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B70 01016

SUBJECT: LRV Design Evaluation Traverses - Cases 320 and 340

DATE: January 13, 1970

FROM: P. Benjamin
J. W. Head

MEMORANDUM FOR FILE

INTRODUCTION

In addition to designing the LRV for various individual worst-case conditions, it is necessary to exercise the design against a typical set of traverses to evaluate the interaction of multiple factors under reasonably realistic conditions. The traverses presented here, the result of a joint effort of W. R. Perry/MSFC, G. E. Ulrich/USGS, and the authors, are an attempt to meet that need.

Since the most detailed topographic and terrain information for a reasonably rugged site was available for the Fra Mauro Formation, three traverses were constructed from segments at this site. Each traverse was designed to match the terrain and topography of one of three specific J mission sites--Marius Hills, Copernicus Peaks, and Hadley-Apennines--and was constructed out of individual segments selected from disparate areas in the Fra Mauro Formation. The combined segments form traverses which are analogous to specific traverses in the three J mission sites.

The traverses as developed provide sampling stations and sampling times. These stations do not reflect a rational geologic sampling of the Fra Mauro Formation, but rather represent the sampling which would be done on the analogue traverse at the corresponding J mission site. The traverses are designed to exercise the LRV under relatively stringent conditions somewhat in excess of those expected on the actual missions. No attempt was made to introduce realistic operational constraints such as PLSS consumables limitations or emergency walkback requirements.

J MISSION TERRAIN ASSESSMENT

The three J mission landing sites were studied in order to gain an understanding of the types and distribution of terrain characteristic of lunar roving vehicle exploration sites. Geologic maps and photographs of the sites aided in

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ABSTRACT

A set of traverses was designed to permit LRV evaluation under conditions approximating those expected for the J missions. Three traverses, each designed to match the terrain and topography of one of three J mission sites--Marius Hills, Copernicus Peaks, and Hadley-Apennines--were constructed out of individual segments selected from disparate areas in the Fra Mauro Formation. The traverse segments were defined at the Fra Mauro Formation site because more detailed terrain and topological data is available for this site than at succeeding sites.

The sequences of representative terrain segments are designed as analogues of the J mission traverses and do not represent a rational geologic plan of exploration for the Fra Mauro Formation. They also do not include many of the operational constraints which would normally limit traverse design. Their only purpose is to provide a basis for evaluating the interaction of multiple factors on LRV capability for typical terrain and activity sequences.

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the terrain assessment. The types of terrain encountered at these sites were grouped into four categories--smooth mare, rough mare, hummocky uplands, and rough uplands--which had previously been established by R. J. Pike, et al of USGS. The characteristics of these four terrain types are outlined in References 1, 2, and 3. The geologic units at each site and the equivalent terrain types determined are summarized in Table 1.

BASE MAP OF THE FRA MAURO FORMATION

A topographic photomap of a portion of the Fra Mauro Formation, including the Apollo 13 landing target, is shown in Figure 1. The inserted rectangle indicates the topographic base map, shown in Figure 2, constructed by the Mapping Sciences Branch of MSC and used in this study. This is the only existing topographic map of a lunar site which might simulate characteristic J mission landing site terrain to a sufficient degree of detail for LRV analysis. In order to compare the terrain on the Fra Mauro Formation topographic base map to characteristic J mission terrain types, a slope overlay for the topographic map was prepared by George Ulrich/USGS, and is illustrated in Figure 3.

The topography illustrated in Figure 2 and the slope distribution shown on Figure 3 were compared to the J mission terrain types, and terrain equivalents for all candidate J mission site terrain types were devised. Table 2 indicates the Fra Mauro Formation slope map equivalents to the four broad J mission terrain types defined above. The smooth mare category is equivalent to map terrain 1 (<5°) in Figure 2. The rough mare category is composed dominantly of map terrain 1 (<5°) with portions of map terrain 2 (6-10°), and the hummocky uplands category is characterized by combinations of map terrain 2 and 3. The rough uplands category is dominantly map terrain 3 (11-20°) with portions of map terrain 4 (>20°) and map terrain 2 (6-10°). Additional data on the characteristics of each terrain type, such as slope cumulative frequency distribution, typical crater cumulative frequency distribution, block size frequency distribution, and power spectral density terrain roughness estimates should be taken into consideration in LRV capability analysis, and are outlined in References 1 and 3.

REPRESENTATIVE TRAVERSE SEGMENTS

A series of representative traverse segments of varying lengths and orientations were then plotted on the Fra Mauro Formation topographic base map (Figure 2) for each

terrain type. These traverse segments in no way represent a rational geologic exploration of the Fra Mauro Formation site, but instead simulate topographic features and terrain types seen on representative J mission traverses.

Traverse segments were oriented with respect to the surrounding terrain and geographic coordinates in an attempt to approximate the characteristics seen at J mission sites. For instance, traverse segment No. 2 is oriented along the edge of a topographic prominence although it lies in smooth mare terrain. This is analogous to areas at Marius Hills where smooth mare terrain will be traversed along the base of punctured cones and steep-sided domes.

Individual traverse segments were plotted which attempted to duplicate terrain characteristic of a specific site. For instance, segments No. 26, 27, and 28 are analogous to segments at the central peaks of Copernicus. Segments No. 19, 20, and 23 are designed to simulate traverse segments in and around Hadley Rille. Segments No. 21 and 22 simulate the elevation and steep slopes encountered on punctured cones and similar units at the Marius Hills site. Other segments attempt to duplicate the diverse terrain seen at the various landing sites.

