[redacted]

FACILITY FORM 602

2	
(ACCESSION NUMBER)	(THRU)
19	/
(PAGES)	(CODE)
CR 84125	31
(NASA CR OR TMX OR AD NUMBER)	(CATEGORY)

JET PROPULSION LABORATORY

CALIFORNIA INSTITUTE OF TECHNOLOGY

PASADENA, CALIFORNIA

THE SCIENTIFIC UTILITY OF UNMANNED LUNAR SURFACE ANALYSIS PROBES

March 1967

APPROVED BY: P. N. Haurlan

P. N. Haurlan
Manager, Future Projects

J. A. Dunne
Senior Scientist
Planetology Group

JET PROPULSION LABORATORY
CALIFORNIA INSTITUTE OF TECHNOLOGY
PASADENA, CALIFORNIA

FOREWORD

This paper describes one phase of a study conducted at the Jet Propulsion Laboratory (JPL). The information given herein is the result of a brief, preliminary study: Therefore, it should be used only for general planning purposes and not for situations in which JPL sanction is required.

SECTION I

NEED FOR UNMANNED PROBES

1.1 GENERAL

In terms of scientific utility, the unmanned surface probe has been proven by Ranger, Surveyor, and Luna spacecraft. Besides surface information, Ranger and Surveyor have given us valuable landing site data for initial Apollo manned landings.

The question of the scientific utility of unmanned probes has been discussed in detail by Speed, Adams, and Nash (Ref. 1). This Section will summarize, in part, the philosophy developed by them and present reasons for inclusion of unmanned surface-contacting probes in the scientific exploration of the moon.

1.2 GEOLOGICAL INVESTIGATIONS

Of fifteen questions posed by the Space Science Board of the National Academy of Sciences concerning the moon, several require geological investigation of the surface. Included in this category are:

1) Tectonic activity
2) Erosion and transport
3) Average surface composition and compositional variations
4) Absolute and relative ages of surface units
5) Relief-forming processes
6) Thermal history

All of the above questions are important for an understanding of the nature of the moon and its evolution. They involve an assessment of the relative effectiveness of internal and external forces on lunar evolutionary processes: They ask to what extent internal activity has shaped the face of the moon as opposed to external agents, such as impact processes and gravitational interaction with the earth. The answers to these questions lie in understanding the lithology, stratigraphic sequence, and structural relationships between surface rocks - this will provide the necessary geological information from which interpretations of origin and emplacement can be derived.

1.3 GEOLOGIC RECONNAISSANCE

Characterization of major surface lithologic units, which provides a portion of the necessary geological information described in the preceding subsection 1.2, is a fundamental requirement for the construction of geologic maps. Gross characterization of surface lithology, which can be performed by LSP's or similar unmanned surface analysis probes, should be accomplished in combination with measurements acquired from lunar orbit, since there are specific correlations between orbital and surface measurements (e.g. radar, infrared, ultraviolet, and X-ray sensing).

Measurements made from an orbiter, although not capable of unambiguous rock identification, are included here because they may provide a basis for extrapolation of surface analyses over wide areas. The measurements needed for lithologic characterization by surface analysis probes are listed in Table 1-1. A detailed discussion of these measurements and the rationale employed in their selection can be found in Ref. 1. Initial litologic characterization of major surface units will assist in the formulation of exploration goals and strategies for the manned geological investigations.

Extensive field-geology expeditions, an important element in the lunar scientific exploration program (Refs. 1 and 2), would have their productivity greatly increased with reconnaissance data. In view of the greater capability and proportionately greater cost of these expeditions, the efficiency of the overall program would undoubtedly be enhanced by the advance planning permitted by the employment of unmanned surface analysis probes. It has been pointed out (Ref. 1) that the reconnaissance role is best served by the unmanned probes, while the manned geological expeditions should be employed to attack critical problems in which the investigation requires the full capabilities of the men. These problems will, in general, exist at unit boundaries where complex structural and stratigraphic relationships must be analyzed by experienced field geologists.

