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GEOLOGIC CHARACTERISTICS OF THE NINE LUNAR LANDING MISSION SITES RECOMMENDED BY THE GROUP FOR LUNAR EXPLORATION PLANNING

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ABSTRACT

The Group for Lunar Exploration Planning (GLEP) selected nine sites for manned surface exploration missions; Crater Censorinus, Littrow Area, Abulfeda (Crater Chain), Hyginus Crater and Rille, Apennines-Rima Hadley, Rim of Crater Tycho, Crater Copernicus, Schroeter's Valley, and Marius Hills. These nine sites are analyzed in this report. Emphasis is put largely on the geologic setting of the areas in question. However, some technological problems are considered. A summary of this analysis is given on the following pages.

The report provides a base for future discussions of the Lunar Exploration Plan in general. The data and information provided in Chapter II, which deals with the characteristics of the individual sites, will be of value in the first stages of future mission planning.

SUMMARY

Nine areas on the Moon's earthside were recommended by the Group for Lunar Exploration Planning (GLEP) for manned surface exploration missions, with the understanding that they would be preceded by three missions to two different mare and a site in the Fra Mauro Formation. These nine sites and their salient features are:

1. Crater Censorinus: A small, fresh (impact) crater in highland terrain, on the projected outer rim of Mare Nectaris, or the southern rim of Mare Tranquillitatis.

2. Littrow Area: Very dark (volcanic) blanket material which mantles both Serenitatis Bench rocks and a fresh mare ridge.

3. Abulfeda (Crater Chain): (Deep-seated) material in and around a (volcanic) crater chain in the Southern Highlands and its associated "cinder cones".

4. Hyginus Crater and Rille: The floor of crater Hyginus, the walls of its linear rille, and the surrounding plains which include the Cayley Formation.

5. Apennines - Rima Hadley: The Apennine mountain front, its contact with the mare and relationship to a young sinuous rille, and the controversial crater Hadley C.

6. Rim of Crater Tycho: Textures and structures of part of the rim of a large rayed crater in highland terrain.

7. Crater Copernicus: The (deep-seated) rocks at the central peaks, the floor, and the flow, mass wasting features and ponds along the walls.

8. Schroeter's Valley: A large lunar valley, its median sinuous rille, and their genetic relationships to the "Cobra Head", and the latter's transient phenomena.

9. Marius Hills: A complex of (volcanic) domes, cones, mare ridges and sinuous rilles in Oceanus Procellarum.

Chapter II of this report includes discussions of the nine sites, namely: descriptions of the general and geologic settings of the areas in question; listings of the major objectives and the scientific merits of the sites; and a proposal of a landing point and consequent surface operations for each site. Many of the discussions are based on scientific-geologic considerations; reference is made, however, to some engineering and technological problems involved.

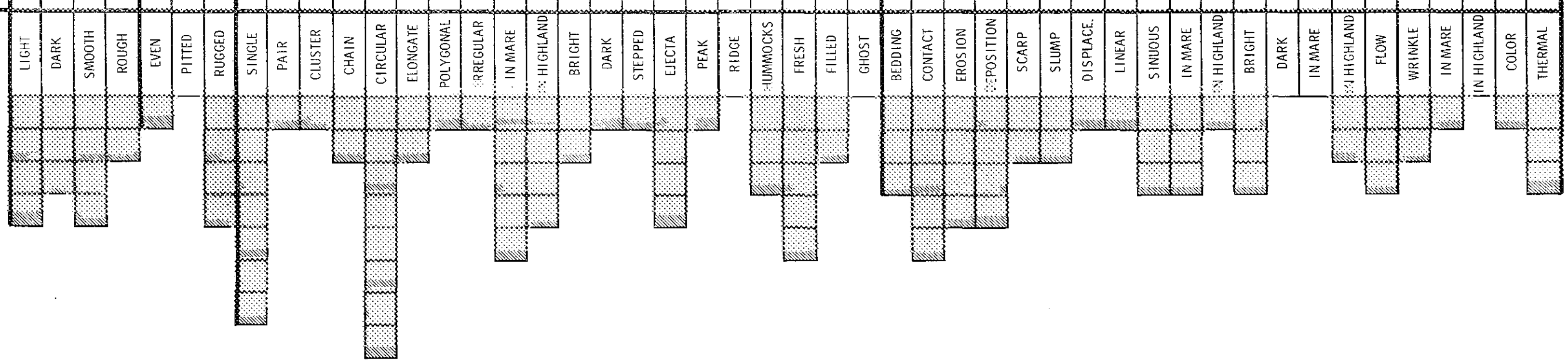
Three of the nine sites, Crater Censorinus, Littrow Area, and Abulfeda (Crater Chain), were previously considered as candidates for "walking missions", i.e., no mobility aids to be used in the 1.5 km radius of operations, with the Littrow site being a borderline case. Preliminary photo-geologic studies indicate that both Censorinus and Littrow sites may be considered for "walking missions". The Abulfeda site, however, requires the extension of the mobility range to at least 5 km in order to achieve all of the mission objectives. It was also found that a "walking mission" to the rim of crater Tycho, and in the vicinity of the Surveyor VII spacecraft, would achieve almost all of the objectives of studying this crater. Exploration plans for the rest of the sites, however, require one or more of the mobility aids now under consideration (Lunar Flying Units, Field Assistants, Manned and Unmanned Lunar Roving Vehicles).

In Chapter III of the report, an analysis of the GLEP plan <u>in toto</u> is given. This analysis includes a summary of the characteristics of the nine sites and the nature of the areas to be explored (as given on p. viii), a summary of the mobility requirements based on the objectives of a given mission and the nature of the terrain to be explored, and an array of the expected achievements in the fields of technology, geology, geophysics and geochemistry, as shown on p. ix.

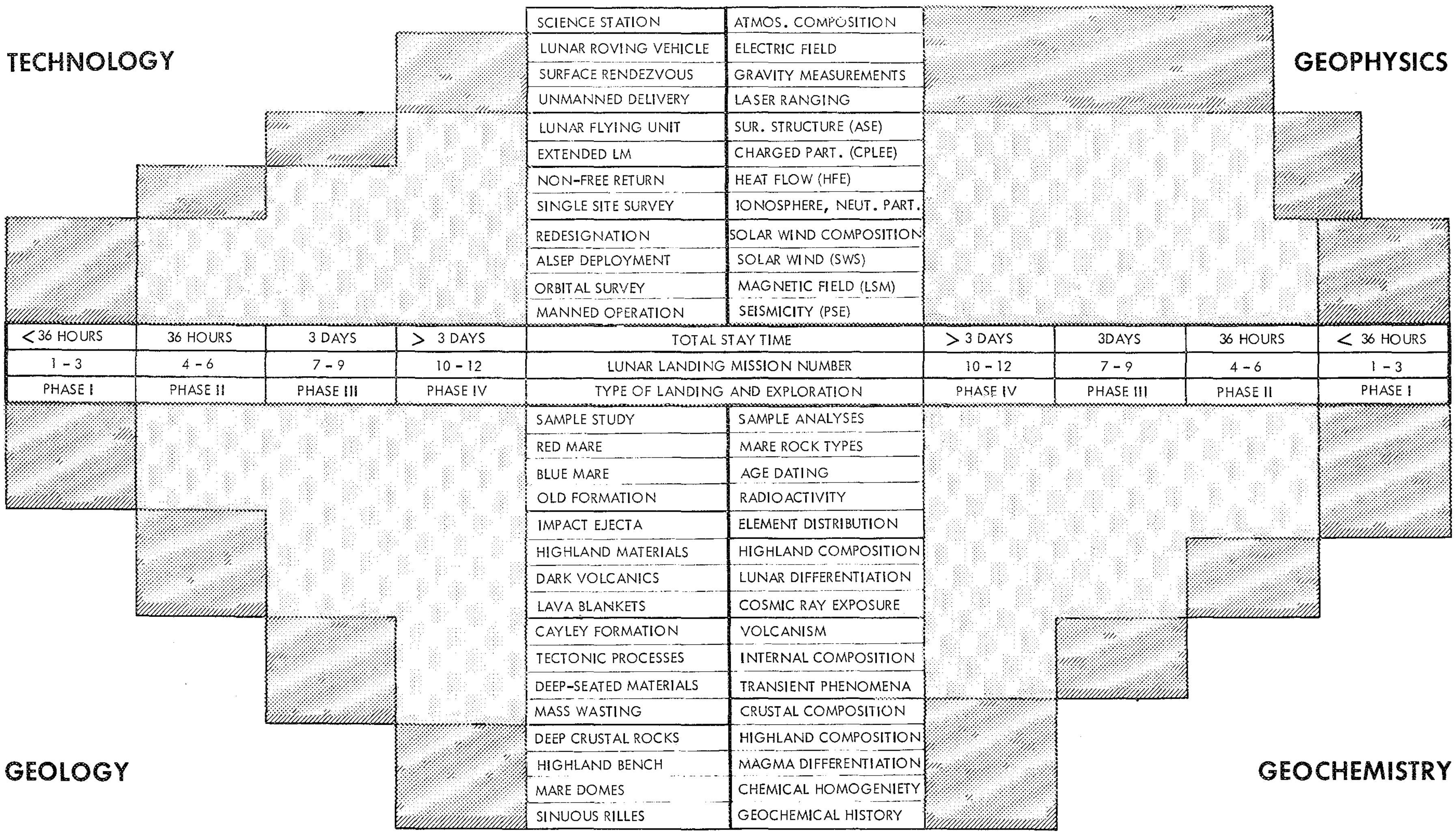
It is concluded that the GLEP plan, including the first three Apollo missions, constitutes a well balanced selection of scientifically important areas. It is also concluded that the exploration of the selected sites should broaden our knowledge of the Earth-Moon system and give clues to major questions concerning the Moon including: 1) The chemical heterogeniety of lunar rocks, 2) The differentiation of the Moon as a whole and that of lunar magmas, 3) Extra-lunar processes and cratering events and their frequency 4) Geophysical properties of the Moon, and 5) The geochemical (organic and inorganic) history of the near lunar environment.

CUMULATIVE GRAPH OF THE CHARACTERISTICS AND STRUCTURAL FEATURES OF THE AREAS TO BE EXPLORED IN THE NINE SITES

MAJOR UNITS		MARIA				HIGHLAND			CRATERS																						STRUCTURAL FEATURES																									
		ALBEDO		SURFACE		SURFACE			NUMBER				GEOMETRY				SITE		HALO		RIM		STRUCTURE			AGE			STRATA				FAULTS			RILLES				RAYS				RIDGES		DOMES		ANOMALY	
NO.	SITE DESIGNATION	LIGHT	DARK	SMOOTH	ROUGH	EVEN	PITTED	RUGGED	SINGLE	PAIR	CLUSTER	CHAIN	CIRCULAR	ELONGATE	POLYGONAL	IRREGULAR	IN MARE	IN HIGHLAND	BRIGHT	DARK	STEPPED	EJECTA	PEAK	RIDGE	HUMMOCKS	FRESH	FILLED	GHOST	BEDDING	CONTACT	EROSION	DEPOSITION	SCARP	SLUMP	DISPLACE.	LINEAR	SINUOUS	IN MARE	IN HIGHLAND	BRIGHT	DARK	IN MARE	IN HIGHLAND	FLOW	WRINKLE	IN MARE	IN HIGHLAND	COLOR	THERMAL
1	CRATER CENSORINUS							X	X				X					X	X			X			X	X														X			X						X
2	LITTROW AREA	X	X	X	X				X				X				X									X	X			X														X	X				
3	ABULFEDA (CRATER CHAIN)					X			X	X		X	X	X				X									X																						
4	HYGINUS CRATER & RILLE	X	X	X								X	X	X	X		X									X			X	X	X	X	X			X		X											
5	APPENNINES-RIMA HADLEY		X	X				X	X				X				X					X				X			X	X	X	X					X	X											
6	RIM OF CRATER TYCHO							X	X				X					X		X		X			X	X				X										X			X	X					X
7	CRATER COPERNICUS	X			X				X				X				X		X		X		X		X				X	X	X	X		X	X					X				X					
8	SCHROETER'S VALLEY							X			X							X				X									X	X	X	X			X		X									X	X
9	MARIUS HILLS	X		X					X				X			X	X																				X	X							X	X			



EXPECTED SCIENTIFIC AND TECHNOLOGICAL ACCOMPLISHMENTS OF THE LUNAR EXPLORATION PLAN



GEOLOGIC CHARACTERISTICS OF THE NINE LUNAR LANDING MISSION SITES RECOMMENDED BY THE GROUP FOR LUNAR EXPLORATION PLANNING

I. INTRODUCTION

In August, 1967, at Santa Cruz, California, NASA sponsored a Summer Study of Lunar Science and Exploration. During that conference, it became obvious to the participants that the selection of many lunar scientific experiments and the establishment of operational requirements (lunar staytime, mobility aids, etc.) were site-dependent. It was necessary, therefore, that before commencing detailed planning, one should specify the sites. In response to this need, a Site Selection Subgroup (Appendix A) of the Group for Lunar Exploration Planning (GLEP)* met on December 9, 1967 to select targets of salient value in the quest for understanding many of the major lunar surface units and features, their origin, evolution, and modifying processes. Nine areas on the lunar earthside were selected and are shown on the index map of Figure 1. The numbers assigned to these nine sites are neither indicative of priorities, nor do they correspond to a time sequence, although the first three (Censorinus, Littrow, Abulfeda) were considered as sites where no mobility aids would be available. Further study is required before establishing priority and sequence.

It was understood that manned missions to the nine sites would follow three Apollo flights to mare regions or other smooth terrain units, thus, making a total of 12 missions in this exploration plan. Sites for the first three missions, dictated primarily by engineering considerations, are not discussed here other than to say that it would be scientifically advantageous to land one each in an eastern mare, a western mare, and an "old" surface unit, preferably the Fra Mauro Formation.

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*The GLEP, composed of representatives of the disciplinary working groups at Santa Cruz, is a continuing advisory body reporting to Dr. W. N. Hess, Director of Science and Applications at the Manned Spacecraft Center.

In the following section of this report, the nine GLEP sites are described separately. Descriptions of the individual sites are supplemented by explanatory figures. In all cases, one part of a given figure (part "a") is devoted to basic data pertaining to the site, including:

1. Data relevant to the location of the site (coordinates of LO-V camera axis intercepts on the lunar surface), the corresponding LAC chart number and designation, average albedo of the area, LO-IV frame number, and LO-V site and frame numbers.

2. A reproduction of the footprint of LO-V photographic coverage keyed to the corresponding LAC chart.

3. A medium resolution photograph depicting the site and its relationships to the surrounding terrain.

4. A reproduction of the available USGS geologic map of the area. This part is lacking in the case of Tycho where no geologic maps are available yet.*

Part "a" of any given figure is followed by one or more parts where the landing point and area of surface operations are specified. Targets of specific interest are also enumerated, making the figures useful for future detailed studies and drafting of mission plans.

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*See Appendix B for explanation of the lunar stratigraphic systems and the origin of the geologic symbols.

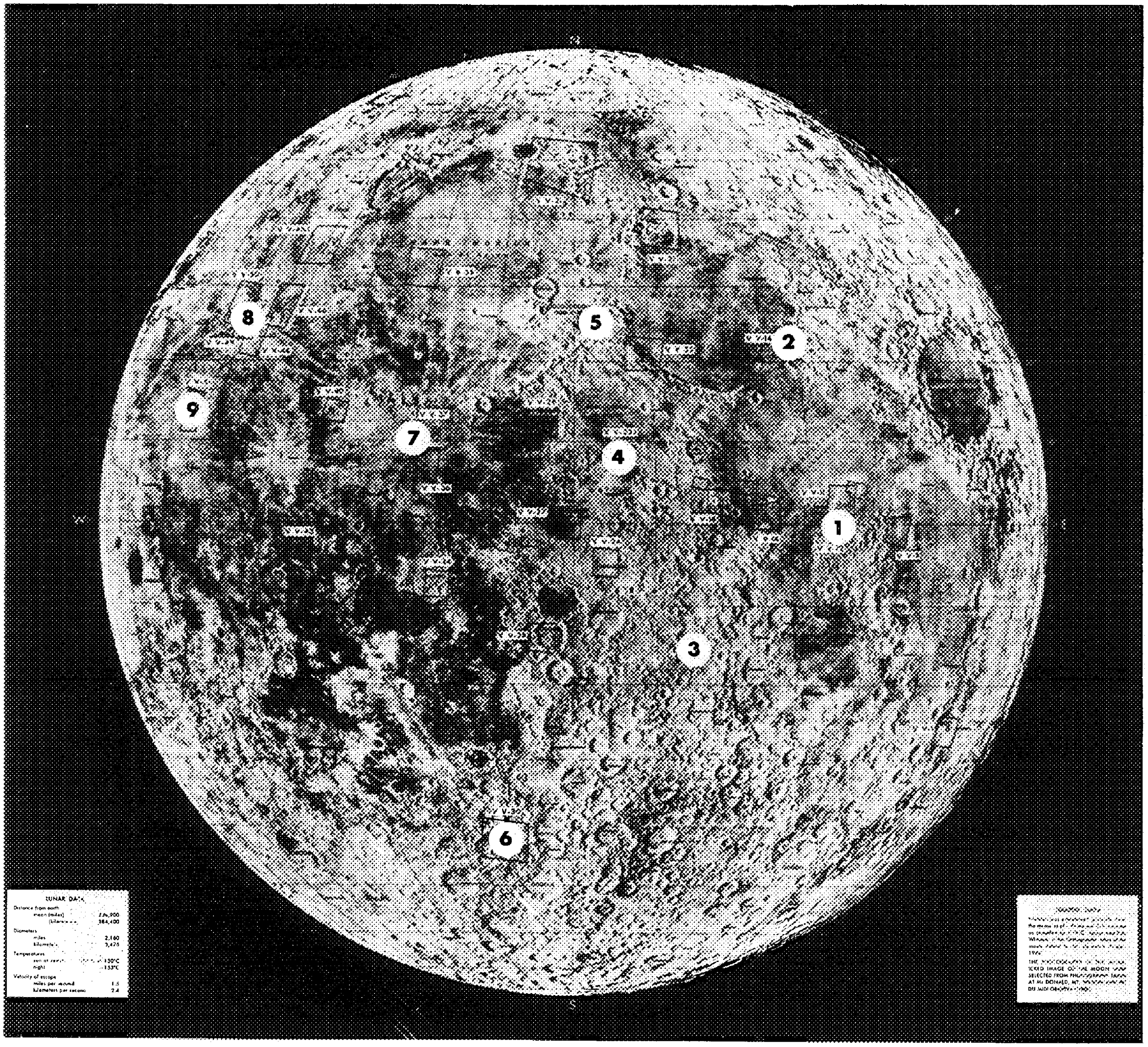

FIGURE 1. INDEX MAP

1. CRATER CENSORINUS
2. LITTROW AREA
3. ABULFEDA (CRATER CHAIN)
4. HYGINUS CRATER & RILLE
5. APENNINES-RIMA HADLEY
6. RIM OF CRATER TYCHO
7. CRATER COPERNICUS
8. SCHROETER'S VALLEY
9. MARIUS HILLS

II. CHARACTERISTICS OF THE NINE SITES

1. CRATER CENSORINUS

A. Description and Setting*

The crater Censorinus is a small (3.5 km in diameter) but very bright and young crater, with a high thermal anomaly, named after the Latin grammarian and mathematician. It lies on the northwestern edge of a highland plateau between Mare Tranquillitatis and Mare Nectaris, being closer to the former.

