BELLCOMM, INC.
Washington, D. C. 20024

TR-69-340-4

EVALUATION OF MOBILITY MODES ON LUNAR EXPLORATION TRAVERSES: MARIUS HILLS, COPERNICUS PEAKS, AND HADLEY-APENNINES MISSIONS

November 14, 1969

P. Benjamin
T. A. Bottomley
J. W. Head
M. T. Yates

Work performed for Manned Space Flight, National Aeronautics and Space Administration under Contract NASW-417.

TABLE OF CONTENTS

ABSTRACT

This study is a comparative analysis of the influence of riding or walking traverses on the capability for meeting lunar science objectives on J-type missions at Marius Hills, Hadley-Apennines and Copernicus Peaks. In addition to making trade-offs between distance traveled and number of sites visited to maximize scientific return, the analysis evaluated the effect of a LM landing at locations other than the preferred point in Marius Hills.

Energy and time costs for walking, riding, and scientific tasks in the lunar environment were estimated consistent with the work capabilities of the A7L suit and uprated life support systems.

Operationally, it was concluded that:

1. The five hour time-in-suit constraint usually limits the traverses on riding missions.

2. Primary life support consumables are usually the limiting factor on walking missions.

3. Strategies of defining traverse direction and selecting additional sites on the return leg of riding traverses increase the scientific yield on some traverses.

4. Relaxing the time-in-suit and emergency walk-back constraints on riding traverses would significantly increase the scientific return from a mission.

Scientifically, it was concluded that:

1. Riding missions, on the average and excluding ALSEP contribution, approximately double the amount of significant scientific activity achievable over walking missions.

2. At Marius Hills, the rover enables a significant amount of science to be recovered which would be unachievable on walking missions if a biased target were substituted for a science mission target. However, traverses which originate at a biased target yield a lower confidence in achieving mission objectives than missions utilizing similar mobility modes and originating at the science landing point.

EVALUATION OF MOBILITY MODES ON LUNAR EXPLORATION TRAVERSES: MARIUS HILLS, COPERNICUS PEAKS, AND HADLEY-APENNINES MISSIONS

1.0 INTRODUCTION

This study evaluates the scientific effectiveness of J-mission walking and riding traverses as limited by crew safety and operational constraints associated with the A7L suit and uprated life support systems. In addition, comparative evaluations are made of the impact on scientific effectiveness of biased LM landings in an area remote from the science targeted location.

Three lunar locations (Ref. 1, Figure 1) were selected for use in making the traverse evaluations. They were:

1. Marius Hills
2. Hadley-Apennines
3. Copernicus Peaks

The analysis for Copernicus Peaks assumes a landing north of the area of scientific interest. The analysis for Marius Hills and Hadley-Apennines assumes a LM landing in the middle of the science area. In addition, the Marius Hills mission was evaluated for down-range and up-range touchdowns in a landing area eight kilometers east of the preferred landing point in order to determine how much scientific return can be regained with a rover if the landing area is biased away from the point of scientific interest.

The approach used was to evaluate the ability to attain the scientific objectives defined by a reference set of four EVA traverses developed for each of the three landing locations by the Ad Hoc Working Group on Science Objectives of Apollo Missions 12 through 20 (Ref. 2,3) and by Bellcomm in "Apollo Lunar Exploration Program Science Objectives and Mission Plans." Modified traverses were constructed in which trade-offs were made between distance traveled and the number of science locations visited within the capability envelope dictated by current engineering and operational constraints. Site locations on each traverse were selected on the basis of gathering enough information and samples to provide confidence that the scientific objectives of each mission would be met.

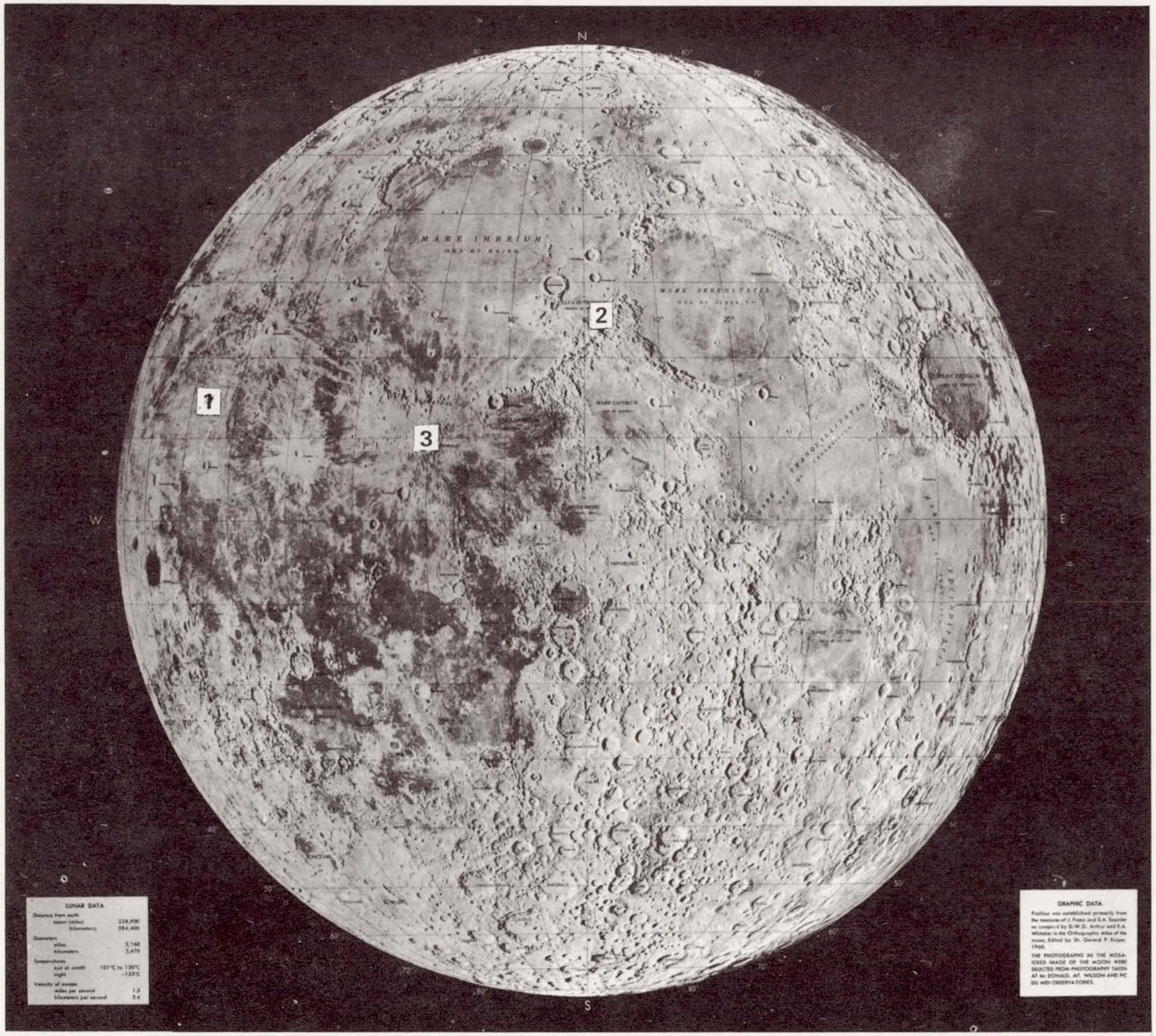


FIGURE 1 - LOCATION AND COORDINATES OF LANDING POINTS STUDIED

1. MARIUS HILLS

SCIENCE

56° 34 W 14° 36′ N

BIASED

56° 09′ W 14° 45′ N

2. HADLEY-APENNINES

2° 27′ E 24° 47′ N

3. COPERNICUS PEAKS

19° 55′ W 9° 52′ N

COORDINATES BASED ON LAC CHARTS

56, 41, AND 58

2.0 ENGINEERING AND OPERATIONAL CONSIDERATIONS

2.1 Engineering Constraints

The primary system constraint which limits astronaut capability for meeting the scientific objectives of a lunar surface EVA is the energy capacity (i.e., usable quantity of consumables) of the life support system. The principal parameters for assessing consumables usage are metabolic rate and time demands for performing specific activities. The parametric values selected for use in this study are based on 1/6 g simulator data and analyses performed by NASA and associated contractors (Ref. 4).

The energy cost (in BTU's) of gathering scientific information is related to the systems configuration provided for accomplishing the mission objectives and the nature of the EVA tasks. The systems configuration considered in this study is the one given tentative approval by the MSF Management Council on September 10, 1969. It consists of the:

a) A7L suit,

b) Uprated Portable Life Support System (-7 PLSS),

c) Secondary Life Support System (SLSS), and

d) Lunar Roving Vehicle (LRV).

In addition it is assumed that each astronaut may be required to carry other equipment (e.g., tools, samples, etc.) having a maximum total earthweight of 80 pounds. It is assumed, also, that emplaced scientific instrumentation (ALSEP) will be carried on non-rover missions. Therefore, provision is made for deployment of an ALSEP on walking missions only.

The total energy available for each lunar EVA traverse is allocated to overhead*, science, and locomotion. Based on available data consensus was reached during recent conferences at MSC to use the baseline data shown in Table 1 for the systems configuration described above (Ref. 4).

---

*Overhead is defined as the Portable Life Support System penalty incurred during LM depress and repress, equipment stowage and sample transfer, and egress and ingress operations.

BASELINE COSTS OF LUNAR SURFACE EVA

TASK OR MODE	TIME (HRS)	VELOCITY OF LOCOMOTION (KM/HR)	ENERGY RATE (BTU/HR)
OVERHEAD	1.5	-------------	1100
SCIENCE			
SITE TASKS	0.25	-------------	1100
ALSEP DEPLOYMENT	1.00	-------------	1100
LOCOMOTION			
WALKING–NOMINAL	--------------	4	1625*
–EMERGENCY	--------------	4	1400**
RIDING–	-------------	5*	700
–	-------------	10*	700

*REFLECTS DERATING FOR LOAD CARRYING, SLOPES AND LUNAR SURFACE PROPERTIES.

**ASSUMES ANY CARRIED LOAD IS ABANDONED AT THE FAILURE LOCATION.

TABLE 1

2.2 Operational Constraints

In addition to the limitations resulting from the EVA systems configuration, a number of constraints were imposed based on crew safety, LM staytime capability, and medical considerations. These are:

1. A maximum of three EVA's shall be performed on each mission based on a LM staytime capability of 54 hours.

2. Two men shall be out and shall remain within sight of one another on each EVA.

3. Maximum continuous time in a pressurized suit shall not exceed 5 hours for a nominal EVA mission and 6 hours in case of an emergency.

4. In event of a PLSS failure, the crewmen shall be able to return to the LM on the SLSS using the nominal EVA mobility mode.

5. In event of an LRV failure, the crewmen shall be able to walk back to the LM on the consumables remaining in the PLSS.

It was recognized that relegating most of the scientific activity to the return leg of some riding traverses would increase the total number of sites which could be visited as the reserves required for emergency return were reduced. Where this fact was applied, the preferred traverse direction (i.e., clockwise or counter-clockwise) is noted by arrows.

A number of factors were not considered in this study. These include:

1) distance limitations to meet communications and navigation requirements,

2) distance limitations to ensure return to the LM in time to cope with LM systems failures,

3) EVA time for LM inspection, environmental familiarization and LRV set-up and servicing,

4) average metabolic energy expenditures during walking missions which may require limiting the crewman's activities in order to avoid excessive fatigue, and

5) inefficiency introduced on riding missions by having short separation distances between sites (i.e., the cost of getting off and on the LRV, etc.).

The authors believe that these factors are important considerations for making absolute determinations of traverse capability and for planning of actual traverses. Because this is a comparative study, however, it is felt that application of these constraints would not have significantly altered the results of this analysis.

2.3 Method of Traverse Analysis

Two graphical aids were constructed for use in traverse planning. Both are attached for information and use as desired.

Figure 2 was constructed to relate the parameters of time and energy required for science and mobility in the A7L suit configuration to the life support systems capacity and operational time limit for pressurized suit operation. It permits determination of the BTU's and time required to accomplish a particular traverse and to walk back on PLSS reserves following LRV failure. It also provides quantitative assessment of energy and time margins. Use of this chart in planning traverses provided the capability for making science and mobility trade-offs at a level of detail which was not required for comparison purposes. Its main value proved to be as a basis for developing a more useful nomograph and as a check on the results of each planned traverse when completed.

Figure 3 was constructed and used for planning traverses during later stages of this study. It shows the operational envelope for traverse distance, science sites visited, and walkback capability as defined by the limits of the systems and operational constraints. This chart provided a quick look at the overall traverse and permitted rapid iterations in effecting the trade-offs between science and mobility costs.

Modifications of these planning aids were developed at the completion of this task. These new charts and a detailed description of their use are contained in Reference 5.

The analysis of the capability to travel the necessary distance and to accomplish the scientific tasks at each site was made in consecutive steps as follows:

1. Each of the four reference EVA's was examined and compared on the basis of the respective scientific return to find a candidate EVA traverse for deletion in order to satisfy the present limit of three EVA's per mission.

2. Each of the three remaining reference EVA's was tested to determine the capability for meeting the established scientific objectives at the velocities assumed for each mobility mode beginning with the highest (riding at 10 km/hr).