Table 1-1. Nominal requirements for an unmanned surface analysis probe	
No.	Requirement
1.	The identification of major (>5 vol%) mineral phases in the analyzed sample, including sheet silicates and hydrated phases (X-ray diffractometer).
2.	A visual survey of the vicinity of the spacecraft, with 360° total horizontal field of view, extending from 1/2 m to the horizon, stereo base line of about 1 to 1-1/2 m, mast height 2 m, 100 : 1 light level dynamic range, and angular resolution of 0.1°.
3.	The provisions of high quality image data on crushed grains, using polarized and cross-polarized monochromatic light, with magnification on the vidicon target of 25 diameters, five focus steps per field of view, thirty fields of view per sample (petrographic microscope).
4.	Bulk chemical data to within ±5% of the amount present at a minimum detectable limit of approximately 1-2 wt % for K, Ca, Al, Si, Fe and Ni (X-ray spectrometer).
5.	Detection of absorbed and chemically bound H_2O to ±20% of the amount present at a minimum detectable limit of 0.1 wt % (heater with water reaction cell).
6.	Should be capable of providing a 5 g sample from depths of 0, 1/2 and 1 m in particulate material, or one 5 g sample of crystalline rock at whatever depth (≤ 1 m) encountered (for measurements 1 to 5 only — drill).
7.	The system should be deliverable to and capable of operation at nearly any point on the lunar surface. *
8.	The landed instrument package should be detectable on high (≤ 10 m) resolution images obtained from lunar orbit.
9.	Landing accuracy dispersion should not exceed 15 km 1 σ since this accuracy is considered adequate for characterization of major lunar terrain units.
	* A study should be conducted on the loss of science if full coverage is not achieved.

Since a number of surface points will be visited and sampled by manned exploration parties, the argument for the inclusion of unmanned systems in the lunar exploration program rests largely on the probable lithologic heterogeneity of the lunar surface (Ref. 1). It is known from telescopic observation that the moon is physiographically heterogeneous on a scale of tens of kilometers (Ref. 3). It is the opinion of the Lunar study team that an important exploration objective should be the acquisition of data which relate to physiographic character of a surface element to its lithology, thereby gaining insight into the genetic nature of and differences between physiographic provinces. This kind of information is necessary, although not sufficient, to determine the nature of relief-forming processes and the sources of energy responsible for the elevation differences on the moon.

The Planetology Group of the JPL Space Sciences Division has developed a terrain map of a portion of the lunar equatorial region (Ref. 3). This map, reproduced in Section 3, designates major physiographic units based upon their telescopic appearance, and the units are listed and briefly characterized in the map's legend. The terrain map is not intended to be a geologic map and the various terrain units do not carry genetic connotations. However, when a geologic map is drawn, it is not surprising that the formation boundaries turn out in many cases to be coincident with terrain unit boundaries. This is equivalent to saying that the general physiographic character of an area reflects to some extent the manner in which it was formed.

Unlike the map presented in Section 3, existing preliminary geologic maps (Ref. 4) represent an attempt to postulate the lithologic nature of stratigraphic and structural relations between surface units. By comparing the terrain map and the stratigraphic map of the same region, a number of problems relating to the genetic character of the terrain types can be defined. Some of these problems could be resolved by reconnaissance analysis using unmanned probes, thereby thereby testing the hypotheses upon which the geologic interpretations are based.

1.4 EXAMPLES OF MISSIONS

Examples of missions for unmanned probes can be illustrated by considering a set of possible surface-analysis-probe targets such as those listed in

Table 1-2 and plotted in Section 3. Targets 1 through 6 inclusive are located in different representative areas of terrain unit H_0, a highland basin fill. This unit is a generally smooth, high albedo deposit mantling topographically low areas in the highlands. In the central highlands (Targets 1 through 3), H_0 is interpreted on the geological maps (Ref. 4) as locally derived volcanic material (Cayley formation), as it is interpreted in the crater Parry (Target 6). However, in the central portion of Caesar (Target 4) and the ancient crater Fra Mauro (Target 5), H_0 is mapped as smooth Imbrian throwout mantle. Reconnaissance surface analysis of these target areas, which represent H_0 knowledge of lunar depositional processes, is desirable if they provide data which allows one to accept or reject hypotheses regarding their mode of formation and emplacement.

Targets 7 through 14 lie in the terrain unit M_4, a smooth, dark deposit typically occurring as a crater fill (as in Billy and Magelhaens). On the basis of low albedo, smoothness and apparent homogeneity, M_4 is tentatively interpreted as young material of internal origin, either coalescing ash flows or lava. Stratigraphically, it is generally designated Copernican-Eratosthenian dark mare (Targets 8 and 13), as opposed to the ubiquitous Procellarum mare base material of more ancient (Imbrian) age. However, Targets 9 through 12 represent areas in which M_4 is assigned to the Procellarum group. Target 14, in the crater Alphonsus, is intended to sample one of a series of small M_4 deposits which have been examined at relatively high resolution by Ranger 9 (Ref. 5). These dark halo craters near the eastern wall of Alphonsus appear to be analogous to terrestrial maar-type volcanoes (Ref. 4), and may represent initial stages of M_4-type basin filling. Therefore, the M_4 targets offer the opportunity to sample similar appearing terrain of possibly very different ages. The success with which these sampled areas can be differentiated physically or petrologically is difficult to predict, but petrographic data on volcanic material of diverse ages is valuable in itself since it might contain information concerning lunar magmatic evolution.