The plateau itself appears to be part of a raised ring concentric with the Nectaris Basin, N-NE of a continuation of the Altai Scarp. This plateau is probably made of either 1) primitive lunar material which has undergone little or no chemical change since the formation of the Moon; or 2) Nectaris ejecta which may or may not be covered by younger materials.

The morphology of the crater Censorinus and its conspicuous effects on and modifications of the surrounding terrain suggest that it is most probably an impact feature. As illustrated in Figure 2a (lower left), the crater is characterized by a round, sharp rim crest and a very distinct pattern of ejecta. As will be discussed later, it is also characterized by a great abundance of fresh large blocks in the vicinity of its raised rim which account for the high thermal anomaly displayed by the crater. Many of these ejected blocks have impacted on the mantled wall of the neighboring crater Censorinus A, leaving marked imprints.

The geologic units represented in the area of the crater Censorinus (Figure 2a: lower right) are as follow:[1]

Copernican System

Cc: Cratered materials, undifferentiated

Copernican-Eratosthenian

CEcc: Cratered cone materials, indeterminate position

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*This section includes information which is contributed by Messrs. John W. Dietrich and Harrison H. Schmitt of MSC; members of the GLEP Site Selection Subgroup (Appendix A).

Eratosthenian System

Ec: Crater materials, undifferentiated

Imbrian System (?)

IpIs: Smooth veneering material

Pre-Imbrian System

pIce: Censorinus Formation (fragmental materials)
pIgu: Gutenberg crater materials, undifferentiated

B. Major Objectives

1. Sampling of the ejecta blanket, which should represent the upper 1/2 to 3/4 km of the highland plateau, with some preservation of the stratigraphic succession.

2. Close examination of the structural and textural characteristics of a probable impact crater, and definition of a fixed time for the event by cosmic ray exposure age determination of ejecta.

3. Emplacement of a geophysical station on a highland plateau but very close to Mare Tranquillitatis. This is a very favorable location, especially if supplemented with other stations at sites 2 and 3.

C. Landing Area

The proposed mission to crater Censorinus is limited to a 1.5 km radius of mobility, thus a "walking mission" requiring no mobility aids. Such a mission would require the capability of "pin-point" landing at a predesignated spot which is within range of all areas to be explored.

An area most favorable for exploring the site is marked by a circle in Figure 2b. The radius of the circle is 1 km although, as stated above, it is postulated that the astronauts are capable of getting as far as 1.5 km away from the landing point with no mobility aids. In this case a slope of 10 - 15 degrees on the crater rim (up to 400 meters from the rim crest) is taken into account.

Numbered spots represent targets of importance to the mission objectives and correspond to the following:

1. Landing area including sharp but irregular crater directly north of the landing point.

2. Blocks of rock, on the ejecta blanket, and their surroundings.

3. The sharp rim crest of the crater itself and the view of the inside wall and its characteristics.

4. Patterns of the ejecta blanket as far as possible from the rim crest, including a small, sharp, raised, dark-haloed and round crater.

An alternative landing point lies west of the crater Censorinus and is marked X in Figure 2b. However, in this case, Censorinus would be an obstacle from the engineering (approach path) viewpoint.

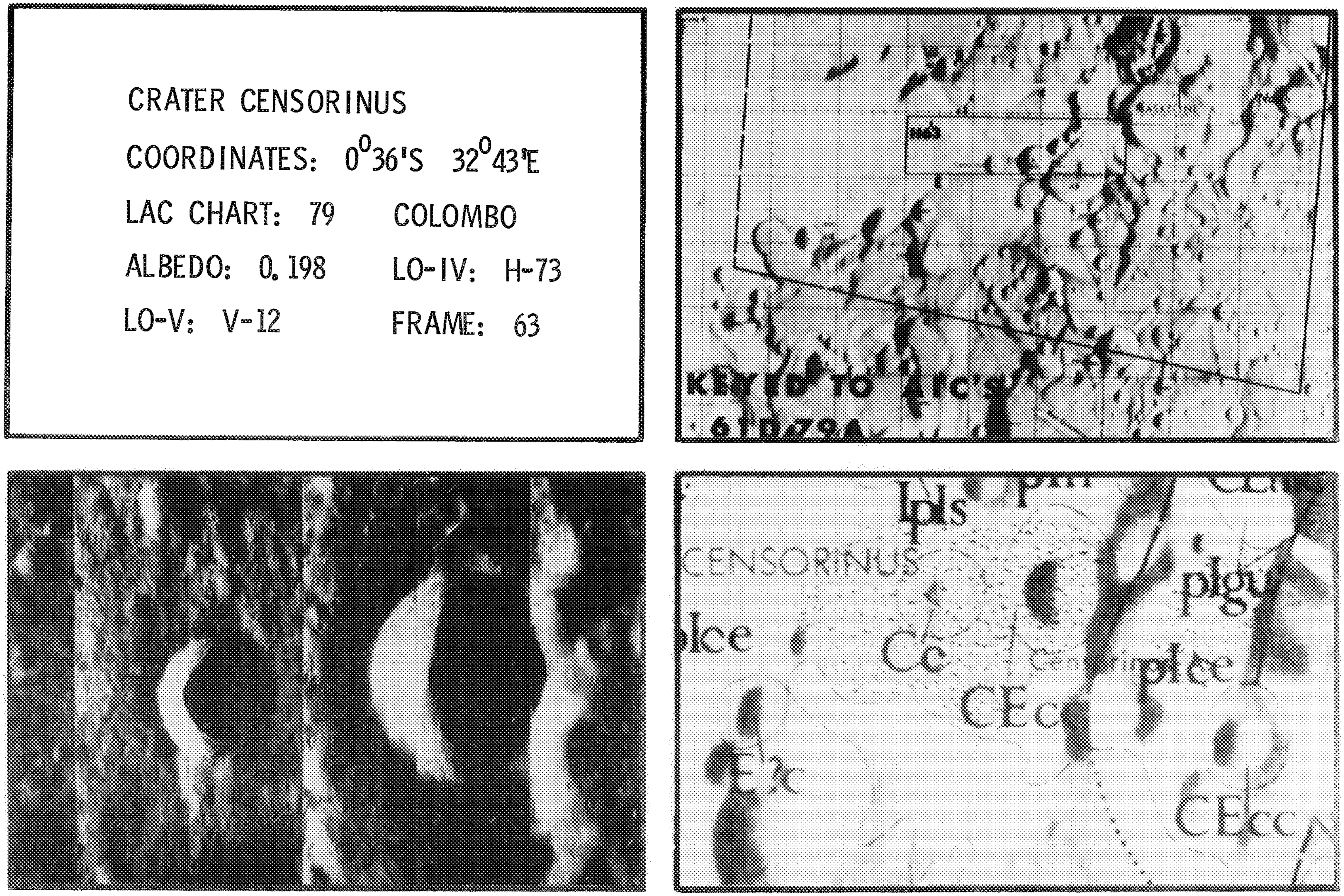

CRATER CENSORINUS
COORDINATES: 0°36'S 32°43'E
LAC CHART: 79 COLOMBO
ALBEDO: 0.198 LO-IV: H-73
LO-V: V-12 FRAME: 63
CENSORINUS

FIGURE 2a

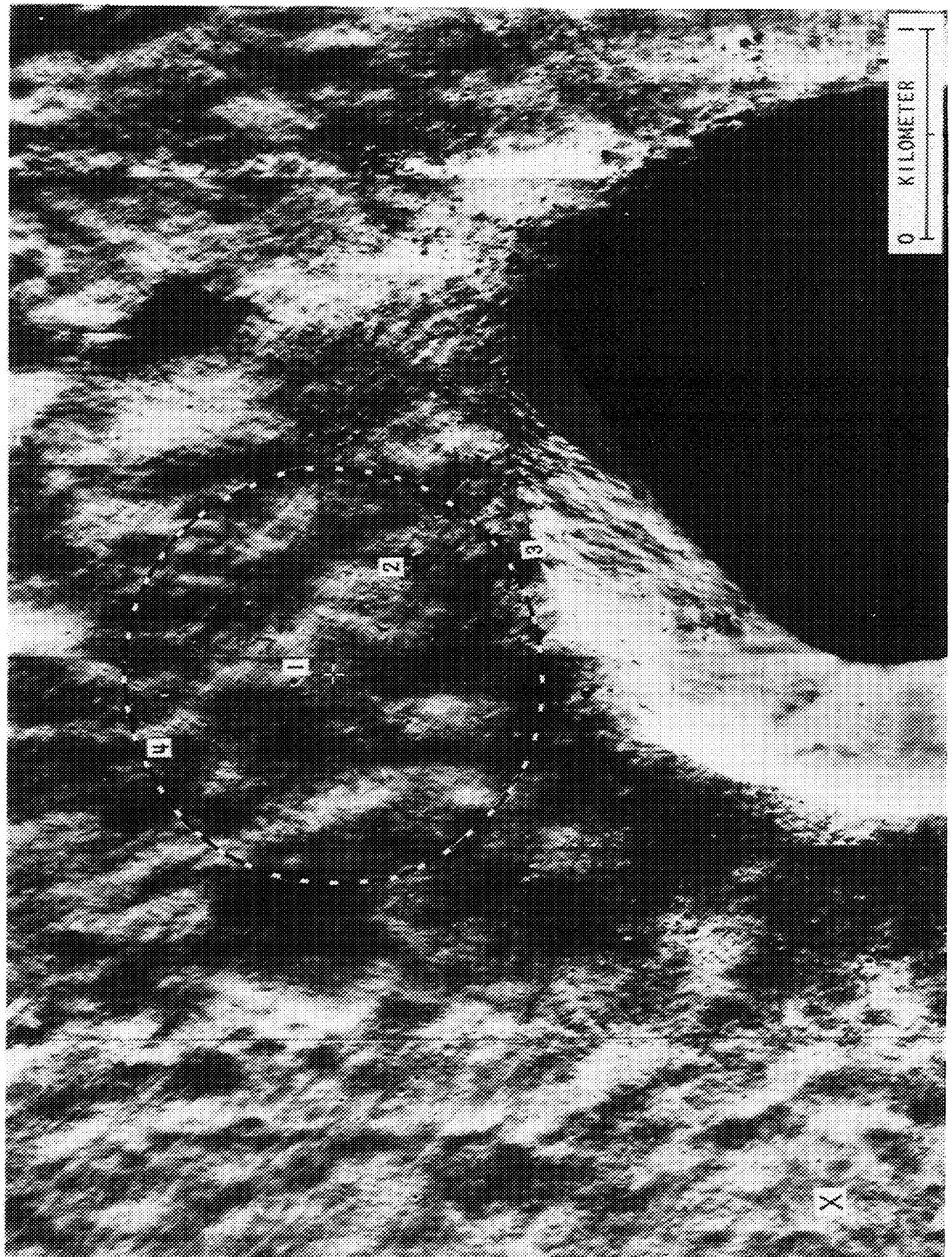


FIGURE 2b. PROPOSED LANDING SITE FOR CRATER CENSORINUS

2. LITTROW AREA

A. Description and Setting

Rimae Littrow constitute one part of a series of rille networks around the margin of Mare Serenitatis and lie close to its eastern edge. Associated with the rille systems are low albedo blanketing materials which, in the vicinity of Littrow, include some of the darkest material on the lunar surface.

The dark materials occur mostly on a level cratered plateau, here called the Serenitatis Bench, between typical mare to the west and rugged uplands to the east. However, part of the mare and uplands in the immediate vicinity of the plateau are anomalously dark.

The Littrow area is also characterized by an abundance of fresh looking wrinkle ridges in the mare. Mare Serenitatis in this area is also characterized by a number of minute cracks forming systems subparallel to the ridges, and thus, appears to be a stage in wrinkle ridge formation. In one spot, the dark blanketing material conspicuously covers part of a fresh ridge, which suggests that the dark material is relatively young and may be of volcanic origin.

The geologic units represented in the Littrow area (Figure 3a; lower right) include the following:[2]

Copernican System

Cc: Crater material, undifferentiated
Cs: Slope material (freshly generated talus)

Eratosthenian System

Ec: Crater materials, undifferentiated
Emd: Mare material, dark

Imbrian System (Archimedian Series)

Ipm3: Mare material (volcanic); albedo 0.061-0.062
Ipm4: Mare material (volcanic); albedo 0.060-0.061

B. Major Objectives

1. Study and sampling of the dark mantling material associated with Rimae Littrow. The low albedo of

these rocks may be due to a distinctive chemical composition, a form of alteration, or a thin veneer of dark material such as carbon.

2. Sampling of the lighter materials of the bench, mare, and mare ridge, and the study of their relationships to the dark mantling material.

3. Study of the structural characteristics of the mare (wrinkle) ridge which is one of the freshest in all the proposed sites including those suggested for the first three Apollo missions.

4. Study and sampling of the variably subdued craters on the mare surface, on the bench and the dark mantling material. This should yield significant information on the origin of craters and their geometric characteristics.

5. Geophysical investigations of the subsurface structure beneath the Maria of Serenitatis and Tranquillitatis and their adjacent highlands.

C. <u>Landing Area</u>

As illustrated in Figure 3b, there are two alternatives for exploring the Littrow area, one without the use of mobility aids and the other utilizing such aids to expand the exploration limit from 1.5 km to 5 km from the landing point.

From the illustration, it is obvious that most targets of interest could be reached in a "walking mission" to this area. The only dubious matter would be encountering Serenitatis Bench material. However, it should be possible to do that by shallow drilling 1.5 km E-SE of the designated landing point. It should be kept in mind that the smaller circle in the figure is 2 km and not 3 km in diameter, and the larger circle is 10 km in diameter.

The numbered targets in Figure 3b correspond to:

1. Dark mantling material underlain by bench material

2. Fresh wrinkle ridge in mare

3. Mare ridge covered by the dark mantling material

4. A relatively large, fresh crater in mare.

LITTROW AREA

COORDINATES:

22°12'N 29°20'E

LAC CHART: 42

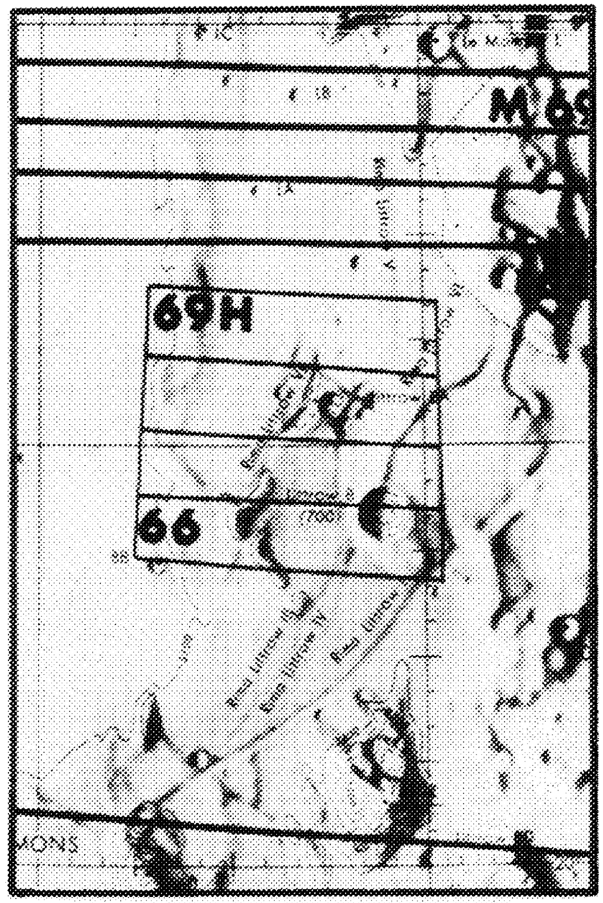
MARE SERENITATIS

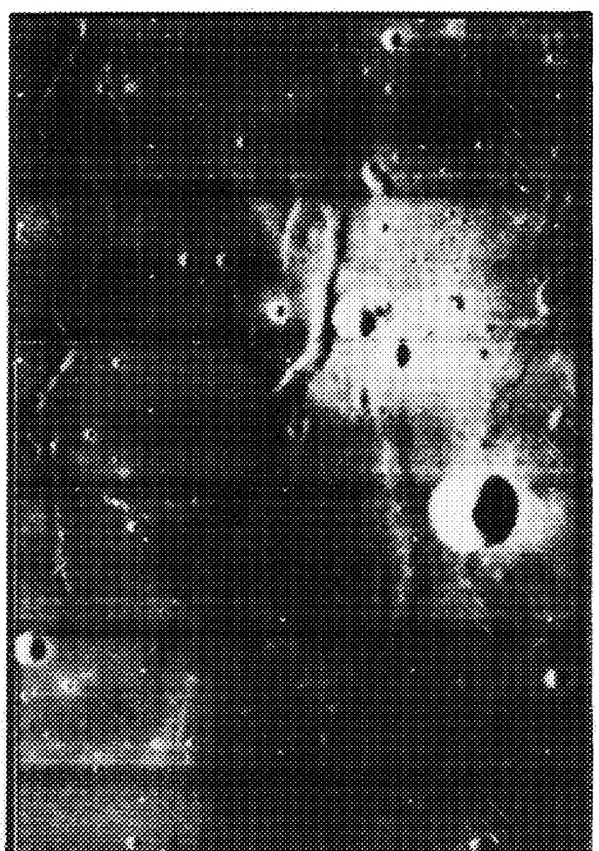
ALBEDO: 0.086

LO-IV: H-78

LO-V: V-14

FRAMES: 66-69





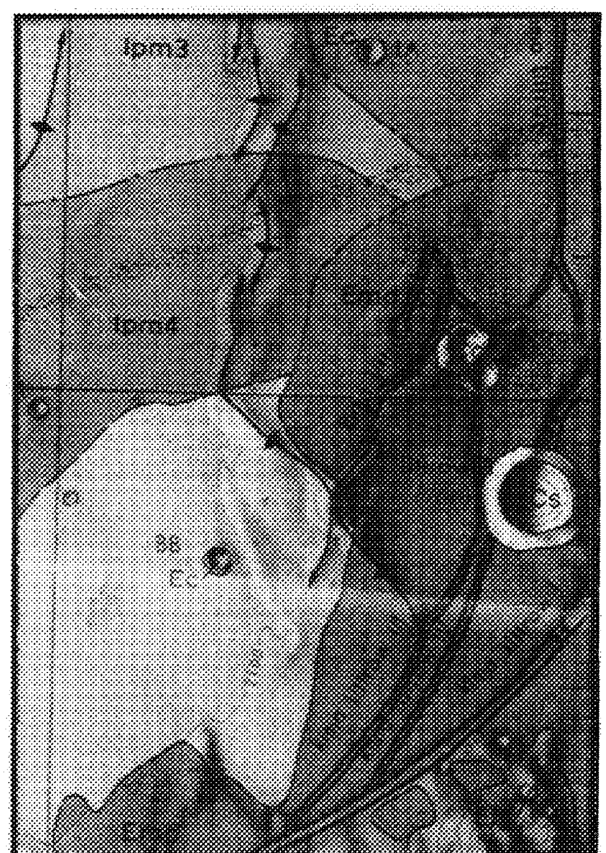


FIGURE 3a

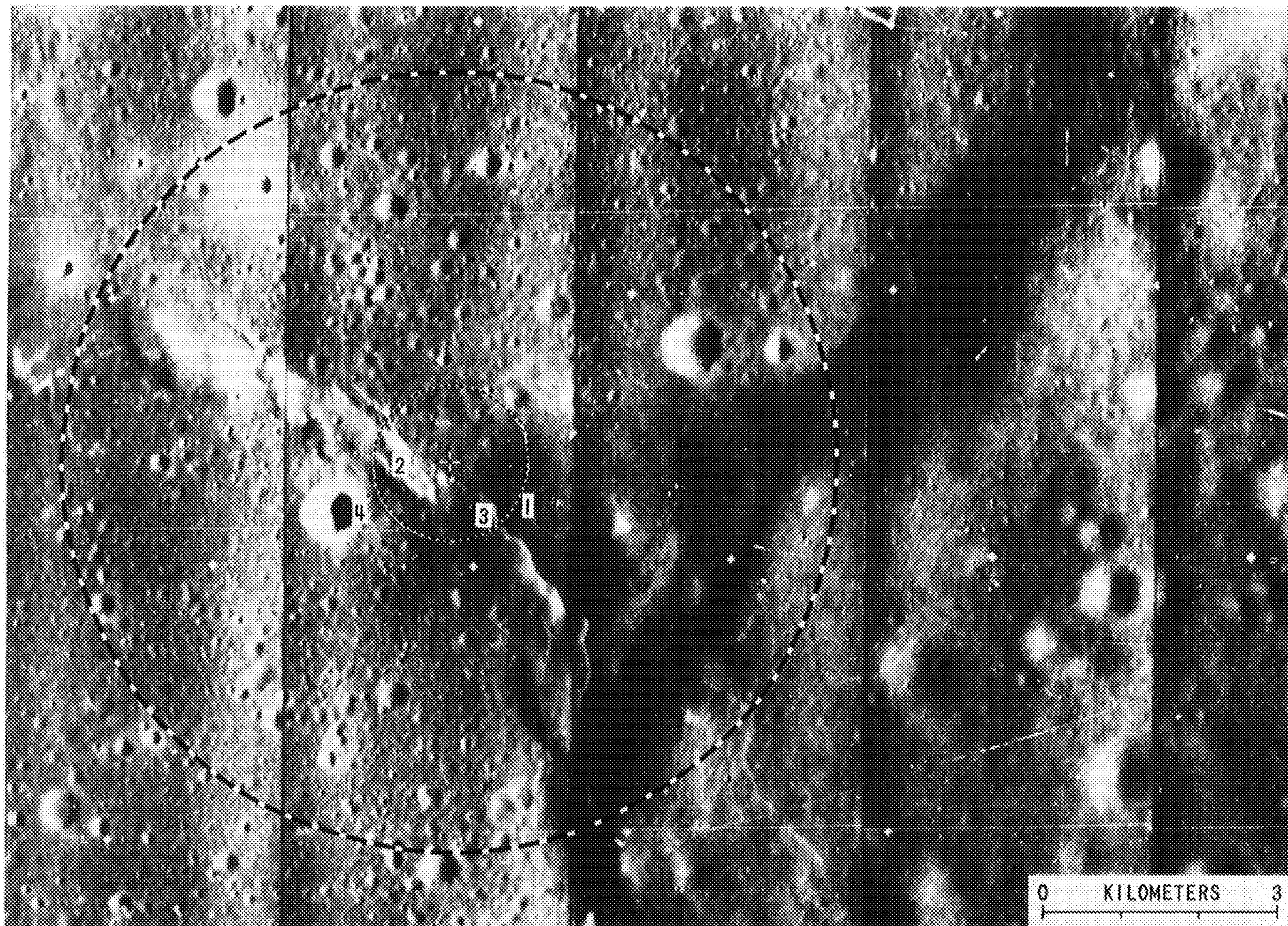


FIGURE 3b. PROPOSED LANDING SITE IN THE LITTROW AREA

3. ABULFEDA (CRATER CHAIN)

A. Description and Setting

The crater Abulfeda is situated in southern highland terrain and is surrounded by presumably old terra in all directions, with the nearest mare being over 200 km away. The crater is about 50 km in diameter and displays a circular terraced wall which rises up to 3 km above its floor.

A remarkable crater chain, the longest on the Moon's earthside, runs tangentially to Abulfeda's southern rim, where Abulfeda T and Abulfeda X form part of the chain. The chain can be traced for more than 150 km to the southeast where it cuts across the Altai Scarp.

The geometric relationships between the crater chain and crater Abulfeda do not reveal their genetic relationships, if any. However, the chain itself bears similarities to certain volcanic crater chains on earth, and by analogy, it is possible that one may encounter deep-seated rocks at this site.

A preliminary geologic map of the area is provided in Figure 4a where the geologic units are classified as follows:[3]

Copernican System

Ccr: Crater rim material, undifferentiated
Cs: Slope material (freshly generated talus)

Imbrian System

Ifm?: Fra Mauro Formation
In: Plains-forming material
Int: Thin plains-forming material

B. Major Objectives

1. From the geologic and geochemical viewpoints, it is most important to examine and sample "typical" southern highland material, an unclassified and little understood unit covering more than 30% of the Moon's earthside. The coarsely-patterned ground at this site is typical of a good portion of the southern highlands. The comparison of this with "freshly" exposed terra, such as that in the Censorinus and Tycho sites, would provide valuable data on the composition of the terrae,

their aging processes and the nature of the lunar near-surface environment.

2. The origin of the Abulfeda crater chain most probably involved deep-seated volcanic-tectonic processes. One would expect that the study of returned samples from this site would give some answers to major questions concerning the differentiation of lunar materials at depth. Furthermore, close examination of the characteristics of the area may shed light on lunar volcanism and the formation of volcanic crater chains in general.

3. Emplacement of a geophysical station. The simultaneous operation of observatory-type geophysical stations at Littrow area and the craters Censorinus and Abulfeda (and possibly also at Tycho) would result in a well-distributed network.

C. Landing Area

The Abulfeda (crater chain) site was originally proposed by the Site Selection Subgroup for a "walking mission", i.e., maximum mobility radius of 1.5 km. From Figure 4b it is clear that such a mission would allow the astronauts to study the landing area, its textural patterns and the various small craters peppered on the surface (numbers 1 through 3), up to the edge of the duct connecting Abulfeda T and Abulfeda X (number 4).

A very important feature in this area is the abundance of dark "cinder cones" inside the chain. The floors of, and the connecting rille between, Abulfeda T and Abulfeda X display several of those crater cones. At A (to the lower right), one major cone with a round sharp summit crater is surrounded by several secondary cones, most of which display a well developed summit crater. At A' (to the lower left) two distinct cones with summit craters are also conspicuous. These "cinder cones" constitute a major feature of interest and a mission to this crater chain should be extended to 5 km mobility, e.g., utilizing Lunar Flying Units, to reach, sample and study the cluster marked A in Figure 4b.

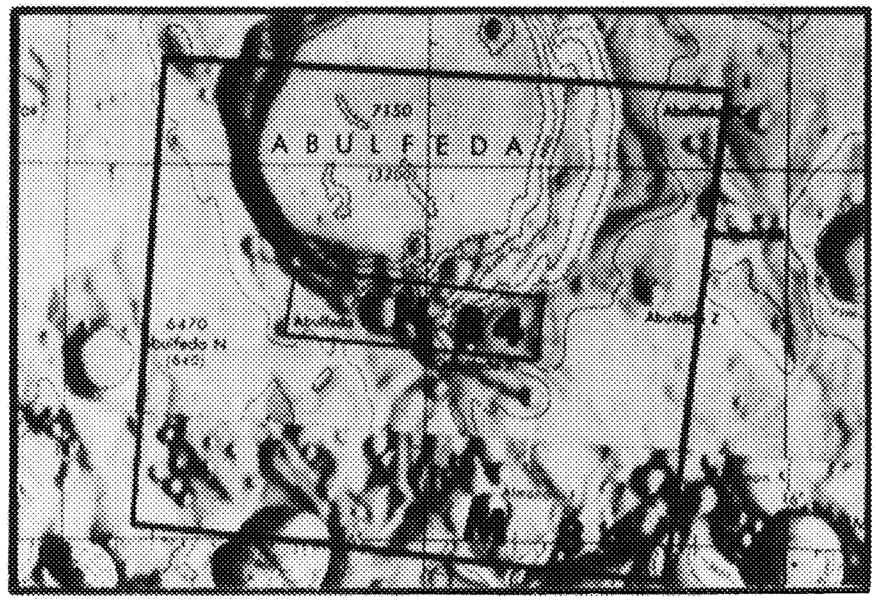
ABULFEDA (CRATER CHAIN)

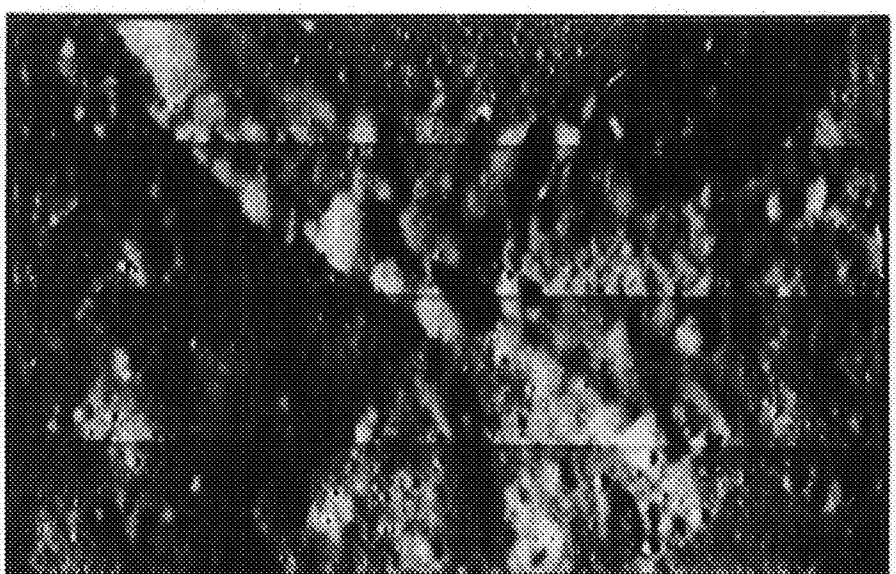
COORDINATES: $14^{0}50'S$ $14^{0}00'E$

LAC CHART: 78 THEOPHILUS

ALBEDO: 0.148 LO-IV: H-89

LO-V: V-19 FRAME: 84





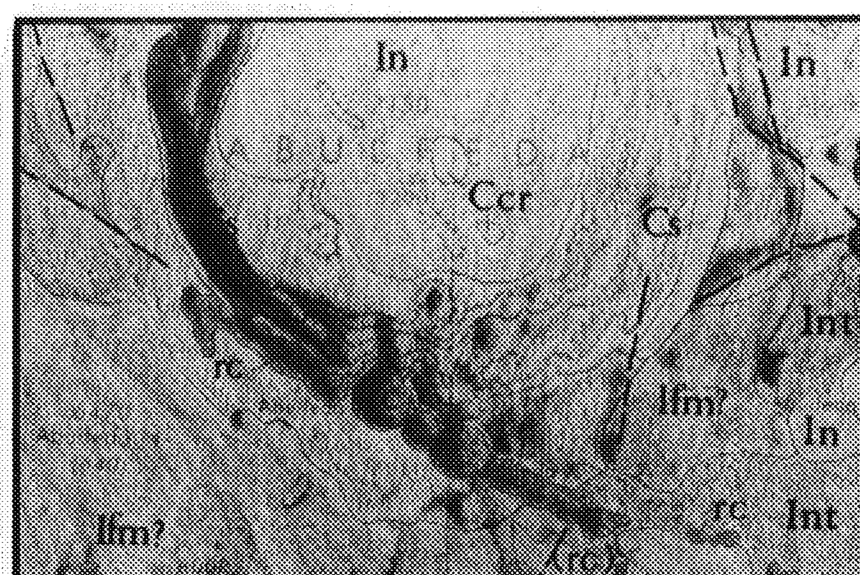


FIGURE 4a

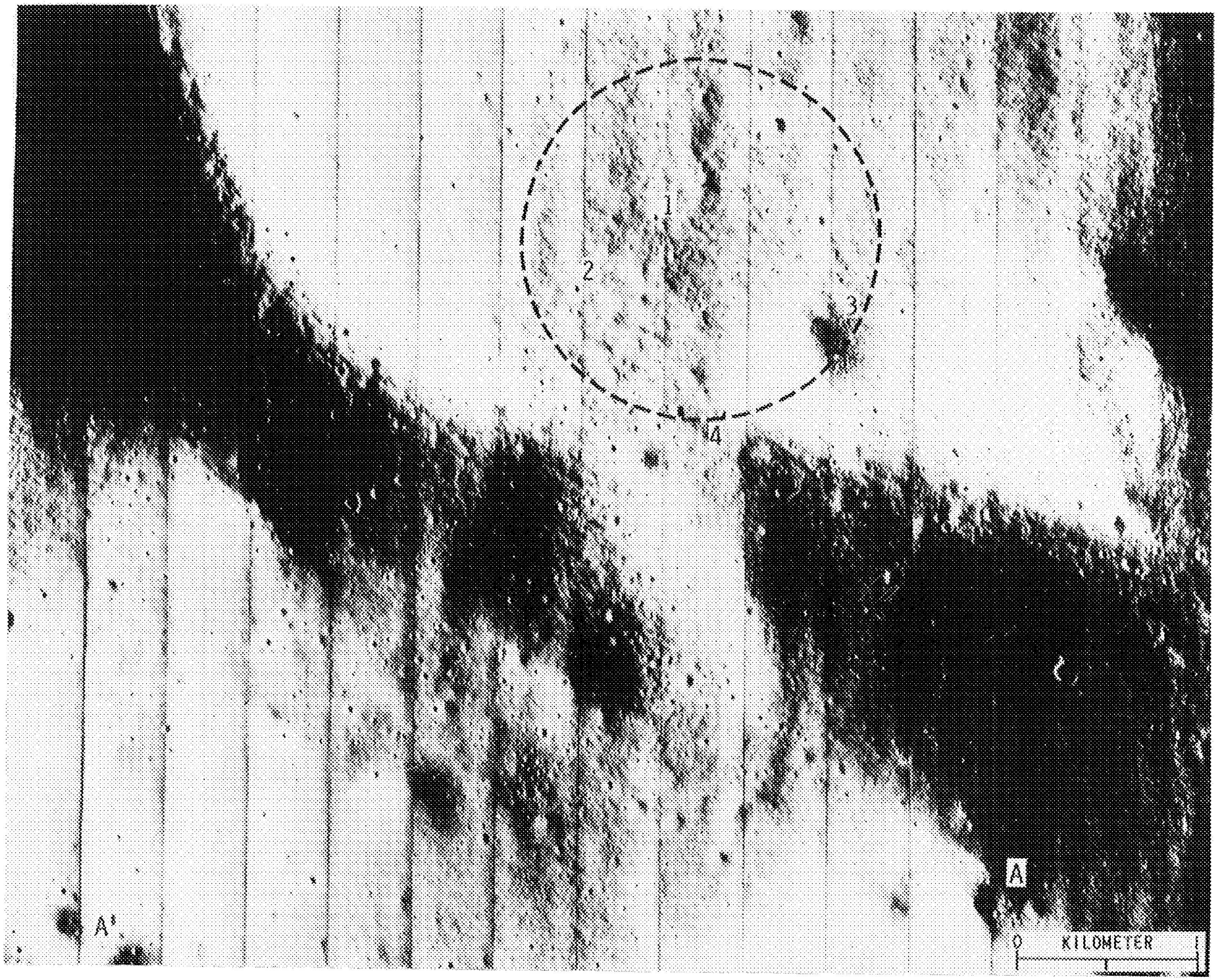


FIGURE 4b. PROPOSED LANDING SITE FOR ABULFEDA (CRATER CHAIN)

4. HYGINUS CRATER AND RILLE

A. Description and Setting

Named after the Spanish astronomer, the crater Hyginus is some 10 km in diameter with a very low rim and numerous small domal masses on its floor. A great cleft, Rima Hyginus, branches from the crater at two points, trending toward the northwest and east-southeast. The cleft, a well developed linear rille, is characterized by an abundance of crater chains. The latter are composed of low-rimmed craters closely associated with the rille and, thus, appear to have been a result of endogenic lunar processes rather than an external (meteroid impact) origin. The morphology of the craters suggests that they are volcanic craters of a type (maar) that on Earth commonly produces erupted materials from deep within the crust or mantle. Similar, but not identical situations, exist at the Abulfeda site, as well as at the Davy G crater chain.

Near the rim of the crater Hyginus is a contact between two units (one dark, one light) of smooth plains-forming materials which surround the crater. Although both units have numerous rimless depressions of possible collapse origin, the low total density of craters indicates a relatively young age. The smooth, light material, designated the Cayley Formation (Icy in Figure 5a, lower right), may be: 1) an old regional unit of unknown origin in which the crater Hyginus and its associated rille system were formed; or 2) a deposit of materials which originated from the crater and rille. The smooth dark material appears to overlie the Cayley Formation. It could have originated from the elongate crater on the northern rim of crater Hyginus through volcanic processes.

The stratigraphic units represented in the area include:[4]

Copernican System

Cc: Crater material, undifferentiated
Cs: Slope material

Copernican-Eratosthenian

CEc: Crater material, indeterminate stratigraphic position

Eratosthenian System

Ec: Crater material, undifferentiated

Imbrian System

Archimedian Series

Ipd?: Dome material
Icy: Cayley Formation

Apenninian Series

Ifm: Fra Mauro Formation

B. Major Objectives

1. Examination of the physical and chemical heterogeniety of materials that constitute two important units of the lunar crust. These two units (the Cayley Formation and the dark overlying rock) are probably different, compositionally, from both typical mare and typical highlands.

2. Sampling of what may prove to be deep-seated lunar rocks in and around the crater chains associated with Rima Hyginus.

3. Examination and sampling of the wall and floor of the crater Hyginus itself to unravel its origin and the nature of the domal structures on its floor as well as the abundant rock ledges on its wall.

4. Examination of the structural characteristics of a well-developed linear rille and its role in the tectonic history of the area.

5. The spatio-temporal relationships of the many volcanic features and materials in this site would shed some light on the presence or effects of lunar effluents and the local evolution of volcanic processes in the lunar environment.

C. Landing Area

A 5 km mobility radius of surface operations was tentatively set for the mission to the Hyginus site as well as all the following sites. The circle in Figure 5b represents the limit of mobility in all directions from a favorable landing point from both the scientific and engineering viewpoints.

Numbers within the circle in Figure 5b denote the following:

1. Dark mantling material of probable volcanic origin

2. Light, smooth, plains-forming "Cayley Formation"

3. Hyginus crater floor

4. Rimless (maar) crater, a part of a discontinuous crater chain

5. Walls and floor of a straight linear rille (Rima Hyginus)

If feasible from the engineering viewpoint, two alternative landing points are: A) on the floor of crater Hyginus itself, and closer to its western rim; B) due west from the center of crater Hyginus, and on typical terrain of the high-albedo, plains-forming unit tentatively called the Cayley Formation. The terrain south of the crater Hyginus appears to be very favorable because of its smoothness. However, it would be rather difficult to land there and still reach the targets of scientific interest within the present mobility range limitations.

