303, 14305, 14306, 14307, 14310, 14311, 14318, and 14321. Rocks commonly are pitted on all sides, indicating that they have occupied more than one position on the lunar surface. This type of study has strengthened the evidence for "*gardening*" at the lunar surface and helps to define rates of turnover, or tumbling, of specific samples.

Photographic surveys taken during the Apollo 14 lunar stay were designed to (1) locate and illustrate topographic features at each major geologic station (pls. 2–6), (2) record the surface characteristics of each sample area and determine the orientation and location on the lunar surface of the samples at the time of collection, and (3) document geologic *targets of opportunity*.

Other photographic surveys were taken to document the deployment of the ALSEP and the *soil mechanics experiment*.

A total of 417 photographs were taken on the lunar surface with the *Hasselblad Electric Data Camera* (referred to as the Hasselblad camera throughout this paper). Fifteen panoramas, consisting of 275 photographs, were taken for major station location and general geologic documentation (pls. 3–6). Forty-nine pictures were taken for specific sample documentation, and 27 pictures were taken to document ALSEP deployment. The remaining pictures were of miscellaneous targets of opportunity. The major geologic stations were located on a rectified copy of Lunar Orbiter III frame H–133 by feature correlation between the Hasselblad and Lunar Orbiter photographs and by resection (pls. 2–6). Tables 6 through 9 are a log of the Hasselblad photographs taken on the lunar surface.

The nature of the lunar environment, and the limitations on doing conventional field geologic studies during Apollo missions, necessitate a somewhat different approach than is used in terrestrial geology to obtain field data. Much emphasis must be placed on detailed study of photographs taken on the lunar surface, and the application of interpretations from these photographs to interpretations of photographs taken from lunar orbit.

The primary sources of data for this report are photographs of the site and surrounding area taken before the Apollo 14 mission by Lunar Orbiters and Apollo 12, and photographs taken on the surface during the Apollo 14 mission. Other information is derived from preliminary examination of returned samples, published reports that discuss analyses of the samples, and oral descriptions by the astronaut crew.

The overall approach to this study included:

1. Pre-mission photogeologic mapping of the site.
2. Study of the astronaut crew's oral descriptions.
3. Preliminary study of returned samples, confined mostly to hand-sample and binocular microscope examination of rock samples larger then 20 g.
4. Detailed study of photographs taken on the lunar surface, including photometric and photogrammetric measurements.
5. Measurements of polarimetric and albedo characteristics of a limited number of samples.
6. Review of literature pertaining to analyzed samples.
7. Limited updating of the pre-mission geologic map (Eggleton and Offield, 1970) based on information gained from the mission.

GEOLOGY

Nearly all of the lunar surface is covered by a layer of comminuted rock debris, commonly several metres thick, formed by repeated meteorite impact. This layer, generally referred to as the lunar regolith, makes finding actual rock outcrops difficult. None were seen along the Apollo 14 traverse routes, and the local bedrock stratigraphy and structure must be inferred from a knowledge of cratering mechanics and from detailed study of boulders thought to represent local bedrock.

Craters that penetrate the regolith can provide much the same sort of information as drill holes. Cone crater at the Apollo 14 site is an example. Mixing of the regolith by cratering complicates the problem of determining what part of the local stratigraphic sequence a rock fragment from the regolith represents. This same process, however, transports materials over large distances so that at any one site, one can expect to obtain materials representative of other localities, some far away. Sampling regolith materials on the Moon is similar to sampling an alluvial fan, slide, or moraine at the foot of a mountain on Earth to obtain materials representative of the entire mountain. It is more complicated, however, because of the random character of cratering processes, to determine which materials are exotic and where they originally came from.

In general, we assume that the less time a fragment has been exposed at the lunar surface (as determined by geochemical exposure age techniques and by its state of erosion from micrometeorites), the less likely that it has had a complicated surface history. We also assume that a larger rock fragment is less likely to have had a history of multiple transport, and therefore it is more likely to be near its original source (see for example Shoemaker and others, 1970).