Targets 15 through 17 sample the dark, hummocky terrain unit M_2 which is designated as a part of the Fra Mauro formation (Imbrian ejecta) on the geologic maps. Certain of the characteristic features of M_2, including its extraordinarily low albedo, its association with domes and rilles and close relationship with M_3, suggest the alternative possibility that it might be of internal origin. Petrographic reconnaissance at the designated target positions may provide sufficient data to resolve this question.

Table 1-2. Possible mission targets for unmanned surface analysis probes in the lunar equatorial region

Target No.	Feature	Coordinates
1	Ptolemaeus	9° S, 2° W
2	D'Arrest	2° N, 14° E
3	Hipparchus	6° S, 6° E
4	Julius Caesar (central portion)	9° N, 15° E
5	Fra Mauro	6° S, 16° W
6	Parry	8° S, 16° W
7	Julius Caesar (northern portion)	10° N, 15° E
8	Billy	14° S, 50° W
9	Marius	12° N, 51° W
10	Marius D region	11° N, 44° W
11	Gutenberg	9° S, 41° E
12	Magelhaens	12° S, 46° E
13	Boscovitch	10° N, 11° E
14	Alphonsus (dark halo craters)	13° S, 2-1/2° E
15	Copernicus CD region	6° N, 15° W
16	Rima Bode II region	12° N, 3° W
17	Schneckenberg region	10° N, 7° E

Of the terrain units shown in Section 3, only three have been discussed. These represent a small fraction (approximately 7%) of the area mapped. Seventeen targets have been listed in Table 1-2 to provide general reconnaissance information on the selected units. The foregoing discussion implies that a large number of surface analysis probes will be required to accomplish the reconnaissance role.

It is believed that the landing accuracy of 15 km (1σ) is adequate for characterization of the major lunar terrain units.

1.5 LUNAR SURFACE COVERAGE

Although the discussion of example missions in the foregoing subsection was restricted to the region ±50° longitude and ±16° latitude, the arguments presented apply to the moon in general. The extent to which surface investigations must be conducted outside of the readily accessible areas (Apollo Belt, Surveyor Landing Zone) is difficult to assess in the absence of photo coverage over the entire surface and reconnaissance data in the accessible regions. Sufficient data from earth-based observation exists, however, to suggest that the Apollo Belt as understood by this study group (±45° longitude and ±5° latitude) does not contain representative examples of the major recognized surface units. Of the targets listed in Table 1-2, for example, only two lie within this region. In addition, there are a number of unique features outside of the area covered in Section 3 which should be investigated by surface reconnaissance spacecraft, such as the region around Aristarchus and the crater Wargentin.

Therefore, it would appear that an important secondary role for surface analysis probes will lie in the investigation of areas inaccessible to manned surface parties. Although this is an important consideration, the arguments given in previous sections of this chapter deal primarily with the utility of these probes as necessary reconnaissance instruments in the planning and execution of the exploration program. In other words, their primary role is viewed by the Lunar Study Team as complementary to manned surface investigations, with the employment of surface analysis probes in inaccessible areas representing an additional justification for their inclusion in the exploration program. With a capability to land anywhere, the surface analysis probes would provide access to any location on the lunar surface.

1.6 INSTRUMENT EMPLACEMENT

Unmanned probes may have an important role in instrument emplacement, particularly if the moon proves seismically active. In this case, probes offer the possibility of emplacing simple seismic instruments in a surface net without regard to landing restrictions such as apply to manned missions. If the moon is aseismic, the utility of emplacing instrument stations will depend upon the feasibility of an active seismic experiment, i.e. providing artificial impulses to the moon (Ref. 1).

1.7 POTENTIAL APPLICATIONS

In addition to surface reconnaissance and instrument emplacement missions, other applications of unmanned probes may be desirable in the lunar exploration program. These include atmospheric analysis, life detection experiments, active region investigation, etc. Potential applications of this sort will be studied by the Lunar Study Team, if the need for such concepts becomes apparent in the planning process which is a follow-on effort to Ref. 6.