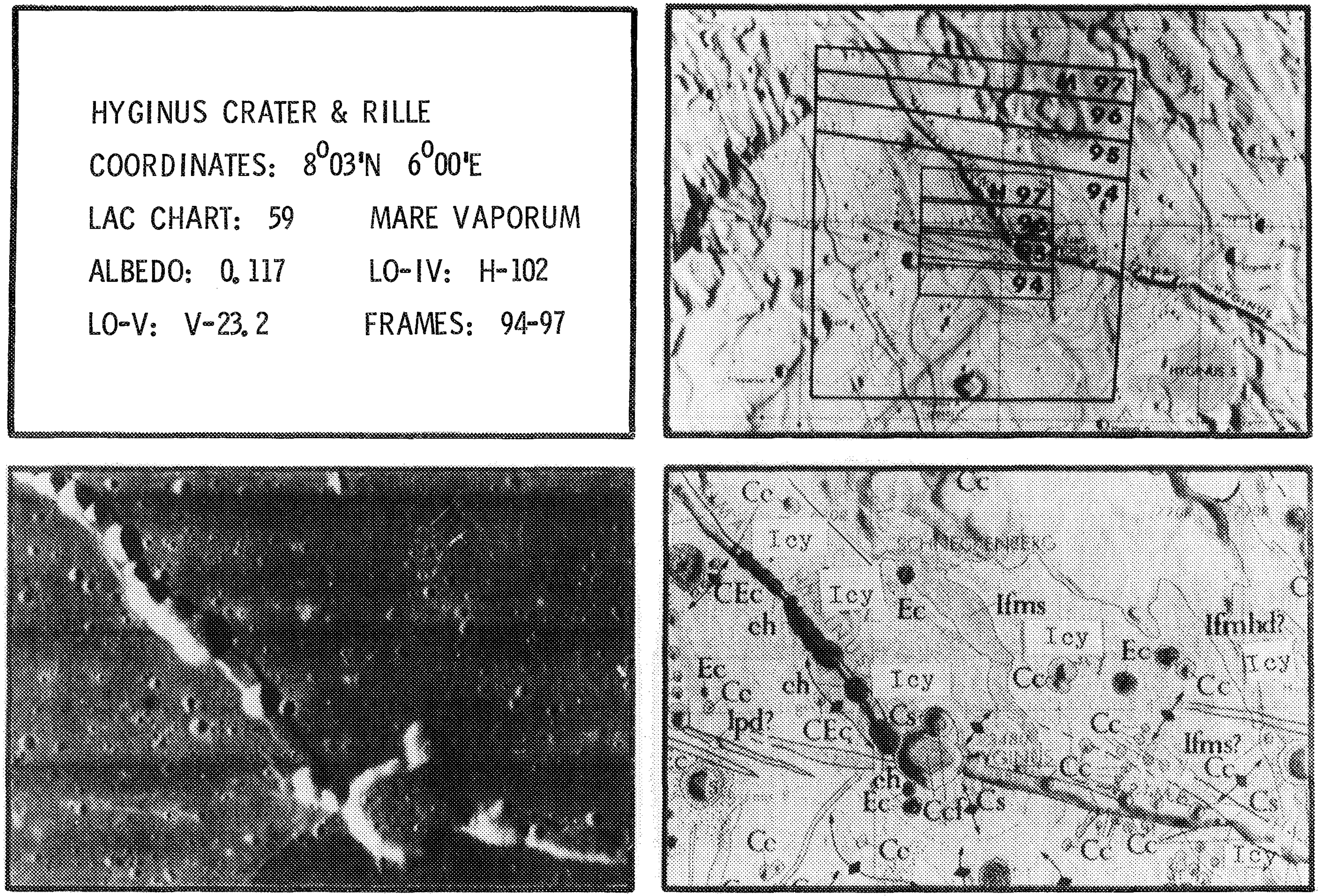

HYGINUS CRATER & RILLE
COORDINATES: 8°03'N 6°00'E
LAC CHART: 59
MARE VAPORUM
ALBEDO: 0.117
LO-IV: H-102
LO-V: V-23.2
FRAMES: 94-97
Ifms
Ifmlxd?
Ifms?
Icy
CEc
Ec
Cc
Cs
ch
Ipd?

FIGURE 5a

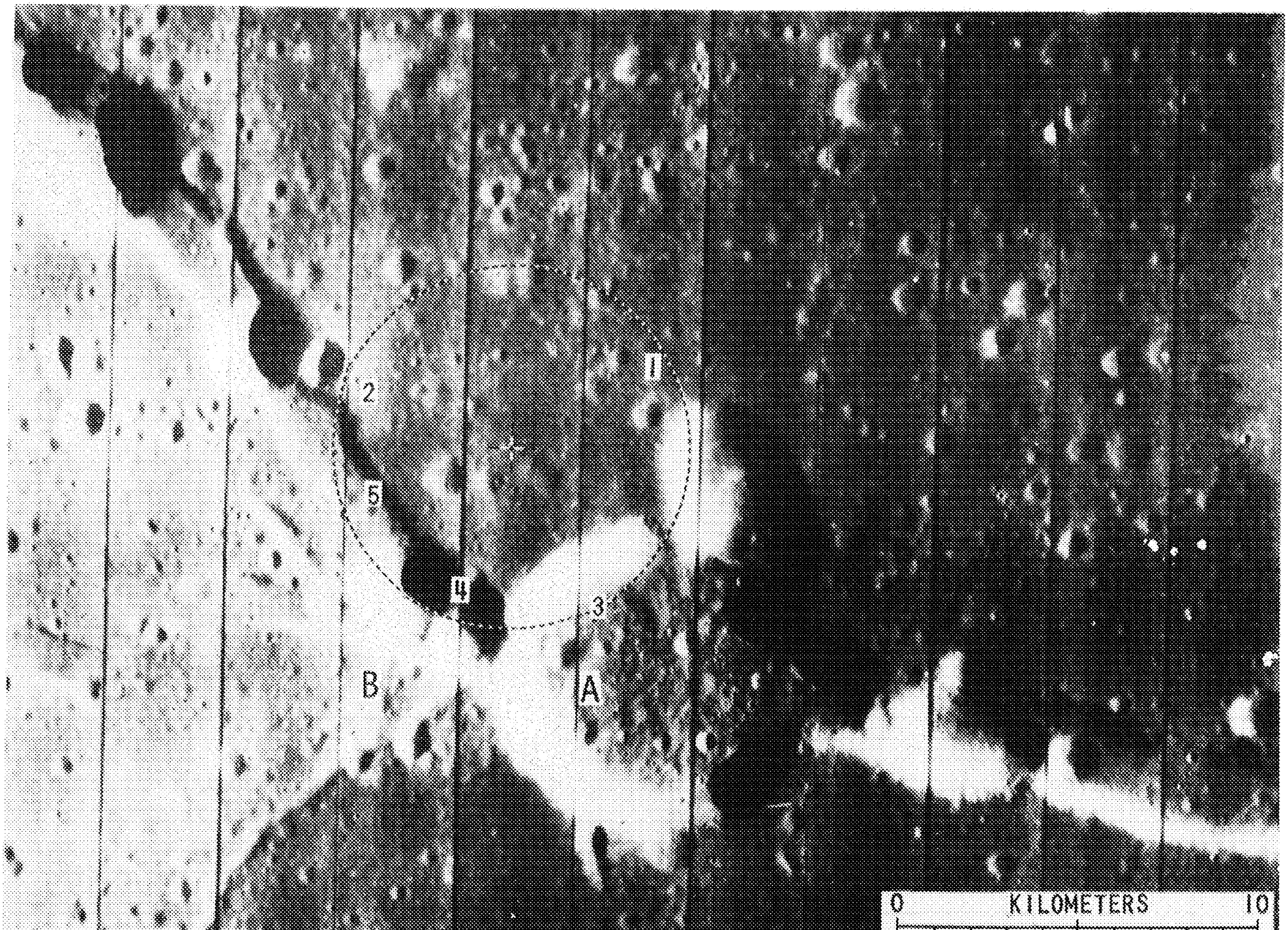


FIGURE 5b. PROPOSED LANDING SITE FOR HYGINUS CRATER & RILLE

5. APENNINES-RIMA HADLEY

A. Description and Setting

The Apennine Mountains constitute by far the most imposing of the lunar mountain ranges, and form the southeastern boundary of Mare Imbrium. They form the base of a triangle-shaped elevated highland region between Mare Imbrium, Mare Serenitatis and Mare Vaporum. At the area of the proposed site, the mountain front rises 1,280 meters above the adjacent mare level to the west, i.e., the southeastern portion of Palus Putredinis.

Rima Hadley is a V-shaped sinuous rille which terminates to the south at an elongate depression (lower left corner in the LO-IV photograph in Figure 6a) and runs in a northeasterly direction, parallel with the Apennine front, for over 50 km until it merges with Rima Fresnel II to the north. Fresh exposures, possibly of stratified mare beds, occur along the top of the rille walls from which numerous blocks have rolled down the walls to settle on the floor of the rille.

In the area of the site, a small (5.5 km in diameter) but conspicuously sharp and round crater appears to have partly covered the rille. This crater, Hadley C, is characterized by a raised rim and an ejecta blanket which covers the mare craters and Autolycus secondaries in the vicinity. The origin of Hadley C is a matter of controversy, although its morphologic characteristics suggest that it is probably a maar.

The geologic map of the area (Figure 6a, lower right) displays the following stratigraphic units:[5]

Copernican System

- Ccr: Crater rim material
- Cs: Slope material
- Csc: Satellite crater
- Cscl: Satellite crater secondary to Autolycus

Eratosthenian System

- Ecr: Crater rim material

Imbrian System (Apenninian Series)

- Ifhl: Fra Mauro Formation

B. Major Objectives

1. The Apennine front constitutes a major physical anomaly of the lunar crust. It provides an excellent opportunity to study and sample an extensive vertical section of a primary physical feature of continental scale. Study of the samples from the nearly 1,300 meter highland scarp will bear directly on the problems of the physical and chemical heterogeniety of the Moon.

2. The less rugged parts of the Apennines are partly covered by the Fra Mauro Formation. The study of textural and compositional characteristics of this type of terrain should allow a refined understanding of the distribution and origin of this regional unit.

3. Rima Hadley is geologically interpreted either as a surface flow channel or a collapsed lava tube. Examination of the rille will shed light on its origin as well as on the genesis of other sinuous rilles which display similar characteristics. Furthermore, if the exposures in the rille are indeed bedded, they would afford an unmatched opportunity to sample a considerable Imbrian stratigraphic section and, therefore, a historical record of one of the major lunar mare.

4. Close examination and sampling of the crater Hadley C and its ejecta are fundamental in unraveling its origin and its interrelationships with Rima Hadley.

5. The location of the site is extremely favorable for regional and/or local geophysical surveys to be aimed at the spatio-temporal relationships of the Apennine front and the Imbrium Basin. Some of the more important ALSEP experiments at this site include: 1) Observations of seismic surface wave to unravel the subsurface structure beneath the Apennine Mountains and Mare Imbrium, 2) Testing of the concept of isostasy at the base of the escarpment, and 3) Measurements of heat flow to detect possible variations caused by large continental mass.

C. Landing Area

In Figure 6b, two landing points, one south-southeast and the other northwest of the crater Hadley C, are suggested. Both points are within 5 km of all important features in the site; however, high resolution photography is available only of the first (point A).

Numbers in the figure refer to: 1) Apennine materials; 2) Rima Hadley; 3) Crater Hadley C. In the 5 km radius circle surrounding landing point B two additional features of interest are within reach: the area of Rima Hadley most disturbed by the Hadley C event (number 4); and an interesting linear feature characterized by small troughs, discontinuous crater chains and small domal structures (number 5).

From the engineering viewpoint and approach path considerations the two landing points are equally difficult, due to the height of the Apennine Scarp. Therefore, it would be logical to give higher priority to landing area B. However, as mentioned above, no high resolution photography at LO-V scale is available for this area. Further photography of this area would be most desirable before the establishment of a landing point.

An Unmanned Lunar Roving Vehicle is a suggested development in the GLEP Plan. It is postulated that the ULRV would be landed some 500 km away from the point of rendevouz with an Extended LM Mission. The Apennines-Rima Hadley site was chosen for an exercise, the outcome of which was the development of four alternative traverses all leading to the area of Hadley C. As illustrated in Figure 6c, the traverses start at 1) the Sulpicius Gallus region, 2) Plains-forming material south of the crater Alexander, 3) Center of Mare Imbrium; and 4) Southeastern Mare Imbrium.

The utility of an ULRV has not been established. However, if such an instrument is to be developed, it would especially pay off from the geophysical viewpoint. A mainly geophysical traverse similar to that marked 4 in Figure 6c would produce valuable information concerning the subsurface structure of Mare Imbrium.

APENNINES-RIMA HADLEY

COORDINATES:

26°52'N 3°00'E

LAC CHART: 41

MONTES APENNINUS

ALBEDO: 0.115

LO-IV: H-102

LO-V: V-26

FRAMES: 104-107 (S)

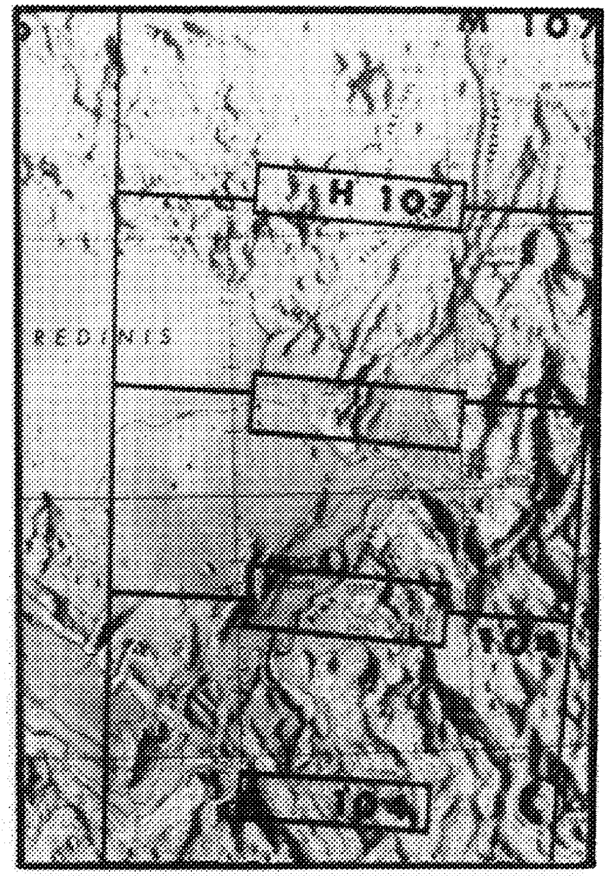


FIGURE 6a

FIGURE 6b. PROPOSED LANDING SITES FOR THE APENNINES-RIMA HADLEY

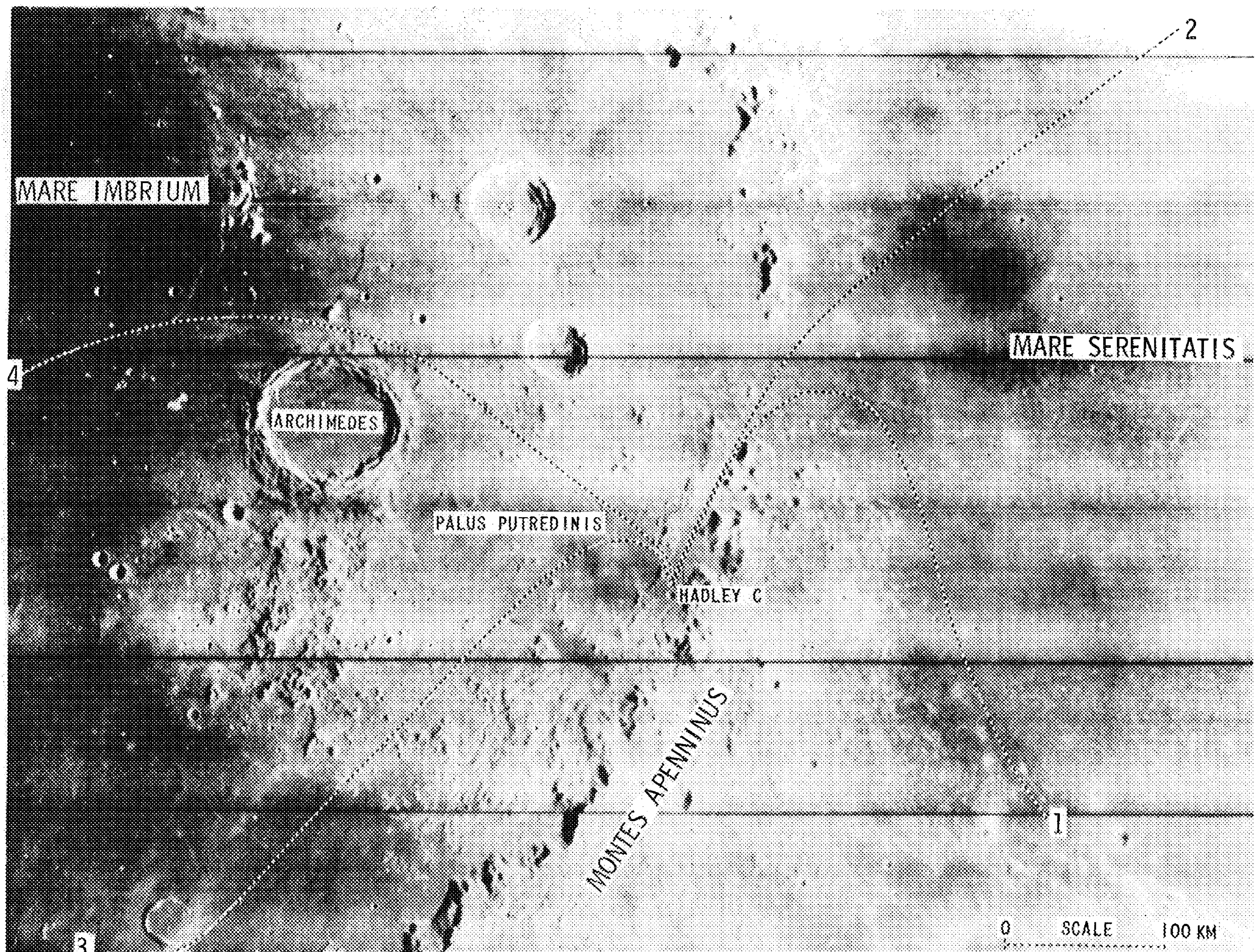


FIGURE 6c. FOUR POSSIBLE ULRV 500 km TRAVERSES

6. RIM OF CRATER TYCHO

A. Description and Setting

Tycho is the most prominent of all lunar craters at full moon. It is characterized by high albedo values, and high radar and eclipse thermal anomalies. No other crater is like Tycho in that it is the focus of the most extensive system of bright rays on the entire lunar earthside. Tycho is also unique among the larger lunar craters in being extremely fresh and young looking besides being situated entirely in highland terrain. However, most of its textural and structural details are common to other large craters on the Moon.