The original sources of many rock fragments can be inferred from the ejecta patterns observed around impact craters. Materials nearest the rim most commonly come from deepest within the crater, and those far out on the ejecta blanket come from nearest the surface of the *target materials* (Shoemaker, 1960). Boulders in the ejecta are presumed to be generally representative of local bedrock ejected from the crater, and ray patterns commonly indicate the sources of the ray materials. The source of any one fragment on an ejecta blanket or ray may, however, be different from that of the bulk of the ejecta. A qualitative evaluation can be made as to whether a fragment is part of the ejecta by comparing its appearance—rock type, degree of rounding, fillet buildup, exposure ages—with other rocks in the ejecta.

Because cratering erodes geologic features to form regolith, a relationship exists between ages of surfaces and thickness of regolith. This relationship can be determined if the rate of meteorite flux, which has been derived (Shoemaker and others, 1970; Shoemaker, 1971) is known. In order to determine the relative ages of surfaces at the Apollo 14 site, we have assumed that lunar materials darken with time upon exposure at the lunar surface (Adams and McCord, 1971), that crater rims erode with time (Soderblom, 1970; Soderblom and Lebofsky, 1972), that rock fragments erode with time so that the size-frequency distribution of rocks at the surface is an index of age of the surface (Shoemaker and others, 1970), and that the development of rock fillets (Shoemaker and others, 1968) on level surfaces increases with time.

All the boulders in the traverse area that were photographed and that show features that appear representative of the Fra Mauro rocks are discussed and illustrated. Where the photographs are suitable for stereoscopic models, they were set up on an AP/C analytical plotter, and contour maps were made at scales of 1:5 to 1:10 with contour intervals of 1 to 4 cm.

The scales, and therefore the contour intervals, were determined by visual estimate, because of a lack of precise photogrammetric control within the photographs.

OPTICAL PROPERTIES

Optical properties of lunar materials have long been used in lunar geologic mapping. The first lunar maps were made primarily from visual observations, which relied not only upon topography and surface textures but also on the apparent variations in reflectivities of materials. Quantitative measurements of the colors, reflectivities at zero *phase angle* (albedos), and polarimetric qualities of lunar surface materials have been derived from Earth-based telescopes integrating areas of several square kilometres and from *Surveyor* and Apollo photographs resolving surface features to centimetre scale.

The lunar surface exhibits a wide range in reflected surface brightness. The differences are considered indicative of different materials. Lunar surface processes produce a fine-grained reflective layer from materials of different compositions and albedos. The photometric function for the Moon indicates that the fine-scale microtexture controls the nature of the photometric function. The different composition of materials affects the brightness, and these brightness differences are greatest near zero phase angle (full Moon from Earth or downsun view on lunar surface).

The recognition that the photometric signatures of lunar materials might help put the samples and photographs into their broader regional geologic context led to preliminary photometric studies of lunar samples and of closeup lunar surface photographs. A total of nine samples (three from Apollo 11, two from Apollo 12, and four from Apollo 14) were allotted for this study. This is not enough for a comprehensive comparison of the different geologic units, but the results of the polarimetric measurements compare favorably with those from telescopic and Surveyor data.

The variation in amount of light reflected from the sample surfaces as the lighting angle is changed was measured in the laboratory. Each sample was mounted with its top surface level in the center of a goniometer. The goniometer has a movable light source and light-measuring detector, and angular positions are measurable to within 6 minutes of arc. The light source simulates sunlight in collimation and spectral variation. The detector is sensitive over the wavelengths (380–820 nanometres) of the lunar surface film spectral sensitivity. This measuring system simulates the geometry viewed on the Moon as well as the spectral range that the lunar surface film recorded. The photometric measurements of samples in the laboratory are directly correlated with measurements recorded in the returned lunar surface film.