SECTION II

REFERENCES

1. Speed, R. C., Adams, J. B., and Nash, D. B., The Utility of Unmanned Probes in Lunar Scientific Exploration, JPL T. M. No. 33-241, 15 July 1965.

2. NASA 1965 Summer Conference on Lunar Exploration and Science, Falmouth, Mass., July 19-31, 1965.

3. Adams, J., Conel, J., Felice, A., Kopal, Z., Loomis, A., Nash, D., Nickle, N., Speed, R., and Steinbacker, R., Surveyor Block II Phase 3: A Study of Lunar Terrain Assessment, JPL T. M. No. 33-172 (pre-release)

4. Preliminary Geologic Maps of the Lunar Surface, prepared by members of the Astrogeology Branch of the United States Geological Survey.

5. Ranger VIII and IX: Part II, Experimenters' Analyses and Interpretations. JPL T. R. No. 32-800, 15 March 1966.

6. Lunar Exploration Report (in process of being written by the JPL Lunar Study Team).

SECTION III

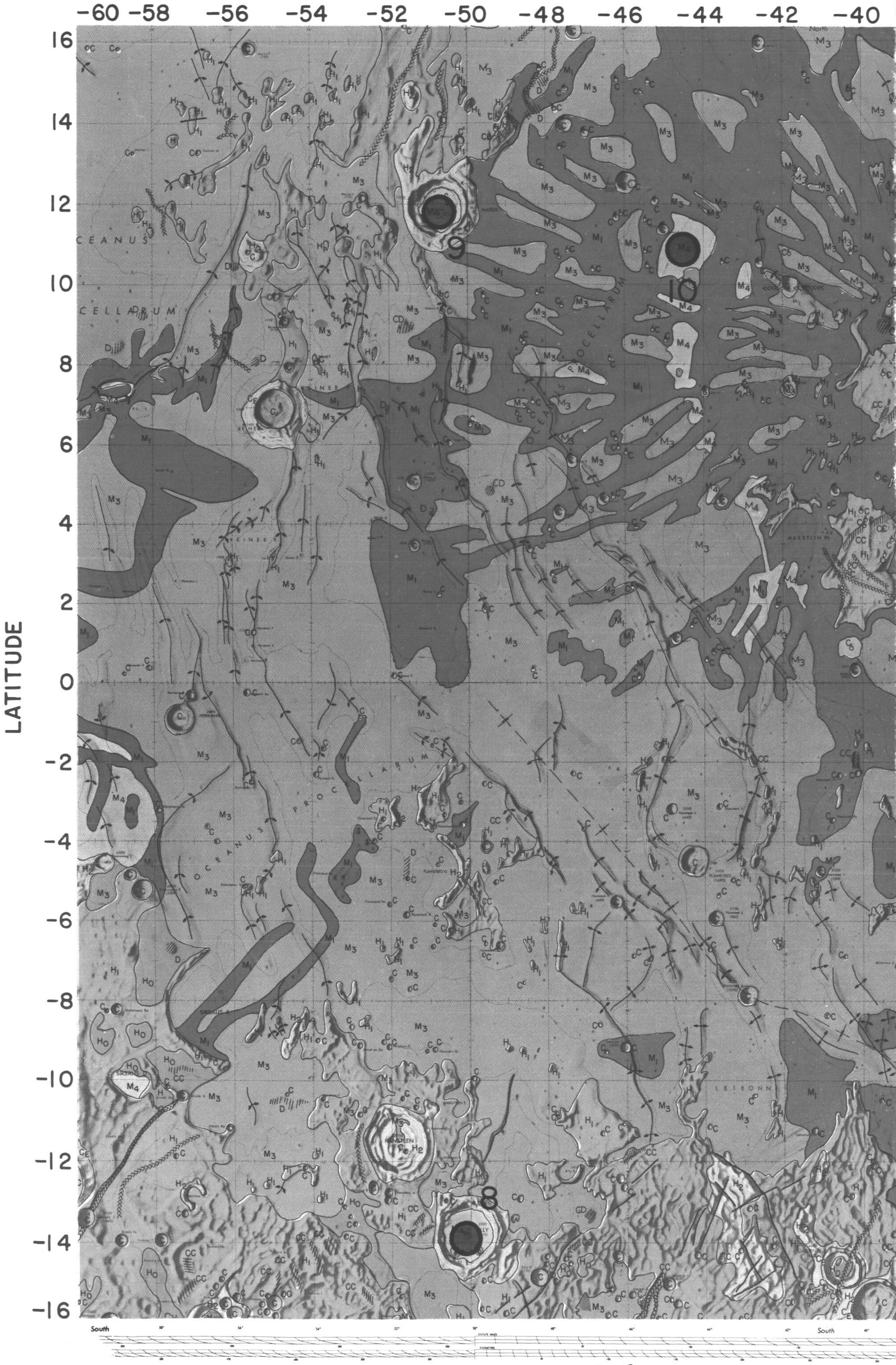
TERRAIN MAP OF THE LUNAR EQUATORIAL AREA