From crest to crest, Tycho measures about 80 km in diameter. Its walls, which are terraced and which enclose distinct ponds, avalanche trails and flow sculptures, rise about 4 km above the floor. The latter is a maze of cracks connecting blocks and dome-like prominences, all surrounding a central peak which rises over 1.5 km above the floor (see Figure 7a).

The rim of Tycho displays a plethora of textural and structural details which were registered for the first time by LO-V photographs. What was thought to be a dark halo surrounding the crater appears to be the effect of concentric dune-like textures which prevail within the segment of the ejecta closest to the rim. This is followed by the radial pattern of ejecta which is typical of many other craters of comparable size or larger. The rim also contains ponds of flat, smooth, partly cracked material of dubious origin. This material has been interpreted as post-cratering volcanic flows; mudflow masses of debris or particulate matter; or syn-cratering shock-melted glassy materials.

It is because of this diverse fabric and perhaps compositional array of the material that a mission to the rim of Tycho is of salient scientific value. It must be added that the floor and walls of Tycho appear to be too rough for any feasible surface mission. Furthermore, Surveyor VII has successfully landed on the rim and transmitted some information dealing with the terrain, its texture, bearing strength, and approximate composition. This adds to the merit of a manned mission to the same area as will be discussed below.

B. Major Objectives

1. To examine the Surveyor VII spacecraft itself.

2. To collect information and samples from the immediate vicinity of the spacecraft to further evaluate the technological efficiency and the scientific accuracy of the Surveyor-type instruments in future lunar and/or planetary missions.

3. To extend the area of exploration beyond what was tested by the Surveyor VII spacecraft. This would include such important features as: blocks of rock which were ejected from Tycho itself; the many flow-like surface blankets on the rim; the dune-like concentric bands of hummocky material; ray materials radial to Tycho; and at least one of the "pools" which are commonly observed on the rim of Tycho as well as craters of comparable or larger size.

4. Emplacement of a geophysical station in the southern highlands.

C. Landing Area

As mentioned above, the mission to Tycho is proposed for a 5 km mobility-type mission. However, it appears feasible to achieve the aforementioned objectives without utilizing mobility aids. Figure 7b illustrates a one km radius circle which encloses most targets of salient scientific and technological interest on the rim of crater Tycho, where the numbers within the circle correspond to the following:

1. Location of Surveyor VII spacecraft

2. A field of large blocks, which may have been derived from within Tycho

3. An area where several flow blankets could be recognized, studied and sampled

4. Dune-shaped terraces of hummocky terrain similar to that along the rim crest of the crater Tycho and possible ray materials

5. A large pool (of post-cratering volcanic rocks; or syn-cratering particulate or shock-melted material) which displays well developed shrinkage cracks as well as small collapse, crater-like features.

From the above discussion, it is concluded that a very profitable "walking mission" could be planned to the rim of crater Tycho. Mobility aids do not seem essential at the moment, although the use of LFU's would enhance the value of the mission.

RIM OF CRATER TYCHO

COORDINATES:

41°45'S 11°30'W

LAC CHART: 112

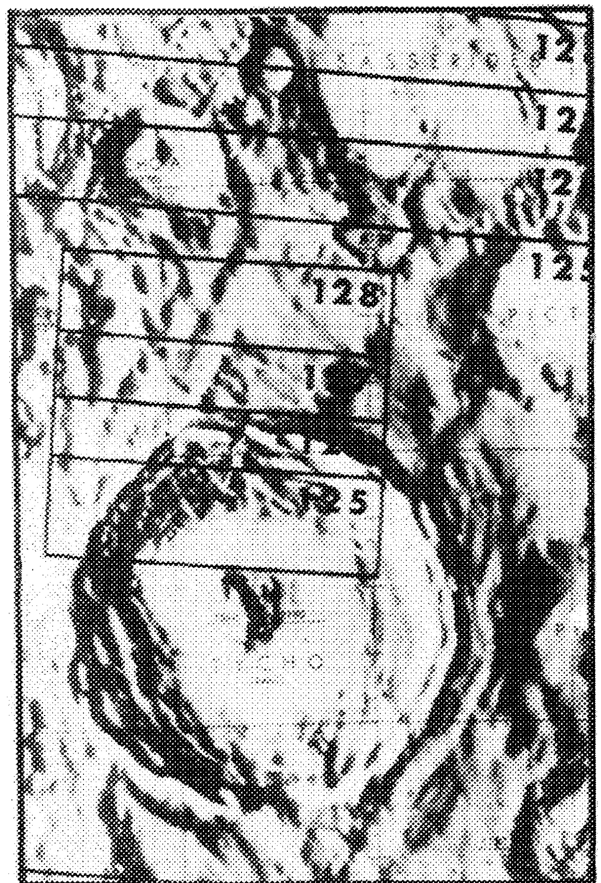
TYCHO

ALBEDO: 0.155

LO-IV: H-119

LO-V: V-30

FRAMES: 125-128



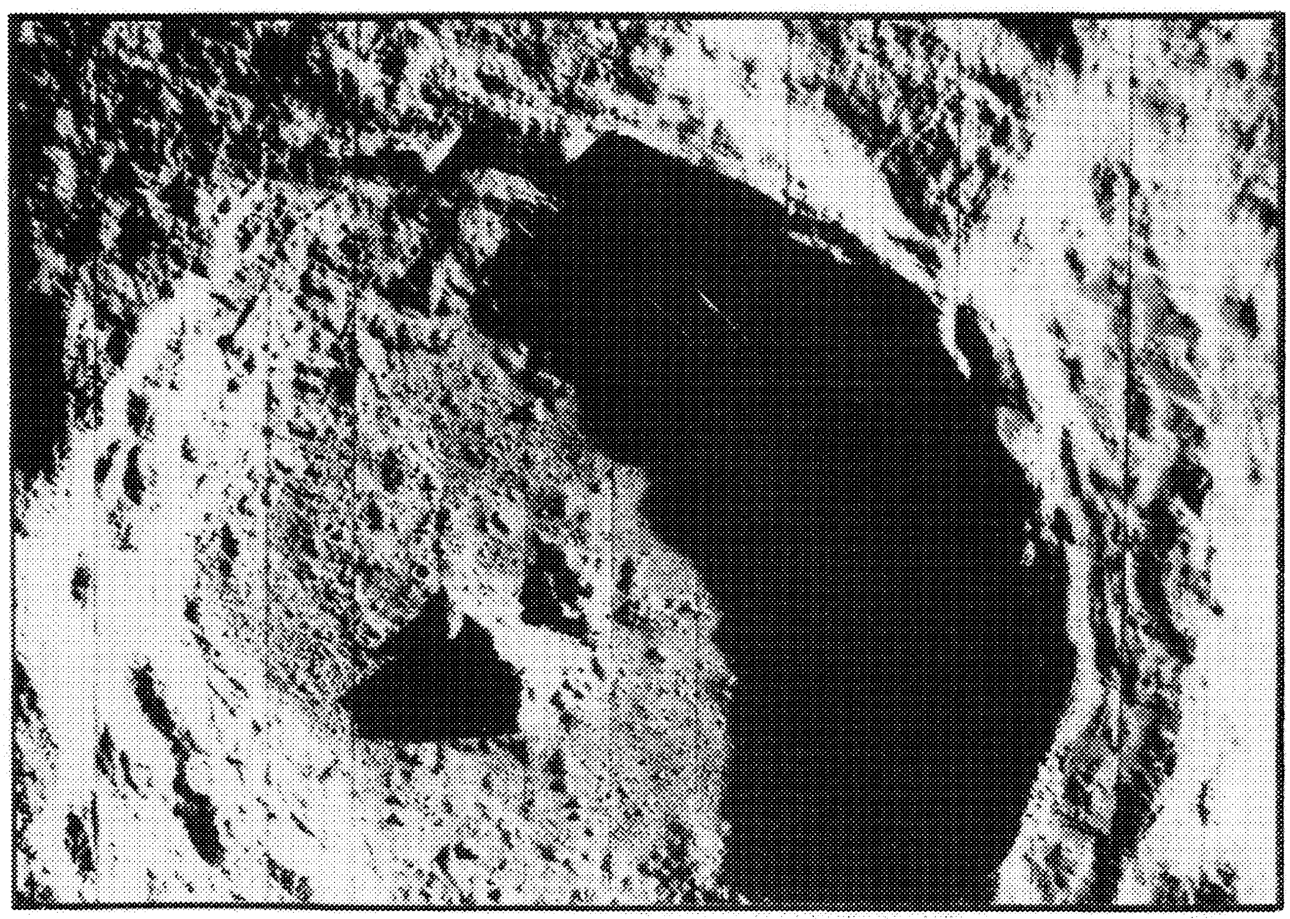


FIGURE 7a

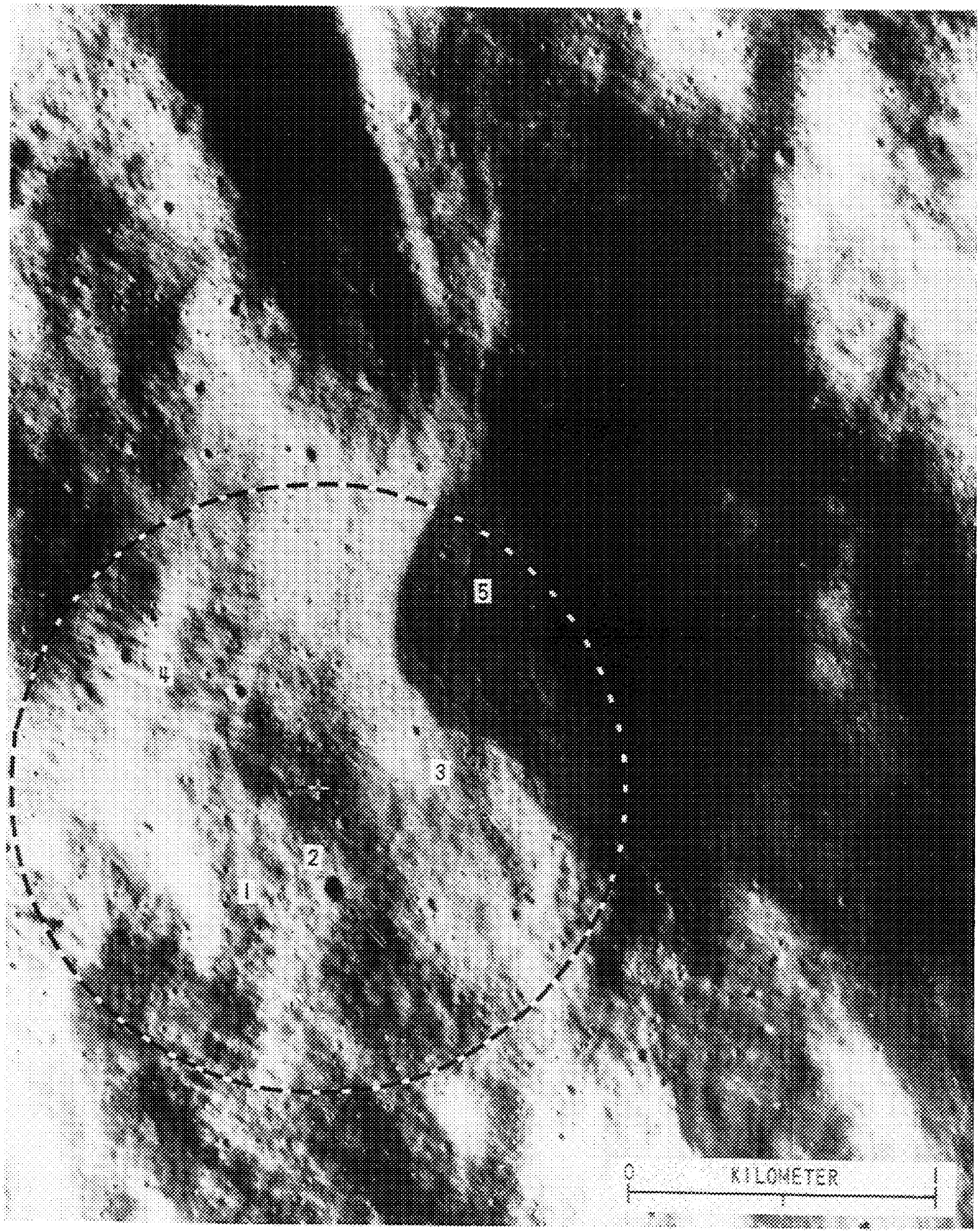


FIGURE 7b. PROPOSED LANDING SITE ON THE RIM OF CRATER TYCHO

7. CRATER COPERNICUS

A. Description and Setting

The crater Copernicus is one of the most conspicuous features of the Moon's earthside. It is a bright rayed crater, up to 95 km in diameter, whose visible radial rays spread out distances of several hundred kilometers. The walls of the crater Copernicus expose a vertical section of about 4 km of the lunar crust. Its rim crest, although approximately circular, consists of a dozen partly-linear, crenulated portions, giving the crater a pseudo-polygonal form.

The floor, 60 km in diameter, is nearly circular, and contains a small, almost central, multiple peak, with large masses to the east and the west, where the highest peak rises 800 meters. These peaks may have brought to the surface material that once lay at considerable depth. They are interpreted as plugs that originated as either 1) shock-crushed breccia uplifted by a rebound process immediately following the crater-forming event; or 2) volcanic domes which were formed a considerable time after the crater formation. In both cases, one would expect the central peak materials to be deep-seated in origin.

The inner slopes of the crater are extensively terraced, are separated by deep ravines, and exhibit many vast landslides. Orbiter photographs and photogeologic mapping indicate that both highland and mare materials are exposed on the walls and that there has been a large amount of lateral and downslope transport of material on the crater walls. These terraced walls are also characterized by an abundance of smooth-surfaced pools, a feature common to most relatively young, large craters.

The density of small craters in the Copernicus region is variable. In addition, the freshness of these craters, i.e., the geometry and number of blocks, varies considerably. This factor _per se_ suggests that there has been a substantial history superimposed on the initial crater Copernicus. Although the detailed stratigraphic history has not yet been established, a geologic unit classification (see Figure 8a) includes, in alphabetical order, the following:[6]

Copernican System

Ccd : Dark-halo crater material
Ccfh: Floor material, hummocky
Ccfs: Floor material, smooth
Ccrd: Rim material, radial

Ccp : Peak material
Cs : Slope material (freshly exposed bed rock and freshly generated talus).

B. Major Objectives:

1. To sample the floor material, the central peaks, the wall materials and the pools superposed on them. The extent of compositional variations will give clues as to the differentiation of the Moon.

2. The study of structural patterns of the central mountains and the walls, where both have undergone considerable mass wasting as shown by the apron of debris near the base of the peaks and the "deltas" of flow-like materials at the base of the walls. The middle of the three prominent central peaks also displays a dark stripe running down its side. This stripe may be a tilted resistant bed or a dike of deep-seated origin. The structural interrelationships of these major features will shed light on their origin, and the origin of the crater itself.

3. Determination of cosmic ray exposure age of the large blocks around the peaks, the layered wall materials, and the ejecta surrounding small craters on the floor. This will allow deductions concerning the time element of the crater history based on actual measurements.

4. Observations of geophysical parameters at Copernicus will not only extend the regional coverage but will provide local data for the interpretation of this large crater. It will be valuable to examine the differences between craters in mare and those in the highlands and to see whether or not they exhibit subsurface differences. Local geophysical measurements, such as seismic and gravity profiles, should be useful in elucidating the origin of the central peaks. Also, the question of whether large craters are in isostatic balance could be examined on the basis of data on the local gravitational field.

C. Landing Areas

The above mentioned objectives could be accomplished best by two missions to the crater Copernicus, one to the central peaks and the other to the walls; or by a dual mission that would cover both. If two single missions were to be planned, it is feasible, although restrictive, to achieve the objectives without the use of mobility aids.

A mission to the central peaks would be mainly a sampling mission, with some emphasis on structural relationships. As illustrated in Figure 8b, it is possible to cover (within less than 1 km from the designated landing point) the following:

1. Floor material exhibiting small low domes and a variety of craters
2. A field of blocks originating from the top of the peak
3. A possible extension of the resistant bed (or dike)
4. A sharp contact between the floor and a small mound

A similar type of mission could be planned for the exploration of a portion of the crater wall and one of the numerous pools on the wall terraces. An example is illustrated here as Figure 8c where the numbers within the 1 km radius circle correspond to:

1. The cratered surface of a major pool
2. Contact between the pool, a large vertical section of the wall (where some bedding may be observed), and a field of blocks
3. A crater displaying a well-developed central mound, which may have been formed by a fallen rock from the wall
4. An irregular multi-ring crater which is geometrically similar to these formed in a thin fragmental layer.
5. A bright-halo crater situated on a mound which may allow a good viewing area of the crater Copernicus.

Logistically, it may not be feasible to plan the above mentioned missions to the crater Copernicus. However, in any case, both the central peak and the wall remain as the essential areas to be explored. The information to be gained from both areas are complementary and the value of exploring only one of the two is dubious. For this reason, a dual mission or any other type of mission to this crater must utilize those mobility aids and enough stay time which would allow covering both areas.

As far as the central peaks area is concerned, the objectives as well as the surface operations would not vary much in a different type of mission. The one factor that may enhance the value of this part of the mission would be the use of Lunar Flying Units which would allow the investigation of the upper parts of the peaks.