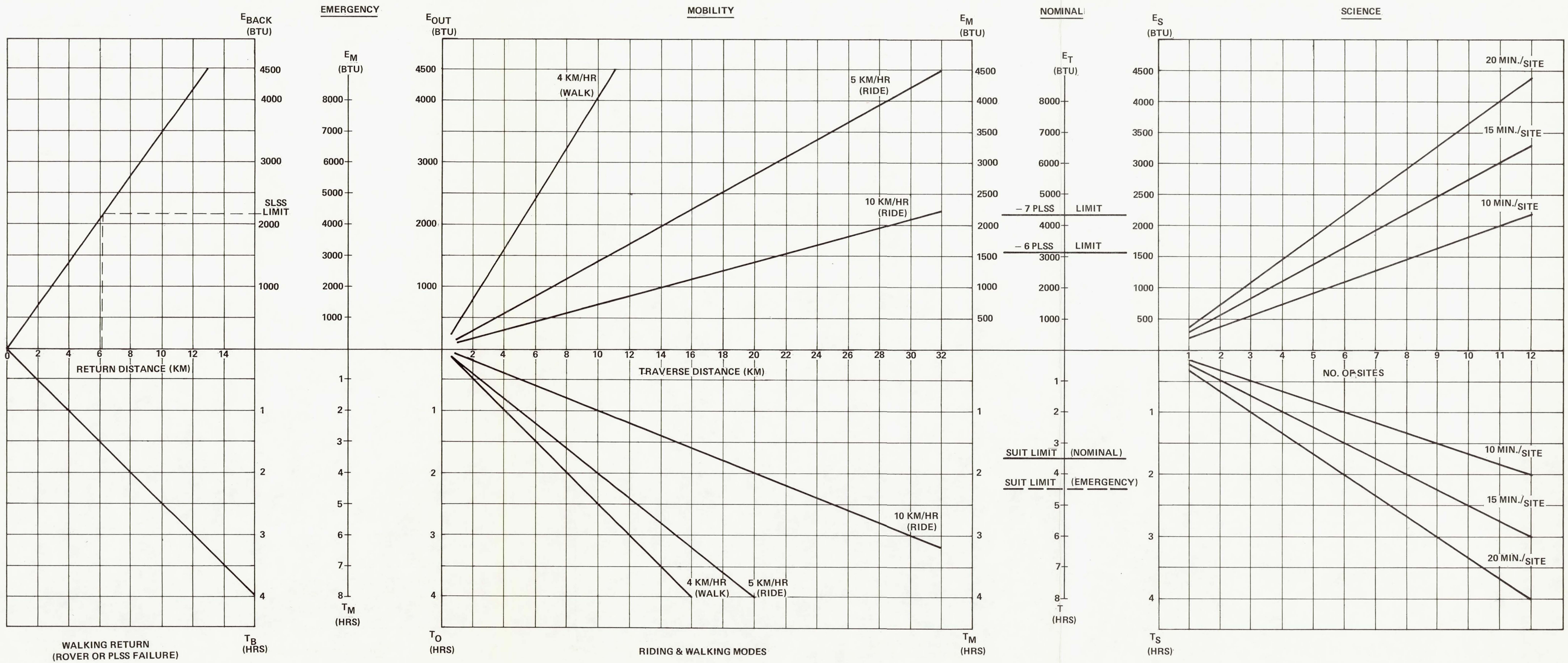


FIGURE 2 - LUNAR EVA TRAVERSE COMPUTATION CHART- A7L SUIT

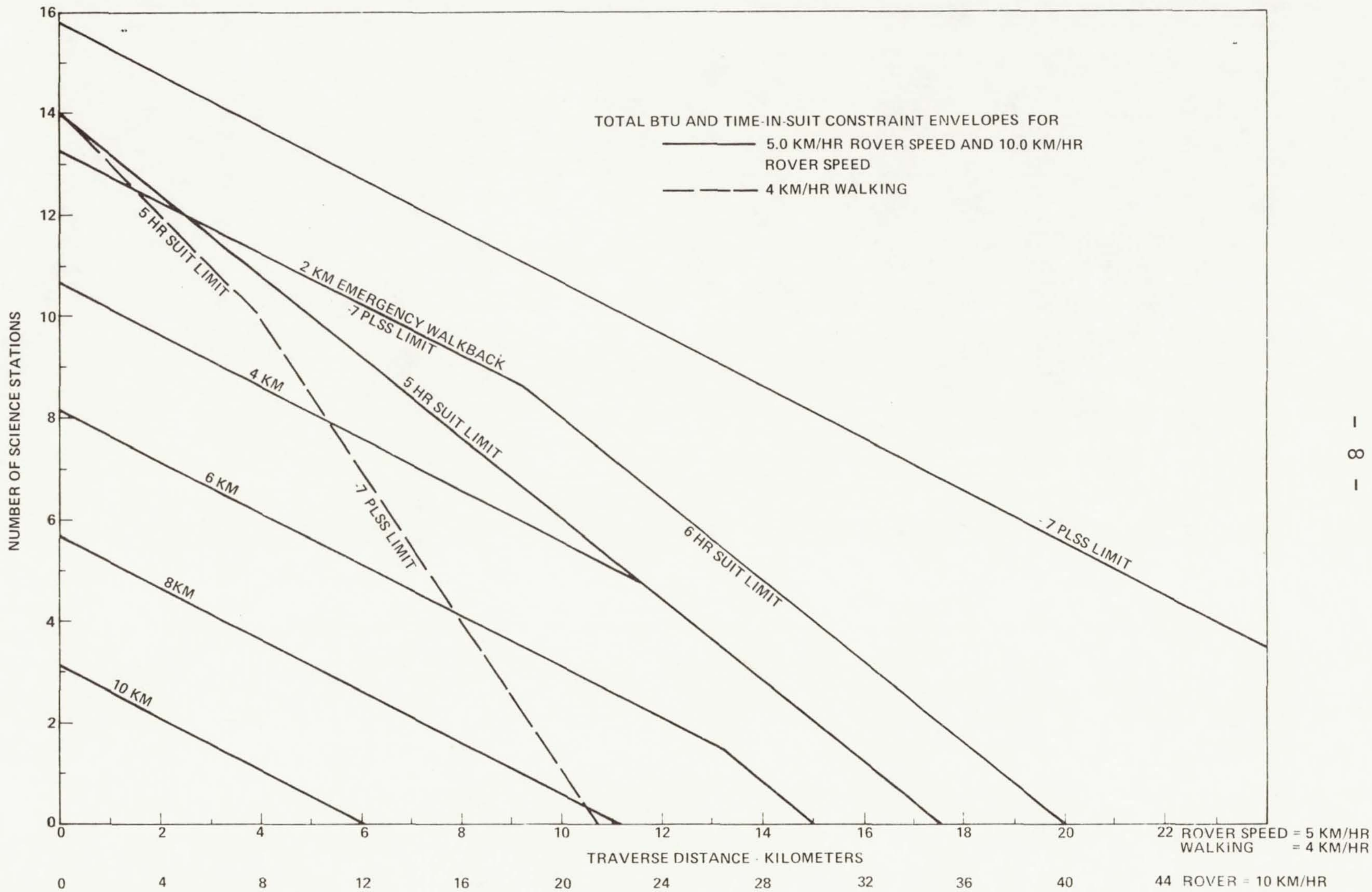


FIGURE 3 - LUNAR EVA CAPABILITY — A7L SUIT

3. Trade-offs were then made between sites visited and distance traveled for each mobility mode. These were based on value judgments of the scientific return on a site-by-site basis and a consideration of total mission objectives, as well as a satisfactory fit within the capability envelope defined by activity costs for nominal tasks, emergency return and time-in-suit limits, whichever were applicable.

4. In some cases the final traverse was modified by inclusion of some locations from the deleted reference EVA, selection of a traverse direction which biased science activity beyond the traverse mid-point or maximum return distance, and addition of new sites on the return leg (when not constrained by time-in-suit) in order to use life support capacity no longer needed for safe return.

3.0 SCIENTIFIC EVALUATION OF THE TRAVERSES

How well the scientific objectives can be accomplished on a particular mission depends not only on how many sampling locations there are but also on where they are, how much time is spent at the various sites, and also on the geologic training and support provided to the astronaut. Thus the effectiveness of a mission must be judged by a relatively subjective geologic evaluation of all the traverses in relation to the primary scientific objectives.

3.1 Marius Hills Mission

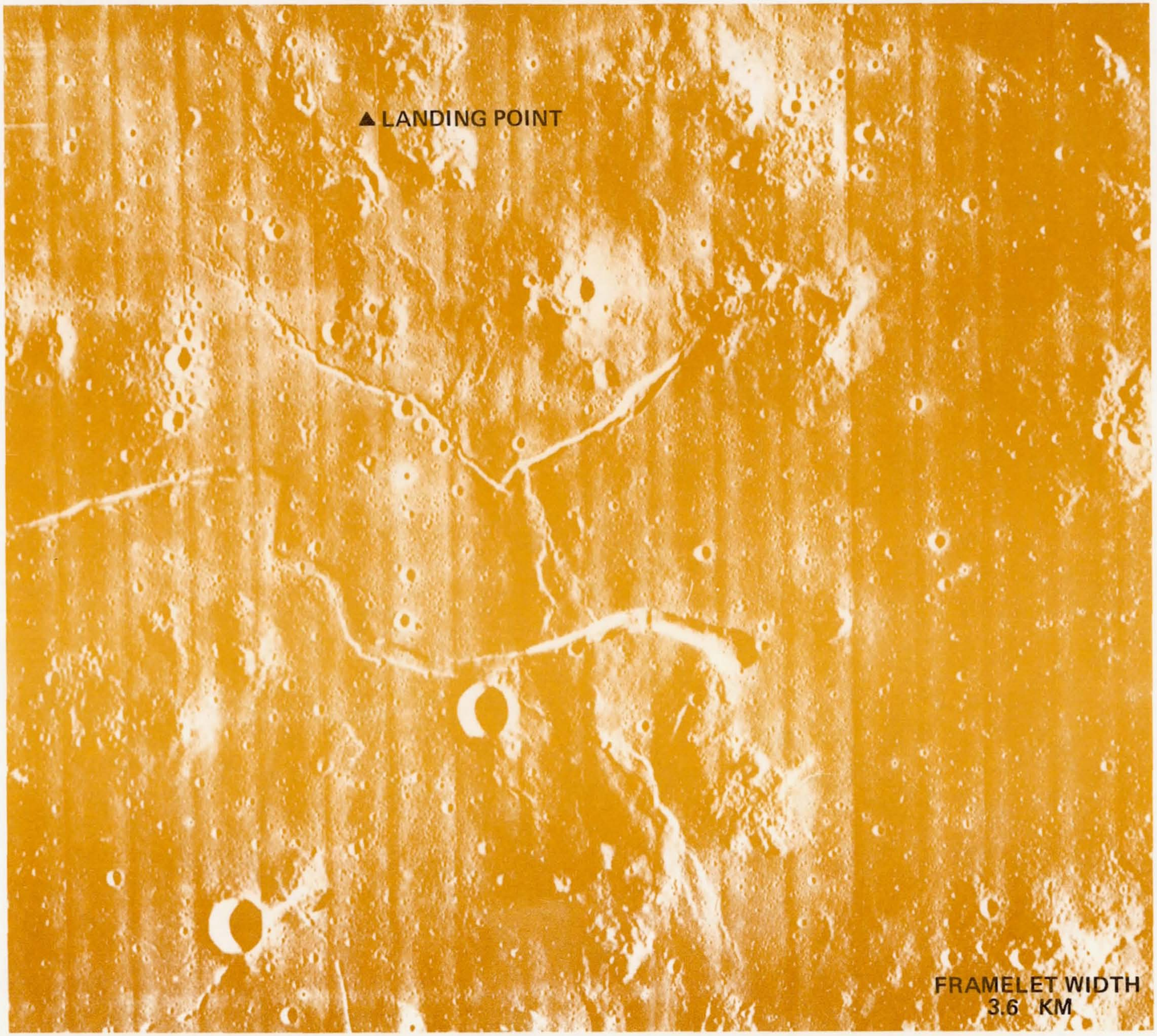
The Marius Hills are domes and cones near the center of Oceanus Procellarum and west-northwest of the crater Marius (Figure 4). Isolated hills and clusters of hills rise above the mare surface and form part of a major north-south median ridge system that stretches irregularly for some 1900 km through Oceanus Procellarum. Many of the hills exhibit the convex upward shapes suggestive of terrestrial shallow dome-shaped igneous intrusions, and some resemble terrestrial shield volcanos (Figure 5). 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 geologic map (Figure 6) illustrates the distribution of the wide variety of morphologic units typical of young volcanic terrain. A schematic cross-section (Figure 7) across line AA' of this map shows the topographic characteristics of these units. The most significant features are:

FIGURE 4

FIGURE 5

MARIUS HILLS



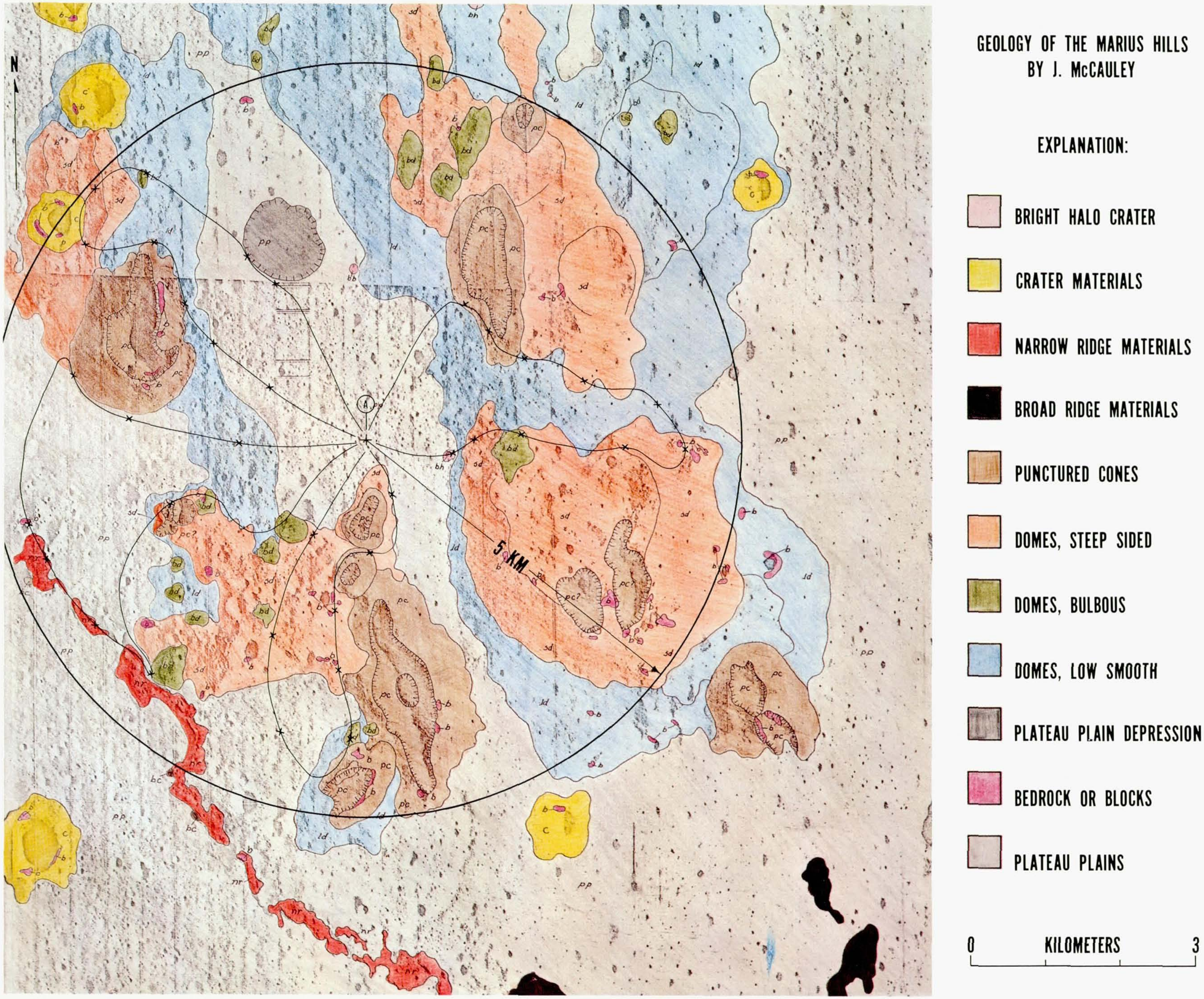


FIGURE 6 - GEOLOGY OF MARIUS HILLS AND ORIGINAL SCIENCE MISSION

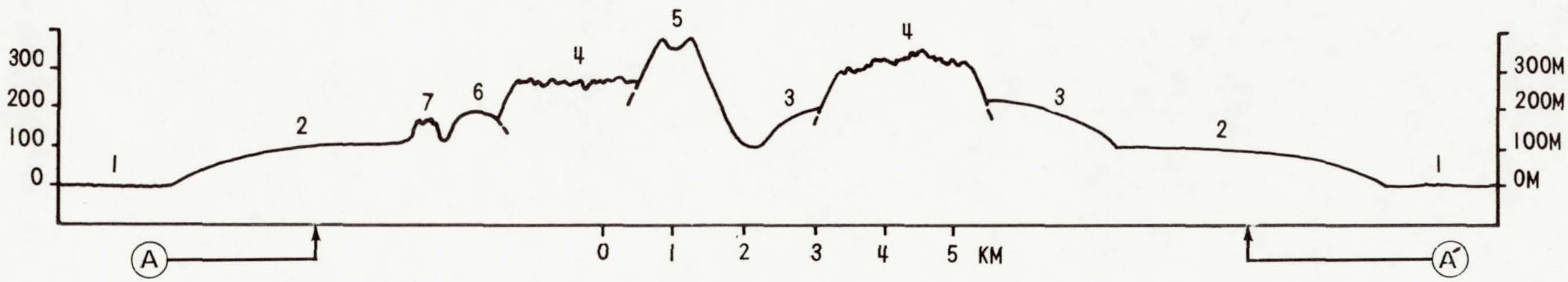


FIGURE 7

SCHEMATIC CROSS SECTION OF THE MARIUS HILLS REGION
(NOTE VERTICAL EXAGGERATION)

1. MARE MATERIAL
2. "MARIUS PLATEAU" MATERIAL
3. SMOOTH LOW DOMES UP TO 100 M
4. RUGGED STEEP DOMES (200-300 M)
5. PUNCTURED CONES (UP TO 300 M)
6. BULBOUS DOMES
7. MARE RIDGE MATERIAL

1. Smooth, cratered plains similar in appearance to the maria.

2. Low, smooth domes 50-100 meters above the plains with similar surface textures.

3. Steep-sided, rough textured domes of irregular shape, 200-300 meters high, which are generally superposed on the low domes.

4. Steeply convex upward, (or bulbous) domes which have smooth surfaces and are generally smaller and more equidimensional than the other domes.

5. Steep-sided relatively smooth cones with either single or multiple summit pits. These smooth cones are usually superimposed on the steep domes and are often as much as 300 meters high.

Comparisons in form and scale to young terrestrial volcanic regions suggest that the low domes may be shallow dome-shaped igneous intrusions. The steeper rough domes and the bulbous domes may be later extrusive features produced by viscous lavas. The cones appear to be late in the eruptive sequence and may be pyroclastic in origin. The diverse morphology of these volcanic forms argues for variation of composition of the parent magmas and appears to be strong evidence for lunar differentiation.*

The composition of rocks returned from Tranquility Base suggests that lunar igneous processes may differ from analogous terrestrial processes. Therefore, examination of a differentiated suite of lunar igneous rocks may provide valuable clues to the geochemical origin and evolution of the moon. Determination of the geochemistry of samples from the compositional spectrum probably existing at Marius Hills may provide evidence about the composition of the original magma and, by inference, the interior of the moon. Therefore, the Marius Hills region provides an excellent site to attempt to determine the extent of lunar magmatic differentiation and to provide comparative data for terrestrial magmatic differentiation. In addition, the acquisition of samples and study of structural relationships of a wide variety of

---

*J. McCauley, U.S.G.S. Astrogeology Branch, is responsible for the Marius Hills geologic map and for the above description and interpretation.

volcanic constructional landforms will provide important information about other lunar volcanic terrain. An important point on the lunar time scale will be provided by the age dating of this volcanic sequence.