UNIT	DESCRIPTION	TYPE AREA(S)
	Rayed maria	Kepler region
	Dark rough deposits	Bode area, 250 km SE of Eratosthenes
	Regional maria	Oceanus Procellarum, 50 km NE of Flamsteed
	Dark basin fill	Boscovich basin
	Highland basins	Lade area, E of Hipparcus
	General highlands	1) 50 to 100 km N of Hipparcus 2) Riphaeus Mountains, 3) Area surrounding Copernicus outside ejecta blanket C_E
	Rough highlands	Flanks of Ptolemaeus
	Young craters	Copernicus
	Young crater ejecta blankets	Area surrounding Copernicus

SYMBOL	FEATURES
	Contact
	Regional syncline
	Wrinkle ridge
	Rille, outlined where wider than 1 km
	Fault
D	Dome
CD	Dome with superimposed craters
CC	Crater chain
CCD	Dome with superimposed crater chain

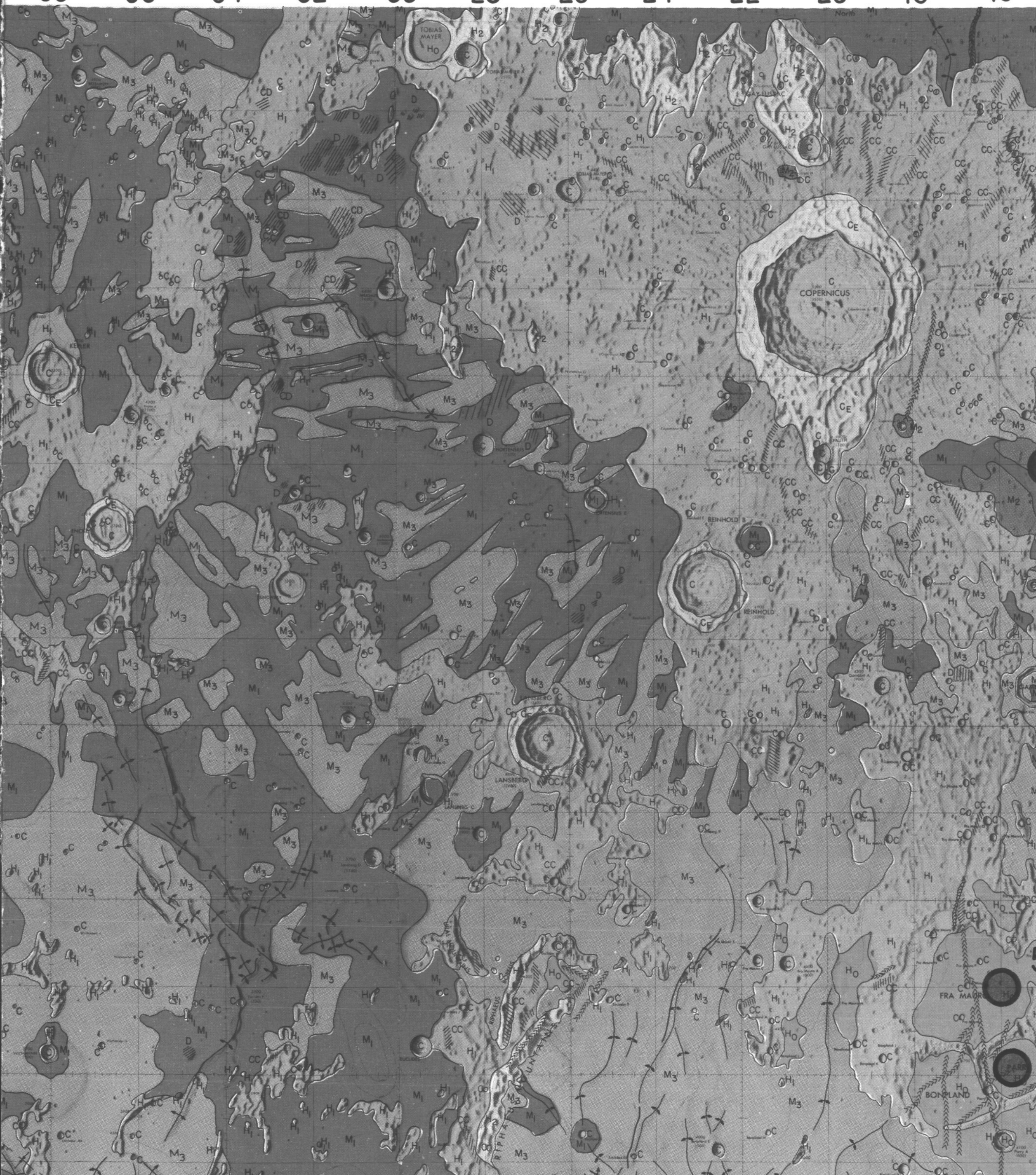
TERRAIN MAP OF LUNAR EQUATORIAL AREA

Prepared by: Planetology Group, JPL, 1964
Edited by: Alan Felice, JPL, 1965
(Base maps from ACIC charts, 1st edition)



-60 -58 -56 -54 -52 -50 -48 -46 -44 -42 -40
16
14
12
10
8
6
4
2
0
-2
-4
-6
-8
-10
-12
-14
-16
LATITUDE
9
10
8
CEANUS
CELLARUM
OCEANUS PROCELLARUM
OCEANUS PROCELLARUM
South
South

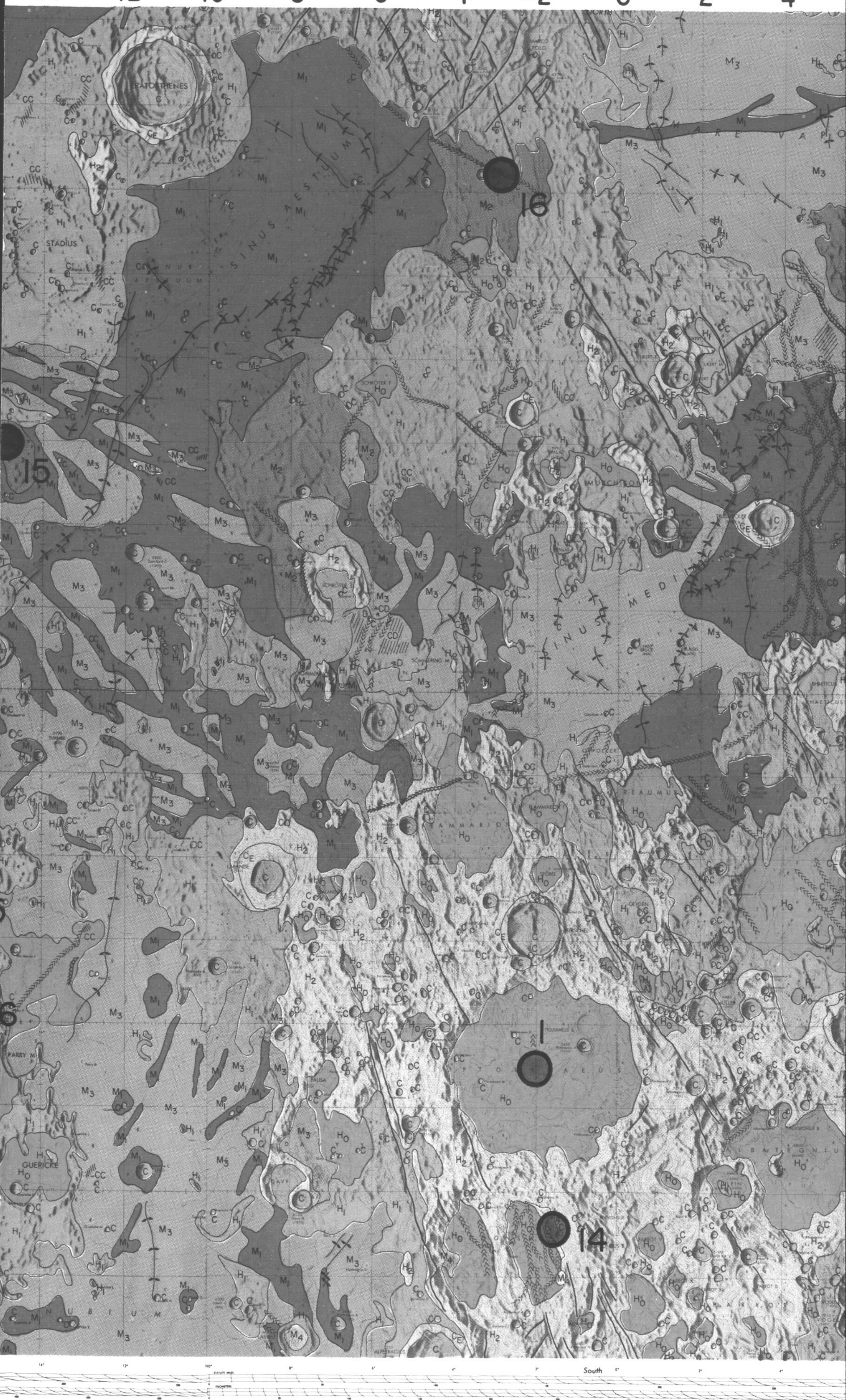
-38 -36 -34 -32 -30 -28 -26 -24 -22 -20 -18 -16