The part of the mission devoted to the study of the wall, however, may differ considerably, where only the basal parts of the wall would be available for surface exploration. An example is illustrated in Figure 8d where the numbers within the 5 km radius circle refer to the following:

1. Cracked floor material

2. Fronts of down-slope flow

3. A block of wall material (<u>in situ</u>/or slump block)

4. Mounds attaining circular dome configurations

5. Craters and other depressions

6. Small valleys produced by relatively large cracks and fractures.

CRATER COPERNICUS

COORDINATES:

$10^{0}25'N \quad 20^{0}18'W$

LAC CHART: 58

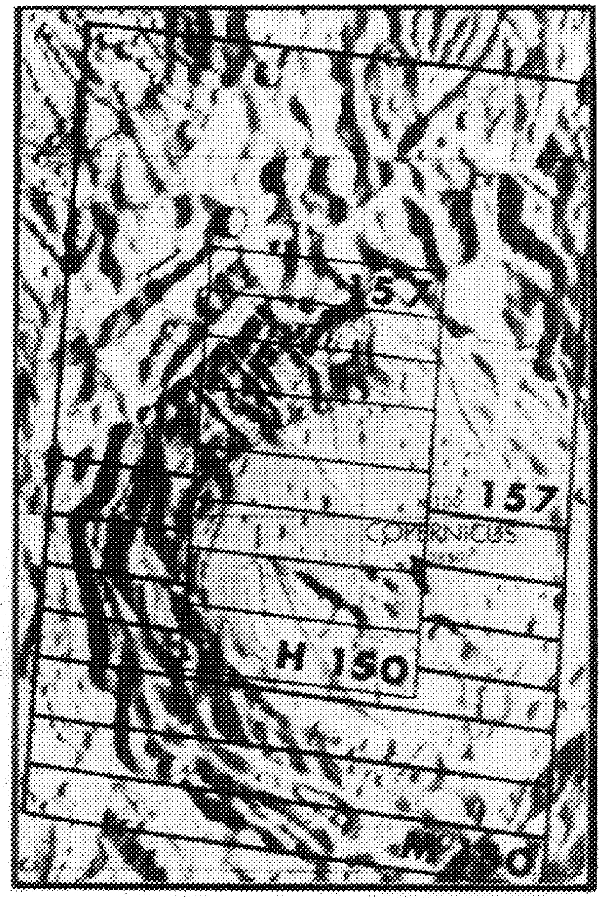
COPERNICUS

ALBEDO: 0.142

LO-IV: H121

LO-V: V-37

FRAMES: 150-157



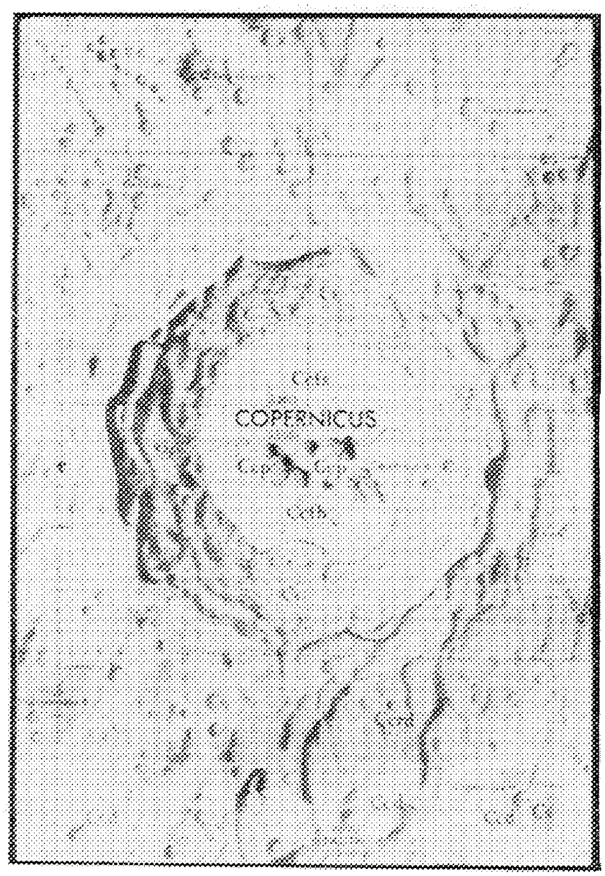


FIGURE 8a

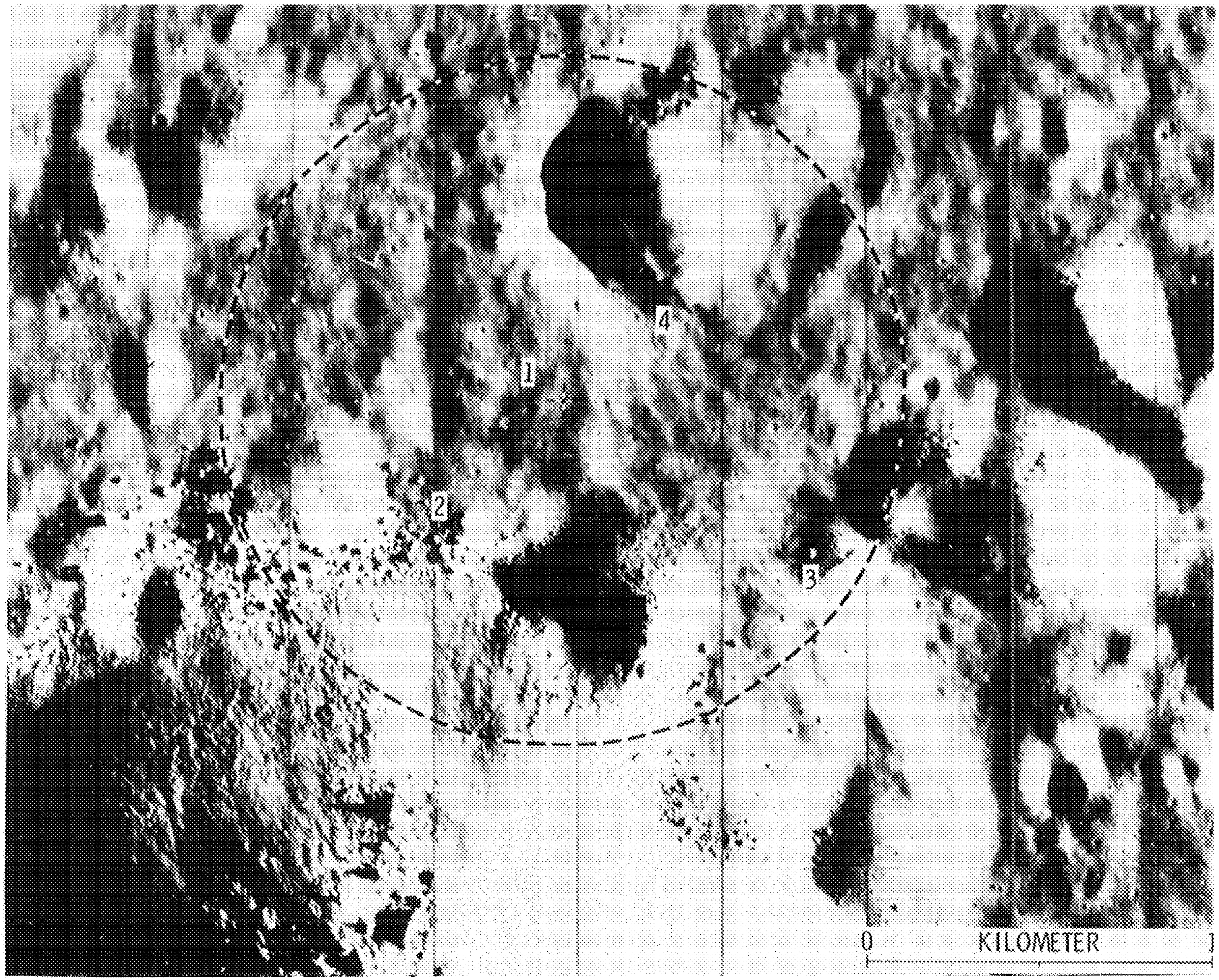


FIGURE 8b. PROPOSED LANDING SITE FOR THE CENTRAL PEAK OF CRATER COPERNICUS

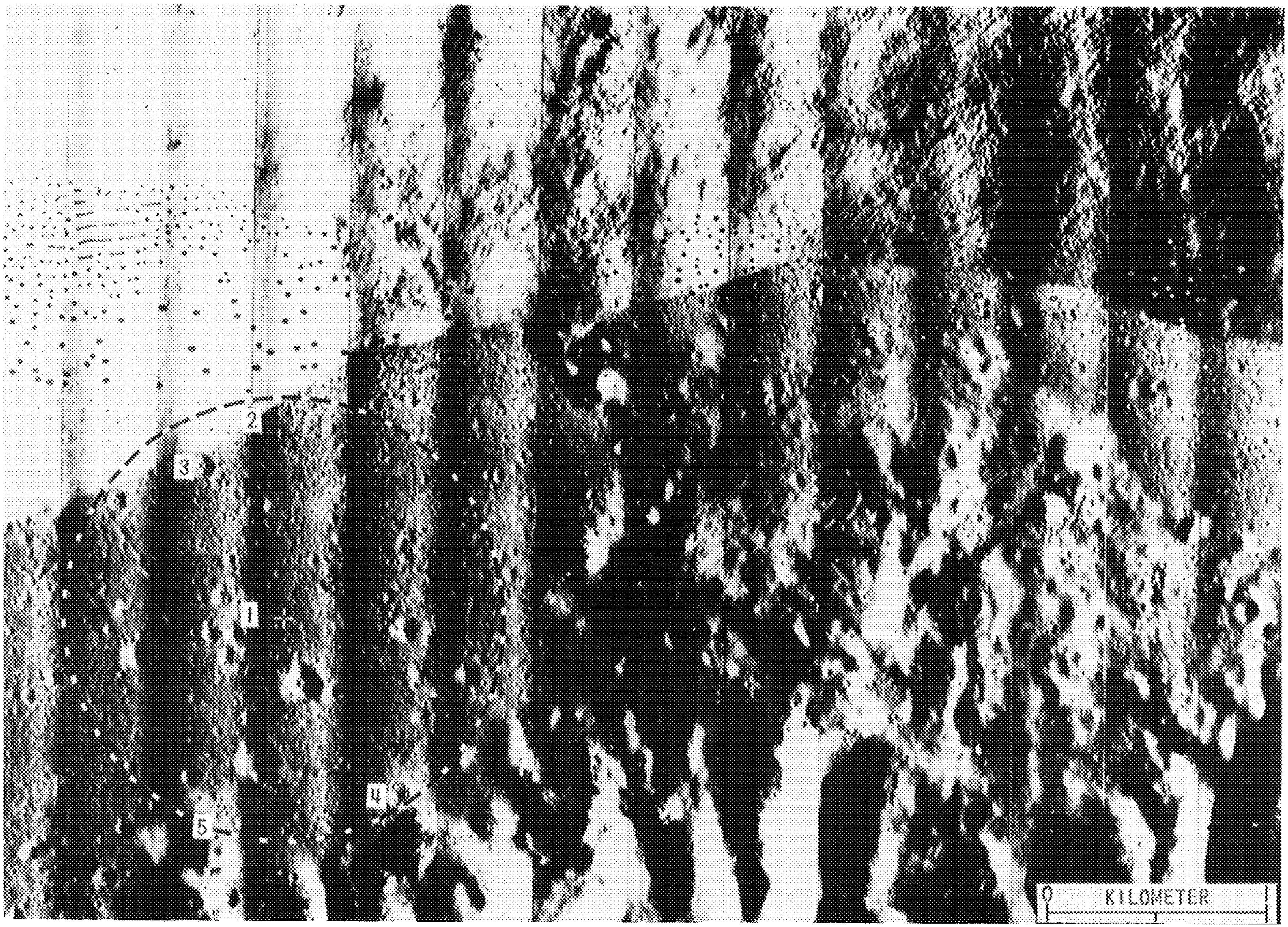


FIGURE 8c. PROPOSED LANDING SITE ON A WALL TERRACE OF CRATER COPERNICUS

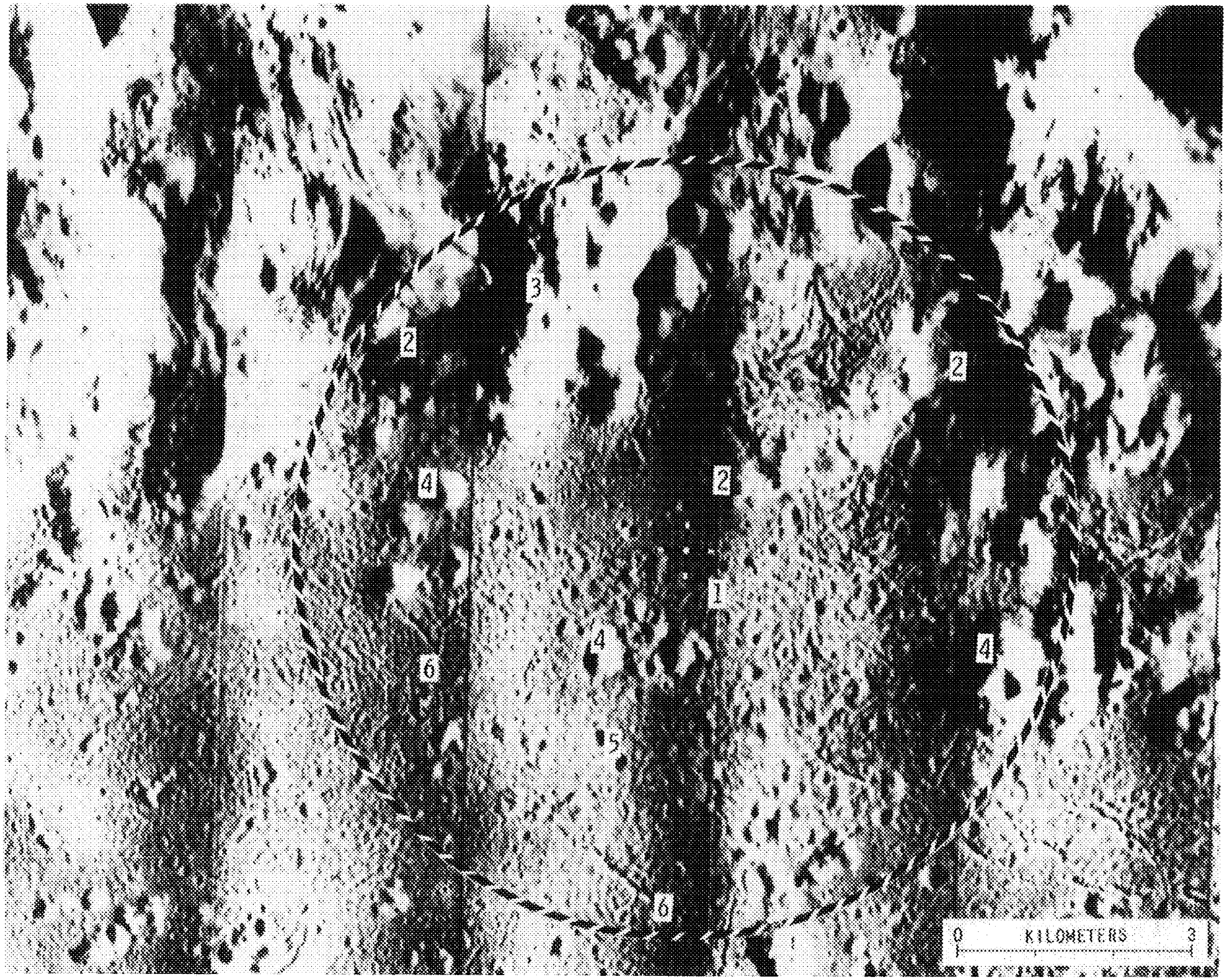


FIGURE 8d. PROPOSED LANDING SITE FOR THE WALL AND FLOOR OF CRATER COPERNICUS

8. SCHROETER'S VALLEY

A. Description and Setting

One of the major lunar valleys is named after the renowned German selenographer J. H. Schroeter. It lies within the Aristarchus Plateau and forms a sinuous depression of up to 1300 meters from the floor to the rim. Schroeter's Valley terminates on one end in what early selenographers were inspired to call the Cobra Head, a large deep depression which is interpreted as its source. From the Cobra Head also springs a smaller sinuous rille that meanders along the whole length of the valley floor. This median rille is common to other, similar, valleys on the Moon's earthside, such as those in the Harbinger Mountain Region and the Alpine Valley. In addition to this, it is characterized by its high thermal anomaly and the repeated occurrence of transient phenomena.

Lunar Orbiter photographs revealed significant details of the walls and floor of Schroeter's Valley, its median sinuous rille and of the adjacent smooth dark deposits. Some of the latter appear to be of volcanic origin and younger than the Aristarchus secondary craters. The morphology of the numerous cones and domes, if they are indeed analogous to terrestrial examples, suggests that these rocks are intermediate in composition, i.e., more silicic than the material of the mare.

The geologic interpretations of the various units in and around the valley (Figure 9a, lower right) include the following:[7]

Copernican System

- Ccrd: Crater rim material
- Csc : Copernican satellite craters (secondary impact craters)
- Ch : Cobra Head formation (Ejecta-flow blanket)
- Csv : Sinuous rille material

Copernican-Eratosthenian

- CEv : Vallis Schoeteri Formation

Eratosthenian-Imbrian

EIcf: Crater floor material, breccia (undifferentiated)

Imbrian System

Ipm : Mare material (Archimedian Series)
If : Fra Mauro Formation (Apenninean Series)

B. Major Objectives

1. Investigation and sampling of the varied rock types in the vicinity of the valley, preferably close to the Cobra Head.

2. Exploring the possibility of finding primordial volatile substances (unmodified by an atmosphere or hydrosphere) which may have been connected with the repeatedly observed transient color phenomena.

3. Study of the structural relationships between the valley and its median rille to decipher their genesis.

4. Emplacement of a geophysical observatory station in one of the suspected tectonically active areas on the Moon's earthside.

C. Landing Area

As illustrated in Figure 9b, a desirable landing area (A) lies northeast of the Cobra Head on the eastern flanks of Schroeter's Valley. The terrain in this area is rather rugged, but it is also rough all along the valley due to the structural setting of the valley and its proximity to the crater Aristarchus. Landing in this area would allow the achievement of all the major objectives listed above. Two alternative landing areas are marked B and C where the major targets would be a gigantic landslide along the valley's wall, and a conspicuous cut-off channel of the median rille, respectively. However, in both cases, the Cobra Head, which is a very important feature, would be inaccessible.

SCHROETER'S VALLEY

COORDINATES:

25°09'N 49°30'W

LAC CHARTS: 38-39

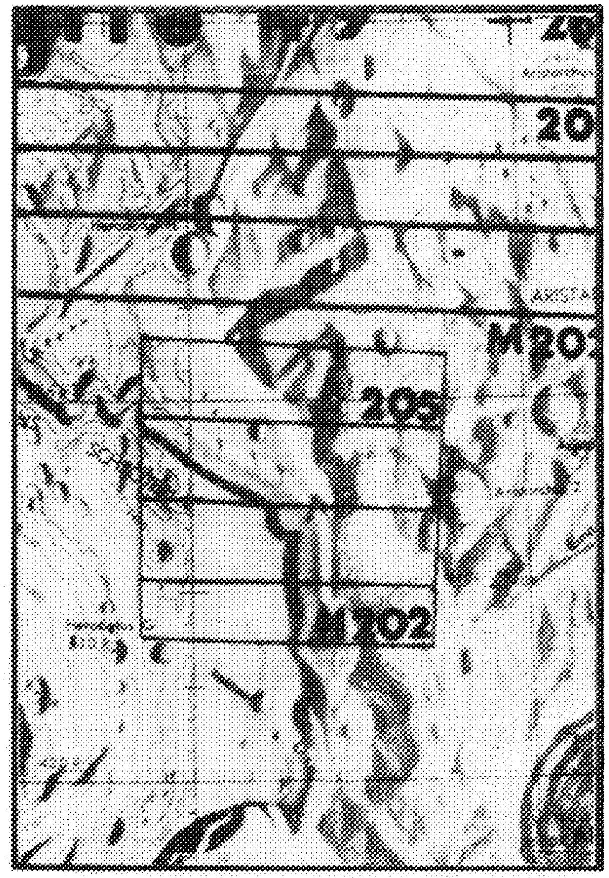
SELEUCUS - ARISTARCHUS

ALBEDO: 0.103

LO-IV: H-150

LO-V: V-49

FRAMES: 202-205



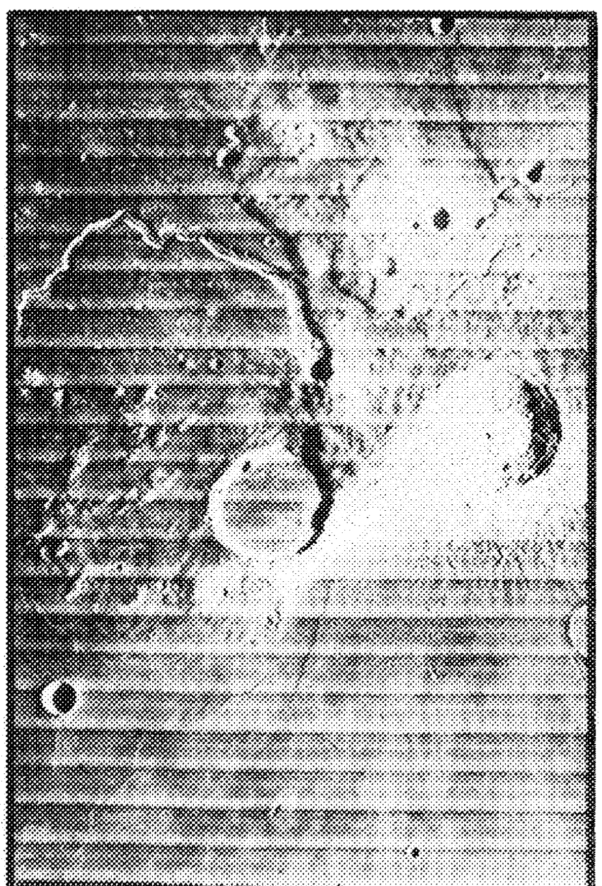


FIGURE 9a

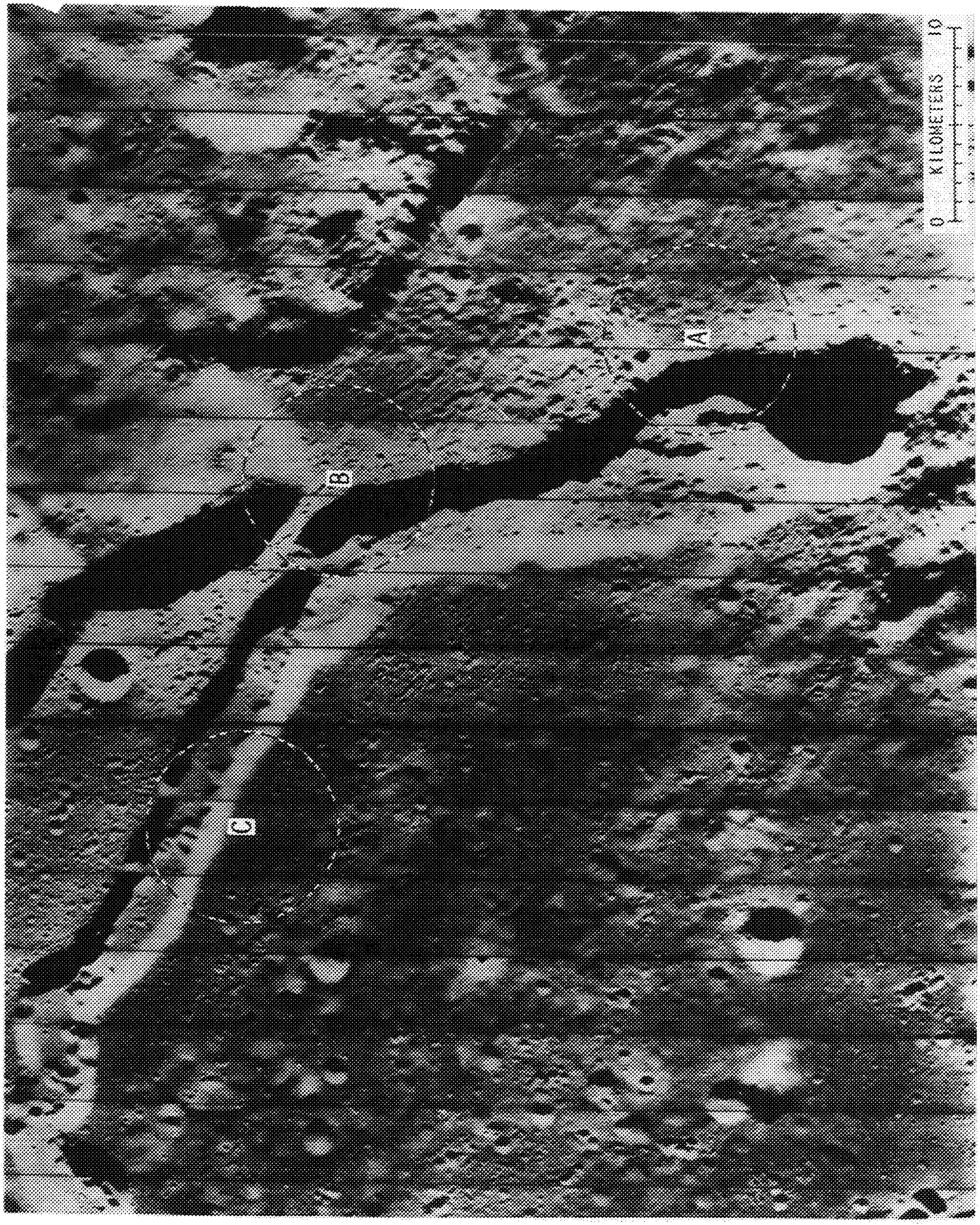


FIGURE 9b. PROPOSED LANDING SITES FOR SCHROETER'S VALLEY

9. MARIUS HILLS

A. Description and Setting*

The Marius Hills is a group of domes and cones near the center of Oceanus Procellarum, and west, northwest of the crater Marius, where isolated hills and clusters of hills rise above the mare surface and form part of a major north-south median ridge system that stretches irregularly some 1900 km through Oceanus Procellarum. Many of the hills exhibit the convex upward shapes suggestive of terrestrial laccolithic intrusions; and some resemble terrestrial shield volcanos. Generally, these hills are pocked with numerous large craters and are conspicuously rougher than the adjacent mare surface. Other hills have irregular outlines, low steep sides, and flat or slightly concave tops with a crater density similar to the nearby mare surface. The variety of these features and their similarity to terrestrial volcanic structures strongly suggests that the area has been subjected to intensive and prolonged volcanic activities.

The expression of the local median ridge is complex, consisting of a broad, prominent ridge system up to 10 km wide, bounded by sharp slopes at the margins. The generally convex upper surface of the ridge is locally broken by narrow ropey ridges and irregular linear depressions that deviate as much as 30 degrees from the trend of the main ridge. Narrow ropey ridges subparallel to the main ridge locally interrupt the surrounding mare surface.

Two sinuous rilles cross the main ridge from east to west. The larger rille, more than one km wide near its circular head, crosses the ridge approximately at right angles. The rille is V-shaped where it crosses the ridge, whereas its segments east and west of the ridge exhibit a flat floor. Craters with diameters comparable to the rille's width have deformed the rille near the east side and middle of the ridge, and ejecta from a 2-1/4 km crater at the western margin of the ridge has partially filled the rille. The smaller sinuous rille (300-500 meters wide) has an elongated head and the rille makes an abnormally abrupt turn within the ridge. Younger craters have modified this rille at the eastern margin, as well as west, of the ridge.

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*Based on descriptions by J. F. McCauley of the U. S. Geological Survey.

As illustrated in Figure 10a the area is divided into the following stratigraphic units:[8]

Copernican System

Cs : Slope material; poorly sorted rock fragments

Eratosthenian System

Ecr: Crater rim material

Marius Group

Em1: Smooth undulating material
Em2: Material of low domes
Em3: Material of steep domes

B. Major Objectives

1. The position of Marius Hills in a probable volcanic province that straddles the median ridge of Oceanus Procellarum provides an excellent opportunity to study materials, processes and structures associated with the formation of a major planetary ridge which is comparable in extent to the mid-oceanic ridges on earth. These ridges may be surface expressions of fundamental processes connected with the differentiation and/or convection in the planetary body.

2. As a volcanic province, the Marius Hills region also provides an opportunity to sample a nearly continuous sequence of material which originated from within and was then subjected for varying lengths of time to lunar and extra-lunar processes. The rock in the area should provide data relating to: the nature of the primitive lunar materials, the extent of magmatic differentiation on the Moon, time dependency of surface alteration processes such as cratering or mass wasting, cosmic ray exposure times and solar wind fluxes, etc.

3. Geophysical investigation of the region to allow a basis for the three-dimensional interpretation of the local features, as well as for comparison with other and similar physiographic provinces.

C. Landing Area

Due to the large areal extent of the Marius plateau plains, identical features may occur at several places in the region. Hence, there are a great number of possible landing areas for manned surface exploration. The area shown in Figure 10b offers a good choice. The numbers within the 5 km radius circle refer to the following:

1. A rimless circular depression, which may be a collapse feature, in mare material of the Marius plateau plains.

2. Smooth textured low domes which rise up to 100 meters above the surrounding plains.

3. Rugged, pock-surface, steep-sided domes which are generally "perched" upon the low domes.

4. Elongate, steep sided, relatively smooth conical structures with one or several linear depressions.

5. A steep-sided, relatively narrow and sharp wrinkle ridge in mare material of the plateau plains.

6. A partly sinuous, partly linear subdued trough.

These and many other features such as bulbous domes, exposures of bedrock or blocks, bright halo craters, etc., are well defined in a preliminary large scale geologic map of the area (Figure 10c) recently prepared by J. F. McCauley. The map also includes graphical delineations of a preliminary mission plan which is described at length in a U. S. Geological Survey report.[9]

MARIUS HILLS

COORDINATES:

$13^{0}45'N$ $56^{0}00'W$

LAC CHART: 56

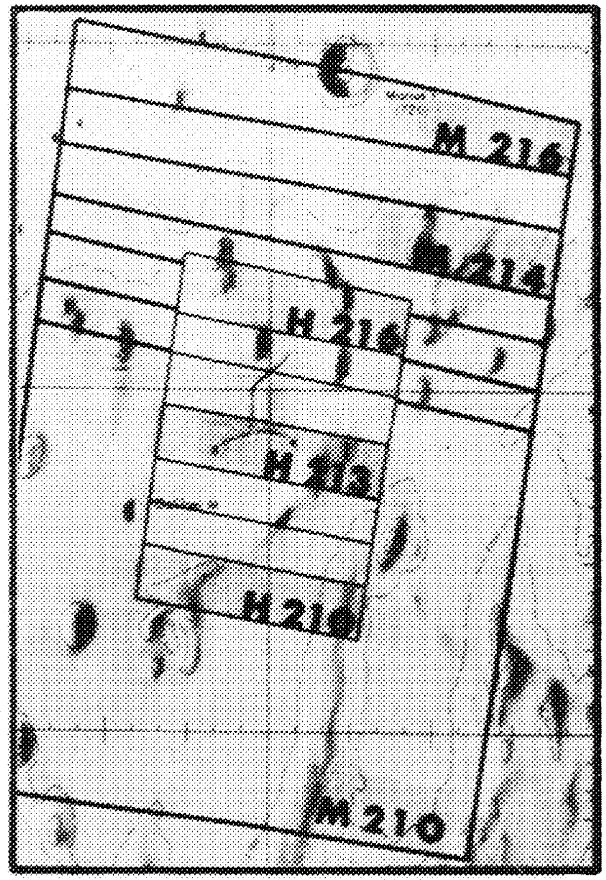
HEVELIUS

ALBEDO: 0.077

LO-IV: H-157

LO-V: V-51

FRAMES: 210-217



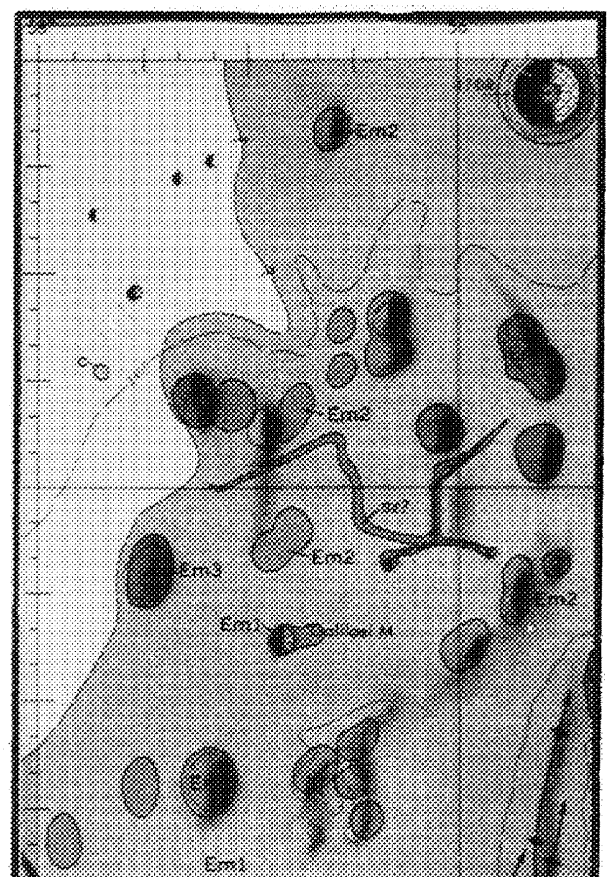


FIGURE 10a

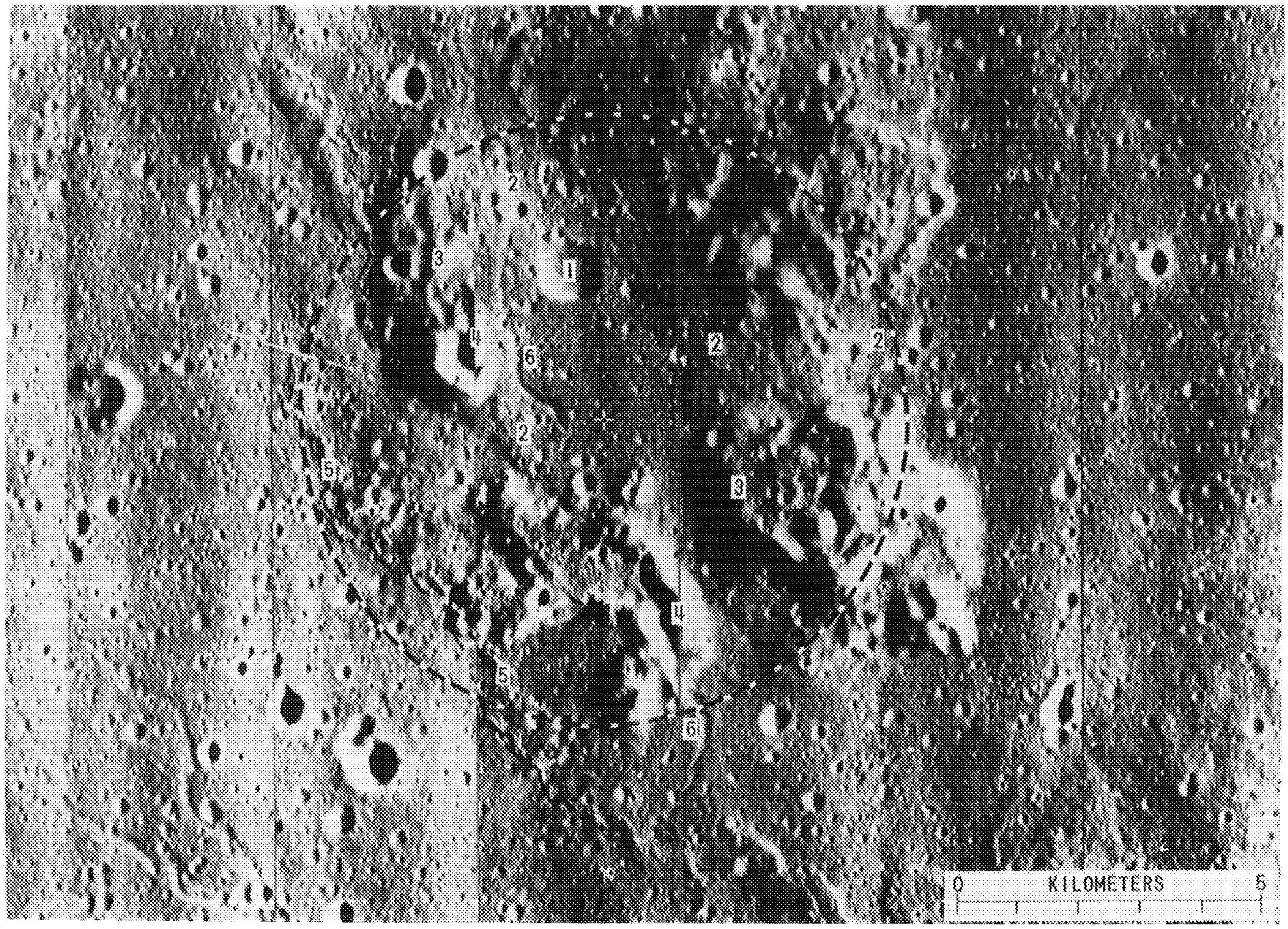


FIGURE 10b. PROPOSED LANDING SITE IN THE MARIUS HILLS REGION

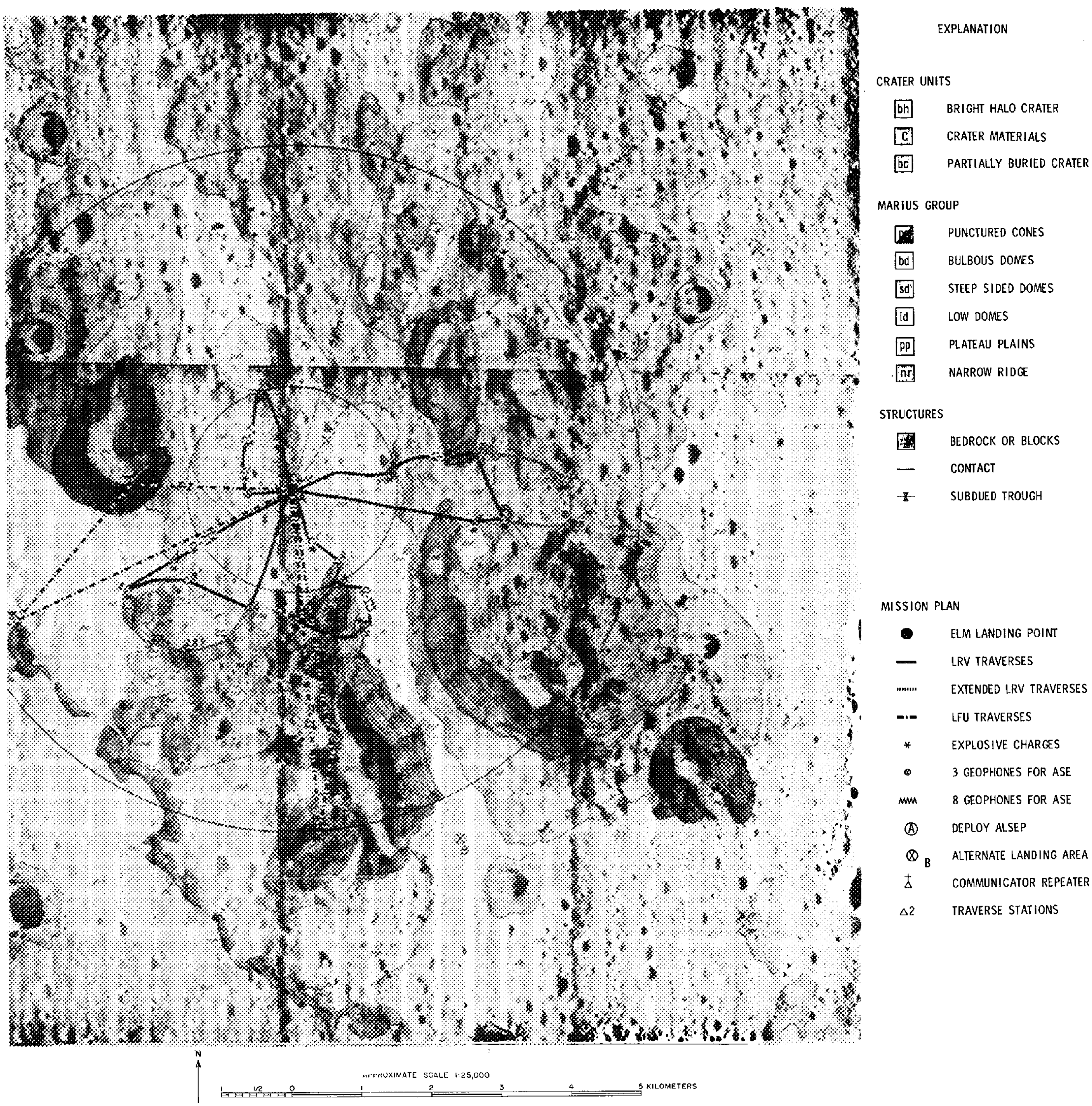


FIGURE 10c. GEOLOGIC MAP OF THE MARIUS HILLS AREA (FIGURE 10b)
(AFTER J.F. McCAULEY, 1968)

III. THE PLAN IN PERSPECTIVE

A. Summary of the Characteristics

The nine sites proposed by the Group for Lunar Exploration Planning (GLEP), for manned exploration of the Moon's earthside, constitute a well-balanced selection of scientifically important areas. This is demonstrated in Table I which lists the geologic characteristics of the individual sites and shows a histogram of the textural and structural features of the areas to be explored at these sites.