The primary scientific objective of the Marius Hills mission is to better understand the role played by volcanic and magmatic processes in shaping the surface of the moon by determining the structural and chemical history of a multi-unit volcanic complex. Since the morphologic features and rock types in a volcanic terrain differ in variety and composition, the objective is by definition broader than the sampling of a specific rock feature.

3.1.1 Science Target Landing

The reference traverses and those developed in this study for the three mobility modes are shown in Appendix A, all drawn to the same scale. These figures illustrate penalties incurred due to decreasing mobility capabilities.

An evaluation of the three types of mobility modes (walking, rover 5 km/hr, rover 10 km/hr) and the reference science mission is summarized in Table 2 for a landing at the original science target. This evaluation is expressed in terms of the level of confidence of acquiring an adequate sampling of the various geologic units to allow an understanding of the specific unit and the relationship of that unit to the volcanic complex as a whole.

At the science target landing point, the reference science traverses yield a high confidence of achieving the mission objectives since they were specifically designed without strict operational constraints. The representative sampling of the spectrum of volcanic units existing in the Marius Hills as indicated on the reference traverses should provide an understanding of the volcanic and magmatic processes which may have produced lunar magmatic differentiation in this area. In addition the emplaced scientific instruments should provide important geophysical information about the Marius Hills area.

Since all the volcanic units are visited and sampled during the course of the 10 km/hr rover mission at the science landing point, the confidence in achieving the objectives is also high. Although not reflected in Table 2, the confidence is somewhat lower than in the reference science mission. This is because the reference science mission provides for sampling larger numbers of each unit and includes a geographically more diverse sampling of specific units. Furthermore, the lack of geophysical data from emplaced instruments subtracts from the confidence in achieving the Marius Hills mission objectives.

MARIUS HILLS - SCIENCE TARGET

CONFIDENCE IN ACHIEVING OBJECTIVES

VOLCANIC UNITS	WALKING MISSION	ROVER 5KM/HR	ROVER 10KM/HR	REFERENCE SCIENCE MISSION
PLATEAU PLAINS	LOW	HIGH	HIGH	HIGH
DOMES, LOW SMOOTH	LOW	HIGH	HIGH	HIGH
DOMES, STEEP SIDED	LOW	LOW	HIGH	HIGH
PUNCTURED CONES	HIGH	LOW	HIGH	HIGH
BULBOUS DOMES	LOW	HIGH	HIGH	HIGH
BEDROCK OR BLOCKS	NONE	HIGH	HIGH	HIGH
NARROW RIDGE	NONE	HIGH	HIGH	HIGH

EMPLACED INSTRUMENTS				
ALSEP (HFE, ASE, PSE)	HIGH	NONE	NONE	HIGH

TABLE 2

Since fewer stations are visited and sampling of some units is less broad, the 5 km/hr rover traverses originating at the science landing point yield a lower confidence in achieving mission objectives than the 10 km/hr rover traverses. In particular two important volcanic units, steep sided domes and punctured cones, are not sampled adequately, and as in the 10 km/hr rover mission, no geophysical instrumentation is emplaced.

A walking mission at the science landing point generally yields little confidence in the achievement of the scientific objectives of the Marius Hills mission. Not only are a large percentage of the volcanic units inadequately sampled, but the narrow ridge unit is not sampled at all, although it is widespread and characteristic of this terrain. Similarly, no samples are obtained from blocky areas or areas of bedrock, units of critical sampling importance since wide areas of the Marius Hills region may be blanketed by volcanic ash. On a walking mission, however, scientific instrumentation will be emplaced and since the radius of operations is closer to the LM, a specific punctured cone may be concentrated on and examined and sampled in detail, resulting in a high level of confidence of understanding this specific unit.

Note that the difference in confidence levels between the 5 km/hr rover and the 10 km/hr rover is relatively minor compared with the difference between the walking (4 km/hr) and the 5 km/hr rover, even though the speeds differ by a factor of 2 for the two rover cases compared to a factor of 1.25 for rover versus walking. This striking difference is due to the effect of the low metabolic cost of riding (regardless of speed) compared to walking.

3.1.2 Biased Target Landing

In addition to the previous set of traverses originating from the original landing point, a mission was planned from a smoother target area approximately 8 km to the east of the original science landing point. This target area was chosen to illustrate the effects of biasing the landing site away from the science site to a relatively smoother area and using the rover to reach the region of interest. Two sets of traverses (Appendix B) were planned; one assuming a landing 2 km uprange of the biased target point and one assuming a landing 2 km downrange.

Table 3 compares the results of 5 km/hr rover missions originating at these two extremes of the biased target area and at the original science target. A landing at the science target and a 5 km/hr rover mission is less desirable than the reference science mission because fewer stations are visited and sampling of some units is less broad. A downrange landing at the biased target with a 5 km/hr rover mission further degrades the confidence

MARIUS HILLS

CONFIDENCE IN ACHIEVING OBJECTIVES

VOLCANIC UNITS	BIASED TARGET (UPRANGE LANDING) ROVER 5 KM/HR	BIASED TARGET (DOWNRANGE LANDING) ROVER 5 KM/HR	SCIENCE TARGET ROVER 5 KM/HR
PLATEAU PLAINS	LOW	HIGH	HIGH
DOMES, LOW SMOOTH	LOW	HIGH	HIGH
DOMES, STEEP SIDED	NONE	LOW	LOW
PUNCTURED CONES	NONE	LOW	LOW
BULBOUS DOMES	NONE	LOW	HIGH
BEDROCK OR BLOCKS	LOW	HIGH	HIGH
NARROW RIDGE	NONE	NONE	HIGH

EMPLACED INSTRUMENTS			
ALSEP (HFE, ASE, PSE)	NONE	NONE	NONE

TABLE 3

in achieving the Marius Hills mission objectives. In particular, confidence is high in adequately sampling only three out of the seven visible geologic units. Further, two of these units, the low smooth domes and the plateau plains, may be surface manifestations of subsurface intrusion of igneous rock. If this is true, surface sampling may only yield samples of mare material whose morphologic characteristics have been changed by subsurface movements and whose composition may be the same as mare areas sampled elsewhere. Similar comparisons for the 10 km/hr case yielded similar results.

It is clear that when contrasted to a walking mission from a downrange landing at the biased target, the rover enables a considerable amount of science to be salvaged. It is equally clear, however, that missions at the biased target yield a lower confidence in achieving mission objectives than missions utilizing similar mobility modes at the science landing point. An uprange landing at the biased target is so far removed from the center of scientific interest that even with rover mobility there is little confidence in achieving the primary scientific objectives of the Marius Hills mission.

3.2 Hadley-Apennines Mission

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 landing site (Figure 8) the mountain front rises 1,280 meters above the adjacent mare to the west, i.e., the southeastern portion of Palus Putredinis.

A V-shaped sinuous rille, Rima Hadley, originates in the south at an elongate depression 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 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 volcanic (Ref. 1).

The determination of the nature and origin of a sinuous rille and its associated elongate depression and deposits will

FIGURE 8

provide information on an important lunar surface process and may yield data on the history of lunar volatiles. Sampling of Apenninian material should provide very ancient rocks whose origin predates the formation of the major mare basins.

The primary scientific objectives of the Hadley-Apennines mission are to determine the origin of lunar sinuous rilles and associated features and their role in the evolution of the lunar surface, and to collect ancient lunar material (Ref. 6).

The reference science mission for the Hadley-Apennines area (Figure 9) greatly exceeds the rover capabilities with the limitations used here. Due to the great distances involved and the unique route that must be taken to gain access to the rille (requiring a devious emergency return path) even a 10 km/hr rover mission produces little or no confidence that many of the geological objectives will be adequately sampled (Table 4). The accompanying traverses (Appendix C) graphically illustrate the effect of differing mobility capabilities on the scientific planning of this mission.

As at other landing sites, the reference science mission traverses yield a high confidence of achieving the mission objectives since they were specifically designed without strict operational constraints. A 10 km/hr rover mission shows a significant degradation of confidence primarily because of the operational limitations imposed by the emergency return path associated with the point of origin of the rille. Also, Apenninian material interpreted to be of pre-mare filling age is sampled adequately in the 10 km/hr rover mission, but no scientific instrumentation is emplaced.

The 5 km/hr rover mission further degrades the confidence in achieving the scientific objectives of the Hadley-Apennines mission. In particular, access to the sinuous rille itself is no longer possible and sampling of the linear depression associated with the rille is curtailed. Furthermore, confidence in adequately sampling the ancient Apenninian material is considerably reduced and no scientific instrumentation is emplaced.

On a walking mission at this site, no access is gained to the sinuous rille but some stations are investigated in the rille-associated linear depression. Since the origin of sinuous rilles is not known, it is improbable that their origin can be well understood from a brief investigation of rille-associated areas such as the linear depression. Since mobility is limited to a smaller radius around the LM, an area of rille-associated domes of secondary interest within walking traverse distance of the LM is investigated. The probability of sampling ancient Apenninian

GEOLOGY OF HADLEY-APENNINE REGION
BY F. EL BAZ

EXPLANATION:

- BLOCKS AND BEDROCK
- CRATERS AND CRATER CLUSTERS
- HADLEY C EJECTA RIM
- HADLEY C OUTER EJECTA
- SINUOUS RILLE MATERIAL
- SMOOTH RILLE DEPOSITS
- RUGGED RILLE DEPOSITS
- ELONGATE DEPRESSION MATERIALS
- SMOOTH DOME MATERIALS
- RUGGED DOME MATERIALS
- DOMICAL HILL MATERIALS
- SMOOTH PLAINS MATERIALS
- RUGGED PLATEAU MATERIALS
- IMBRIAN MARE MATERIAL
- FURROWED PLAINS MATERIALS
- PITTED PLAINS MATERIALS
- APENNINE BENCH MATERIAL
- APENNINE RIDGE, SUBDUED
- APENNINE RIDGE MATERIALS

0 KILOMETERS 6

FIGURE 9 - GEOLOGY OF HADLEY—APENNINES AND ORIGINAL SCIENCE MISSION

HADLEY-APENNINE

CONFIDENCE IN ACHIEVING OBJECTIVES

RILLE RELATED UNITS	WALKING MISSION	ROVER 5KM/HR	ROVER 10KM/HR	REFERENCE SCIENCE MISSION
SINUOUS RILLE	NONE	NONE	LOW	HIGH
LINEAR DEPRESSION	LOW	LOW	HIGH	HIGH
BLOCKS AND BEDROCK	NONE	LOW	LOW	HIGH
RILLE ASSOCIATED DOMES	LOW	NONE	NONE	HIGH

ANCIENT MATERIAL UNIT				
APENNINE RIDGES AND BENCH	LOW	LOW	HIGH	HIGH

EMPLACED INSTRUMENTS				
ALSEP (HFE, PSE, LR^3)	HIGH	NONE	NONE	HIGH

TABLE 4

material is also considerably reduced from more ambitious missions, but scientific instrumentation is emplaced at this landing site during a walking mission.

In summary, a rover considerably improves the confidence in achieving the scientific objectives of the Hadley-Apennines mission over a walking mission, particularly if the rover speed is near the 10 km/hr range.

3.3 Copernicus (Central Peaks) Missions

The crater Copernicus (Figures 10, 11) is a bright rayed crater, 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. The floor, 60 km in diameter, is nearly circular, and contains small, almost central, multiple peaks with large masses to the east and the west. The highest peak rises 800 meters above the crater floor. These peaks may have brought to the surface material that once lay at considerable depth. A mission to the central peaks (Figure 12) would be mainly a sampling mission, with some emphasis on structural relationships. Samples of large blocks on the peaks, of the floor material, and of the mounds on the floor would be of significance in studying the geochemistry of the moon. Examination of the features of a major lunar crater floor will aid in the understanding of the process of crater floor filling in terms of both composition and age. Therefore, the primary scientific objectives are twofold: first, to obtain samples of the central peaks, and second to investigate aspects of giant impact crater evolution, particularly the formation of the crater floor (Ref. 1).

Because of the uniqueness of the sampling objective (the central peaks) both the reference science mission and the traverses planned in this study tend to be similar in shape although quantitatively different. Table 5 summarizes the results of the planned traverses for the different mission mobilities. The traverses shown in Appendix D illustrate the effects of mobility constraints at this site.

The 10 km/hr rover mission adequately samples all the geologic units except the smooth floor material (a result of omitting the fourth EVA of the reference science mission). In spite of the fact that no scientific instrumentation is emplaced, a 10 km/hr rover mission provides high confidence in achieving the primary objectives of the Copernicus Peaks mission.

A 5 km/hr rover mission will obviously detract from the total radius of operations or from the total number of sampling stations, as defined in more ambitious missions. Since the central

FIGURE 10

COPERNICUS

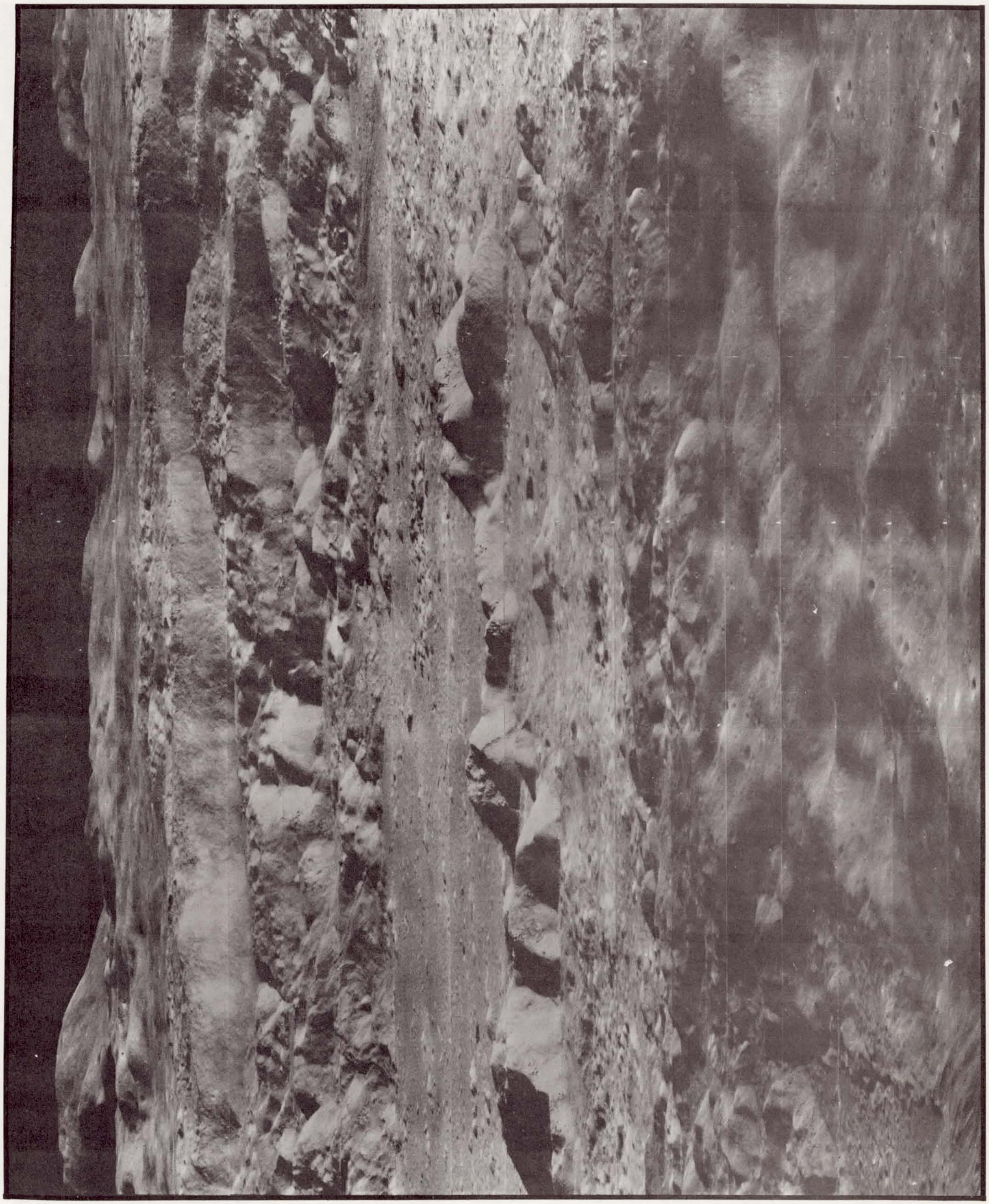
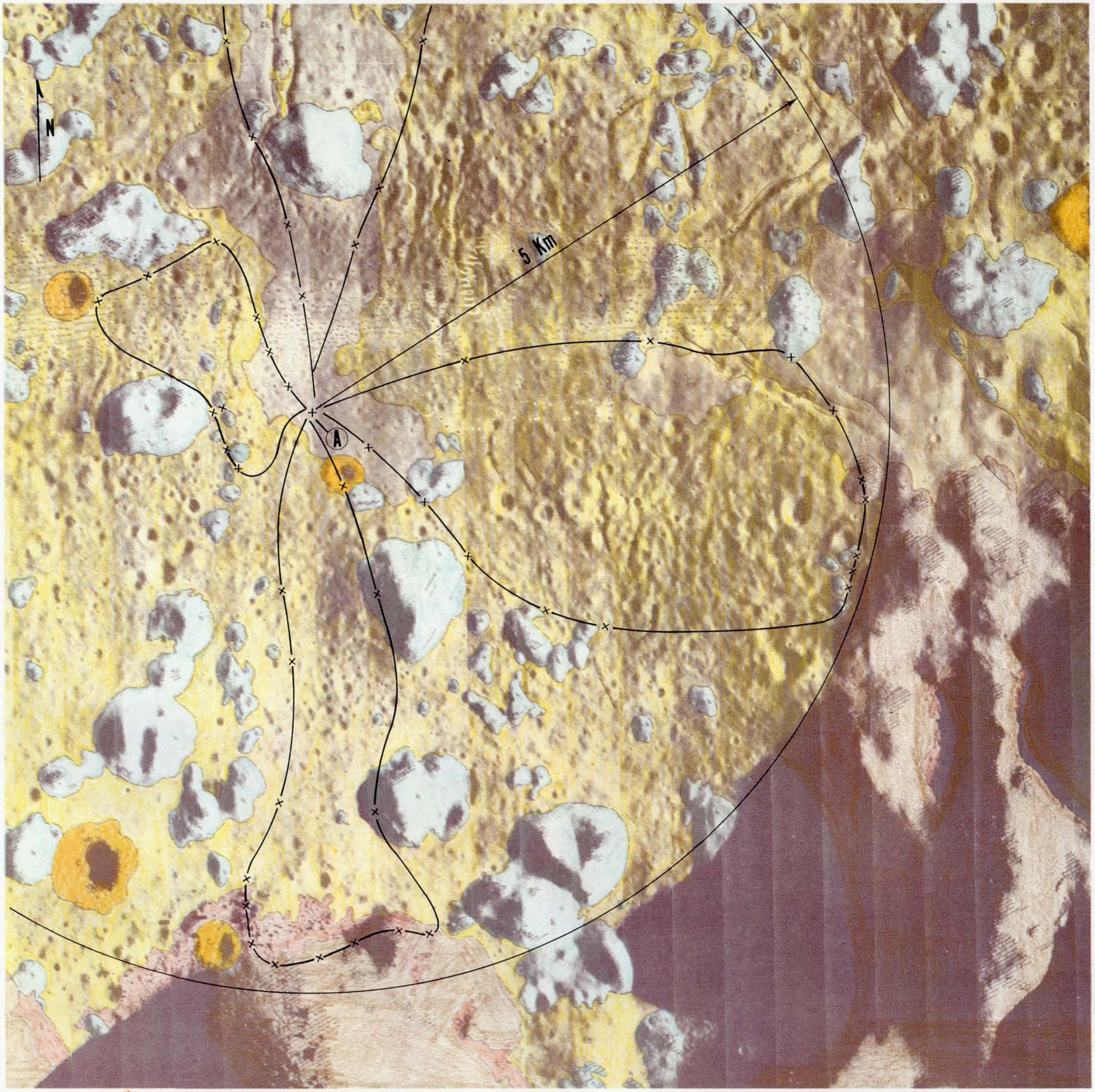