In order to calculate the albedos of surface materials, scene luminances (intensities of reflected light) from the fine-grained surface materials and prominent rocks were measured from surface photographs taken during the EVA's. The measurements were made by microdensitometry, utilizing a 100-micrometre-diameter circular aperture, on second-generation film positives. The luminances were calculated from a sensitometric step wedge which is exposed on each magazine of processed film, and from the reported camera settings of iris and shutter speed used during lunar surface photography, with corrections applied for frame shading (lens vignetting). In photographs containing the *photometric chart* in the field of view, the sensitometric luminances of the gray steps on the chart were compared with luminances computed from the preflight calibration of the chart. The luminance data nominally agreed within 2 percent. Measurements of geologic materials were made at the lowest phase angles possible because lunar reflectance decreases rapidly with increasing phase angle, and the uncertainties in the local lunar photometric function at large phase angles tend to increase errors. All general comparisons between areas of measurements are made by projecting the measured luminance to the zero phase angle luminance (albedo) by means of the *photometric angles,* the lunar photometric function as determined by Willingham (1964), and an assumed solar irradiance of 13,000 lumens. Detailed comparisons of reflectance from lunar geologic materials are made at the same phase angle whenever possible. Comparisons of the optical properties of returned lunar samples with the in situ optical properties as determined from photographs provide a basis for delineation of similar materials in the photographs.

The polarimetric properties of the samples (the amount and orientation of polarized light reflected from the surfaces of the material) were also measured in the laboratory. Each sample was mounted with its top surface level in the center of a goniopolarimeter. The goniopolarimeter supports the light source and detector, which are moveable over 350° in azimuth and from horizontal to vertical, with their angular positions measurable to within 6 minutes of arc. The samples were illuminated by a xenon light source, which radiates a spectrum similar to the solar spectrum. The light is collimated to within ½°, which simulates the sun. The detector is sensitive to radiation from 380 to 820 nanometres, a bandwidth similar to the spectral sensitivity of the film used during the mission. A rotating polarizing filter, its angular position measurable to within 15 minutes of arc, was positioned in front of the detector. Measurements were made with the filter polarizing axis positioned 0° (vertical), 45°, and 90° (horizontal). The maximum and minimum polarizing orientations were also recorded. This measuring technique simulates the lunar surface polarimetric measurements that were planned for EVA 2, but were deleted because of time limitations.

BOULDERS

Detailed analysis of surface photographs of boulders ejected from Cone crater, and comparison of these photographs with returned samples, indicate that the Fra Mauro Formation is mainly composed of moderately coherent breccias in which dark lithic clasts, as large as 50 cm across, and less abundant light clasts are set in a light matrix. Subordinate rock types that may be part of the Fra Mauro Formation include coherent breccias with about equal amounts of light and dark clasts and breccias with irregular bands of very light clastic rock. Wilshire and Jackson (1972) classified the breccias according to their clast populations, color of matrix, and coherence, and have postulated a stratigraphic sequence for that part of the Fra Mauro Formation that was sampled by the Apollo 14 mission. We have adopted their classification and stratigraphic sequence for use in this report.

The lithologies of the boulders ejected from Cone crater reveal a complex history in which the youngest structures (several sets of intersecting fractures that cross clasts and matrices alike) may have resulted from the cratering event. Earlier events, presumably relating to the origin of the Fra Mauro Formation or older ejecta blankets, include lithologic layering, deformation, and induration of the breccias. Clasts of breccia within the breccias may in some cases represent pre-Imbrian cratering in the Imbrium basin region.

ACKNOWLEDGMENTS

We wish to thank the crew of Apollo 14 for the scientific data that they returned from the Moon. Much of the material presented here was drawn from the preliminary report by the Apollo Lunar Geology Investigation Team (Swann and others, 1971). A boulder-distribution map from which we derived the boulder-density map on plate 7 was compiled by J. P. Schafer, and Richard L. Tyner prepared the fragment distribution maps used on plate 7. Val L. Freeman and Eugene L. Boudette critically reviewed the manuscript. This report was prepared under NASA contract number T–5874A.

GEOLOGIC SETTING OF THE FRA MAURO SITE

The surface of the Moon is divided into relatively dark low-lying plains, or maria, and brighter, generally more rugged highlands or terrae (fig. 1). The highlands are texturally heterogeneous, consisting of level plains, gently rolling hills, mountains, scarps, and plateaus. In most parts of the highlands craters 20–100 km in diameter are abundant. On the near side of the Moon, the highlands are dominated by the great circular basins, each with several concentric rings. These basins are completely or partly filled by mare material and are interpreted to have been formed by impact of large meteorites or comets (Gilbert, 1893; Eggleton, 1964; Wilhelms and McCauley, 1971). Around several of the basins there are moderately to well-preserved tracts consisting of ridges that are radial to the basins. The surface materials in these tracts thus appear to be blanketing deposits of ejecta from the adjacent basin. Apollo 14 landed on a terrane of this type, previously mapped as ejecta from the Imbrium basin (fig. 2).

