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SURFICIAL GEOLOGY OF MARS: A STUDY IN SUPPORT OF A PENETRATOR MISSION TO MARS

Paul Spudis
Arizona State University
Tempe, Arizona 85281

and

Ronald Greeley
University of Santa Clara and
Ames Research Center
Moffett Field, California 94035

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16. ABSTRACT

The *penetrator mission* concept has been proposed as a means of continuing exploration of Mars in the post-Viking era. To obtain optimum geologic and geophysical information from such a mission, it is necessary to consider the results in the context of the local geologic environment. Conventional geologic maps produced by NASA's Mars Geologic Mapping Program provide a regional context within which to interpret penetrator results. These maps do not, however, contain information about the *surficial character* which must be considered for successful penetrator emplacement. Surface conditions on Mars vary from eolian fine material to consolidated bedrock and each of these units has characteristic penetrabilities and, since the target ellipse for a hypothetical Mars penetrator may be more than 100 km long, regional topography is also important. For the purpose of this study, physiographic and surficial cover information has been combined into unified surficial geology maps (30 quadrangles and 1 synoptic map). The surface of Mars is heterogeneous and has been modified by wind, water, volcanism, tectonism, mass wasting and other processes. Surficial mapping identifies areas modified by these processes on a regional basis. Viking I mission results indicate that, at least in the landing site area, the surficial mapping based on Mariner data is fairly accurate. This area was mapped as a lightly cratered plain with thin or discontinuous eolian sediment. Analysis of lander images indicates that this interpretation is very close to actual surface conditions. These initial results do not imply that all surficial units are mapped correctly, but they do increase confidence in estimates based on photogeologic interpretations of orbital pictures. Viking results will result in refinements and improvements of existing surficial geology maps.

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A STUDY IN SUPPORT OF A PENETRATOR MISSION TO MARS

Paul Spudis
Center for Meteorite Studies
Arizona State University
Tempe, Arizona 85281

and

Ronald Greeley
University of Santa Clara
NASA/Ames Research Center
Mail Stop 245-5
Moffett Field, California 94035

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Abstract

The *penetrator mission* concept has been proposed as a means of continuing exploration of Mars in the post-Viking era. To obtain optimum geologic and geophysical information from such a mission, it is necessary to consider the results in the context of the local geologic environment. Conventional geologic maps produced by NASA's Mars Geologic Mapping Program provide a regional context within which to interpret penetrator results. These maps do not, however, contain information about the *surficial character* which must be considered for successful penetrator emplacement. Surface conditions on Mars vary from eolian fine material to consolidated bedrock and each of these units has characteristic penetrabilities and, since the target ellipse for a hypothetical Mars penetrator may be more than 100 km long, regional topography is also important. For the purpose of this study, physiographic and surficial cover information has been combined into unified surficial geology maps (30 quadrangles and 1 synoptic map). The surface of Mars is heterogeneous and has been modified by wind, water, volcanism, tectonism, mass wasting and other processes. Surficial mapping identifies areas modified by these processes on a regional basis. Viking I mission results indicate that, at least in the landing site area, the surficial mapping based on Mariner data is fairly accurate. This area was mapped as a lightly cratered plain with thin or discontinuous eolian sediment. Analysis of lander images indicates that this interpretation is very close to actual surface conditions. These initial results do not imply that all surficial units are mapped correctly, but they do increase confidence in estimates based on photogeologic interpretations of orbital pictures. Viking results will result in refinements and improvements of existing surficial geology maps.

SURFICIAL GEOLOGY OF MARS:
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1.0 Introduction

Ames Research Center is currently responsible for the science and engineering studies of the Mars Penetrator as a potential post-Viking mission to continue the exploration of Mars. Preliminary results indicate that this mission could have a high yield of information about the geological and geophysical characteristics of Mars. One of the problem areas that has been defined from these preliminary studies, however, is the determination of the surficial rock types that are likely to be encountered by penetrators landing on Mars. Although preliminary 1:5,000,000 scale geological maps for the entire surface of the planet have been prepared from Mariner 9 (and Mariners 4, 6, and 7) data, these maps have not dealt with specific surface characteristics of the rock types. It is, however, this information that is crucial to engineering considerations of the Mars Penetrator mission from the standpoint of the kinds of test sites that should be examined for feasibility drops on Earth and ultimately for the selection for potential landing sites on Mars. Known geological provinces on Mars range from young volcanic terrains to ancient cratered provinces, and include polar regions undergoing active surface modification. Rock types in these provinces probably range from bare, dense rock surfaces to loose accumulations of wind-blown sand, each having characteristic penetrabilities.

The objective of this report is to present in map form the characteristics of the surface of Mars, as currently understood and as derived from Mariner 9. It must be emphasized that this work can be substantially revised as Viking data become available over the next year or two, as discussed in Section 4.0.

Acknowledgements

The authors express thanks to the Mars Geological Mappers who provided the basic data for this study. The general approach for the work benefitted greatly from discussions with H. Masursky, G. Schaber, and D. Wilhelms of the U. S. Geological Survey, T. Bunch and R. Reynolds of NASA-Ames, and C. Moore of Arizona State University. C. Wilbur assisted in collection of data. Funds for the support of this study have been allocated by NASA-Ames Research Center, Moffett Field, California, under Interchange No. NCA 2-OR035-602, and through the Office of Planetary Geology, NASA, Washington, D. C.