FIGURE 11 - AN OBLIQUE VIEW OF COPERNICUS



GEOLOGY OF COPERNICUS PEAKS
H. WILSHIRE

EXPLANATION:

- BLOCKY CRATER MATERIAL
- TALUS DEPOSITS
- FLOOR MATERIAL, SMOOTH
- FLOOR MATERIAL, TEXTURED
- HILLS AND HUMMOCKS
- CENTRAL PEAK MATERIAL

0 KILOMETERS 2

FIGURE 12 - GEOLOGY OF COPERNICUS PEAKS AND ORIGINAL SCIENCE MISSION

COPERNICUS PEAKS

CONFIDENCE IN ACHIEVING OBJECTIVES

CENTRAL PEAK AND CRATER FLOOR UNITS	WALKING MISSION	ROVER 5KM/HR	ROVER 10KM/HR	REFERENCE SCIENCE MISSION
CENTRAL PEAKS	NONE	HIGH	HIGH	HIGH
HILLS AND HUMMOCKS	LOW	LOW	HIGH	HIGH
FLOOR MATERIAL, TEXTURED	LOW	LOW	HIGH	HIGH
FLOOR MATERIAL, SMOOTH	LOW	LOW	LOW	HIGH
BLOCKY CRATER MATERIAL	LOW	HIGH	HIGH	HIGH

EMPLACED INSTRUMENTS				
ALSEP (HFE, PSE, GRAV.)	HIGH	NONE	NONE	HIGH

TABLE 5

peaks are a major part of the prime objective and since their position in relation to the landing point remains unchanged, they are investigated and sampled at the expense of intermediate science stations. This approach results in a decrease in confidence in adequate sampling of crater floor units such as hills and hummocks, and textured and smooth floor material. Confidence in adequately sampling central peak material remains high, however.

The radius of operations of a walking mission effectively precludes adequate sampling of the central peaks and considerably reduces the possibility of adequately sampling the variety of crater floor units exhibited in the vicinity of this landing site. The fact that scientific instrumentation would be emplaced on a walking mission does not compensate for the low confidence in achieving the major objectives of the Copérnicus Peaks mission. Therefore, from this landing point a rover is necessary to achieve the primary objectives of the mission.

4.0 ENGINEERING AND OPERATIONAL RESULTS

The length of each traverse and corresponding number of sites visited are summarized in Table 6 for all three mobility modes and landing points considered. The table indicates that a typical 10 km/hr rover traverse would cover 10 to 15 km while visiting about 7 to 10 sampling stations, giving an average site separation of about 1.4 km. This means that about 8 minutes on the average are spent riding between two sites and 15 minutes are spent at each site, or the metabolic cost of on-site activities predominates in the consumables analysis. The cost of rover ingress and egress, not considered here, may represent a significant portion of the metabolic cost attributable to riding.

A typical 5 km/hr rover traverse visits 4 to 7 stations in an 8 to 13 km range, a 20% range reduction and 30% reduction in the number of sites from the 10 km/hr rover figure. The walking traverses average 5 to 8 km in length, and include 4 to 6 stations. This is only a 10% reduction in the number of sites from the 5 km/hr rover, but a 30% range decrease, restricting access in many cases to secondary objectives. There is, however, an additional gain in scientific return on walking missions from ALSEP deployment. Thus the primary advantage of the 5 km/hr rover over walking is an increase in range (and hence the availability of certain sites), rather than in the number of sites visited, while a 10 km/hr rover speed increases both the number of sites visited and the range. Implicit in the above is that the primary advantages of the rover occur when large average site separations are involved. These results are consistent with parametric trade-off studies conducted previously (Refs. 7, 8).

TRAVERSE SUMMARY

	ROVER*		WALKING* 4 KM/HR
	10 KM/HR	5 KM/HR	
MARIUS HILLS NOMINAL LANDING POINT	10.4/10	7.7/8	6.4/6
	10.9/9	8.7/7	3.6/4+A
	15.0/8	12 .5/5	6.8/6
MARIUS HILLS BIASED TARGET-DOWNRANGE LANDING	12.3/9	9.6/6	8.6/3
	10.0/10	9.2/6	6.4/6
	10.9/9	9.6/6	4.7/2+A
MARIUS HILLS BIASED TARGET-UPRANGE LANDING	14.5/8	12.5/4	9.2/2
	17.5/7	13.0/3	A
	14.5/7	13.5/3	10.0/1
COPERNICUS PEAKS	12.6/9	11.0/5	3.2/5+A
	12.0/9	11.3/5	8.7/1
	7.3/11	6.2/9	5.4/7
HADLEY-APENNINE	16.0/7	12.0/4	7.5/4
	16.0/6	14.0/3	8.0/4
	18.0/6	14.5/3	5.0/2+A

*TRAVERSE DISTANCE (KM) / NO. SITES VISITED

TABLE 6

The effectiveness of the rover is also dependent on the form of the traverse. This form may vary from an areal traverse - a circular trip around the LM - to a linear traverse - a dash to a point and return. Generally an areal traverse is limited by the 5 hr maximum nominal suit time assumed in the analysis. That is, the planned traverse ends after 3 1/2 hours (1 1/2 hours overhead deducted) with large amounts of PLSS consumables remaining. Neither the SLSS rideback limit nor the PLSS walkback limit are exceeded. Given the constraints assumed, the only operational way to increase scientific yield at a particular landing site is to increase the ratio of total time on site to travel time, to decrease the average scientific station separation, to increase rover velocity, or to increase the time spent at each station.

For linear traverses the 5 km/hr rover case is usually limited by the nominal 5 hr suit limit or the 6 hr emergency walkback suit limit. A linear traverse with a 10 km hr rover is constrained by the PLSS consumables reserved for the emergency walkback requirement. This results in reduced sampling time at large distances and unused PLSS residuals due to the walkback reserve. Of course, as the rover returns to the LM, the walkback reserve required is reduced and may permit the inclusion of additional science stations along the return path. In general, if a linear "dash" has been made to reach a specific high value scientific objective, stations located on the return path are likely to be of low scientific interest. In no case is the SLSS rideback limit exceeded.

Walking missions generally use all of the PLSS consumables, and, of course, emergency walkback is never a constraint. Only for traverses less than 4 km long with visits to more than 10 science stations is it possible to reach the 5 hr suit limit. Since the maximum traverse length of 10 km with only one science site yields a radius of less than the 6 km SLSS walkback capability, the SLSS is not a constraint upon walking missions.

5.0 SUMMARY

From this study it is concluded that, ignoring the contribution of ALSEP, the rover approximately doubles the amount of significant scientific activity achievable on each mission over walking missions. This is reflected by an increase in total traverse distance, an increase in number of sampling stations visited, and an increase in confidence that representative sampling has been accomplished.

In the Marius Hills mission to the science target, the rover not only increased the confidence of obtaining representative samples, but it also provided the capability to sample the narrow ridge material even though it was almost five kilometers from the landing point.

In the Hadley-Apennines area the walking traverses provided no confidence in achieving mission objectives. The rover at 5 km/hr slightly increased the possibility of the scientific success of the mission. At 10 km/hr, however, the increase in distance combined with the increase in representative sampling, allowed much higher confidence in understanding the origin of rilles and the age of Apenninian material.

In the Copernicus Peaks mission the rover provided the necessary capability so that the central peaks could be adequately sampled from the available landing site. In this case sampling of this unit was of major importance in achieving the primary mission objective. The rover, particularly at 10 km/hr, also substantially increased confidence in gathering enough data to understand the origin and evolution of major crater floor units.

It is also concluded that at Marius Hills the rover significantly reduced the scientific losses incurred by biasing the landing area away from the features of interest. In this case, a downrange landing at a biased target in the Marius Hills area resulted in walking traverses which were so poor that only one unit could be sampled adequately. Although employment of a roving vehicle enables a significant amount of mission science to be salvaged over the walking traverses, the confidence in achieving the primary objectives still fell short of that obtained with a landing at the science target point with similar mobility.

For a typical areal type rover traverse the maximum nominal suit time is the limiting constraint, resulting in inefficient use of PLSS consumables. For linear rover traverses, either suit limits or PLSS reserve for emergency walkback constrain the traverse, resulting in reduced science time at large distances and higher PLSS residuals. These effects can be reduced by changes in the hardware, modification of the ground rules, or implementation of operational techniques designed to minimize their effect, as evidenced in the traverses presented here.

The nominal traverse is designed to maximize mission success. In order to provide for crew safety, preplanned emergency return traverses, as shown in the work done here, must be planned with the same care as the nominal traverses. These multiple emergency return routes provide high confidence paths which allow more efficient use of the full system capability during the nominal traverse.

Walkback limitations can be minimized by accounting for the directional sensitivity of the traverse. The fewer number of stops made before the maximum radius point in the traverse, the less critical the walkback constraint. By planning the major portion of the sampling stations to be after the maximum radius, the traverse effectiveness can be increased significantly.

Two changes in the ground rules can most effectively increase traverse capability and utilize the hardware more efficiently. By using a 6 hour nominal suit time limit, with the emergency suit time limit undefined, a better balance between suit time and PLSS consumables usage can be obtained in most typical traverses, with neither being the exclusive limiting case. To reduce the severity of the walkback constraint upon linear traverses, the SLSS, as well as PLSS reserves, could be planned on for emergency walkback use. Thus in case of a rover failure both the SLSS and the PLSS would be used, increasing walkback capability by 6 km over values assumed in this study. The effects of these changed constraints have been analyzed previously (Ref. 9) and found to provide this increased effectiveness.

This analysis did not in any way deal with related traverse problems such as communications constraints or navigation requirements. Since the communications system is presently still undefined and navigation problems are a matter of debate, they have been eliminated from consideration. Clearly in future work they must be integrated into the analysis.

Acknowledgments

Thanks are extended to D. B. James and P. F. Sennewald for their help during the execution of this study. The geologic maps were prepared by J. McCauley (Marius Hills) and H. Wilshire (Copernicus Peaks) both of the U.S. Geological Survey, Astrogeology Branch, and by F. El-Baz (Hadley-Apennines) of Bellcomm, Inc., who also constructed the Marius Hills cross-section.

Peter Benjamin
P. Benjamin

T. A. Bottomley
T. A. Bottomley

James W. Head
J. W. Head

Michael T. Yates
M. T. Yates

2032-PB/TAB-kmj

2015-JWH/MTY-gmr

REFERENCES

1. El-Baz, F., "Characteristics of the Ten Lunar Exploration Sites," Bellcomm Memorandum for File, B69 08003, August 1, 1969.

2. El-Baz, F. and James, D. B., "Minutes of the August 12-14 Meeting of the Ad Hoc Working Group on Science Objectives of Apollo Missions 12-20," Addressed Memorandum to Distribution, August 18, 1969.

3. Sennewald, P. F., "Engineering Implications of Preliminary Scientific Traverses for Apollo 'J' Missions," Bellcomm Memorandum for File, B69 08055, August 25, 1969.

4. Bottomley, T. A. "Definition of Energy Costs for Lunar Surface EVA," Bellcomm Memorandum for File, B69 09027, September 8, 1969.

5. Benjamin, P., "Handy Dandy Charts for Determining Operational Constraint Effects in Lunar Traverse Planning," Bellcomm Memorandum for File, B69 10042, October 15, 1969.

6. El-Baz, F., "Some GLEP Recommendations on Lunar Exploration Sites," Bellcomm Memorandum for File, B69 09025, September 11, 1969.

7. Benjamin, P., "Some Preliminary Results of Tradeoffs Between Walking and the Use of Mobility Aids During Lunar Surface EVA," Bellcomm Memorandum for File, B69 06068, June 19, 1969.

8. Benjamin. P., "Further Results of Tradeoffs Between Walking and the Use of Mobility Aids During Lunar Surface EVA," Bellcomm Memorandum for File, B69 07050, July 14, 1969.