The areas mapped here as basin ejecta, as well as those elsewhere on the Moon, are characterized by a series of elongate hummocks and ridges generally radial to the center of the basin. Away from each basin, the ridges and hummocks grade into gently rolling terrain, the topographic grain of which remains radial to the basin. Hummocky topography that is concentric to the basins is present around some basins near the most prominent ring. Large, subdued craters, so conspicuous on the central part of the southern lunar highlands, are lacking in areas near the basins, where they appear to be covered by ejecta from the basins. Relatively far from the basins old subdued craters appear to be only partly buried by the blanketing material. One such partly buried, ancient crater, Fra Mauro (figs. 1, 4, 5), is covered by the blanketing material from the Imbrium basin on its northwest side but appears unburied on the southeast. Because the blanketing relations are so well displayed in the vicinity of this crater, the blanketing material around the Imbrium basin has been named the Fra Mauro Formation (Eggleton, 1964; Wilhelms, 1970).

Apollo 14 landed 40 km north of the north rim of the crater Fra Mauro in an area of linear to slightly sinuous ridges trending northward (fig. 4) (Eggleton and Offield, 1970). In this area, the Fra Mauro Formation grades southward from a deposit with well-defined ridges to a deposit of more gently rolling terrain with abundant craters in the size range 500 m to 5 km. The gently rolling terrain gives way to level plains material, part of the Cayley Formation (Morris and Wilhelms, 1967), 80 km south of the landing site. Results from the Apollo 15 and 16 missions have suggested that Imbrium basin ejecta may be more extensive over the near side of the Moon than previously thought (Swann and others, 1972; Muehlberger and others, 1972). It should be emphasized, however, that