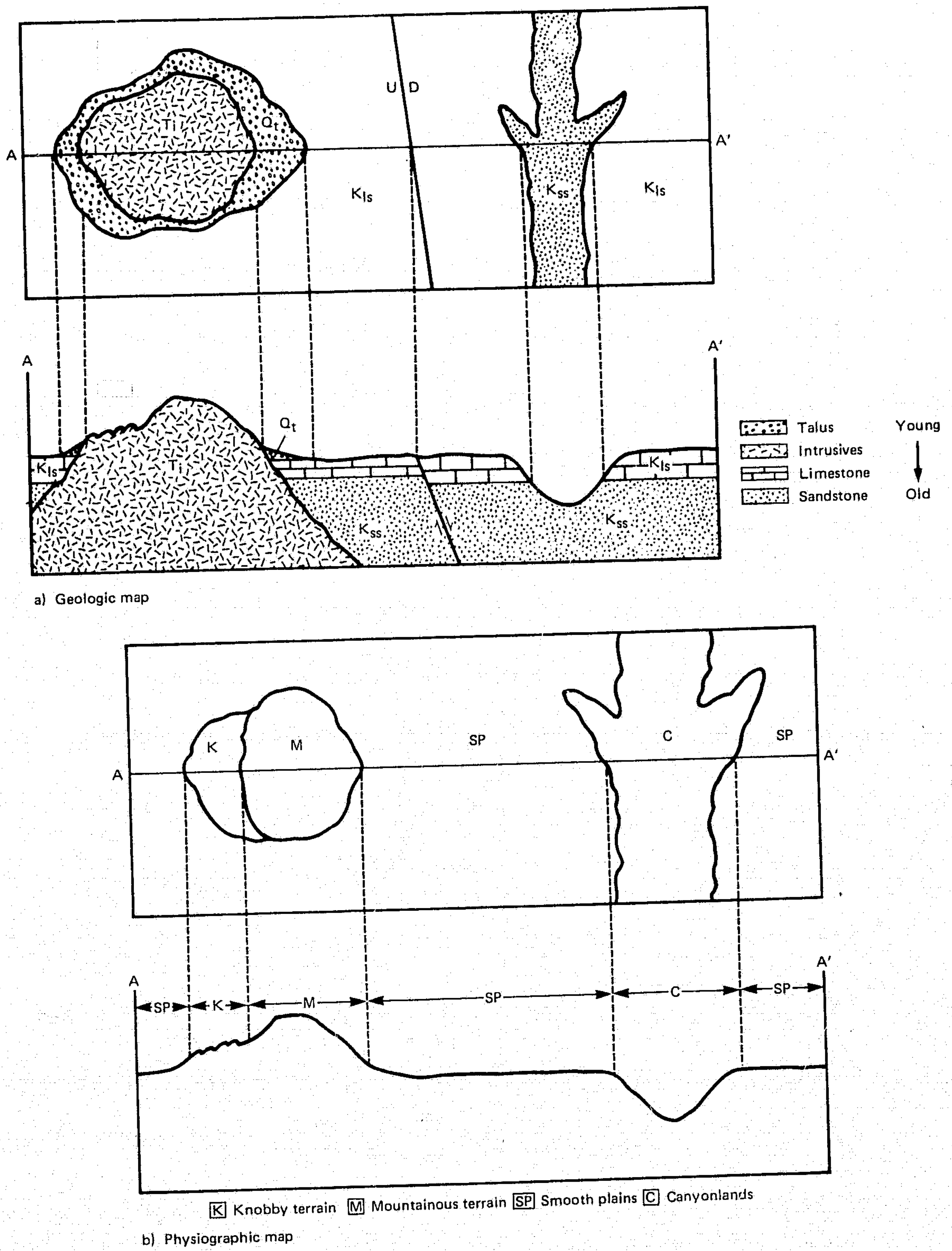
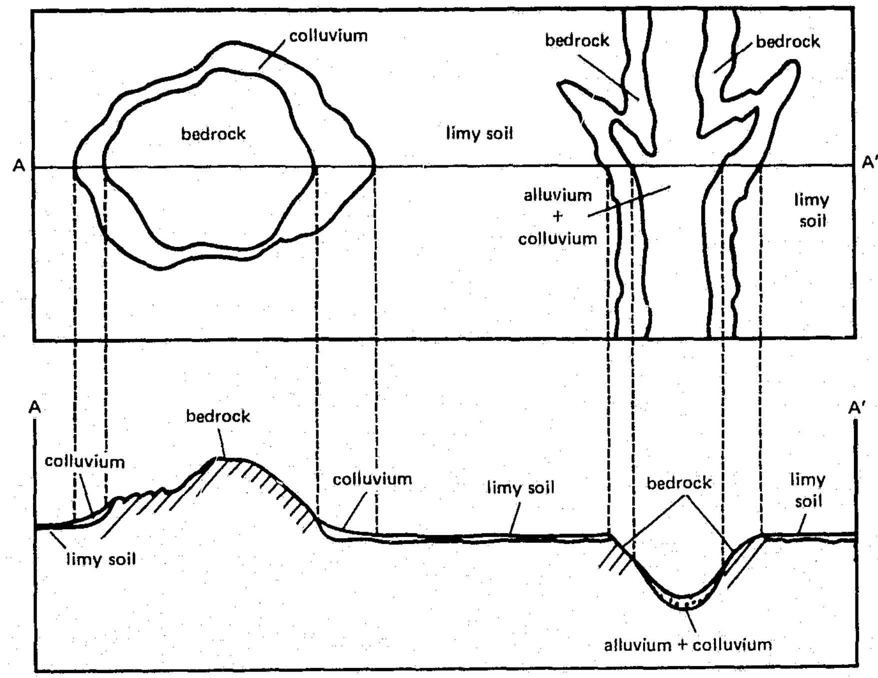
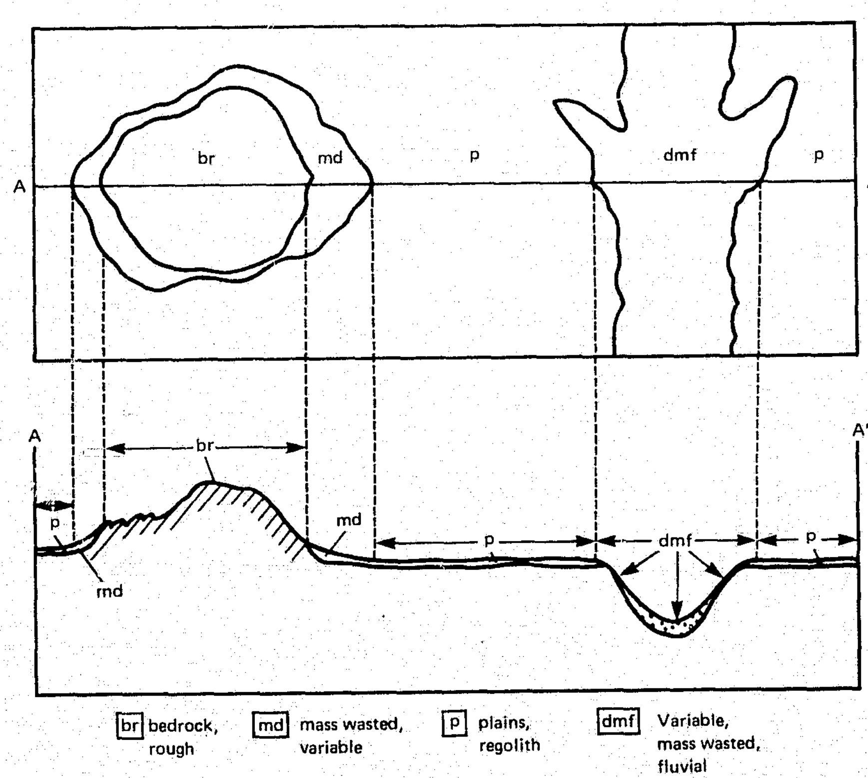


Figure 1. Diagrams of a hypothetical planetary surface, showing how the same region might be portrayed on different types of maps.



c) Surficial (soil) map



d) Surficial Geology map (this study)

Figure 1. Concluded.

1.1 Surficial Geology Maps

Three types of maps are commonly used to portray planetary surfaces: (1) Geologic maps (figure 1a) show three-dimensional rock units in space and time, plus structural features such as folds and faults. They portray the surface of the planet as though all vegetation, soil, and other surficial units were stripped away; sequences of geologic events can be derived from this type of map; (2) Physiographic maps (figure 1b) show land forms such as hills, valleys, and plains (see, e.g., VDAT, 1972); and (3) Surficial (Soil) maps (figure 1c) show the distribution only of surficial covers or the lack thereof and do not show topography or terrain types. At the scale of Mars surficial mapping in this study (1:5,000,000), many small rough areas, such as knobby terrain, cannot be subdivided into bedrock and valley fill surficial units. This information is of utmost importance for a penetrator mission, however, in that rough, variable topography will decrease the probability of penetration. It becomes desirable, therefore, to incorporate terrain and surface roughness information into the portrayal of surficial deposits to characterize the local surficial environment of a given area. The effect of this incorporation is to reduce the complexity of surface portrayal while at the same time presenting the relevant data concerning surficial conditions. This map is a surficial geology map (figure 1d) which characterizes the local geologic, surficial environment of a given area. Note that this map presents all the data of the physiographic (terrain) and surficial (soil) maps with a substantial reduction in map complexity.