Certain traverse segments carry notations to account for exceptions and extreme conditions so that these may be considered in the design reference traverses:

1. Since the type of traverse seen in segments No. 1 and 2 may be carried out both on sun and shadow sides of topographic prominences, these segments should be run with the sun angle oriented on both sides.

2. Traverse segment No. 8 should be run in both directions.

3. Rather extreme topographic and lighting conditions exist at Hadley Rille. In addition to the steep slopes along the rille wall (17°), the floor of the rille is littered with large boulders. Anomalous thermal conditions may result if the bottom of the rille is in full sun or full shadow, or if one side of the rille is in full sun while the other is in full shadow. For these reasons, traverse segments No. 20 and 23 should be run under all three lighting conditions, and the PSD for rough uplands[1] should be utilized.

4. Since the area in the vicinity of the central peaks of Copernicus is in at least partial shadow, traverses segments No. 26, 27, and 28 should be run in both full sun and full shadow.

Sampling stations were plotted on these traverse segments at intervals generally coincident with probable station spacing on equivalent J mission terrain. These stations bear no intentional relation to the geology of the Fra Mauro Formation.

REPRESENTATIVE ANALOGUE TRAVERSES

In order to combine the traverse segments into representative traverses, it was necessary first to design traverses at the three J mission sites. One traverse per site, each resulting in an analogue traverse approximately 20 km long, was designed by joining portions of the scientific reference traverses for these sites described in Reference 4. The traverses were then broken into sections according to terrain types. Matching segments for each terrain type and length were then located on the Fra Mauro Formation topographic map and an analogue traverse was constructed by combining these segments into sequences.

Stop times were then assigned to the stations designated for each segment. It was assumed that the stations were at the actual site, rather than the Fra Mauro Formation, and times were chosen to represent typical activities at the J mission site. They have meaning, thus, only in the J mission site context and do not reflect reasonable Fra Mauro Formation geologic activities. If, when two segments were joined, two stations were superimposed, the time at the second station (later segment) was arbitrarily set to zero. Station times of less than 5 minutes assumed no LRV egress.

Figure 4 shows the Marius Hills traverse which was selected. It begins by following the western reference traverse,[4] departs from it by following the narrow ridge, breaks across the plateau plain, and joins the southern traverse over a steep sided dome back to the LM. The corresponding Fra Mauro Formation traverse segments are marked on the map in Figure 4 and are described in more detail in Table 3. For each segment, the geologic unit at Marius Hills is identified and the corresponding terrain type designated. The segment shown matches that terrain class. The Fra Mauro Formation map length of each segment was measured and the real length calculated using a correction factor based on average slope,

crater distribution, and block distribution. Segment 2 should be exercised in full sunlight with reflection from the hill and in full shadow. The station times for the analogue traverse are shown in Table 4. The longer station times in segment 12 reflect interest in the bulbous domes and narrow ridge, rather than Fra Mauro Formation geology, and the times in segments 25 and 21 are based upon interest in steep sided domes and puncture cones.

The Copernicus Peaks traverse shown in Figure 5 exactly matches the southern reference traverse from Reference 4. The traverse segments are shown and described in more detail in Table 5. Segments 26, 27, and 28 should be exercised by the LRV in full sunlight with sun reflecting from the peaks, and in full shadow. Segment 16 is shown as a hill at Copernicus Peaks and as craters in the Fra Mauro Formation. Therefore, the Fra Mauro Formation topography should be inverted for this segment. Station times are shown in Table 6 and the long times indicated for stations in segments 26, 27, and 28 reflect intensive investigation of the central peak. It is again important that the extended times in these segments be analyzed for both extreme lighting conditions.

The Hadley-Apennines traverse shown in Figure 6 differs from those previously planned in that the LRV descends directly down the side of Hadley Rille rather than gaining entry by the less steep elongate depression. The segments used are described in Table 7. Segments 23, 20, and 19 should be exercised in full sunlight, in full shadow, and for sunlight on one wall and shadow on the other wall of the rille. Any of these conditions could be expected--or planned for--in the traverse into Hadley Rille. The PSD data for these segments should also be modified as indicated previously. The station times indicated in Table 8 reflect the extensive study and sampling to be undertaken in the rille.

SUMMARY

These traverses are designed specifically to exercise the LRV under somewhat exaggerated, although reasonably realistic conditions. The purpose is to evaluate the interaction of multiple factors for typical terrain and activity sequences. The traverses do not necessarily represent actual geologic activities and do not include many of the operational constraints which would normally limit traverse design. The Fra Mauro Formation site was chosen as a test ground only because of the availability of detailed terrain and topological data. Although this proved to be similar to J mission sites, it bears little, if any, geological similarity.

It is assumed that all traverses will be exercised in both directions in order to expose possible marginal LRV operation or to indicate areas of caution for further examination. Extremes of lighting and terrain conditions have been indicated wherever these might occur in order to evaluate possible detrimental effects. Because these are not the actual planned traverses, failure of the LRV to complete any particular traverse should not indicate a requirement for LRV modification. Rather, it shows a necessity for re-evaluation to determine whether hardware redesign is required or operational constraints on traverse design will suffice. Certainly, exposing these possible operational constraints should be a prime result of this study.

Peter Benjamin
P. Benjamin

James W. Head
J. W. Head

2032-PB
2015-JWH-mp

Attachments
Tables 1-8
Figures 1-6

References

1. H. J. Moore, R. J. Pike, and G. E. Ulrich, "Lunar Terrain and Traverse Data for Lunar Roving Vehicle Design Study," Branch of Astrogeology, U.S.G.S. (Unpublished Manuscript).