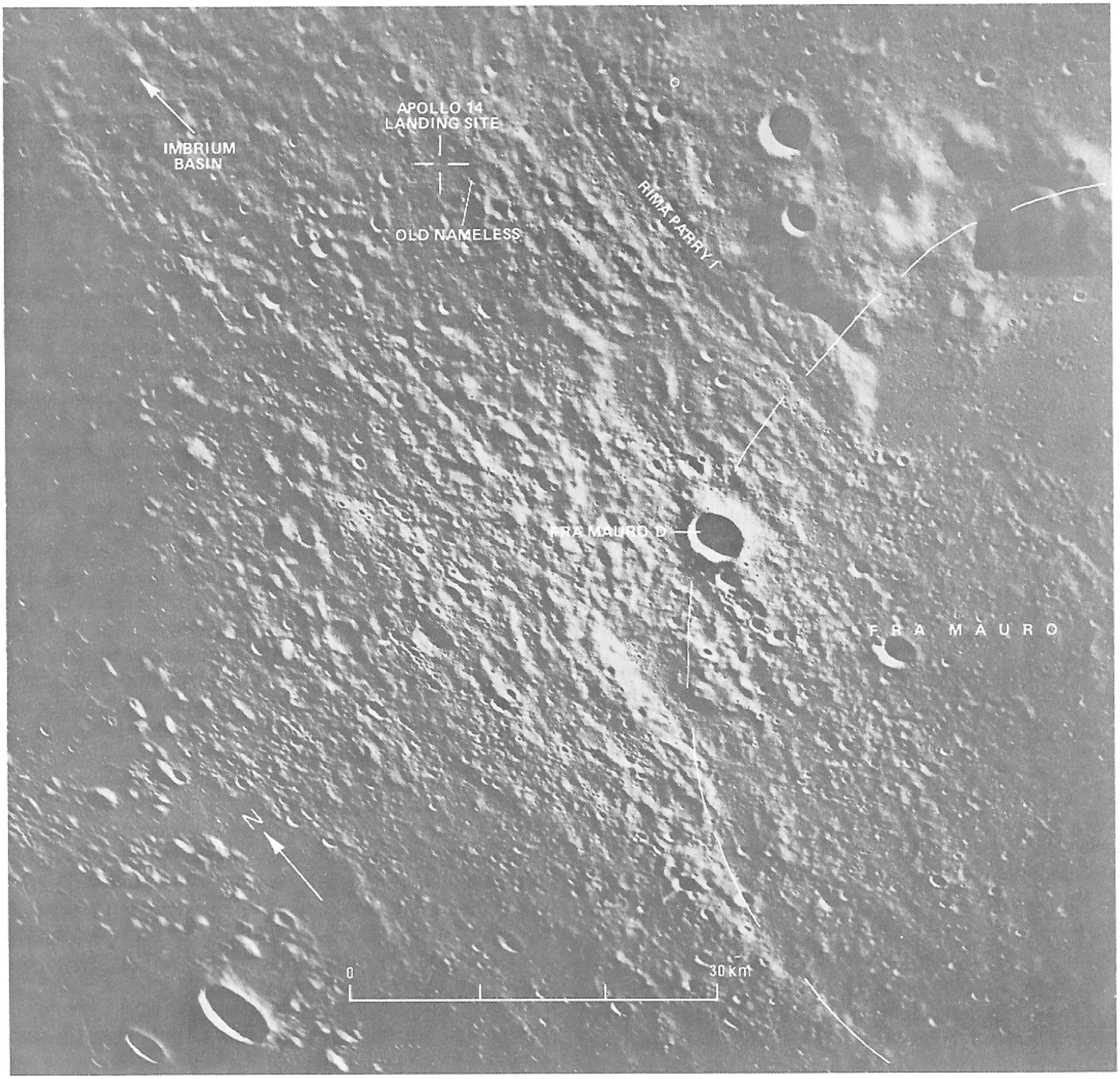

FIGURE 4.—View of the Apollo 14 landing site from the Apollo 12 Command Module, showing the ridgy nature of the Fra Mauro terrain. (NASA photograph AS12–52–7597.)

the Fra Mauro Formation, a mappable unit with well-defined limits, was established on the basis of objective criteria, and is not necessarily synonymous with Imbrium basin ejecta. Apollo 14 sampled a typical part of the formation, and as will be shown in this report, the returned samples very likely do represent Imbrium ejecta. Other formations and material on the Moon may also be composed of Imbrium ejecta, possibly with properties different from those found in the Fra Mauro Formation.

Stratigraphic relations around the margin of the Imbrium basin show that a number of significant geologic events occurred between the time that the basin formed and the time that it filled with mare material. Thus, the filling of mare basins may take place over long periods of time (Baldwin, 1963;