1.2 Data Sources

The primary source of data for the surficial geological maps presented here was the 1:5,000,000 scale geological maps produced by the Mars Geological Mapping Program (MGM), sponsored by the NASA Office of Planetary Geology. This program involved geologists from universities, the U. S. Geological Survey, and NASA Field Centers to produce a series of 30 quadrangles covering Mars, using primarily Mariner 9 images. All of the maps have been completed and are in various stages of publication by the U. S. Geological Survey.

The MGM Program authors of the quadrangles are familiar with the surface characteristics of Mars and are in an excellent position to provide the information needed for the penetrator mission. In this study, each quadrangle mapper was requested to furnish the latest version of the geological quadrangle and data sheets on the surface characteristics of each rock unit in the quadrangle. Information for 22 quadrangles was obtained in this manner. Data for the remaining eight quadrangles were obtained by synthesizing data from the 1:25,000,000 scale global geological map of Scott and Carr (1976), by extrapolating from adjacent maps, and/or by direct discussion with the map authors.

The information from the geological quadrangles was supplemented and extended by examinations of Mariner 9 images for the major units mapped. These images have approximately 3 to 4 km resolution for A-camera frames and 100 m "best" resolution for B-camera frames. Because of this relatively poor image resolution, the surficial nature of geological units must be inferred from plausible geological models based on orbital pictures. The surficial units thus mapped are regional in character and may vary widely within themselves. Information on geological processes modifying the surface has also been inferred from Mariner 9 images and this information has been used to further infer the surficial nature of geological units. These widely variable data have been synthesized in the Scott and Carr (1976) geological map. This map was important in this project in verifying many of the units and in providing continuity from one quadrangle to another.

It had been anticipated before the mapping effort that Earth-based radar data would be useful in elucidating the surficial nature of Mars. These data were found to be of limited use for several reasons. Most importantly, radar data are confined by astronomical positioning of Earth and Mars to an equatorial band of approximately $\pm 20^{\circ}$ latitude. Many of the geological units of the higher latitudes have no analog in the equatorial zone and thus there are no radar data that can be applied towards these units. This equatorial zone also lies within the unmantled zone of Soderblom et al. (1973a) and thus will not contain radar information on the mantling material. The geologic interpretation of some radar parameters, notably measurements of dielectric constant, are highly ambiguous and controversial and have not been considered in this report. The primary value of the existing radar data have been in verifying the average surface slope values derived from photogeologic mapping in the equatorial zone. These slope values correspond fairly well to mapped "rough" and "smooth" areas. An excellent summary of radar data and its geologic applications to Mars is given in Simpson et al. (1974).

2.0 Surficial Geological Mapping

Mars is broadly divisible into two hemispheric physiographic provinces. The physiographic border is inclined about 50° to the Martian equator. The southern hemisphere is predominantly cratered highlands. This cratered highlands hemisphere is somewhat analogous to the lunar highlands, but contains a much more diverse and complex suite of geological units. In addition to the exposed post-accretional surfaces, this province contains the older plateau plains units, basin rim deposits, and various plains units of younger age in various stages of modification and surficial expression.

The northern lowlands are predominantly smooth plains units, although there is considerable relief associated with the volcanic areas such as Tharsis and Elysium (Carr, 1973). The plains are generally associated with eolian activity and surficial deposits, particularly at higher latitudes (Soderblom et al., 1973a). Plains units near the north polar area may be areas where permafrost activity is responsible for surficial deposits and landforms (Soderblom et al., 1973b).

2.1 Mapping Conventions

Surficial geological maps based on the 30 quadrangle maps of Mars are presented in Appendix I; Figure 2 is a synopsis of this mapping on a planet-wide scale; Table 1 gives the areas covered by each major unit.

A single, lower case letter system was devised to indicate the single most important characteristic of a given surficial unit. Subsequent letters are added to modify and clarify the initial designation. A maximum of three letters is used in any given surficial unit. Boundaries between units are drawn such that they indicate the maximum probability of a surficial transition. In many cases, the lines are coincident with geological unit contacts, but in areas of different, small geological units, the surficial character probably has little lateral variation and is mapped as a single surficial unit. For example, complex dissected and eroded geological units in MC-5, Ismenius Lacus, are all mapped surficially as "dr" (variable, rough). Moreover, the landing probability ellipse for a Mars penetrator may be several hundred kilometers in maximum dimension and this mapping convention assures that relevant data concerning surficial properties are considered in areas such as this knobby terrain. The letter designation system for surficial units is given in Table 2.

Dark and light albedo markings are significant in that they appear to represent eolian surficial deposits (Sagan et al., 1972; Sagan et al., 1973). These areas have been mapped using a stipple-dot pattern which may occur discontinuously over any other surficial unit. Some dark albedo markings in crater floors seen at B-frame resolution appear to be dune fields, as in the Hellespontus area (Cutts and Smith, 1973).