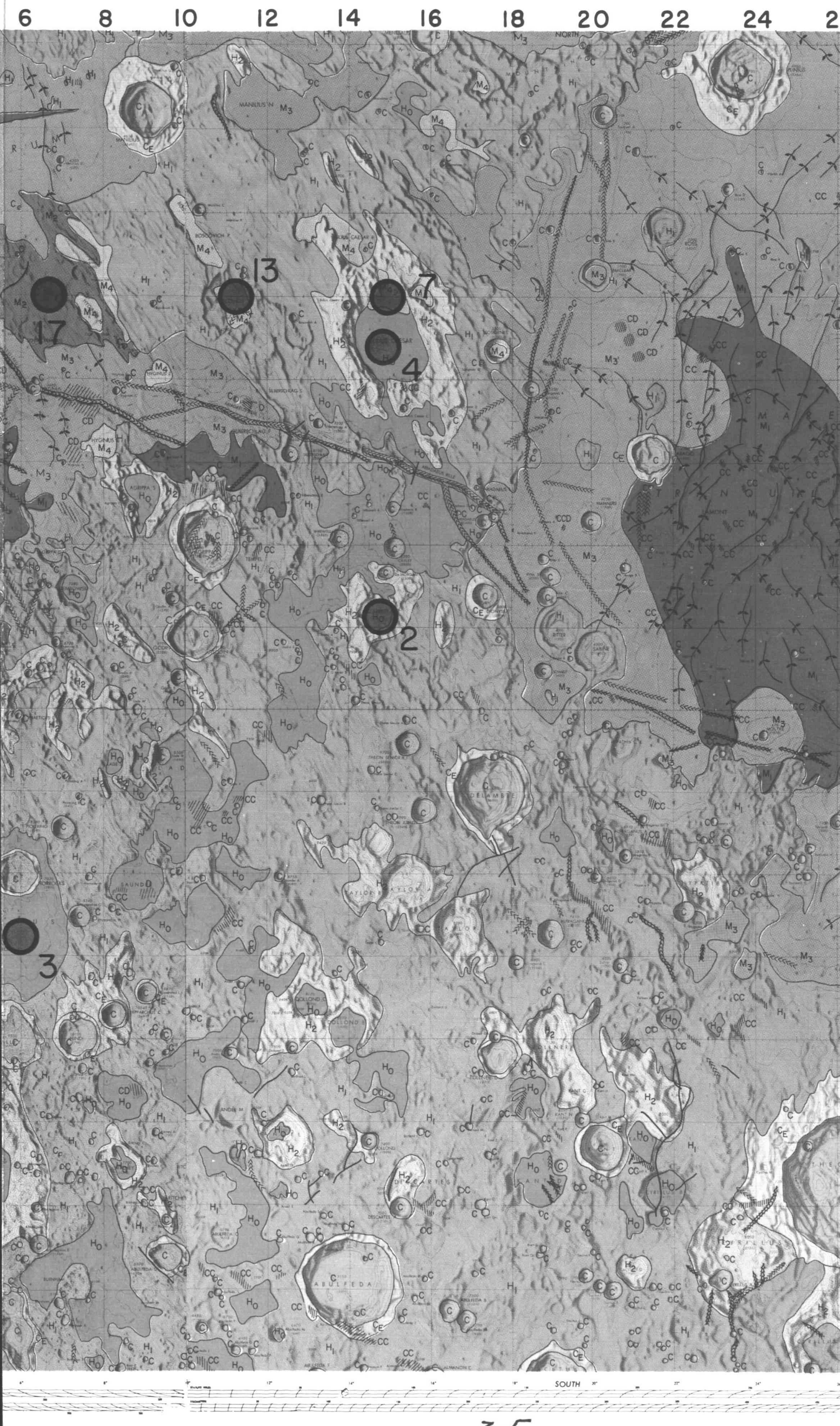


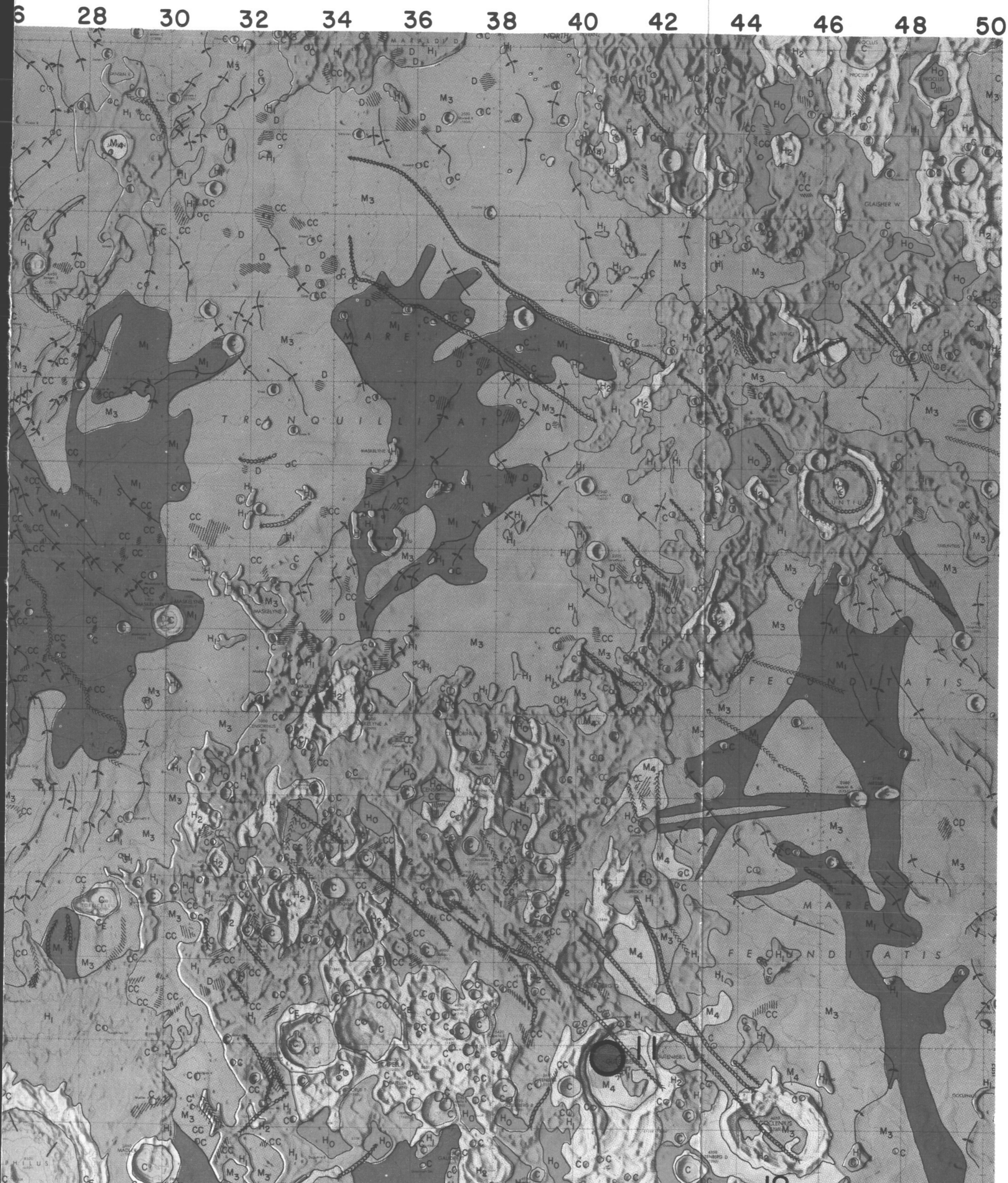
3-3

LONGITUDE

-14 -12 -10 -8 -6 -4 -2 0 2 4




6
8
10
12
14
16
18
20
22
24
NORTH
13
7
17
4
2
3
DELAMBRE
ABULFEDA
DESCARTES
SOUTH



28 30 32 34 36 38 40 42 44 46 48 50
NORTH
MARE
TRANQUILLITATIS
MARE
FECUNDITATIS
MARE
FECUNDITATIS
11
12
South