It is clear, from Table I, that there is emphasis on certain features (for example, single, circular craters in mare), but this is largely due to the relative abundance of the features themselves. The apparent lack of representation of some features (such as domes in highlands and ghost craters) is due to their localization so far away from other important features such that: 1) they could not be reached in any one of the proposed missions, and 2) they are not so important themselves to be considered, alone, for a manned exploration mission.

Prior to reviewing the exploration plan _in toto_, we shall summarize the salient features of the nine sites:

1. _Crater Censorinus_: A small, fresh (impact) crater in highland terrain, at the rim of a large mare basin.

2. _Littrow Area_: Very dark (volcanic) blanket material which mantles both Serenitatis Bench rocks and a very fresh mare ridge.

3. _Abulfeda (Crater Chain)_: Possible deep-seated material in and around a (volcanic) crater chain, and the associated "cinder cones", in the Southern Highlands.

4. _Hyginus Crater and Rille_: The floor of crater Hyginus, the walls of the linear rille and the surrounding plains (Cayley Formation).

5. _Apennines - Rima Hadley_: The Apennine mountain front, its contact with the mare and relationship to a young sinuous rille.

6. Rim of Crater Tycho: Composition, textures and structures of part of the rim of a large rayed crater in highland terrain.

7. Crater Copernicus: Potential deep-seated rocks at the central peaks and the flow and mass wasting structures along the walls.

8. Schroeter's Valley: A large lunar valley, its median sinuous rille, and their genetic relationships to the "Cobra Head".

9. Marius Hills: A complex of (volcanic) domes, cones, mare ridges and sinuous rilles in Oceanus Procellarum.

As previously stated in the introduction, it is assumed that manned missions to these nine sites would follow three missions to less complex areas on mare surface and relatively smoother terrains. These would include one mission to an eastern mare, a western mare and an old terrain, preferably the Fra Mauro Formation.

B. Mobility Requirements

No mobility aids are envisioned for the first three Apollo missions to the mare and other relatively smooth terrains. Furthermore, the nine sites described in this report were selected with the assumption that three of them (Censorinus, Littrow and Abulfeda) would also be "walking missions", i.e., no mobility aids. For the remaining six missions, some form of mobility is required beyond the walking range of the astronauts, whose limit is presently set at 1.5 km. The means of mobility under consideration include:

1. Lunar Flying Unit (LFU)

2. Lunar Roving Vehicle (LRV) and/or Field Assistant (FA)

3. Unmanned Lunar Roving Vehicle (ULRV)*

The minimum radius-of-operations of all manned mobility aids is set tentatively at 5 km, and that of the ULRV is thought of as being about 500 km. The concept of the latter has

---

*Vehicles 2 and 3 may be combined in a dual mode vehicle not been fully developed yet, and, therefore, will not be considered here (see example given in Figure 6c). The use of manned mobility aids is naturally site-dependent. A flying vehicle would be preferred if one's aim is to reach a feature which is several kilometers away, and if the traverse is to cross great differences in elevation. The roving vehicle would be preferred if it is important to make several stops along a traverse, especially if the terrain is relatively flat, and when there is need to conduct extensive geophysical traverses.

With the aforementioned considerations in mind, it seems that the LFU is preferred in many more sites than the LRV. Table II is a listing of mobility aid preferences in the nine (GLEP) sites. The choice of one type of vehicle as a mobility aid for a given site is based mainly on the geologic character of the area to be explored. It represents the author's own viewpoint and further investigations are necessary, especially of geophysical requirements, before the final selection of mobility aids for each of the sites.

C. Expected Achievements

Considering our limited knowledge of the lunar surface, it is a difficult task to visualize the extent and the value of all scientific and technological accomplishments of lunar surface exploration. A modest attempt is made here to demark some of the more obvious expectations.

Naturally, the exploration plan in question does not include all features of scientific interest, but it represents a well balanced selection of them. The plan could be divided into four phases (see Table III); each phase includes a group of three sites with some common characteristics. Following are brief descriptions of these phases:

Phase I includes two landing sites in mare regions (one red and one blue) as well as one site in an old formation such as the Fra Mauro Formation or the Cayley Formation, preferably the former. Common to all three are the following:

1. Location in the Apollo Zone

2. Relative smoothness of the surface to be explored

3. Accessibility of features within walking range (1.5 km)

4. A limited stay time of less than 36 hours.

Phase II embraces two (impact) craters of different sizes, Censorinus (3.5 km) and Tycho (80 km) where one expects to sample deep-seated hummocky ejecta. It also includes the Littrow area where some of the darkest, and probably youngest, (volcanic) mantling material on the lunar surface occurs. Among the parameters common to these three sites are:

1. Non-free return and a limited stay time (about 36 hours)

2. Abundance of blocks and/or in situ bedrock

3. Accessibility of features within walking range (1.5 km)

4. Possibility of establishment of a seismic net.

Phase III includes three sites where tectonism and volcanism are thought to be responsible for the features in question. We expect to encounter endogenous, deep-seated lunar materials at both the Hyginus and Abulfeda sites and to examine the physical expressions of transient phenomena at Schroeter's Valley. Common to these three sites are the following:

1. Non-free return and a stay time of about 3 days

2. Need of mobility aids (LFU's) in surface exploration.

Phase IV includes three sites (crater Copernicus, Apennines-Rima Hadley and Marius Hills) which entail a much more elaborate means of exploration. Their study relates to major questions concerning the Moon mainly because of the anticipated encounter of large stratigraphic sections, both vertical and horizontal. In themselves, they are among the most important sites, and among the parameters common to them are:

1. A stay time of more than 3 days

2. Expected unmanned payload delivery and surface rendezvous

3. Need of mobility aids (LFU and/or LRV)

Table IV illustrates some of the expected scientific and technological accomplishments of the four phases of the plan. The three examples of scientific fields (geology, geochemistry and geophysics) are not the only ones to be considered, and much the same could be said for other fields of endeavour. The dashed blocks in Table IV correspond to the four phases and their expected achievements in a given field. It is clear from the table that the knowledge to be gained from one phase of the plan is fundamental to the success of the following phase.

D. Conclusions

The proposed exploration plan, which includes the 12 sites listed in Table III, constitutes a well-balanced selection of scientifically important areas on the Moon's earthside. From the scientific point-of-view, results of the program would yield significant data on:

1. The chemical heterogeneity of lunar surface rocks and the differentiation of the Moon as a whole

2. The differentiation of lunar magmas and the surface manifestations of endogenic tectonism and volcanism

3. Extra-lunar processes, impact bodies, cratering events and their modifications to the surface

4. Geophysical processes such as isostasy, magnetism, seismicity, and Earth-Moon interaction

5. The geochemical (organic and inorganic) history of the lunar surface and its environment.

Farouk El Baz

2015-FEB-kse F. El-Baz

TABLE I

CUMULATIVE GRAPH OF THE CHARACTERISTICS AND STRUCTURAL FEATURES OF THE AREAS TO BE EXPLORED IN THE NINE SITES

MAJOR UNITS		MARIA				HIGHLAND			CRATERS							
		ALBEDO		SURFACE		SURFACE			NUMBER				GEOMETRY			
NO.	SITE DESIGNATION	LIGHT	DARK	SMOOTH	ROUGH	EVEN	PITTED	RUGGED	SINGLE	PAIR	CLUSTER	CHAIN	CIRCULAR	ELONGATE	POLYGONAL	IRREGULAR
1	CRATER CENSORINUS							X	X				X			
2	LITTROW AREA	X	X	X	X				X				X			
3	ABULFEDA (CRATER CHAIN)					X			X	X		X	X	X		
4	HYGINUS CRATER & RILLE	X	X	X								X	X	X	X	
5	APPENNINES-RIMA HADLEY		X	X				X	X				X			
6	RIM OF CRATER TYCHO							X	X				X			
7	CRATER COPERNICUS	X			X				X				X			
8	SCHROETER'S VALLEY							X			X					
9	MARIUS HILLS	X		X					X				X			X

		CRATERS (cont.)												
		SITE		HALO		RIM		STRUCTURE			AGE			
NO.	SITE DESIGNATION	IN MARE	IN HIGHLAND	BRIGHT	DARK	STEPPED	EJECTA	PEAK	RIDGE	HUMMOCKS	FRESH	FILLED	GHOST	
1	CRATER CENSORINUS		X	X			X			X	X			
2	LITTROW AREA	X									X	X		
3	ABULFEDA (CRATER CHAIN)		X									X		
4	HYGINUS CRATER & RILLE	X									X			
5	APPENNINES-RIMA HADLEY	X					X				X			
6	RIM OF CRATER TYCHO		X		X		X			X	X			
7	CRATER COPERNICUS	X		X		X		X		X				
8	SCHROETER'S VALLEY		X				X							
9	MARIUS HILLS	X												

		STRUCTURAL FEATURES																					
		STRATA				FAULTS			RILLES				RAYS				RIDGES		DOMES		ANOMALY		
NO.	SITE DESIGNATION	BEDDING	CONTACT	EROSION	DEPOSITION	SCARP	SLUMP	DISPLACE.	LINEAR	SINUOUS	IN MARE	IN HIGHLAND	BRIGHT	DARK	IN MARE	IN HIGHLAND	FLOW	WRINKLE	IN MARE	IN HIGHLAND	COLOR	THERMAL	
1	CRATER CENSORINUS												X			X						X	
2	LITTROW AREA		X														X	X					
3	ABULFEDA (CRATER CHAIN)																						
4	HYGINUS CRATER & RILLE	X	X	X	X	X			X		X												
5	APPENNINES-RIMA HADLEY	X	X	X	X					X	X												
6	RIM OF CRATER TYCHO		X										X			X	X					X	
7	CRATER COPERNICUS	X	X	X	X		X	X					X				X						
8	SCHROETER'S VALLEY			X	X	X	X			X		X									X	X	
9	MARIUS HILLS									X	X							X	X				

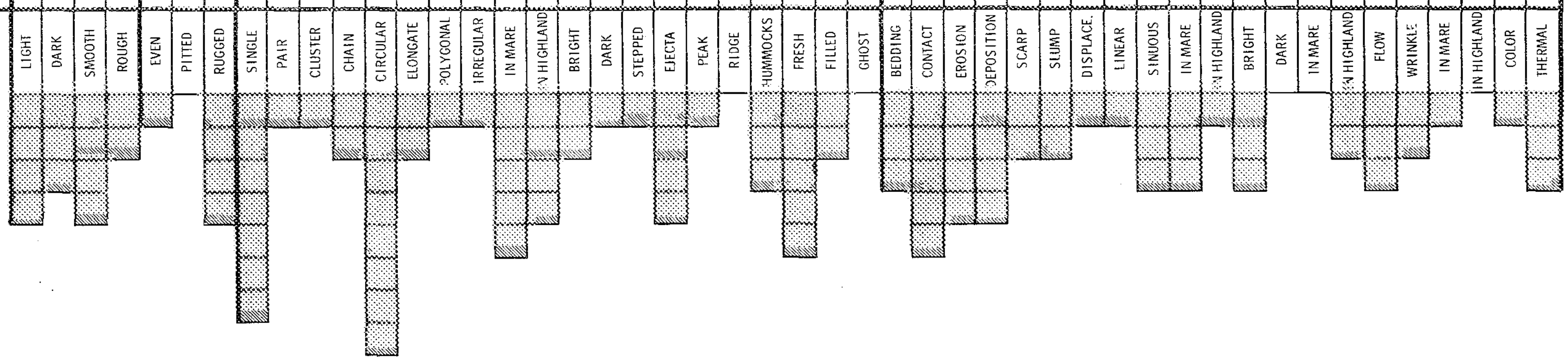


TABLE II

PREFERENCE OF MOBILITY AIDS FOR THE NINE (GLEP) SITES

NO.	SITE DESIGNATION	TYPE OF MOBILITY		
		NONE	LFU	LRV
1	CRATER CENSORINUS	X		
2	LITTROW AREA	X	(?)	
3	ABULFEDA (CRATER CHAIN)	(?)	X	
4	HYGINUS CRATER & RILLE		X	(?)
5	APENNINES-RIMA HADLEY		X	(?)
6	RIM OF CRATER TYCHO	X	(?)	
7	CRATER COPERNICUS		X	(?)
8	SCHROETER'S VALLEY		X	
9	MARIUS HILLS		X	X

TABLE III

PHASES OF THE LUNAR EXPLORATION PLAN

PHASE I	EASTERN MARE WESTERN MARE FRA MAURO FORMATION
PHASE II	CRATER CENSORINUS LITTROW AREA RIM OF CRATER TYCHO
PHASE III	HYGINUS CRATER & RILLE ABULFEDA (CRATER CHAIN) SCHROETER'S VALLEY
PHASE IV	CRATER COPERNICUS APENNINES-RIMA HADLEY MARIUS HILLS

TABLE IV

EXPECTED SCIENTIFIC AND TECHNOLOGICAL ACCOMPLISHMENTS OF THE LUNAR EXPLORATION PLAN

TECHNOLOGY	GEOPHYSICS
SCIENCE STATION	ATMOS. COMPOSITION
LUNAR ROVING VEHICLE	ELECTRIC FIELD
SURFACE RENDEZVOUS	GRAVITY MEASUREMENTS
UNMANNED DELIVERY	LASER RANGING
LUNAR FLYING UNIT	SUR. STRUCTURE (ASE)
EXTENDED LM	CHARGED PART. (CPLEE)
NON-FREE RETURN	HEAT FLOW (HFE)
SINGLE SITE SURVEY	IONOSPHERE, NEUT. PART.
REDESIGNATION	SOLAR WIND COMPOSITION
ALSEP DEPLOYMENT	SOLAR WIND (SWS)
ORBITAL SURVEY	MAGNETIC FIELD (LSM)
MANNED OPERATION	SEISMICITY (PSE)

< 36 HOURS	36 HOURS	3 DAYS	> 3 DAYS	TOTAL STAY TIME	> 3 DAYS	3DAYS	36 HOURS	< 36 HOURS
1 - 3	4 - 6	7 - 9	10 - 12	LUNAR LANDING MISSION NUMBER	10 - 12	7 - 9	4 - 6	1 - 3
PHASE I	PHASE II	PHASE III	PHASE IV	TYPE OF LANDING AND EXPLORATION	PHASE IV	PHASE III	PHASE II	PHASE I

GEOLOGY	GEOCHEMISTRY
SAMPLE STUDY	SAMPLE ANALYSES
RED MARE	MARE ROCK TYPES
BLUE MARE	AGE DATING
OLD FORMATION	RADIOACTIVITY
IMPACT EJECTA	ELEMENT DISTRIBUTION
HIGHLAND MATERIALS	HIGHLAND COMPOSITION
DARK VOLCANICS	LUNAR DIFFERENTIATION
LAVA BLANKETS	COSMIC RAY EXPOSURE
CAYLEY FORMATION	VOLCANISM
TECTONIC PROCESSES	INTERNAL COMPOSITION
DEEP-SEATED MATERIALS	TRANSIENT PHENOMENA
MASS WASTING	CRUSTAL COMPOSITION
DEEP CRUSTAL ROCKS	HIGHLAND COMPOSITION
HIGHLAND BENCH	MAGMA DIFFERENTIATION
MARE DOMES	CHEMICAL HOMOGENEITY
SINUOUS RILLES	GEOCHEMICAL HISTORY

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2. Geologic map of the Mare Serenitatis Region of the Moon by M. H. Carr (1966), U.S. Geological Survey, Map I-489 (LAC-42).

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4. Unpublished preliminary geologic map of the Mare Vaporum Region of the Moon; Map by D. E. Wilhelms is in preparation (1968), U.S. Geological Survey.

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8. Geologic map of the Hevelius Region of the Moon by J. F. McCauly (1967), U.S. Geological Survey, Map I-491 (LAC-56).

9. Preliminary Lunar Exploration Plan of the Marius Hills Region of the Moon, by T. N. V. Karlstrom, J. R. McCauly and G. A. Swann (1968), U.S. Geological Survey.

APPENDIX A

Members of the Site Selection Subgroup of the Group for Lunar Exploration Planning who participated in the Site Selection Meeting of December 8-9, 1967

John Adams	Jet Propulsion Laboratory
Donald A. Beattie	NASA Headquarters
John Dietrich	Manned Spacecraft Center
Farouk El-Baz	Bellcomm, Incorporated
Paul Gast	Lamont Geological Observatory
Wilmot N. Hess	Manned Spacecraft Center
Noel W. Hinners	Bellcomm, Incorporated
Charles Lundquist	Smithsonian Astrophysical Observatory
Harold Masursky	U.S. Geological Survey
Harrison H. Schmitt	Manned Spacecraft Center
Eugene Simmons	Massachusetts Institute of Technology
Donald E. Wilhelms	U.S. Geological Survey

APPENDIX B

STRATIGRAPHY OF THE LUNAR SURFACE*

"The major divisions of the stratigraphic column are called systems; each system corresponds to a period of time whose salient events in the area around Mare Imbrium are listed in the table below, the most recent at the top.

PERIOD	EVENTS
Copernican	Formation of ray craters
Eratosthenian	Formation of large craters whose rays are no longer visible
Imbrian	Deposition of the extensive mare material of the Procellarum Group Crater formation Events related to the formation of Imbrium basin
pre-Imbrian time (not yet formally divided)	Crater formation; formation of other mare basins

The symbol for each map unit consists of two parts: an abbreviation of its age assignment (capital) and an abbreviation of its name (lower case). The units are arranged in chronologic order in the explanation; the distinguishing characteristics of each are followed by an interpretation of its origin or composition. The values of normal albedo were derived from microdensitometer measurements of full Moon photographs calibrated with photoelectrically derived albedos of selected points (unpublished data by Pohn and Wildey, U.S. Geological Survey)."

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*After H. H. Schmitt, N. J. Trask and E. M. Shoemaker (1968): Geologic Atlas of the Moon, Copernicus Quadrangle. U.S. Geological Survey, Map 1-515 (LAC-58).

ACKNOWLEDGMENT

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