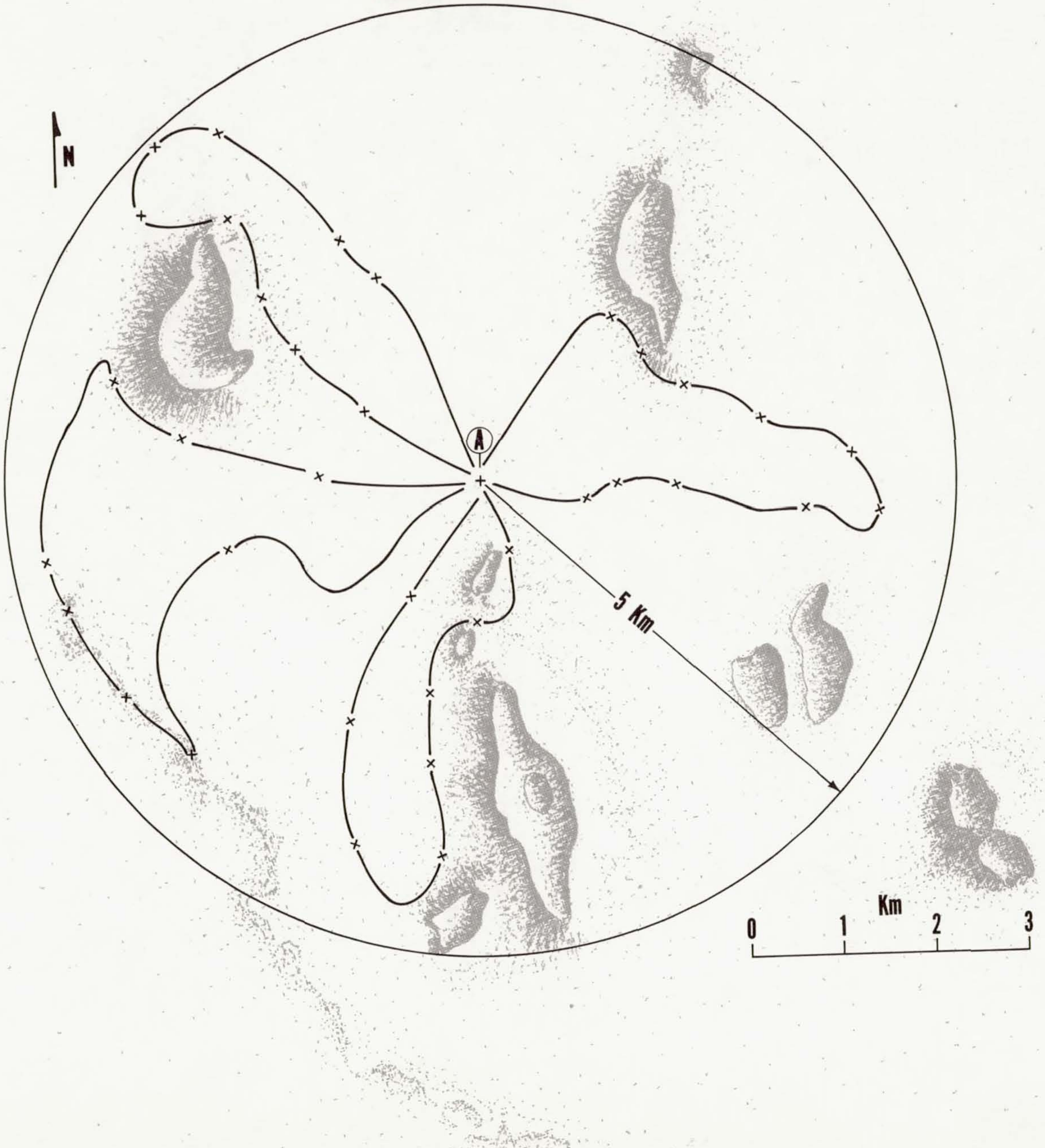
9. Sennewald, P. F., "EVA Operational Capability Envelope of Life Support and Mobility System," Bellcomm Memorandum for File, B69 07048, July 11, 1969.