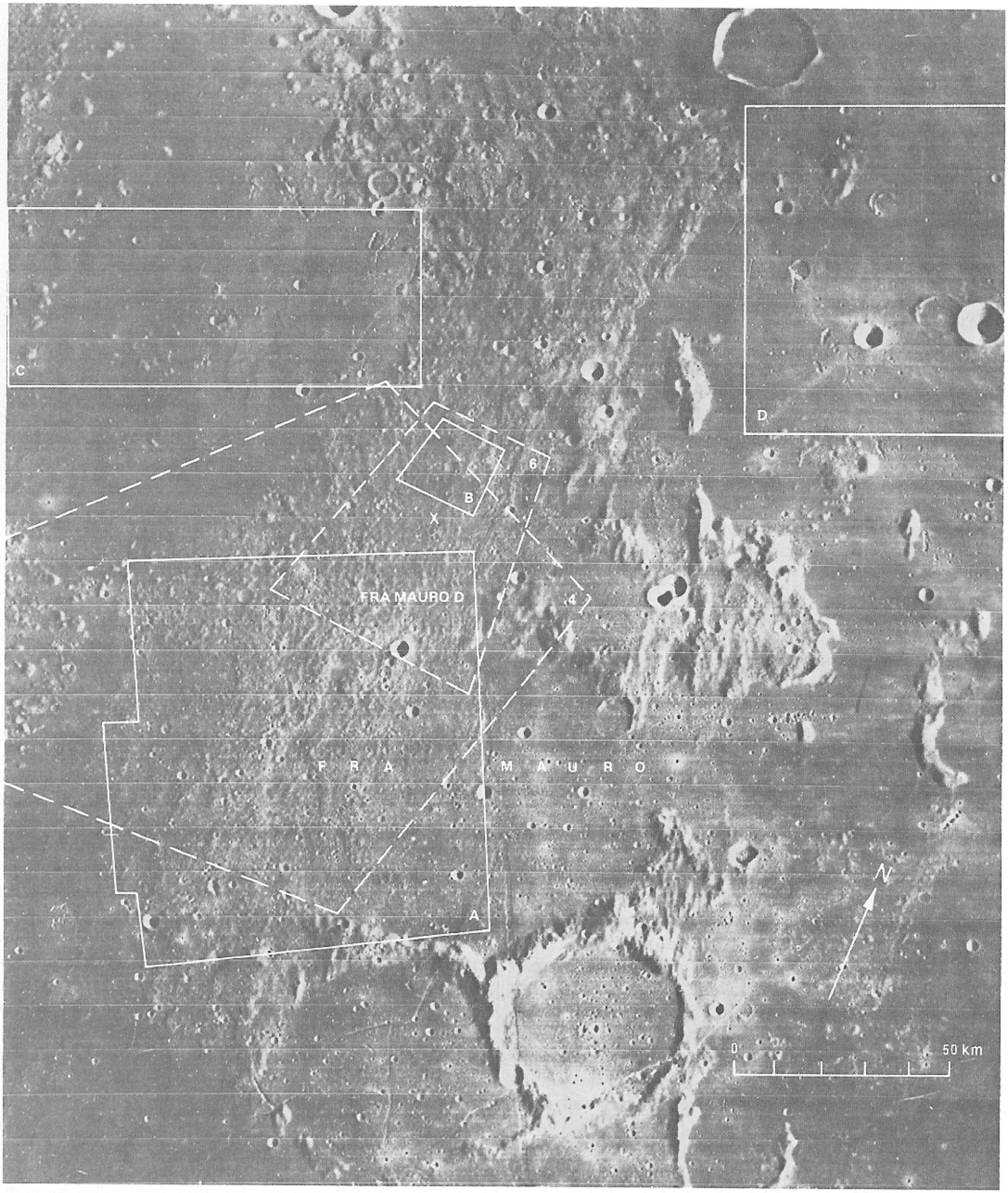

FIGURE 5.—Lunar Orbiter IV, Frame 120H3 showing areas in which craters were counted. Areas A and B are on the Fra Mauro Formation; areas C and D are on the adjacent mare. X is landing site; 4 and 6 show boundaries of figures 4 and 6. Note that area B was counted at two different scales.

Wilhelms, 1970). Events that occurred between the formation and filling of Imbrium included the formation of large craters such as Archimedes, emplacement of relatively light plains-forming highland (pre-mare) materials and, in the western part of the Moon, formation of the Orientale basin. On the basis of photographic evidence, the Fra Mauro Formation is older than the mare materials sampled by Apollos 11, 12, and 15. Another indication of its greater age is the fact that it has more superposed craters in the size range 500 m to 5 km than any mare surface (fig. 5).

The Fra Mauro Formation resembles the Hevelius Formation except for being more eroded and older than it. The Hevelius Formation surrounds the Orientale basin near the west limb of the Moon (McCauley, 1967a, b). The well-preserved ridges of the Hevelius Formation radial to the Orientale basin strongly suggest that the formation is composed of ejecta from the Orientale basin (fig. 6). A comparison of the Hevelius Formation with the Fra Mauro Formation supports the contention that the less well preserved, but otherwise similar, Fra Mauro Formation is composed of ejecta from the Ibrium basin. The ridges of the Fra Mauro Formation in the vicinity of the Apollo 14 landing site are mostly 1 to 4 km wide, a few to several tens of metres high, and on the order of 5 to 10 times as long as they are wide. They are slightly sinuous and roughly radial to the Imbrium basin. The radial ridges present in the Hevelius (McCauley, 1968) and Fra Mauro Formations appear to have formed largely by radial flow of material, probably fragmental rock debris, along the ground during excavation of the basins. Fracturing of the pre-Fra Mauro Formation rocks in a pattern radial to the Imbrium basin may also have contributed, at least locally, to the relief of the ridges. Flatter areas between the ridges have slightly lower albedo than the ridges themselves.