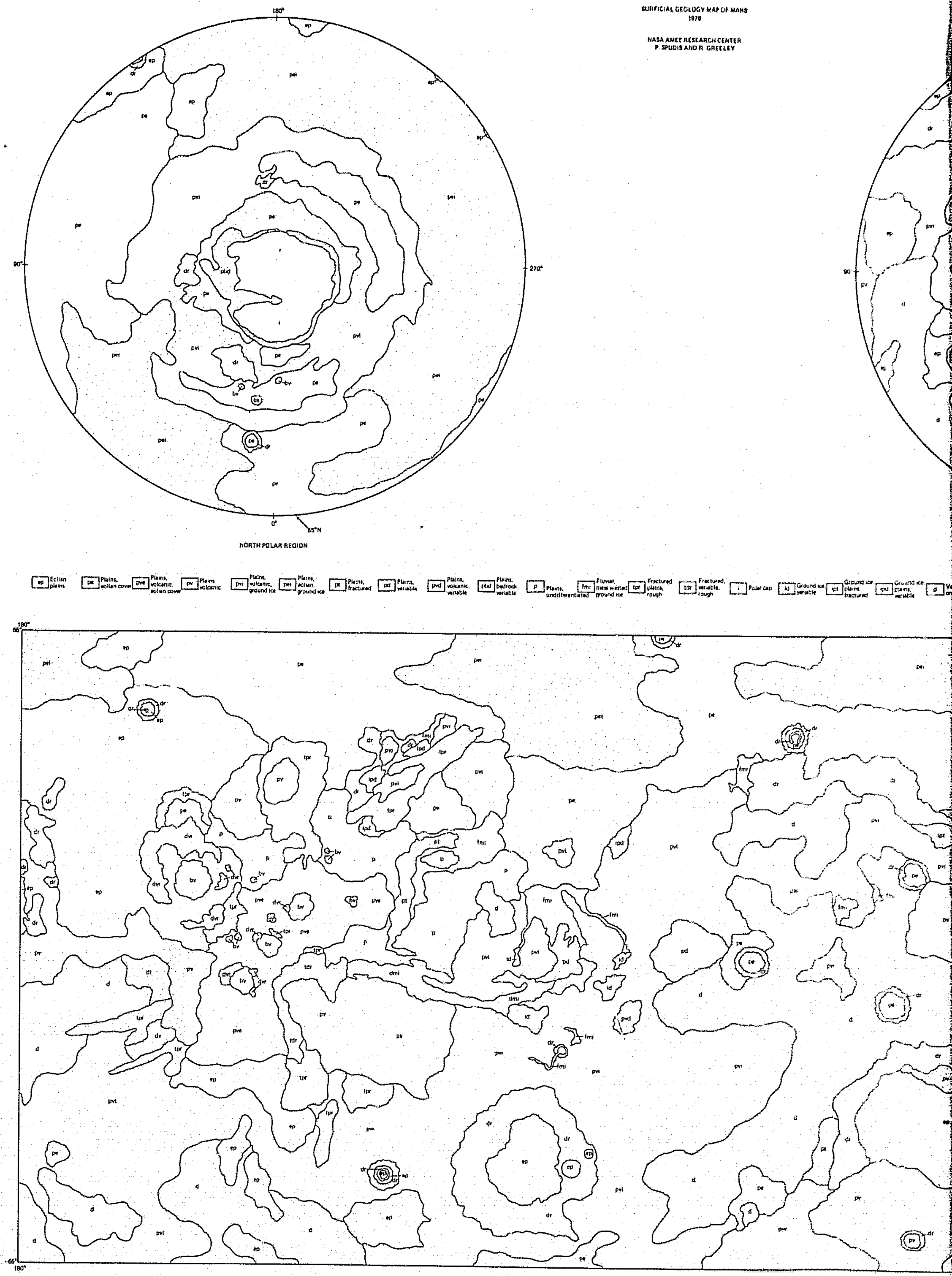


Figure 2. Synoptic surficial geological map for Mars.

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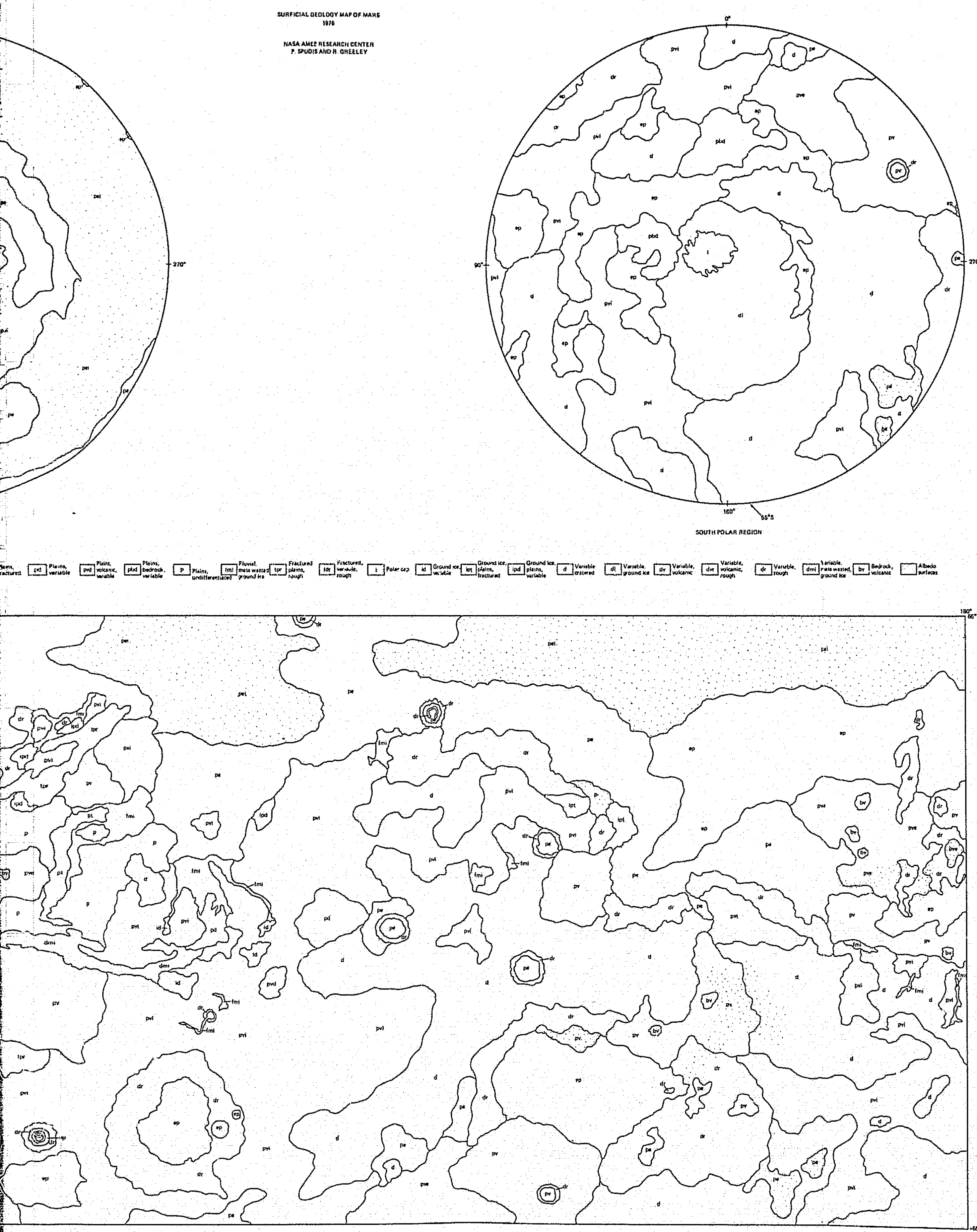

Figure 2. Synoptic surficial geological map for Mars.

TABLE I

AREAL EXTENT FOR THE MAJOR SURFICIAL UNITS MAPPED ON MARS

	Percent	Area (km^2)
ep	11.50%	16,643,882 km^2
pe	10.28%	14,870,868 km^2
pve	4.82%	6,978,998 km^2
pv	7.89%	11,424,780 km^2
pvi	21.18%	30,653,421 km^2
pei	4.69%	6,780,639 km^2
pt	0.40%	574,281 km^2
pd	0.82%	1,188,246 km^2
pvd	0.13%	187,914 km^2
pbd	0.51%	731,085 km^2
p	3.72%	5,383,346 km^2
fmi	1.28%	1,858,935 km^2
tpr	2.19%	3,169,833 km^2
tdr	0.38%	545,544 km^2
i	0.51%	741,810 km^2
id	0.49%	706,688 km^2
ipt	0.17%	245,862 km^2
ipd	0.17%	251,383 km^2
d	19.00%	27,496,928 km^2
di	1.24%	1,791,259 km^2
dv	0.16%	233,875 km^2
dvr	0.76%	1,097,068 km^2
dr	5.80%	8,395,104 km^2
dmi	0.80%	1,152,807 km^2
bv	0.84%	1,210,592 km^2
df	0.27%	384,432 km^2
TOTAL SURFACE AREA	99.97%	144,712,340 km^2

TABLE 2

LETTER CLASSIFICATION SYSTEM FOR MAJOR SURFICIAL UNITS

Letter	Designation	Character
b	Bedrock	Consolidated lithology
d	Variable (diverse)	Heterogeneous surficial nature
e	Eolian	Wind related deposits
f	Fluvial	Water (river) related deposits
i	Ground ice	Permafrost related deposits
m	Mass wasted	Colluvium
p	Plains	Relatively smooth, low to moderate relief areas
r	Rough	High topographic relief
t	Tectonically modified	Debris derived from fracturing and faulting
v	Volcanic	Characteristic landforms of volcanic activity

3.0 Unit Descriptions

The units shown in the surficial geological maps of Figure 2 and Appendix I are described as follows. The units are arranged alphabetically by letter smybol.