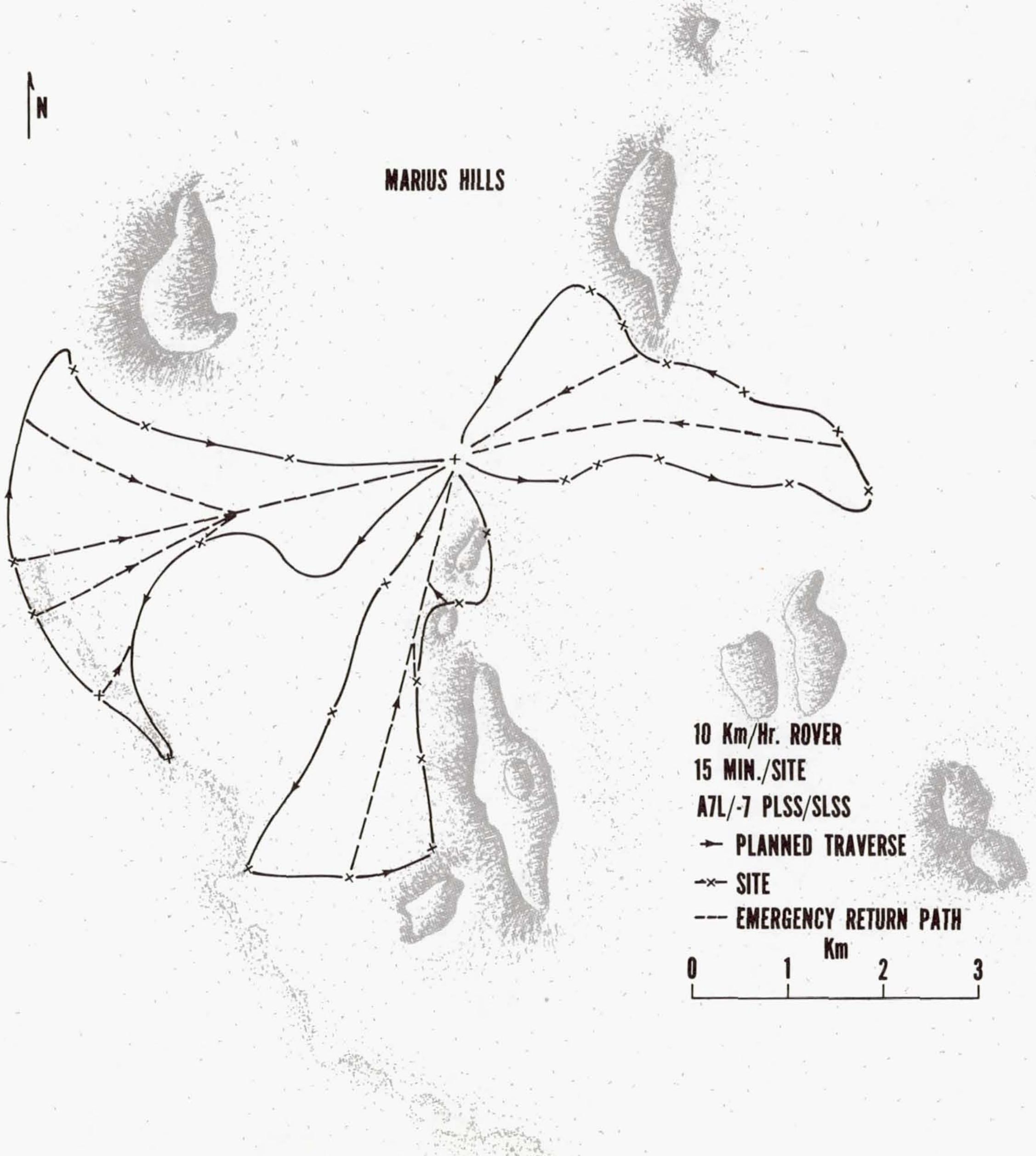
Appendix A

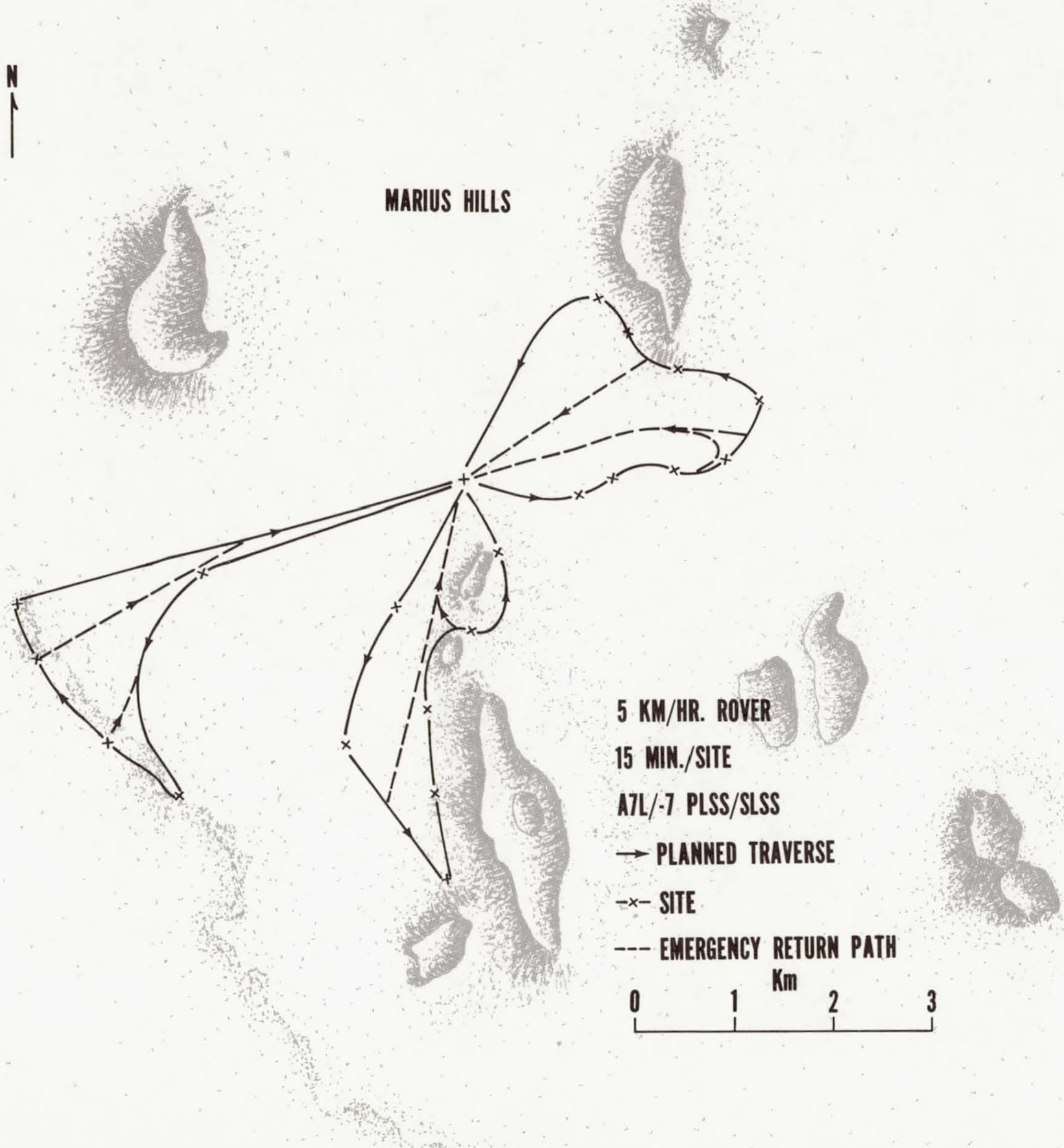
Marius Hills Traverses

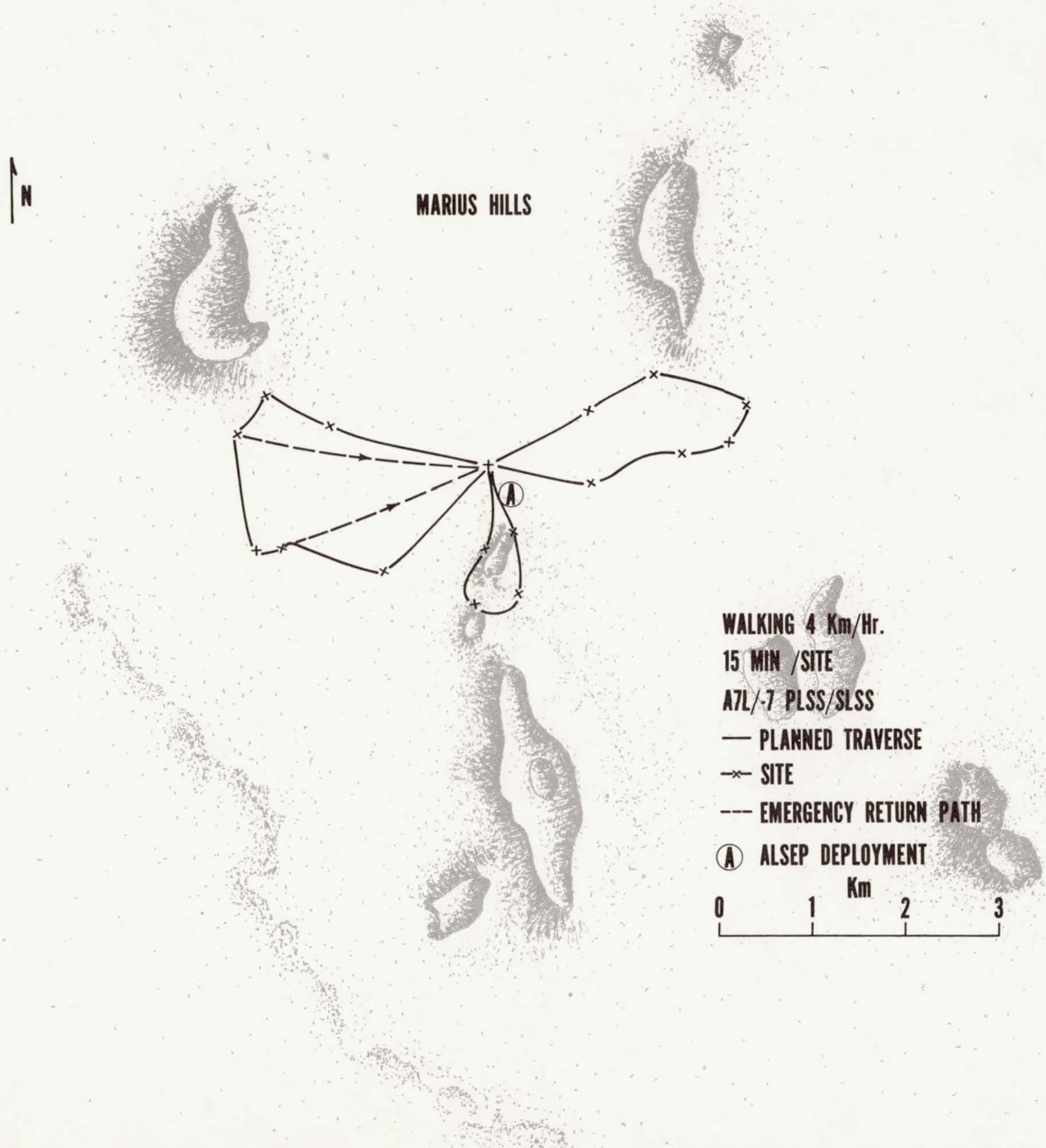
- science landing point

MARIUS HILLS
ORIGINAL SCIENCE MISSION




N
MARIUS HILLS
10 Km/Hr. ROVER
15 MIN./SITE
A7L/-7 PLSS/SLSS
PLANNED TRAVERSE
SITE
EMERGENCY RETURN PATH
Km
0
1
2
3


N
MARIUS HILLS
5 KM/HR. ROVER
15 MIN./SITE
A7L/-7 PLSS/SLSS
PLANNED TRAVERSE
SITE
EMERGENCY RETURN PATH
Km
0
1
2
3

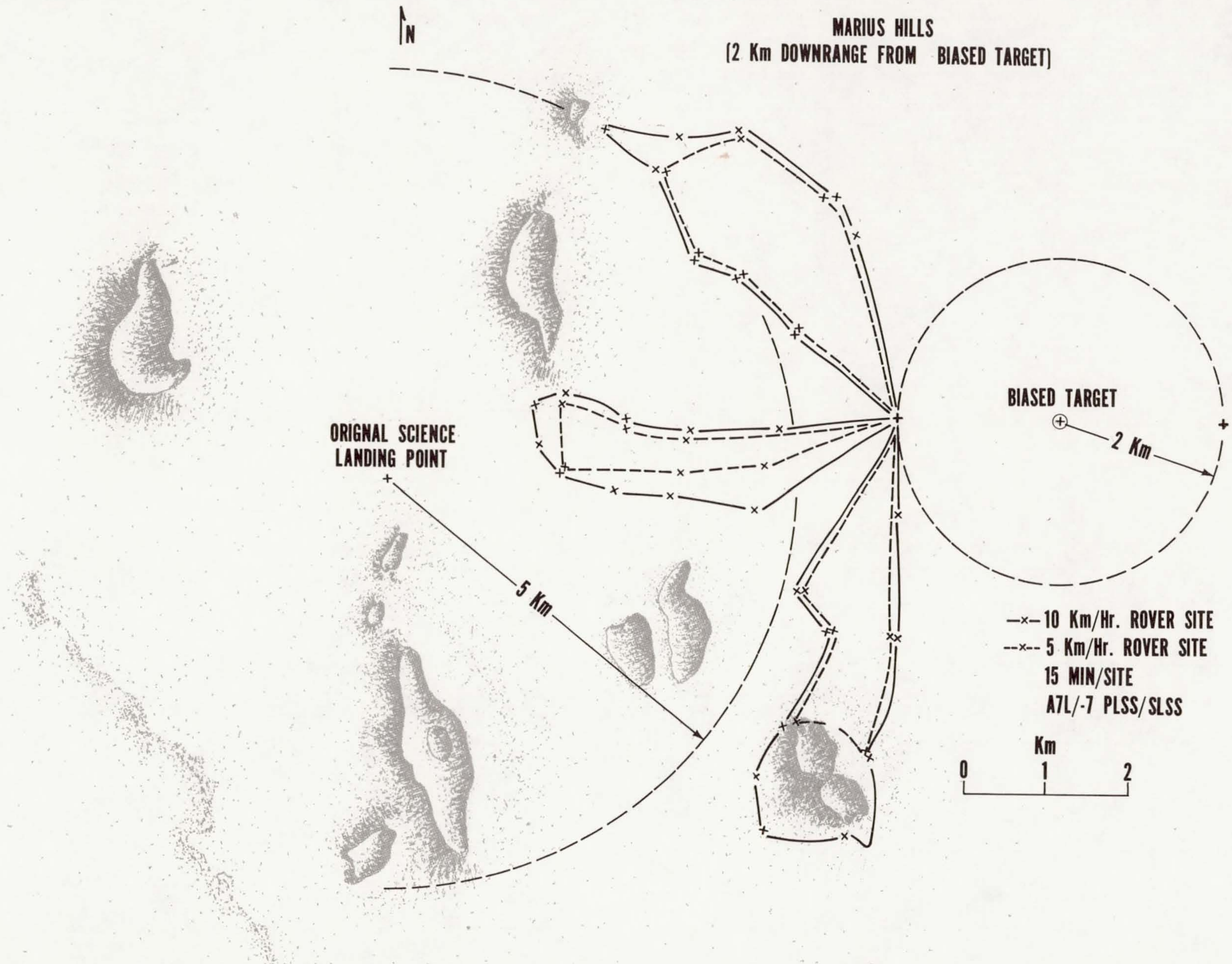


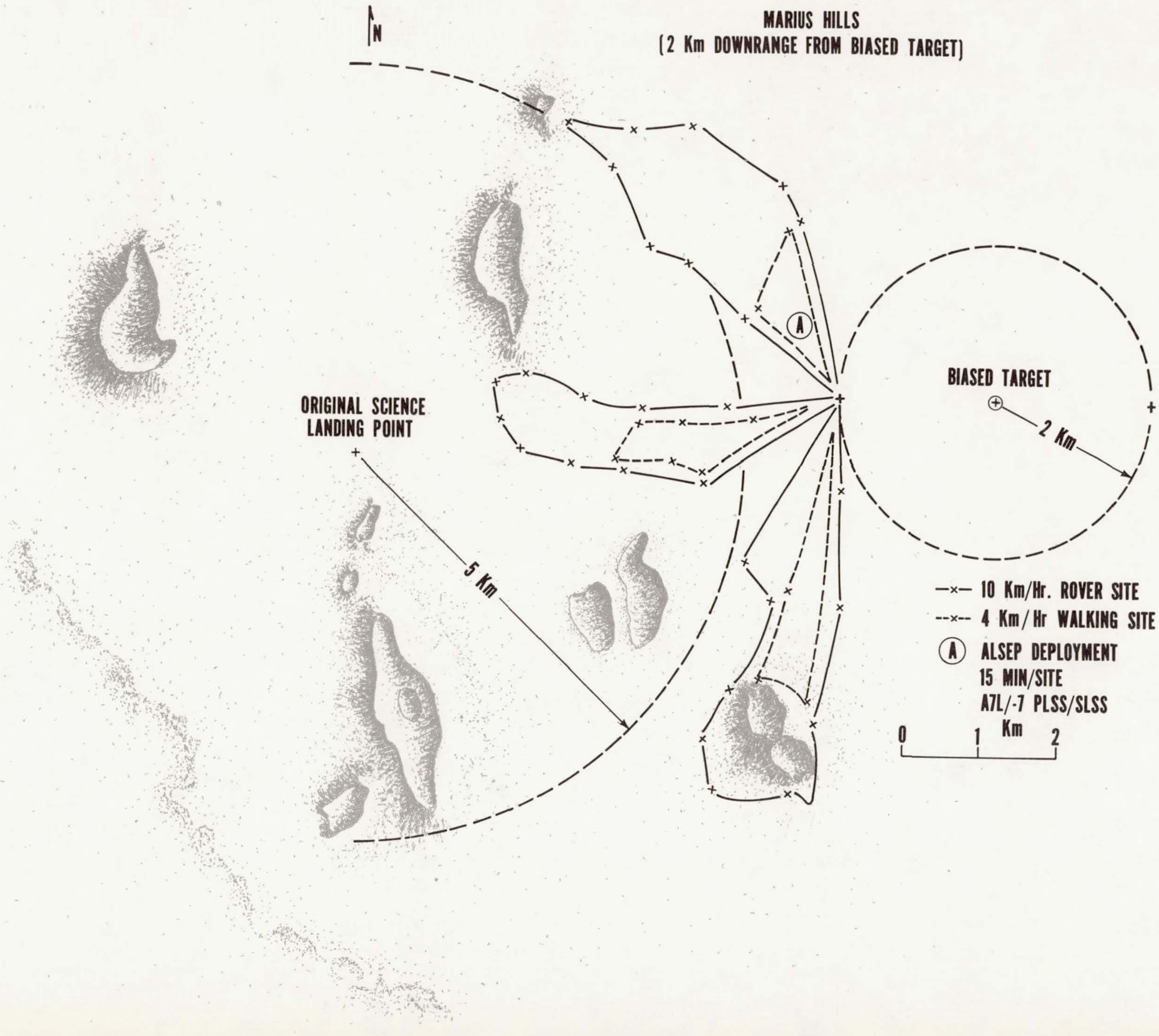
N
MARIUS HILLS
A
WALKING 4 Km/Hr.
15 MIN /SITE
A7L/-7 PLSS/SLSS
— PLANNED TRAVERSE
—×— SITE
--- EMERGENCY RETURN PATH
Ⓐ ALSEP DEPLOYMENT
Km
0 1 2 3

Appendix B

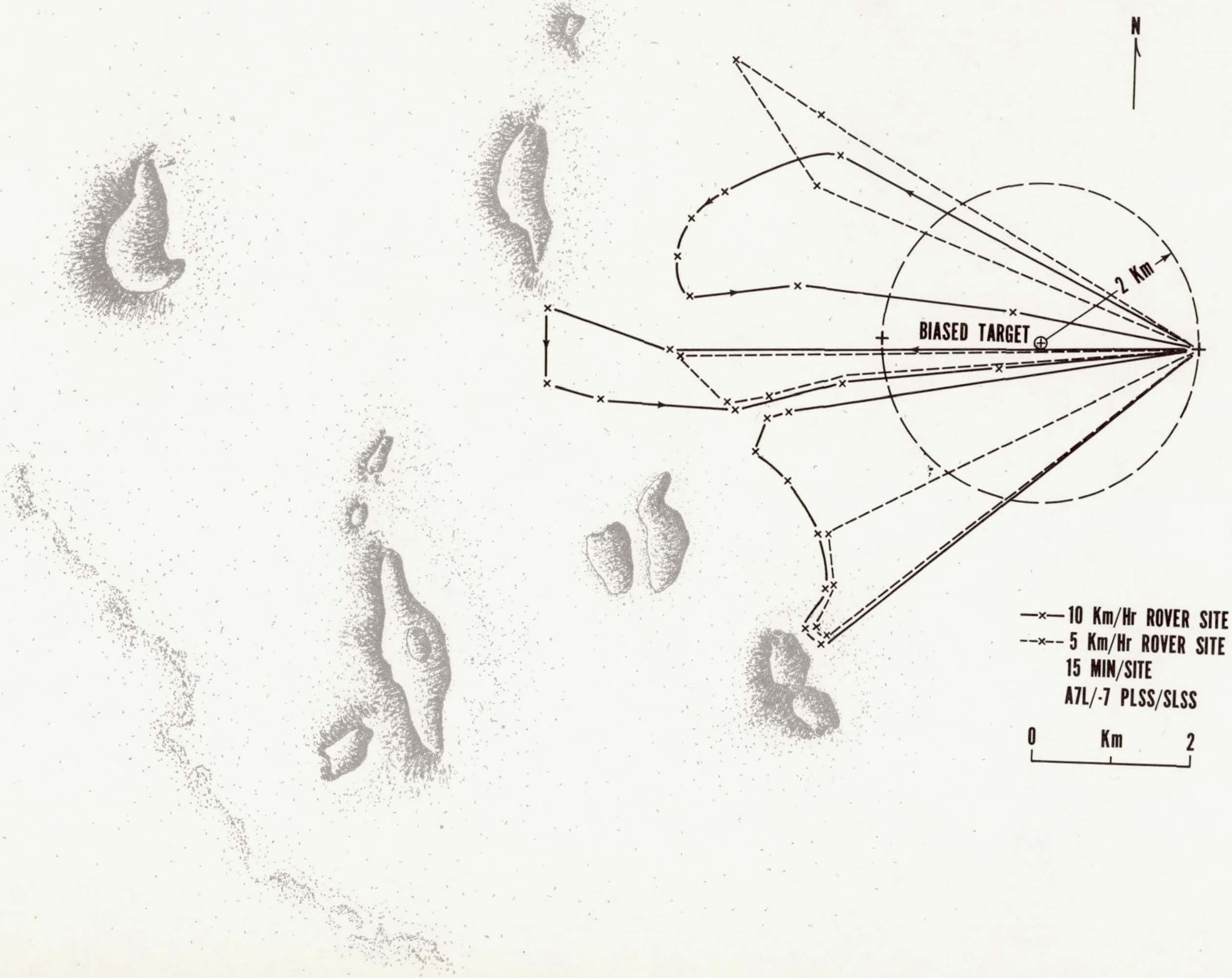
Marius Hills Traverses

- biased landing point

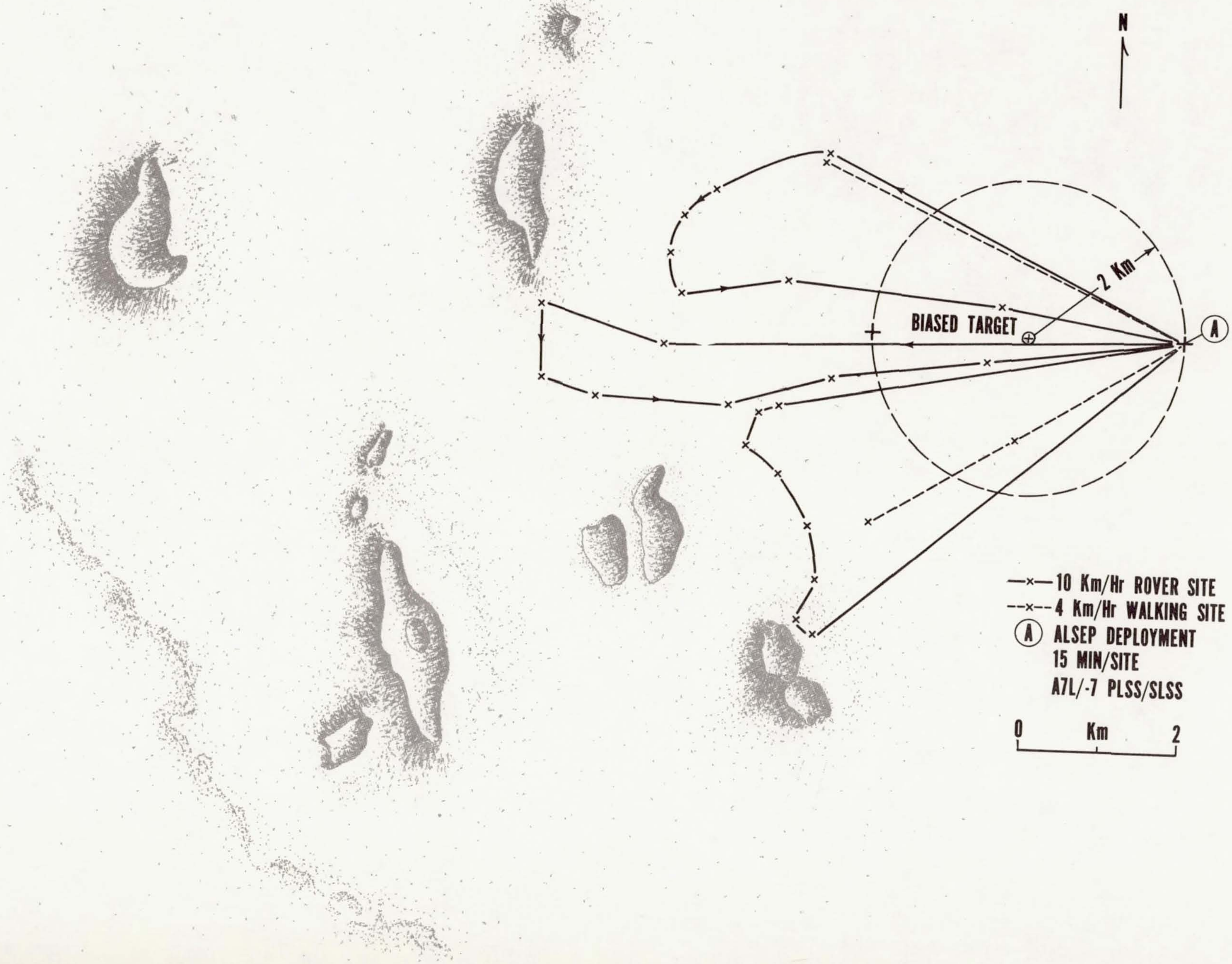

N
MARIUS HILLS
(2 Km DOWNRANGE FROM BIASED TARGET)
ORIGNAL SCIENCE LANDING POINT
5 Km
BIASED TARGET
2 Km
—×— 10 Km/Hr. ROVER SITE
--×-- 5 Km/Hr. ROVER SITE
15 MIN/SITE
A7L/-7 PLSS/SLSS
Km
0 1 2


N
MARIUS HILLS
(2 Km DOWNRANGE FROM BIASED TARGET)
A
BIASED TARGET
2 Km
ORIGINAL SCIENCE
LANDING POINT
5 Km
—×— 10 Km/Hr. ROVER SITE
--×-- 4 Km/Hr WALKING SITE
(A) ALSEP DEPLOYMENT
15 MIN/SITE
A7L/-7 PLSS/SLSS
0 1 2
Km

MARIUS HILLS
(2 Km UPRANGE FROM BIASED TARGET)