2. "Lunar Surface Models," National Aeronautics and Space Administration SP-8023, May, 1969, 55 p.

3. "Natural Environmental Design Criteria Guidelines for use in the Design of Lunar Exploration Vehicles," NASA Marshall Space Flight Center, Alabama (Unpublished Manuscript).

4. P. Benjamin, T. A. Bottomley, J. W. Head, and M. T. Yates, "Evaluation of Mobility Modes on Lunar Exploration Traverses: Marius Hills, Copernicus Peaks, and Hadley-Apennines Missions," Bellcomm Technical Report, TR-69-340-4, November 14, 1969.

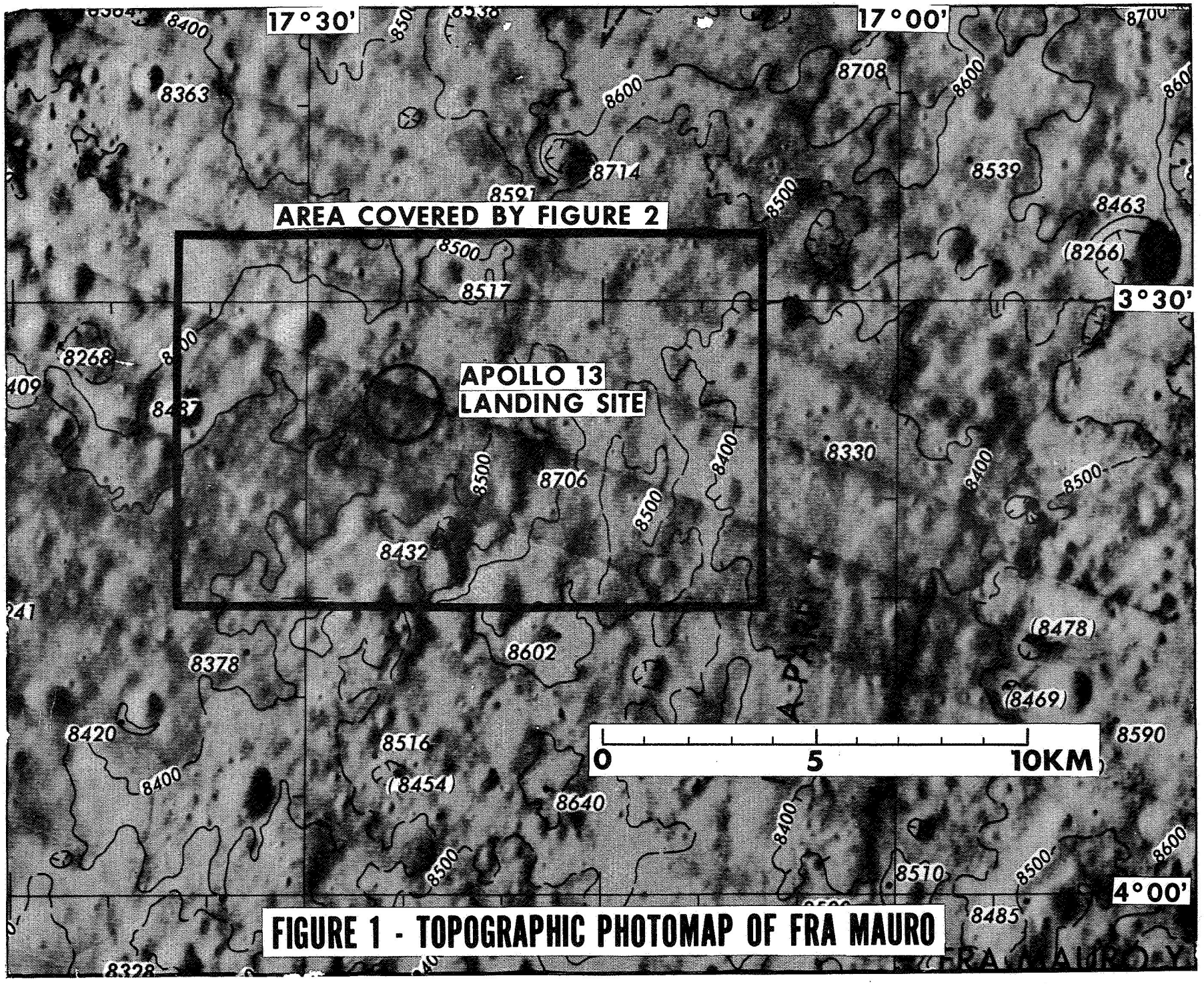

FIGURE 1 - TOPOGRAPHIC PHOTOMAP OF FRA MAURO

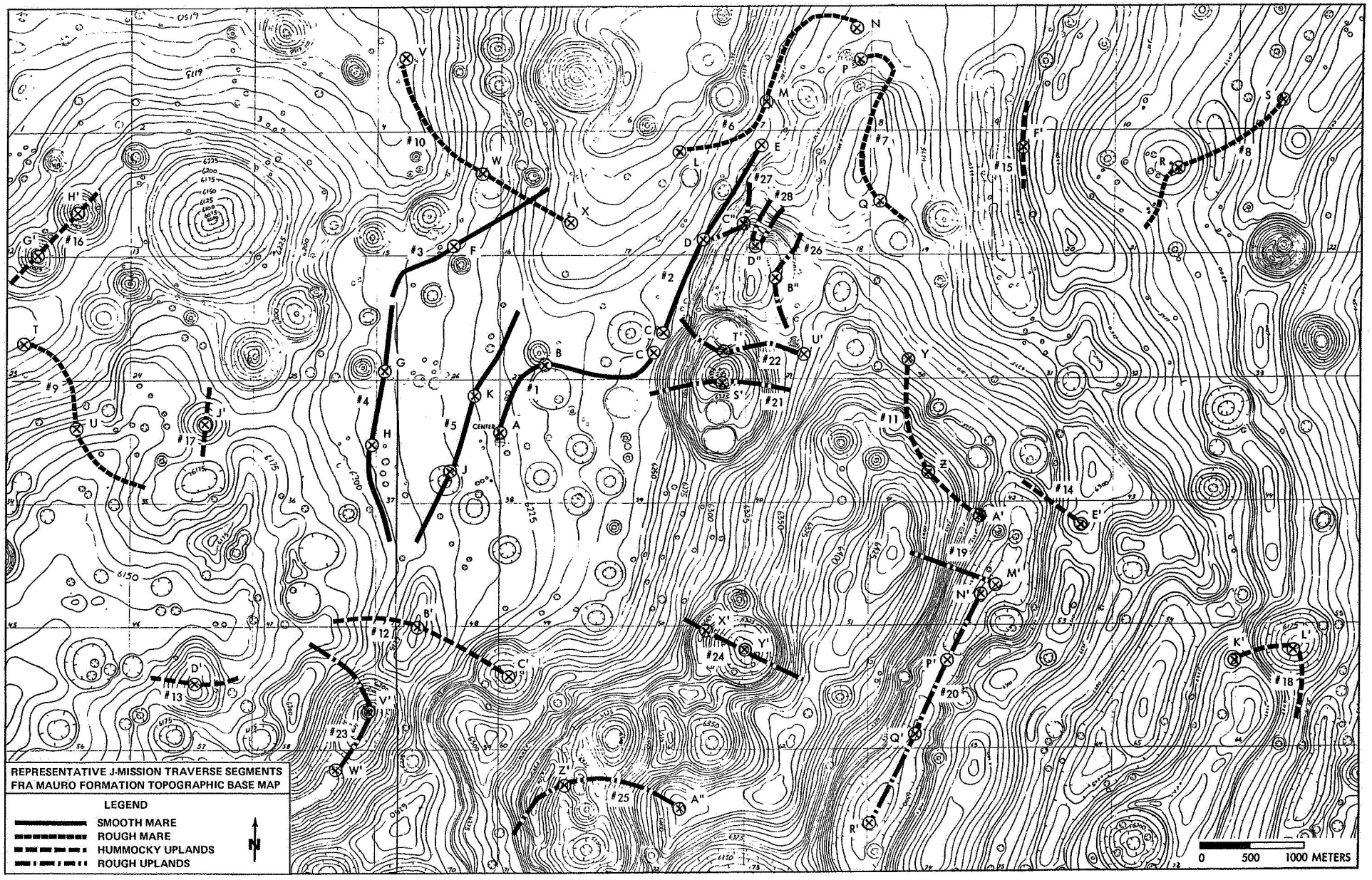

FIGURE 2

FOLDOUT FRAME 1

FOLDOUT FRAME 2

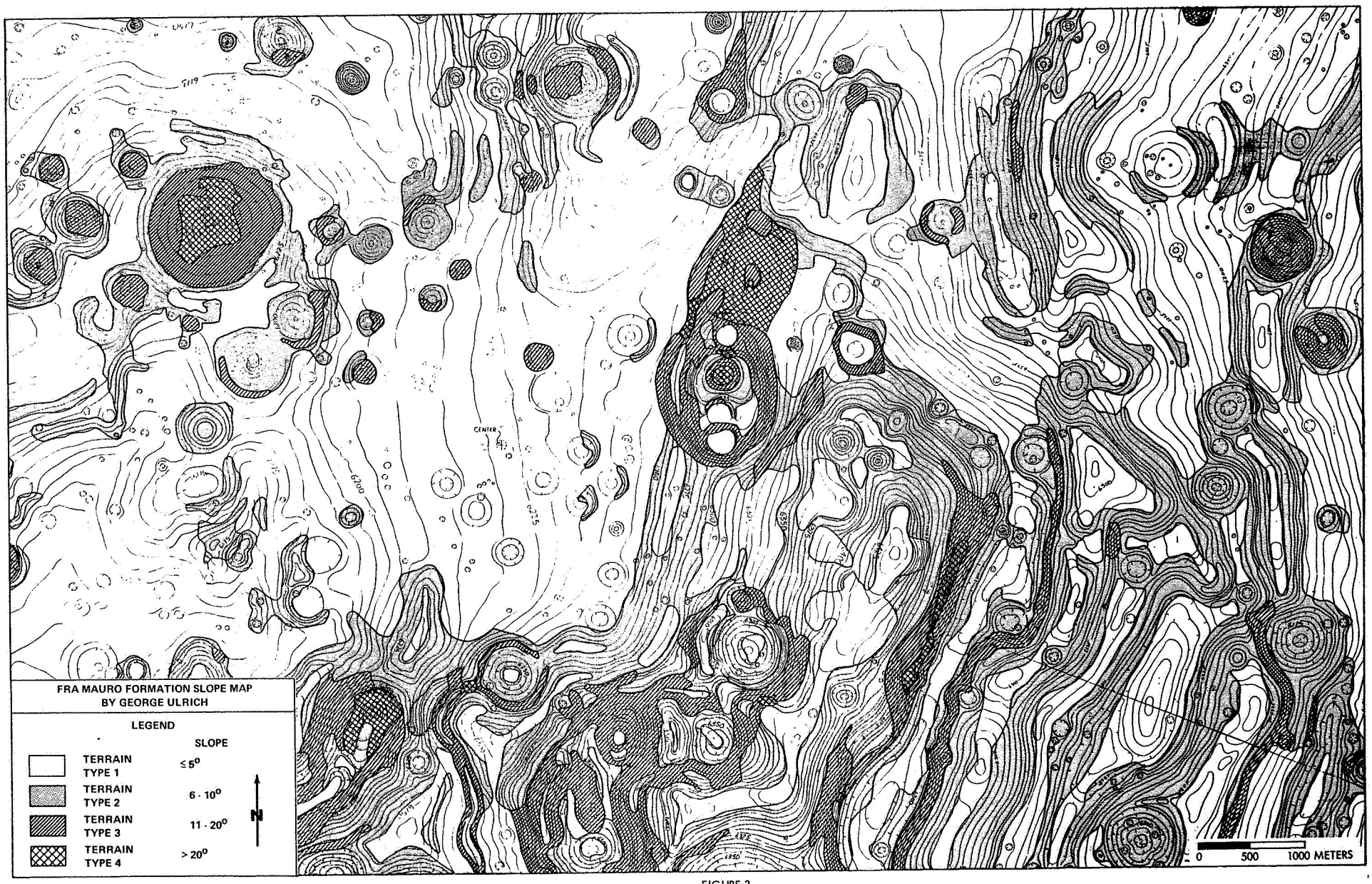

FIGURE 3

FOLDOUT FRAME 1

FOLDOUT FRAME 2

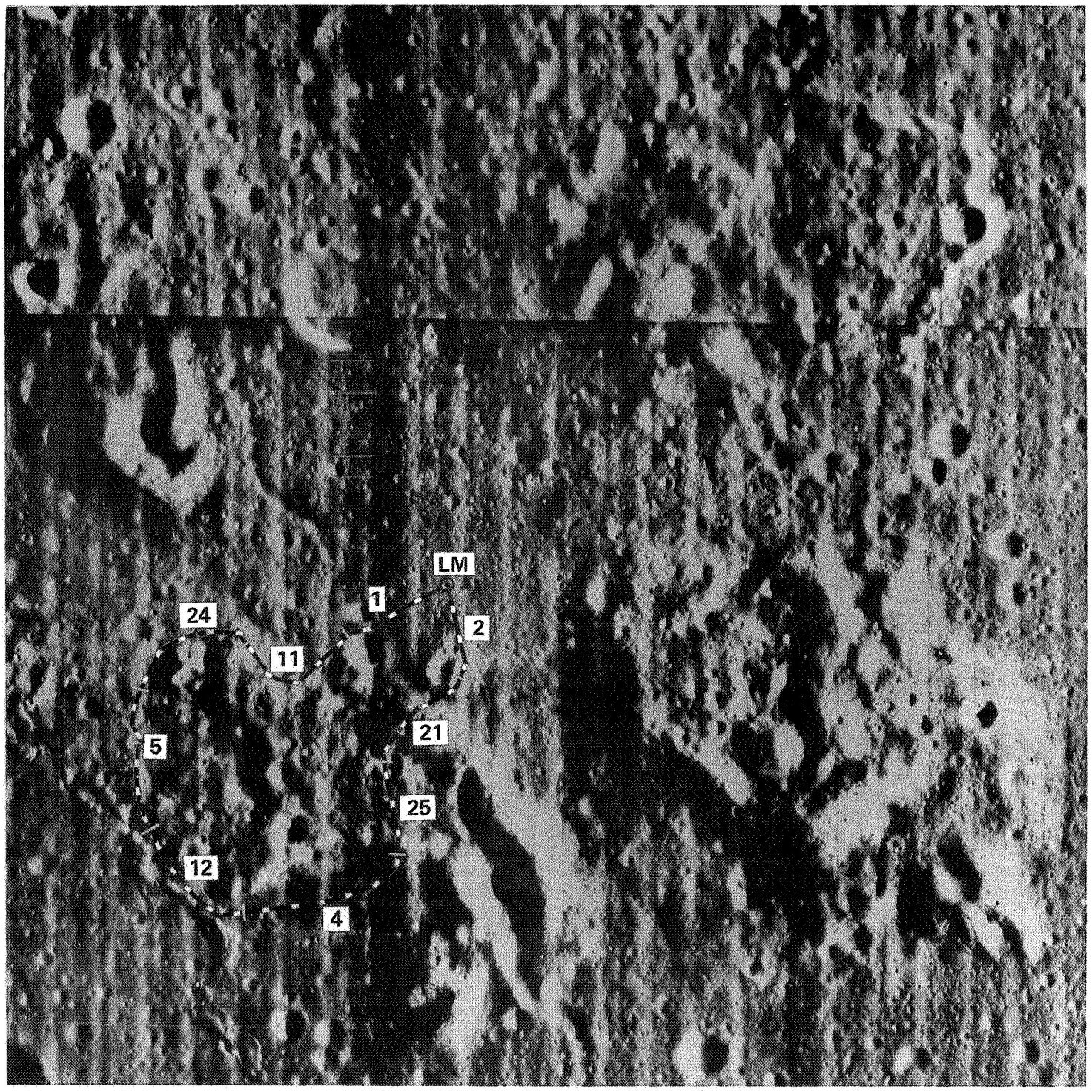

FIGURE 4 - MARIUS HILLS LRV TEST TRAVERSE

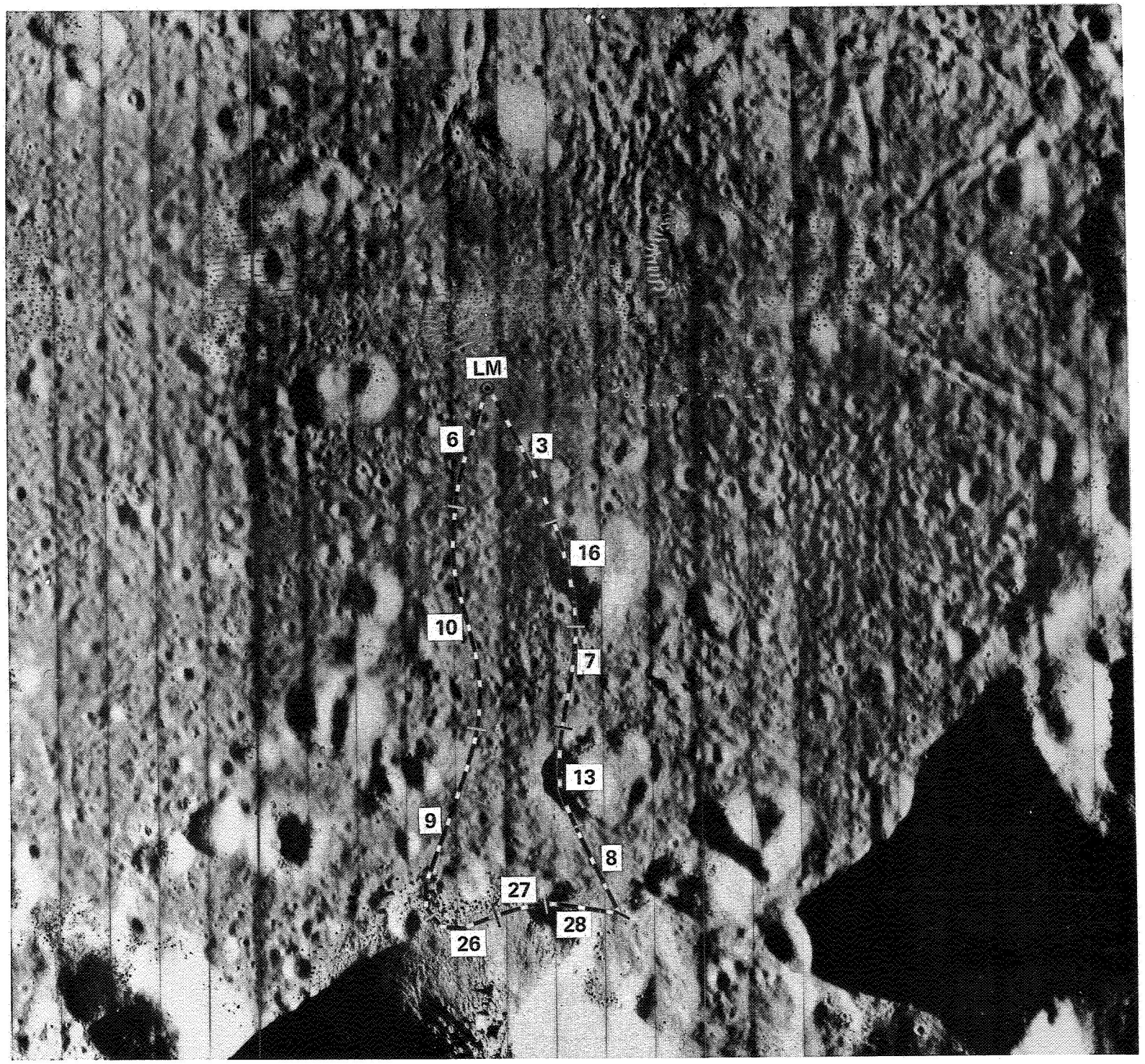

FIGURE 5 - COPERNICUS PEAKS LRV TEST TRAVERSE

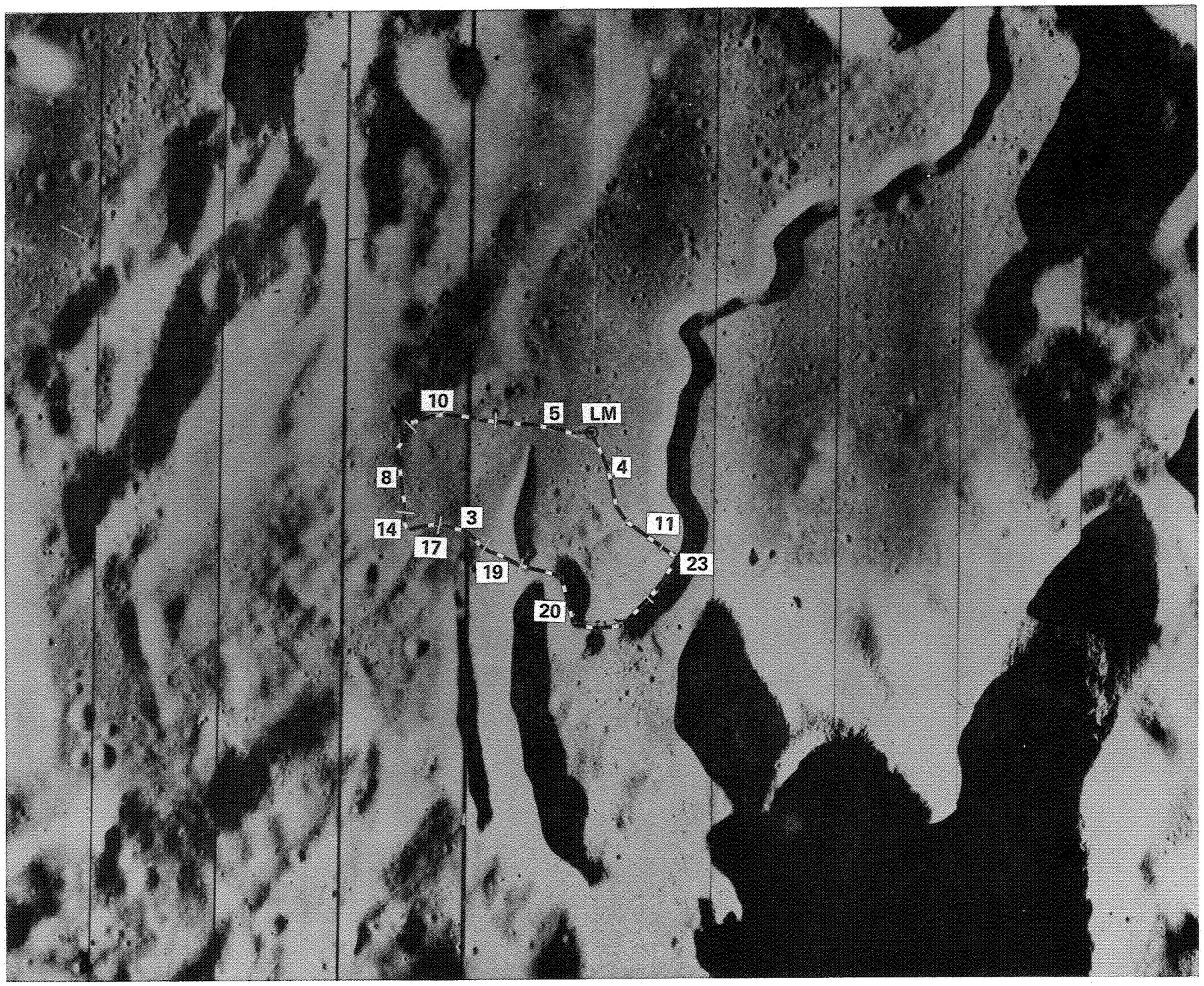