(b) Bedrock surfaces

br (bedrock, rough)

Surface: Uplifted impact breccia with bedrock properties; blocks and block fields common; rough, high topographic relief.

Association: Rough variable topography of basin rims and central peaks of larger craters.

bv (bedrock, volcanic)

Surface: Exposed bedrock on volcanic shield and dome material; high local relief due to primary flow structures; very thin (< 0.5 m), discontinuous surficial cover of eolian and/or mass wasted sediment.

Association: Large volcanic structures of the Tharsis, Elysium, and Mare Tyrrhenum areas.

bvr (bedrock, volcanic, rough)

Surface: Exposed bedrock on volcanic shield material with much higher local relief than unit bv; surface very rough, possible local pockets of fine-grained sediment.

Association: Arsia Mons in MC-17 (Phoenicis Lacus).

(d) Variable surfaces

d (variable, cratered)

Surface: Similar to the megaregolith of the lunar highlands; thick and variable regolith developed on ancient cratered terrain, mantled by eolian cover in places, particularly in high north and south latitudes (Soderblom et al., 1973a); surficial properties extremely variable in both vertical and horizontal extent.

Association: Developed on ancient cratered terrain of Martian highlands, geologic unit hc of Scott and Carr (1976).

df (variable, fluvial)

Surface: Variable surficial materials that have been modified by extensive fluvial activity; properties similar to unit d above.

Association: Eroded cratered terrain bordering Tharsis upwarp (MC-16); also channeled uplands in the Sinus Sabaeus area (MC-20).

(d) Variable surfaces (continued)

di (variable, ground ice)

Surface: Layered deposits consisting of alternating layers of ice and dust; thick; variable topography with high local relief.

Association: Laminated terrain of South polar region (Murray et al., 1972).

dmi (variable, mass wasted, ground ice)

Surface: Rough, variable material containing mass wasted and possibly fluvial sediments; talus accumulations and scarps; high local relief; high possibility of ground ice contained in regolith materials.

Association: Canyon floor materials of Coprates canyon system.

dr (variable, rough)

Surface: Highly variable surface materials of exposed bedrock and valley fill material; blocky; very high local topographic relief; rough.

Association: Mountainous units of the large circular basins (ex. Argyre, MC-26).

dt (variable, fractured)

Surface: Variable surface properties of a thick regolith with a geologically younger structural overprint; fault scarps and breccia common, similar to fractured plains only rougher.

Association: Fracturing of older cratered terrain.

dv (variable, volcanic)

Surface: Heavily cratered volcanic areas and irregular depressions of presumed volcanic origin; surfaces rough and highly variable; high local relief.

Association: Rough volcanic areas adjacent to Tharsis area (MC-16).

dvr (variable, volcanic, rough)

Surface: Rough and variable surfaces with high local relief and block fields; scarps, outcrops and valley fill material; more relief than unit dv.

Association: Aureole material of Tharsis volcanic shields.

(d) Variable surfaces (continued)

d_4 - d_1 (variable, crater ejecta)

Surface: Surficial deposits associated with larger impact craters; blocks and block fields, rays, hummocky areas and slump and talus materials; blockiness is roughly correlative with subscript, 4 being more blocky and rough than 3, etc.

Association: Impact craters in all quadrangles.

(e) Eolian surfaces

ep (eolian plains)

Surface: Very thick layers of eolian sediments overlying plains materials of varying lithologies; may also accumulate in crater bottoms as a fill unit; thickness in high latitude areas may approach 10^2 meters in magnitude (Scott and Carr, 1976); low to very low topographic relief, dune fields may be common.

Association: Mostly distributed in the smooth plains areas of the northern latitudes but may occur locally anywhere on Mars.

(f) Fluvial surfaces

fi (fluvial, ground ice)

Surface: Fluvial sediments, ranging from fine silts to coarse boulders deposited in and by the large Martian channels; moderate to low local relief; subsurface water may be present as ground ice in the finer sediments.

Association: Smaller fluvial channels around the planet.

fmi (fluvial, mass wasted, ground ice)

Surface: Fluvial debris mixed with mass wasted material, many blocks and boulders randomly distributed within finer sediment; moderate to high relief; possibility of ground ice below immediate surface.

Association: Larger fluvial channels and canyons.

(i) Ground ice surfaces

i (polar cap material)

Surface: Polar cap materials, which vary in size according to the Martian seasons; albedo, morphology and occurence suggest it is a residual cap of solid H_2O plus minor and local eolian debris; relief is probably low to moderate.

Association: North and South polar areas of Mars.

(i) Ground ice surfaces (continued)

id (ground ice, variable)

Surface: Surface rough and variable with very high local relief; many blocks and boulders; high possibility of ground ice content.

Association: Chaotic terrain and associated channels.

ipd (ground ice plains, variable)

Surface: Variable plains material with moderate relief and erosional remnants of older plains by ground ice action; variable surface properties.

Association: Plains adjacent to chaotic materials.

ipt (ground ice plains, fractured)

Surface: Tectonic areas with ground ice; derived from breakup of ice-containing plateau material, minor mass wasted and fluvial debris, moderate to high relief.

Association: Fractured and faulted plateau materials adjacent to chaotic terrain.

(m) Mass wasted surfaces

md (mass wasted, variable)

Surface: Large areas of mass wasted materials with variable surface properties (buried blocks and finer materials); faulted and heavily cratered; rough; high local relief.

Association: Basin rim materials of Hellas basin.

(p) Plains surfaces

p (plains, undifferentiated)

Surface: Loose and unconsolidated surficial materials mantling plains of widely varying lithology and origin; impact regolith, eolian mantle, fluvial deposits and mass wasted material may be discontinuously present in varying amounts; relief is low to moderate.

Association: Lunae Planum and other plains areas of unknown lithology on Mars.

(p) Plains surfaces (continued)

pbd (plains, bedrock, variable)

Surface: Wind deflated bedrock plains surfaces with irregular topography of moderate to high topographic relief; local eolian cover in places; variable topography.

Association: Surficial expression of the etched terrain unit of Sharp (1973)

pd (plains, variable)

Surface: Knobby plains materials with bedrock knobs protruding through impact regolith and eolian mantles; moderate to high relief, some blocky areas near the talus aprons of the knobs and hills.

Association: Knobby plains of Mare Australe quadrangle (MC-30).

pde (plains, variable, eolian cover)

Surface: Similar to unit pd only local blanketing of eolian sediments is somewhat thicker; monadnocks are left uncovered at higher elevations; relief is low to moderate; surficial properties are variable.

Association: Knobby plains near the edge of the physiographic divide between cratered highlands and lowland plains.

pdi (plains, variable, ground ice)

Surface: Regolith and eolian mantles on rough plains that have been broken up by permafrost action; relief is moderate to high with hills and ridges.

Association: Broken plains units near Lunae Planum.

pe (plains, eolian cover)

Surface: Eolian sediments, somewhat thinner and more discontinuous than unit ep, overlying plains of probable volcanic origin; low to moderate relief, dunes and dune fields possible.