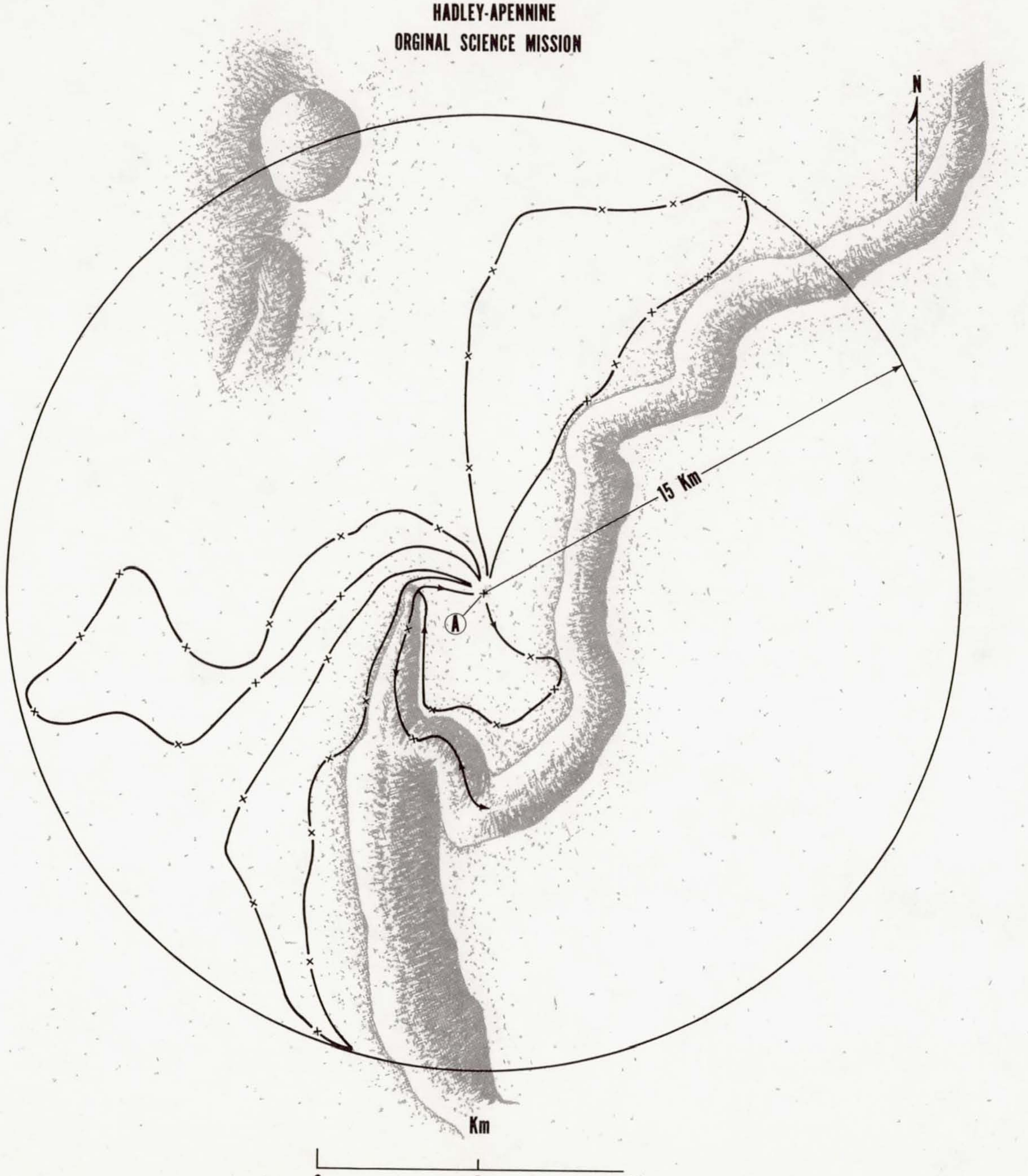


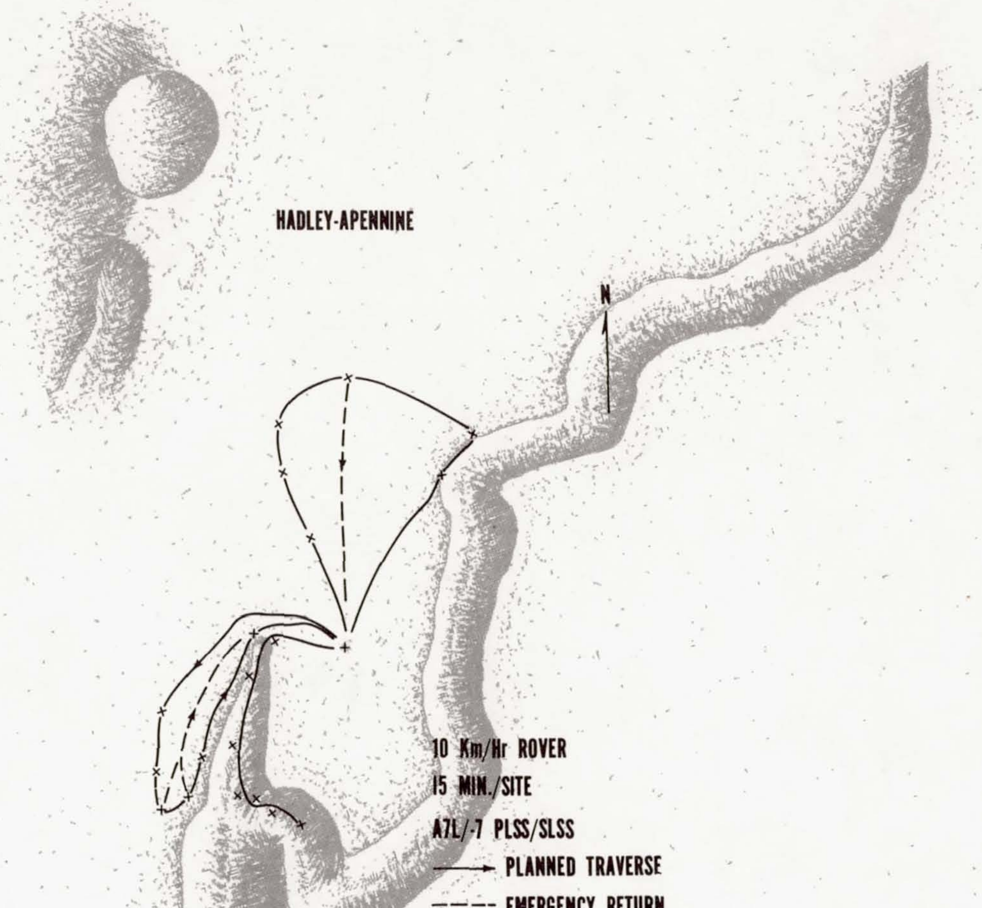
MARIUS HILLS
(2 Km UPRANGE FROM BIASED TARGET)