The regolith on the Fra Mauro Formation was expected to be thicker than that on the mare material because of its greater age and the greater abundance of craters from which regolith is formed. In order to sample bedrock beneath the regolith, the Apollo 14 mission was targeted to land close to Cone crater, a relatively fresh 370-m-diameter crater, at the crest of one of the north-south-trending ridges (pl. 1). Cone crater is surrounded by an extensive block field (pl. 7), presumably excavated from as deep as 65 m. The block field is interpreted to contain Imbrium ejecta excavated from beneath the local regolith.

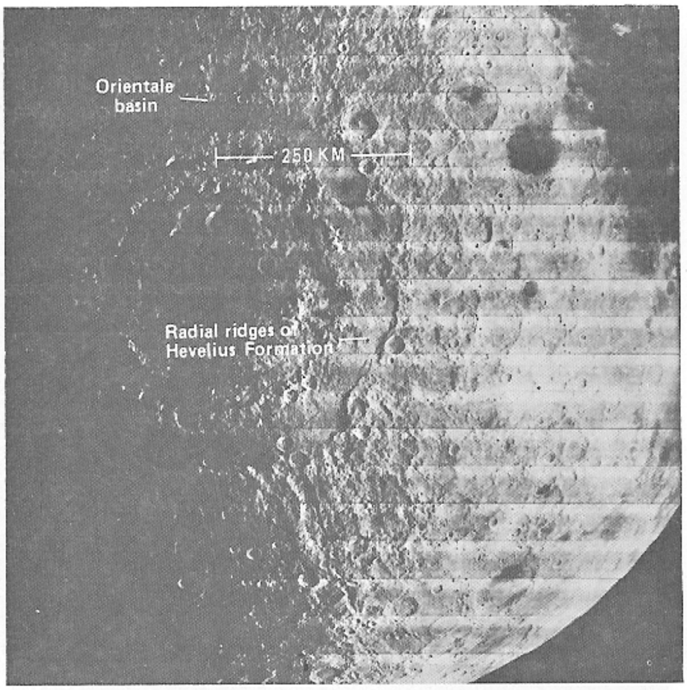

FIGURE 6.—Orientale basin showing radial ridges of Hevelius Formation (Lunar Orbiter IV mosaic.)

Four map units of the Fra Mauro Formation were traversed by the Apollo 14 crew (pl. 1): (1) the smooth terrain unit (Ifs) on which the LM landed, (2) the apron unit (Ca) at the base of the ridge, (3) slopes of the ridgy unit (Ifr), and (4) the blocky rim deposit of Cone crater. The smooth unit is relatively level over distances greater than a kilometre, but is densely populated with subdued crater forms a few hundred metres to a few tens of metres across and a few tens of metres to a few metres deep that give the surface an undulating form. The Fra Mauro ridge, which extends several kilometres north and south of Cone crater, has a slope of about 8° and is hummocky and ridgy at a scale of several metres. At least four moderately subdued craters of Eratosthenian age which are 200 to 1,000 m in diameter occur in the Fra Mauro ridge north, east, and south of Cone crater and within a few hundred metres of the rim crest of Cone crater (pl. 1). Their rim deposits cannot be identified on Lunar Orbiter photographs, but some unmodified crater remnants are probably buried in the regolith. The interiors of these craters have slopes between 10° and 15°, slightly greater than the slopes of the Fra Mauro ridge. The rim of Cone crater is moderately to abundantly strewn with 1- to 15-m blocks. The blocks form rather dense patches that extend as far as 125 m from the rim crest. In the remainder of the rim deposit, blocks 2 m across and larger are commonly spaced as much as a few tens of metres apart (pl. 7).

Craters ranging in size from 64 m to 8 km were counted on Lunar Orbiter III and IV frames that cover the Fra Mauro Formation and the mare areas adjacent to the Apollo 14 landing site (figs. 5, 7). The counting method consists of calculating the area of each parcel, A, B, C, and D, and counting all identifiable craters