Association: Plains of the northern lowlands and some crater bottoms.

(p) Plains surfaces (continued)

pei (plains, eolian cover, ground ice)

Surface: Plains materials almost always associated with splotchy albedo markings indicating variable thicknesses of eolian materials; ground ice likely since area is associated with periglacial features of the North polar area; moderate relief.

Association: Mottled plains of the northern lowlands.

pi (plains, ground ice)

Surface: Plains with landforms similar to terrestrial periglacial landforms suggest presence of significant quantities of ground ice; textured intercrater areas; moderate relief.

Association: Plains southeast of the Argyre basin.

pt (plains, fractured)

Surface: Plains materials with erosional ridges and furrows, joints along which erosion has occurred; lithology unknown but surficial coverings probably include fluvial, eolian and mass wasted sediments, all discontinuous; low to moderate relief.

Association: Channeled areas near Lunae Planum (MC-10).

pv (plains, volcanic)

Surface: Plains materials with mare-type wrinkle ridges and flow structures; impact regolith primarily, but locally may be covered by small amounts of eolian materials; relief low to moderate.

Association: Volcanic areas around the planet.

pvb (plains, volcanic, bedrock)

Surface: Volcanic plains that have been locally wind deflated in places, exposing bedrock; some pockets of eolian materials and impact regolith; relief moderate.

Association: Volcanic areas southwest of Hellas basin.

(p) Plains surfaces (continued)

pvd (plains, volcanic, variable)

Surface: Volcanic plains with slightly more relief than unit pv; scarps and ridges with impact ejecta and eolian mantle, blocks and block fields; moderate relief.

Association: Older volcanic plains units, especially near Tharsis (MC-9).

pve (plains, volcanic, eolian cover)

Surface: Volcanic plains materials with fairly continuous eolian mantle overlying impact regolith; low relief.

Association: Tharsis volcanic plains (MC-9, 17) and mantled volcanics of the high latitudes.

pvi (plains, volcanic, ground ice)

Surface: Mostly impact regolith developed in older volcanic plains and plateau materials with high possibility of ground ice in regolith; moderate relief.

Association: Plateau materials of highlands physiographic province.

(t) Tectonically modified surfaces

tdr (fractured, variable, rough)

Surface: Extremely rough variable topography; fault scarps and breccia deposits; mass wasted debris; bedrock outcrops and block fields common; very high relief.

Association: Coprates rift valley and Nocus Labyrinthus.

tpr (fractured plains, rough)

Surface: Much mass wasted debris and eolian mantles overlying highly faulted plains; fault scarps and breccia common; blocks and bedrock outcrops; high relief.

Association: Volcanic fractured plains associated with Tharsis upwarp.

Albedo surfaces

(albedo surfaces)

Surface: Dark and splotchy albedo markings that may discontinuously mantle almost any other surficial unit; probably dune fields and discontinuous eolian sediments of varying thicknesses and varying lithologies.

Association: Occurs planetwide but most conspicuous in mottled plains unit in northern lowland plains.

4.0 Summary

The surface of Mars has been seen to be extremely heterogeneous on both a regional and fine scale. The surface has been extensively modified and shaped by various complex geological agents such as wind, running water, volcanism, tectonism, and gravity. Surficial deposits are the result of the geological history in given areas and range from loose unconsolidated debris such as eolian dust to the consolidated volcanic bedrock of the young shield volcanoes. Further study of spacecraft images and development of other remote sensing techniques will lead to more accurate and refined surficial interpretations in the future.

In July, 1976, the Viking 1 spacecraft landed on Chryse Planitia at 26.27^{o} N, 48 W. This area had been mapped geologically as alluvial fill, thickening in an eastward direction (Milton, 1975). The landing site and its immediate surroundings have been mapped surficially as unit pe, plains with eolian cover. Analysis of initial images returned by the Viking 1 lander indicates that this is a very close approximation of actual surface conditions. The lander is situated on an undulating, blocky plain with low to moderately low topographic relief. Eolian features are ubiquitous with dunes, ventifacts, and dust accummulations in the wind shadow of rocks. The eolian mantle is discontinuous, as stated in the unit pe explanation and the general character of the landing site was anticipated fairly accurately. These initial ground truth results do not imply that all surficial units are mapped correctly, but they do increase our confidence in surficial estimates based on photogeologic interpretation of orbital imagery. Additional study of Viking results may lead to refinements and improvements of existing surficial geology maps.

4.1 Recommendations

From the results presented here and considerations of the initial Viking results (Carr *et al.*, 1976; Mutch *et al.*, 1976; Masursky and Crabill, 1976), the following course of action is suggested to refine the knowledge of the surface properties of Mars:

1. Examine each major surficial unit mapped from Mariner 9 images, using new Viking Orbital images with the increased resolution.
2. Perform a rigorous "ground truth" analysis of surface characteristics using Viking Orbital data and Viking Lander data.
3. Correlate Viking IRTM (Infrared Thermal Mapper), Viking MAWD (Mars Atmospheric Water Detector), Earth-based radar data, and orbital images to derive surface characteristics (block size, models of surface weathering, etc.) for each geological unit of interest and for potential landing areas.

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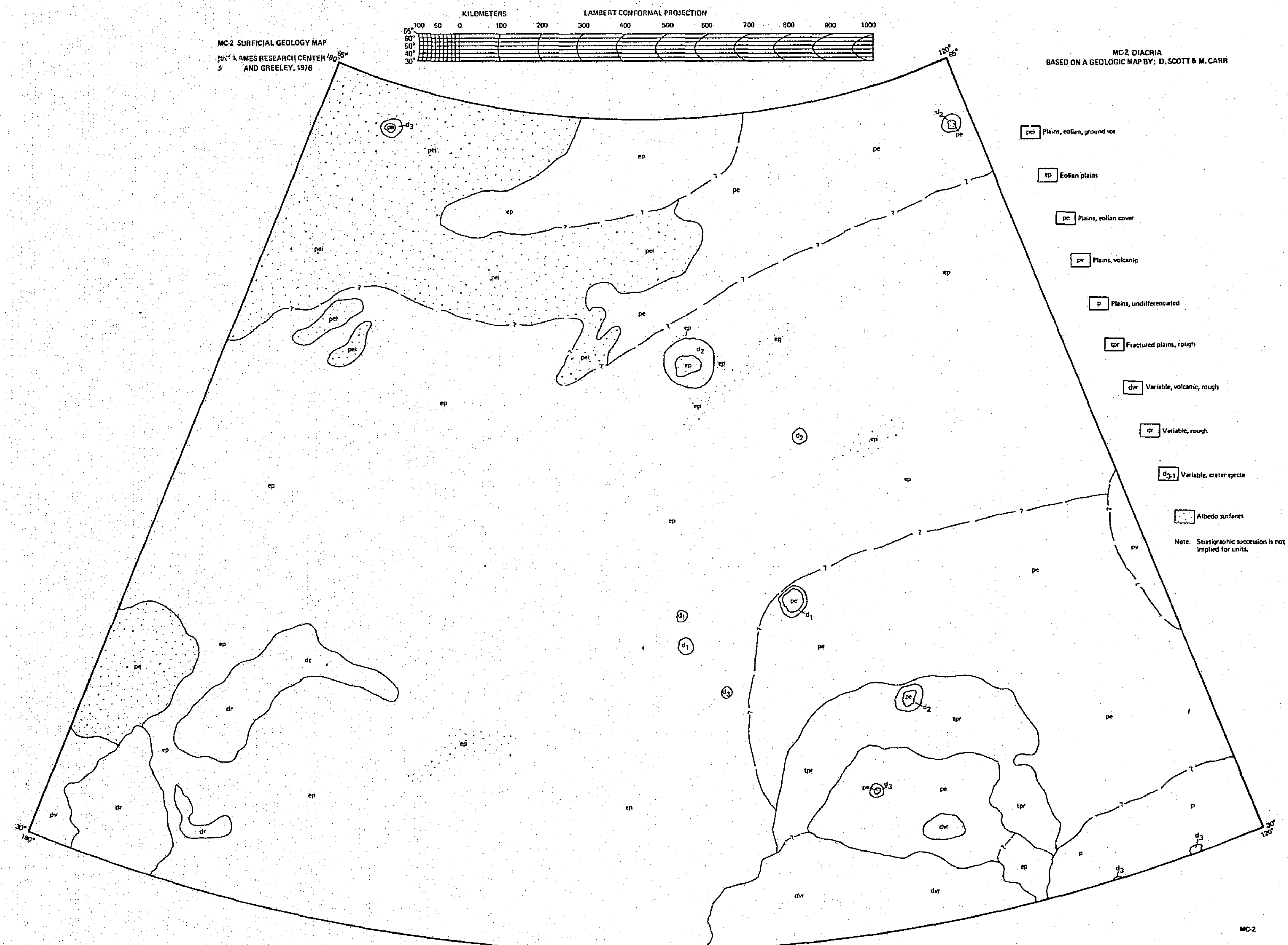
APPENDIX I