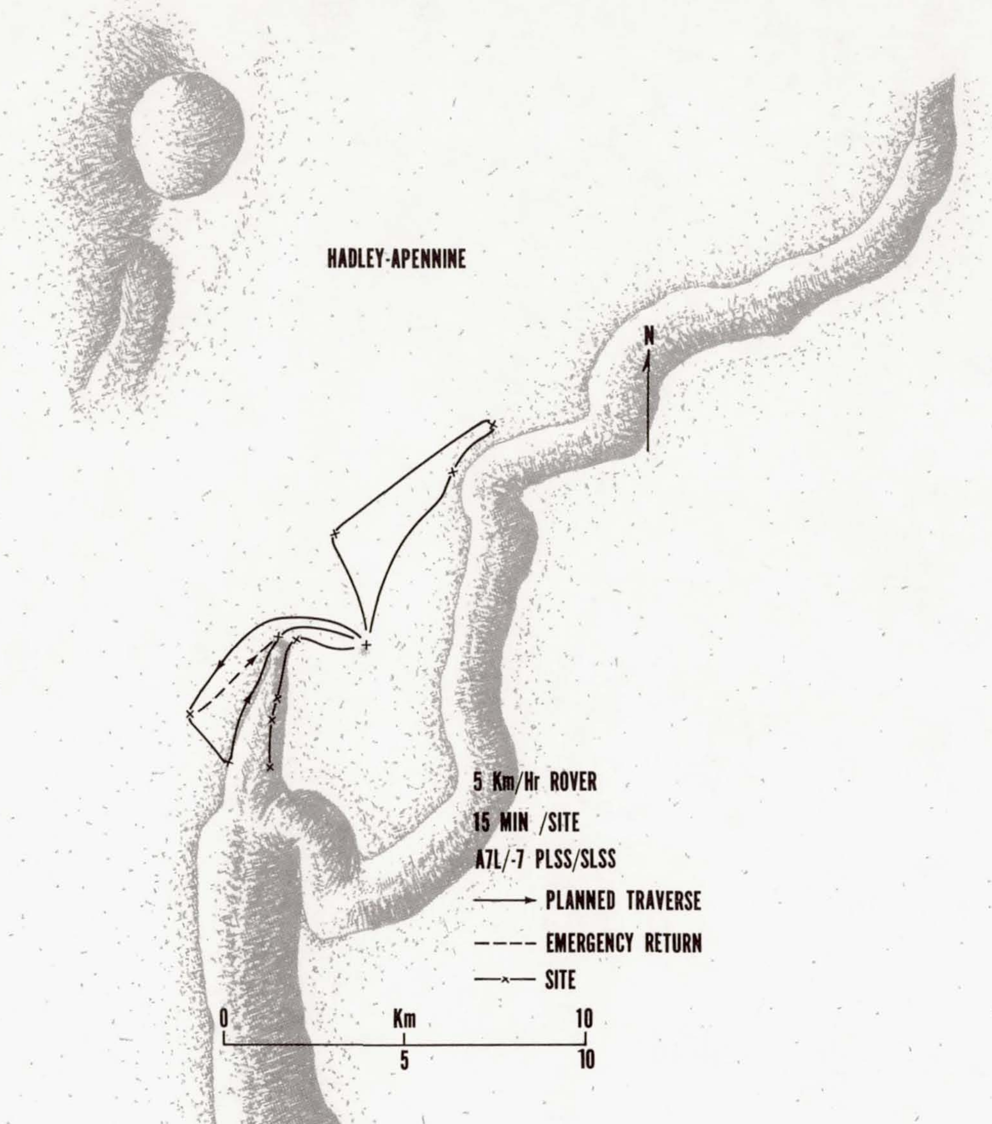


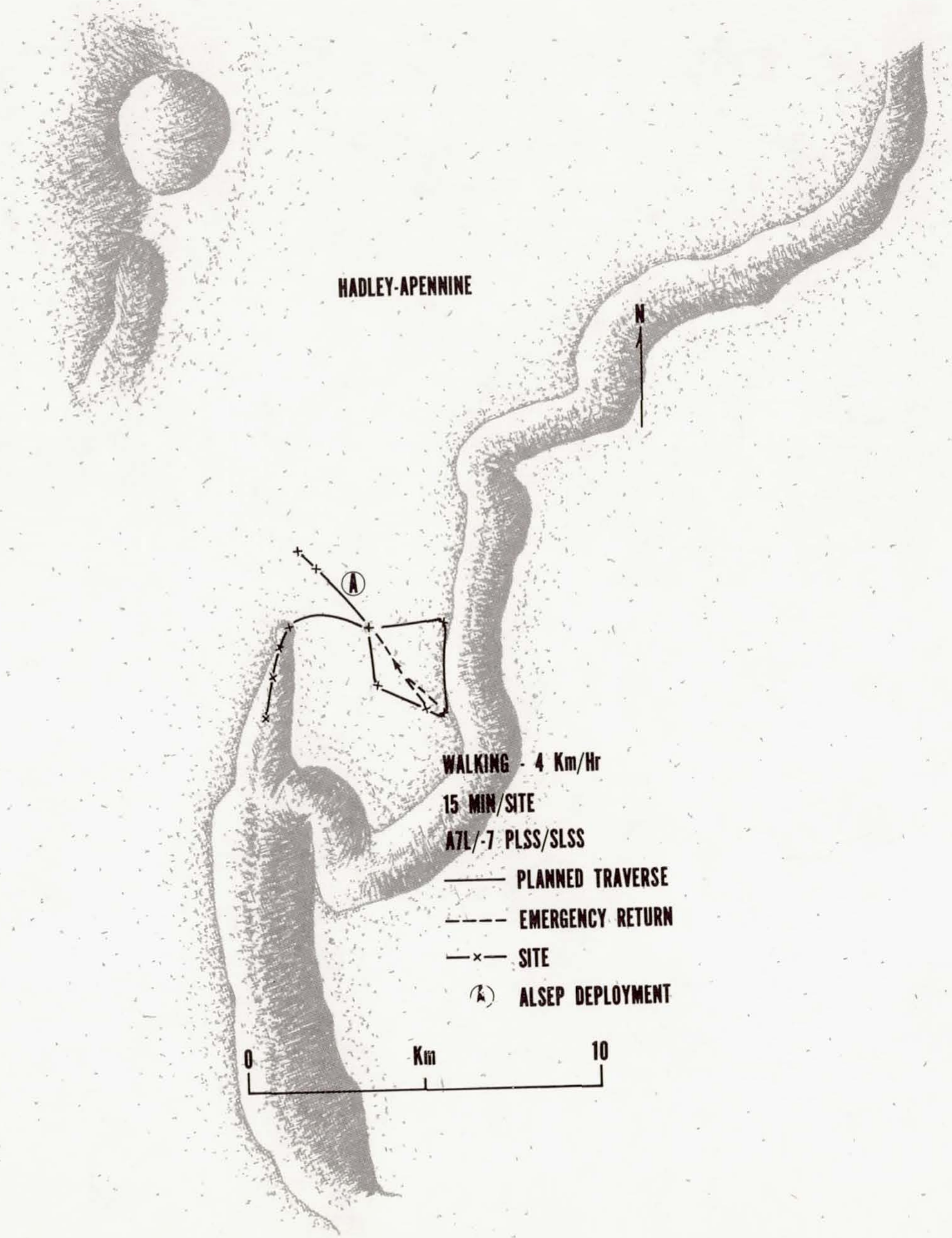
Appendix C

Hadley - Appennine Traverses


HADLEY-APENNINE
ORGINAL SCIENCE MISSION
N
15 Km
A
Km
0
5
10

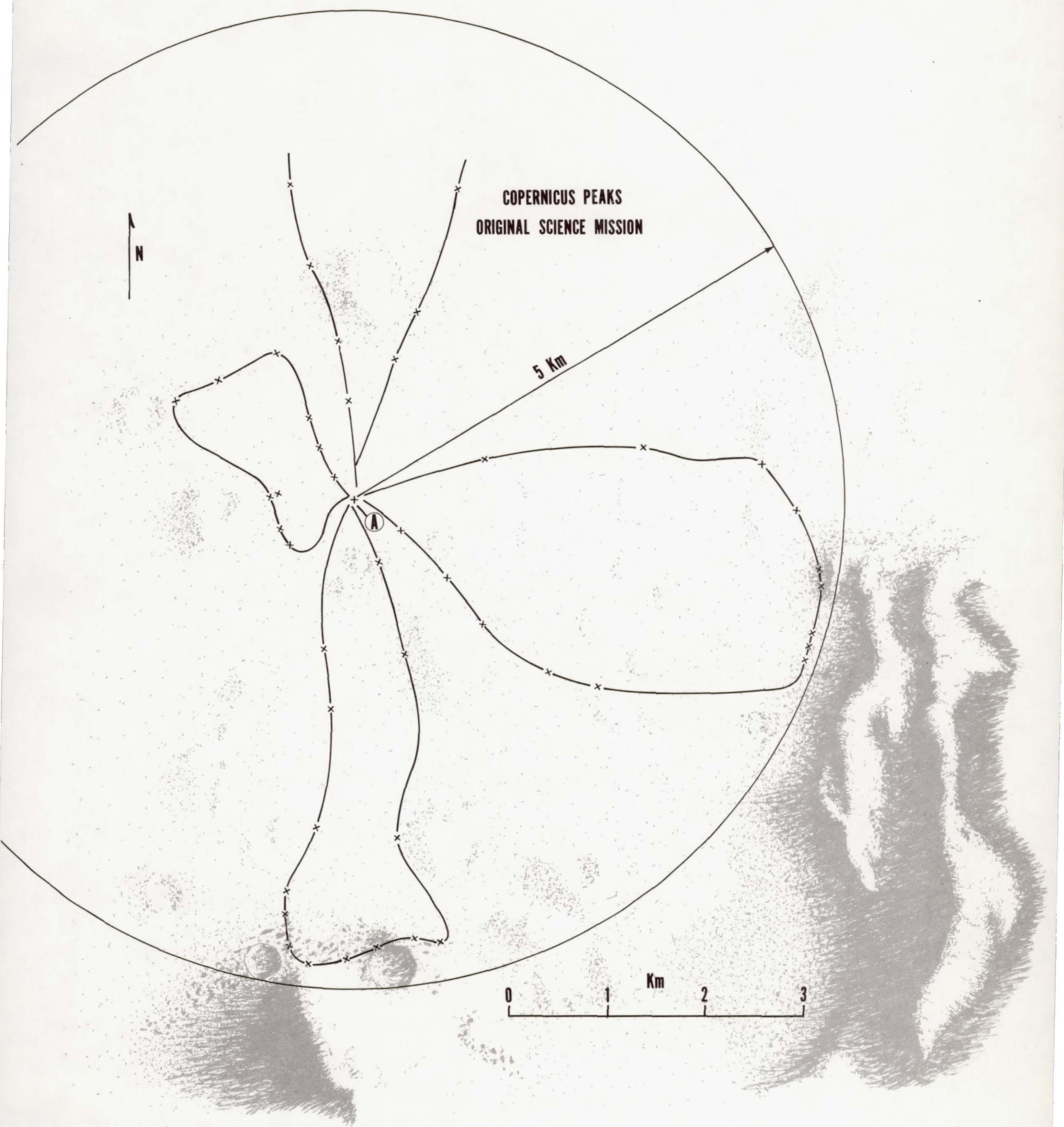

HADLEY-APENNINE
N
10 Km/Hr ROVER
15 MIN./SITE
A7L/-7 PLSS/SLSS
PLANNED TRAVERSE
EMERGENCY RETURN
SITE
0
Km
10


HADLEY-APENNINE
N
5 Km/Hr ROVER
15 MIN /SITE
A7L/-7 PLSS/SLSS
PLANNED TRAVERSE
EMERGENCY RETURN
SITE
0
Km
10
5
10

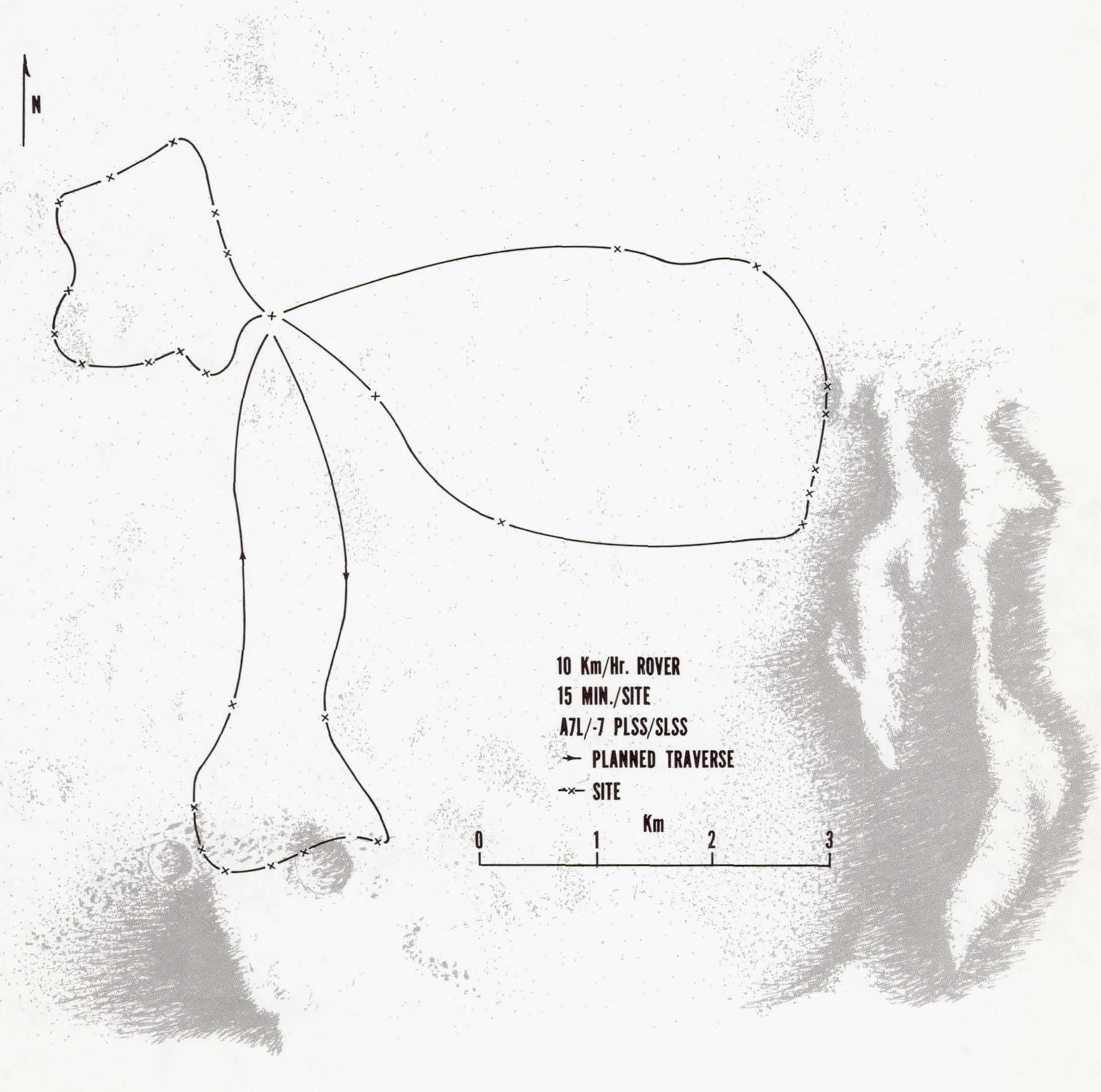

HADLEY-APENNINE
N
A
WALKING - 4 Km/Hr
15 MIN/SITE
A7L/-7 PLSS/SLSS
PLANNED TRAVERSE
EMERGENCY RETURN
SITE
ALSEP DEPLOYMENT
0
Km
10

Appendix D

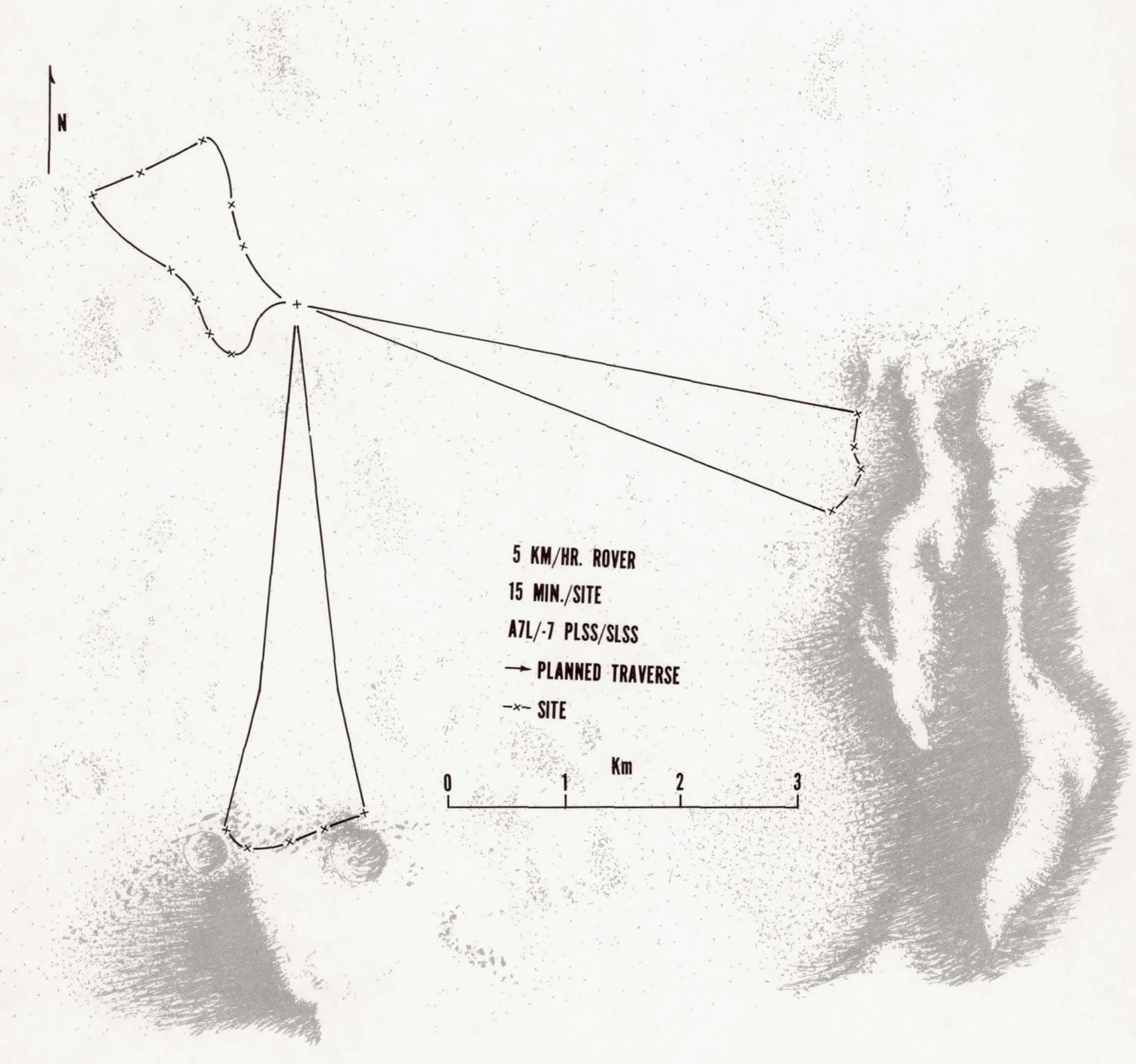
Copernicus Peaks Traverses


COPERNICUS PEAKS
ORIGINAL SCIENCE MISSION
N
5 Km
A
Km
0
1
2
3

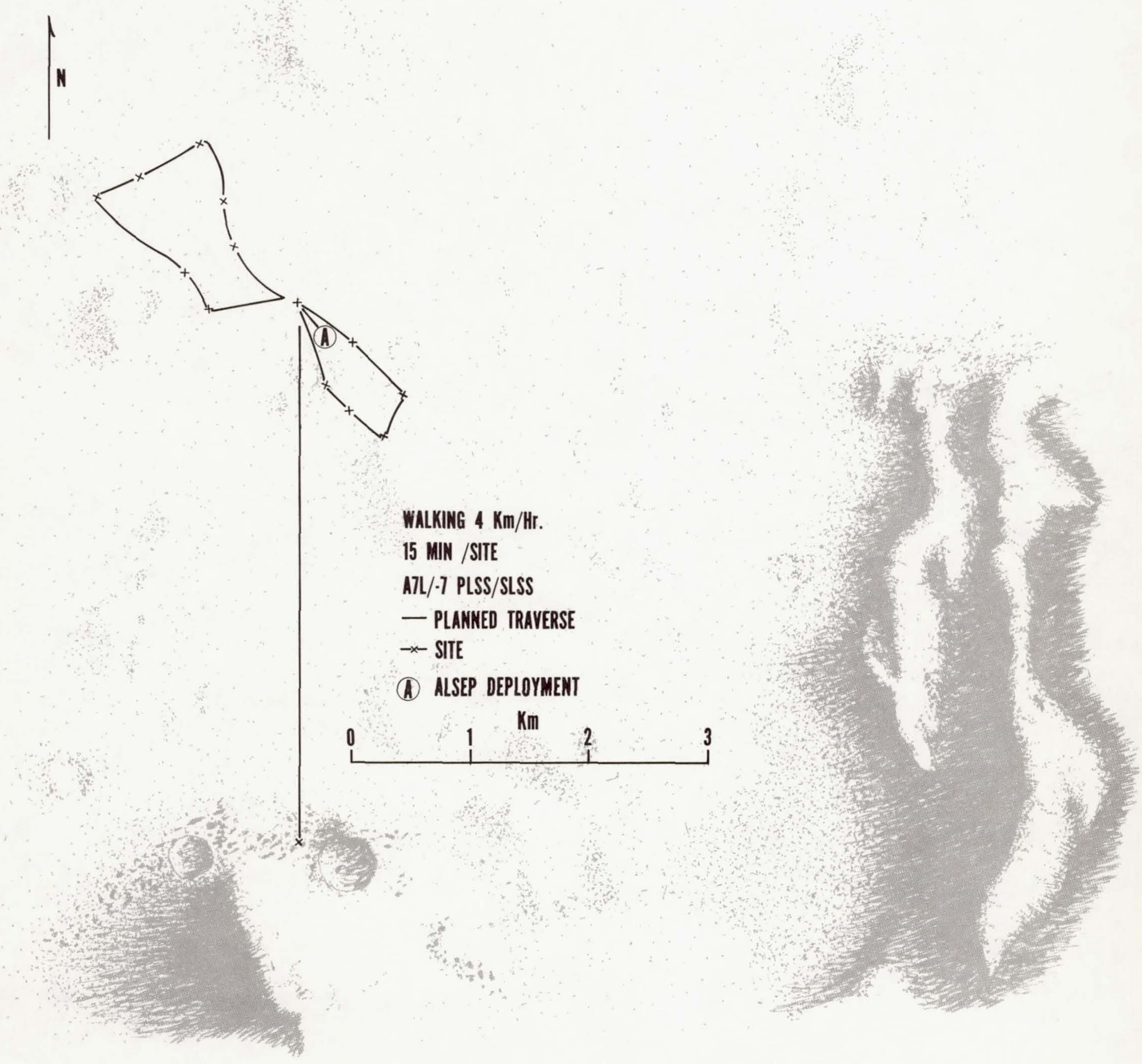
COPERNICUS PEAKS



COPERNICUS PEAKS



COPERNICUS PEAKS



BELLCOMM, INC.

DISTRIBUTION LIST

Complete Memorandum to

NASA Headquarters
R. J. Allenby/MAL
R. O. Aller/MAO
D. A. Beattie/MAL
M. Behun/MAT
F. B. Benjamin/MMR
H. S. Brownstein/MM
R. P. Bryson/MAL
G. P. Chandler/MAO
G. F. Esenwein/MAL
W. B. Evans/MLO
C. C. Gay/MAT
R. J. Green/MAL
J. B. Hanley/MAL
R. R. Hessberg/MMS
J. K. Holcomb/MAO
J. W. Humphreys/MM
T. A. Keegan/MA-2
C. H. King/MAT
L. J. Kosofsky/MAL
E. W. Land, Jr./MAO
C. M. Lee/MA
C. W. Mathews/MD
M. W. Molloy/MAL
B. Milwitzky/MAL
W. T. O'Bryant/MAL
R. A. Petrone/MA
A. F. Phillips, Jr./MAT-1
H. W. Randel/MM
F. I. Roberson/MAL
L. R. Scherer/MAL
R. D. Sheridan/MAO
J. B. Skaggs/MAP
J. D. Stevenson/MO
W. E. Stoney/MA
R. Toms/MAL
R. L. Wetherington/MAT-4
C. Wertz/MAL
G. C. White/MAR
S. P. Vinograd/MMR
NASA Hq. Library (USS-10)

Goddard Space Flight Center
D. J. Williams/612

Jet Propulsion Laboratory
R. G. Brereton/180-302
J. D. Burke/180-302
N. L. Nickle/183-501

Langley Research Center
G. P. Beasley/250
R. W. Stone/152

Manned Spacecraft Center
L. E. Bell/EC6
C. A. Berry/DA
J. Bilodeau/CF2
R. L. Bond/PD8
A. J. Calio/TA
A. B. Carraway/TD2
A. D. Catterson/DA
E. M. Crum/TE5
J. W. Dietrich/TH3
P. D. Gerke/TD3
H. R. Hair/DA
E. L. Hays/EC
J. D. Hodge/HA
Q. S. Holmes/FM5
W. J. Huffstetler/EC6
G. F. Humbert/DD5
C. Klabosh/CF32
R. H. Kohrs/PD7
C. C. Kraft/FA
H. A. Kuehnel/CF32
J. P. Loftus/HE
G. M. Low/PA
P. R. Maloney/TD4
O. E. Maynard/PD
J. A. McDivitt/PA
D. S. McKay/TH3
A. J. Meyer/HD
W. J. North/CF
J. W. O'Neill/CF34
D. B. Pendley/PA
C. H. Perrine/PD
E. B. Pippert/CF34
R. G. Rose/FA3
A. P. Sanders/HD
J. H. Sasser/TJ
H. H. Schmitt/CB
D. C. Schultz/CF25
J. R. Sevier/PD
D. K. Slayton/CA

DISTRIBUTION LIST (CONT'D.)

Complete Memorandum to

Manned Spacecraft Center (cont'd.)
R. E. Smylie/EC
H. W. Tindall/FM
C. A. Vaughan/EP4
L. C. Wade/TJ
J. M. West/AD
D. G. Wiseman/TD
C. H. Woodling/CF3
J. G. Zarcaro/PD
R. G. Zedekar/CF32

Marshall Space Flight Center
J. A. Belew/R-AS-ML
R. E. Godfrey/I-V-MGR
J. S. Hamilton/R-TEST-B
S. F. Morea/I-E-MGR
W. R. Perry/R-AS-ML
R. D. Stewart/I-S/AA
M. J. Vaccaro/R-P&VE-VA
O. H. Vaughn/R-AERO-Y

Boeing Aircraft Company/Houston
J. V. Powers/HA-58

California Institute of Technology
E. M. Shoemaker

Grumman Aircraft Engineering Company
E. Manaker

Lamont/Doherty Geological Observatory
P. Gast

Massachusetts Institute of Technology
M. G. Simmons

Smithsonian Astrophysical Observatory
C. Lundquist

Southwest Center for Advanced Studies
F. Johnson

Stanford University
R. L. Kovach
R. H. Jahns

TRW Systems, Inc.
D. T. Appleton
J. A. Herbaugh
L. E. Wood

University of California/Berkeley
A. L. Burlingame

University of California/San Diego
J. Arnold
H. C. Urey

University of Virginia
L. W. Frederick

U. S. Geological Survey/Flagstaff
A. H. Chidester
D. P. Elston
T. N. V. Karlstrom
H. Masursky
R. Regan
G. A. Swann
G. E. Ulrich

U. S. Geological Survey/Menlo Park
J. F. McCauley
N. J. Trask
D. E. Wilhelms

U. S. Geological Survey/Washington
A. L. Brokaw

Bellcomm, Inc.
D. R. Anselmo
A. P. Boysen, Jr.
J. O. Cappellari, Jr.
C. L. Davis
F. El-Baz
D. R. Hagner
W. G. Heffron
J. J. Hibbert
N. W. Hinners
T. B. Hoekstra
B. T. Howard
D. B. James

DISTRIBUTION LIST (CONT'D.)

Complete Memorandum to

Bellcomm, Inc. (cont'd.)
A. N. Kontaratos
M. Liwshitz
J. A. Llewellyn
H. S. London
D. Macchia
E. D. Marion
J. L. Marshall
K. E. Martersteck
R. K. McFarland
J. Z. Menard
B. G. Niedfeldt
J. J. O'Connor
G. T. Orrok
J. T. Raleigh
P. E. Reynolds
J. A. Saxton
P. F. Sennewald
J. A. Schelke
F. N. Schmidt
R. L. Seldon
L. D. Sortland
R. V. Sperry
A. W. Starkey
W. B. Thompson
J. W. Timko
A. R. Vernon
J. E. Volonte
R. L. Wagner
M. P. Wilson
D. B. Wood
All Members Department 2015
All Members Department 2032
Central Files
Department 1024 File
Library

Abstract Only to

Bellcomm, Inc.
I. M. Ross