FIGURE 6 - HADLEY-APENNINES LRV TEST TRAVERSE

TABLE 1

TERRAIN TYPES

SITE	GEOLOGIC UNIT	TERRAIN TYPE
MARIUS HILLS	PLATEAU PLAINS	SMOOTH MARE
	SMOOTH LOW DOMES	HUMMOCKY UPLANDS
	BULBOUS DOMES	
	NARROW RIDGE MATERIAL	
	DEPRESSIONS	
	STEEP SIDED DOMES	ROUGH UPLANDS
	PUNCTURED CONES	
COPERNICUS PEAKS	FLOOR MATERIAL, SMOOTH	SMOOTH MARE
	FLOOR MATERIAL, TEXTURED	ROUGH MARE
	HILLS AND HUMMOCKS	HUMMOCKY UPLAND
	CENTRAL PEAKS	ROUGH UPLAND
HADLEY-APENNINES	MARE MATERIAL	SMOOTH MARE
	PITTED PLAINS	ROUGH MARE
	APENNINE BENCH	
	FURROWED PLAINS	HUMMOCKY UPLANDS
	SUBDUED RIDGE	
	DOMICAL HILLS	
	HADLEY RILLE	ROUGH UPLAND
	ELONGATE DEPRESSION	
	APENNINE RIDGE	

TABLE 2

TERRAIN TYPE EQUIVALENTS FOR
FRA MAURO SLOPE BASE MAP

TERRAIN TYPE	EQUIVALENT MAP TERRAIN
SMOOTH MARE	MAP TERRAIN 1 (<5°)
ROUGH MARE	DOMINANTLY MAP TERRAIN 1 (<5°) WITH PORTIONS OF MAP TERRAIN 2 (6-10°)
HUMMOCKY UPLANDS	COMBINATIONS OF MAP TERRAIN 2 AND 3 (11-20°)
ROUGH UPLANDS	DOMINANTLY MAP TERRAIN 3 (11-20°) WITH SOME MAP TERRAIN 4 (>20°) AND SOME MAP TERRAIN 2 (6-10°)

TABLE 3

ANALOGUE MARIUS HILLS TRAVERSE

SEGMENT	UNIT/TERRAIN*	MAP LENGTH	REAL LENGTH (KM)	REAL LENGTH SUM (KM)
1	PP/SM	1.9	2.2	2.2
11	LD/HU	1.8	2.2	4.4
24	BD-PC/RU	1.4	1.6	6.0
5	PP/SM	2.4	2.8	8.8
12	NR-BD/HU	1.9	2.3	11.1
4	PP/SM	2.3	2.7	13.8
25	SD/RU	1.8	2.0	15.8
21	SD-PC/RU	1.4	1.6	17.4
2	PP/SM	2.3	2.7	20.1

* GEOLOGIC UNITS:

PP = PLATEAU PLAINS

LD = LOW SMOOTH DOMES

BD = BULBOUS DOMES

PC = PUNCTURED CONES

NR = NARROW RIDGE MATERIAL

SD = STEEP SIDED DOMES

TERRAIN TYPES:

SM = SMOOTH MARE

HU HUMMOCKY UPLANDS

RU = ROUGH UPLANDS

TABLE 4

ANALOGUE MARIUS HILLS TRAVERSE STATIONS

SEGMENT	UNIT	STATION	TIME (MIN)	CUMULATIVE TIME
1	PP	A	0.0	0:00
	PP	B	2.0	0:02
	PP-SD	C	10.0	0:12
11	LD	Y	0.0	0:12
	LD	Z	5.0	0:17
	LD	A'	2.0	0:19
24	BD-PC	X'	10.0	0:29
	BD-PC	Y'	5.0	0:34
5	PP	J	2.0	0:36
	PP	K	1.0	0:37
12	NR-BD	B'	20.0	0:57
	NR-BD	C'	10.0	1:07
4	PP	G	5.0	1:12
	PP	H	2.0	1:14
25	SD	Z'	15.0	1:29
	SD	A"	20.0	1:49
21	SD-PC	S'	20.0	2:09
2	PP	C	0.0	2:09
	PP	D	10.0	2:19
	PP	E	0.0	2:19

TABLE 5

ANALOGUE COPERNICUS PEAKS TRAVERSE

SEGMENT	UNIT/TERRAIN*	MAP LENGTH	REAL LENGTH (KM)	REAL LENGTH SUM (KM)
6	TF/RM	2.3	2.7	2.7
10	TF/RM	2.4	2.8	5.5
9	TF/RM	1.9	2.2	7.9
26	CP/RU	1.0	1.1	9.0
27	CP/RU	0.7	0.8	9.8
28	CP/RU	0.8	0.9	10.7
8	TF/RM	1.8	2.2	12.9
13	H/HU	0.8	1.0	13.9
7	TF/RM	2.0	2.3	16.2
16**	H/HU	1.2	1.5	17.7
3	SF/SM	1.8	2.0	19.7

*GEOLOGIC UNITS:

TF = TEXTURED FLOOR MATERIAL

CP = CENTRAL PEAK MATERIAL

H = HILLS AND HUMMOCKS

SF = SMOOTH FLOOR MATERIAL

TERRAIN TYPES:

SM = SMOOTH MARE

RM = ROUGH MARE

HU = HUMMOCKY UPLANDS

RU = ROUGH UPLANDS

**INVERT TOPOGRAPHY

TABLE 6

ANALOGUE COPERNICUS PEAKS TRAVERSE STATIONS

SEGMENT	UNIT	STATION	TIME (MIN)	CUMULATIVE TIME
6	TF	L	0.0	0:00
	TF	M	5.0	0:05
	TF	N	0.0	0:05
10	TF	V	0.0	0:05
	TF	W	5.0	0:10
	TF	X	0.0	0:10
9	TF	T	0.0	0:10
	TF	U	5.0	0:15
26	CP	B"	30.0	0:45
27	CP	C"	45.0	1:30
28	CP	D"	30.0	2:00
8	TF	R	20.0	2:20
	TF	S	0.0	2:20
13	H	D'	10.0	2:30
7	TF	P	0.0	2:30
	TF	Q	2.0	2:32
16	H	G'	10.0	2:42
	H	H'	15.0	2:57
3	SF	F	3.0	3:00

TABLE 7

ANALOGUE HADLEY-APENNINE TRAVERSE

SEGMENT	UNIT/TERRAIN*	MAP LENGTH (KM)	REAL LENGTH (KM)	REAL LENGTH SUM (KM)
4	IM/SM	2.7	2.7	2.3
18	DH/HU	1.7	4.4	1.4
23	JR/RU	1.4	5.8	1.2
20	SR/RU	2.8	8.6	2.5
19	ED/RU	1.1	9.7	1.0
3	SP/SM	2.0	11.7	1.8
17	FP/HU	0.8	12.5	0.7
14	FP/HU	0.8	13.3	0.7
8	PP/RM	2.2	15.5	1.8
10	AB/RM	2.8	18.3	2.4
5	IM/SM	2.8	21.1	2.4

*GEOLOGIC UNITS:

IM = IMBRIAN MARE MATERIAL

DH = DOMICAL HILL MATERIAL

SR = SINUOUS RILLE MATERIAL

ED = ELONGATE DEPRESSION MATERIAL

SP = SMOOTH PLAINS MATERIAL

FP = FURROWED PLAINS MATERIAL

PP = PITTED PLAINS MATERIAL

AB = APENNINE BENCH MATERIAL

TERRAIN TYPES:

SM = SMOOTH MARE

RM = ROUGH MARE

HU = HUMMOCKY UPLANDS

RU = ROUGH UPLANDS

TABLE 8

ANALOGUE HADLEY-APENNINE TRAVERSE STATIONS

SEGMENT	UNIT	STATION	TIME (MIN)	CUMULATIVE TIME
4	IM	G	5.0	0:05
		H	5.0	0:10
18	DH	K'	10.0	0:20
		L'	10.0	0:30
23	SR	V'	30.0	1:00
		W'	5.0	1:05
20	SR	N'	5.0	1:10
		P'	20.0	1:30
		Q'	5.0	1:35
		R'	30.0	2:05
19	ED	M'	0.0	2:05
3	SP	F	5.0	2:10
17	FP	J'	5.0	2:15
14	FP	E'	15.0	2:30
8	PP	S	0.0	2:30
		R	5.0	2:35
10	PP-AB	V	10.0	2:45
		W	10.0	2:55
		X	2.0	2:57
5	IM	J	3.0	3:00
		K	0.0	3:00

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Subject: LRV Design Evaluation Traverses - Cases 320 and 340

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