Surficial Geological Maps of Mars, based on Mars quadrangles (original scale 1:5,000,000).

NASA AMES RESEARCH CENTER
SPUDIS AND GREELEY, 1976

MC-1 SURFICIAL GEOLOGY MAP

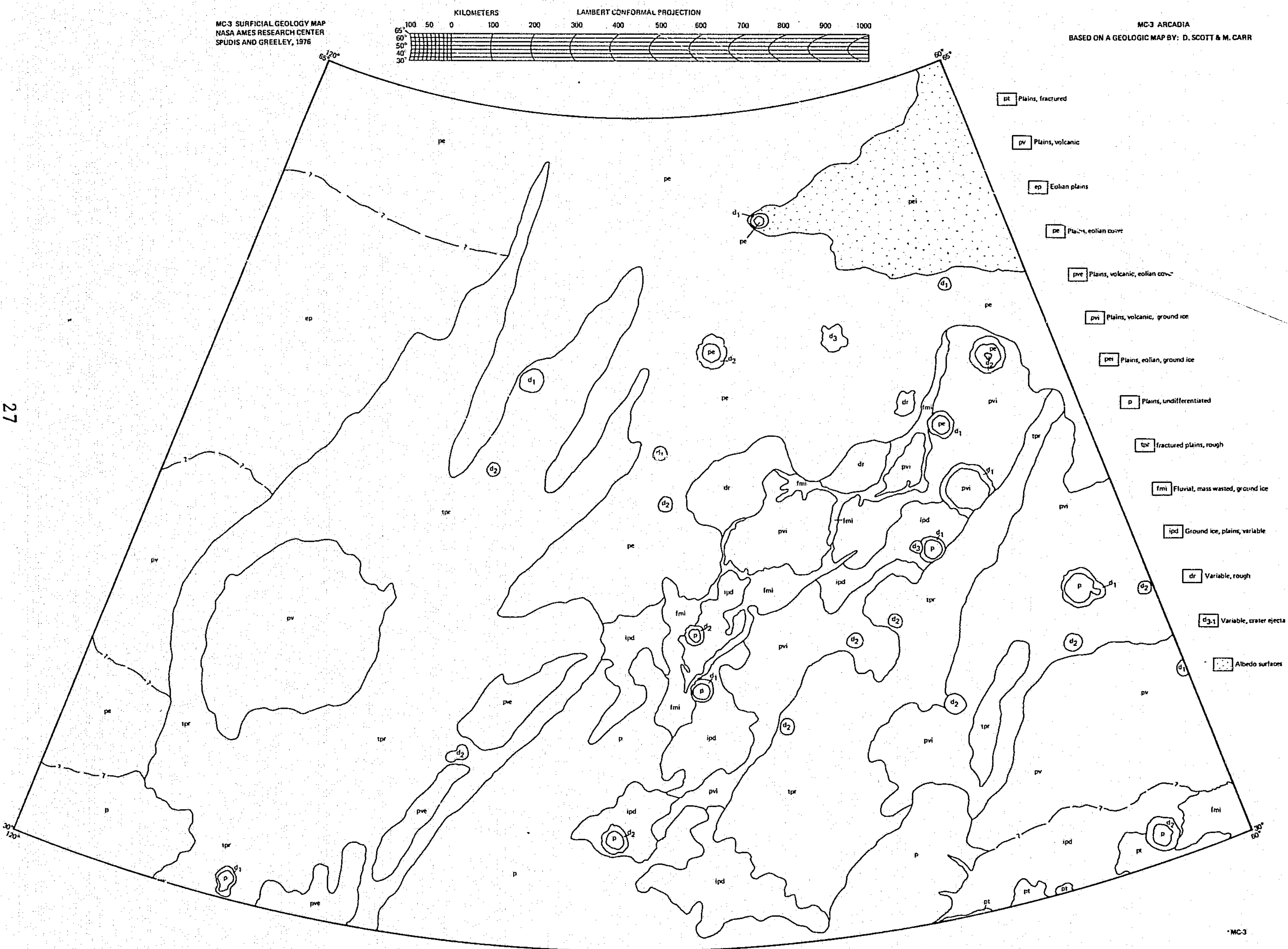
MC-1 MARE BOREUM
BASED ON A GEOLOGIC MAP BY: D. SCOTT & M. CARR

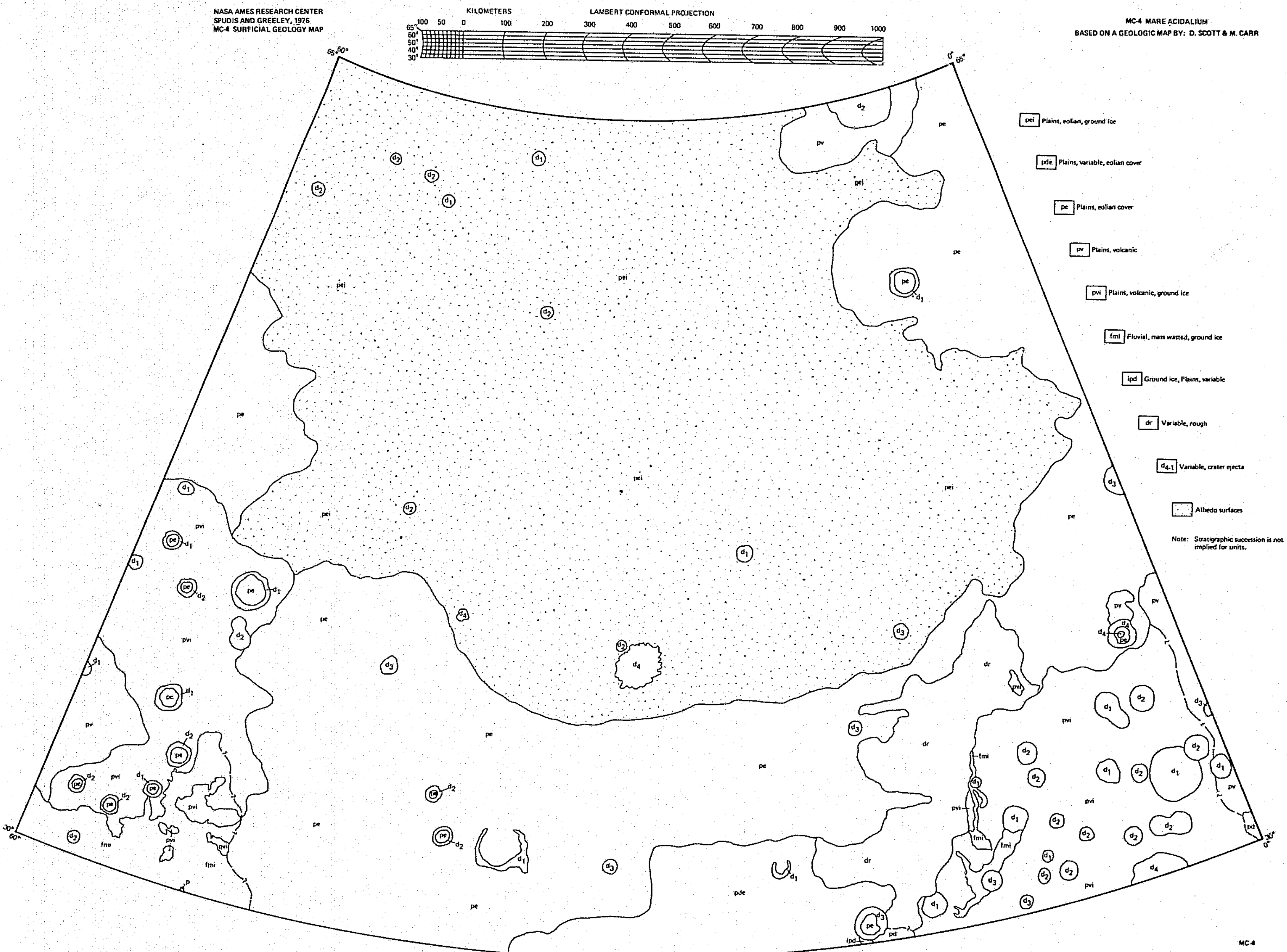


MC-2 SURFICIAL GEOLOGY MAP
AMES RESEARCH CENTER
AND GREELEY, 1976
KILOMETERS
LAMBERT CONFORMAL PROJECTION
MC-2 DIACRIA
BASED ON A GEOLOGIC MAP BY: D. SCOTT & M. CARR
pei Plains, eolian, ground ice
ep Eolian plains
pe Plains, eolian cover
pv Plains, volcanic
p Plains, undifferentiated
tpr Fractured plains, rough
dvr Variable, volcanic, rough
dr Variable, rough
d3-1 Variable, crater ejecta
Albedo surfaces
Note: Stratigraphic succession is not implied for units.
MC-2

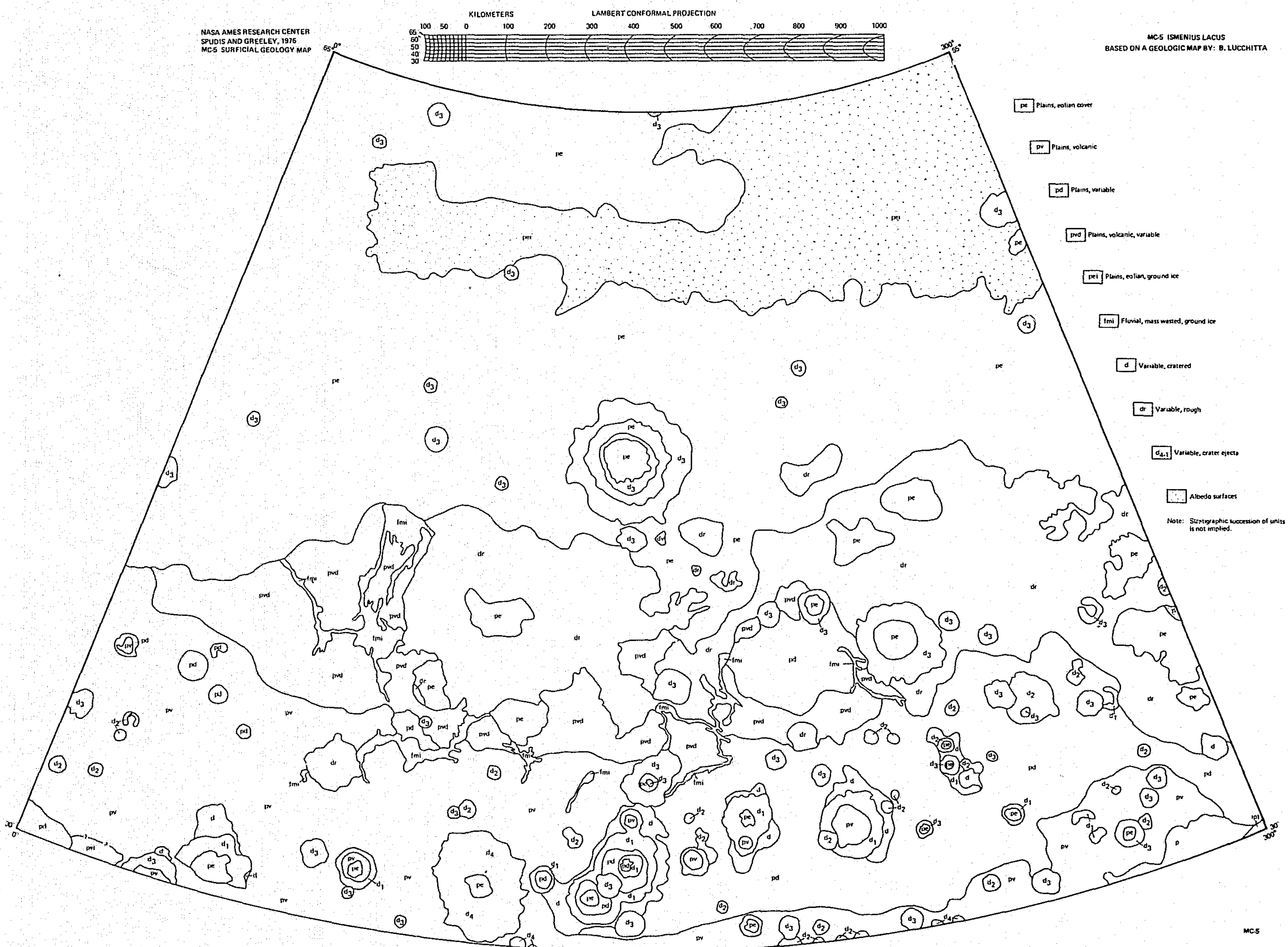
MC-3 SURFICIAL GEOLOGY MAP
NASA AMES RESEARCH CENTER
SPUDIS AND GREELEY, 1976

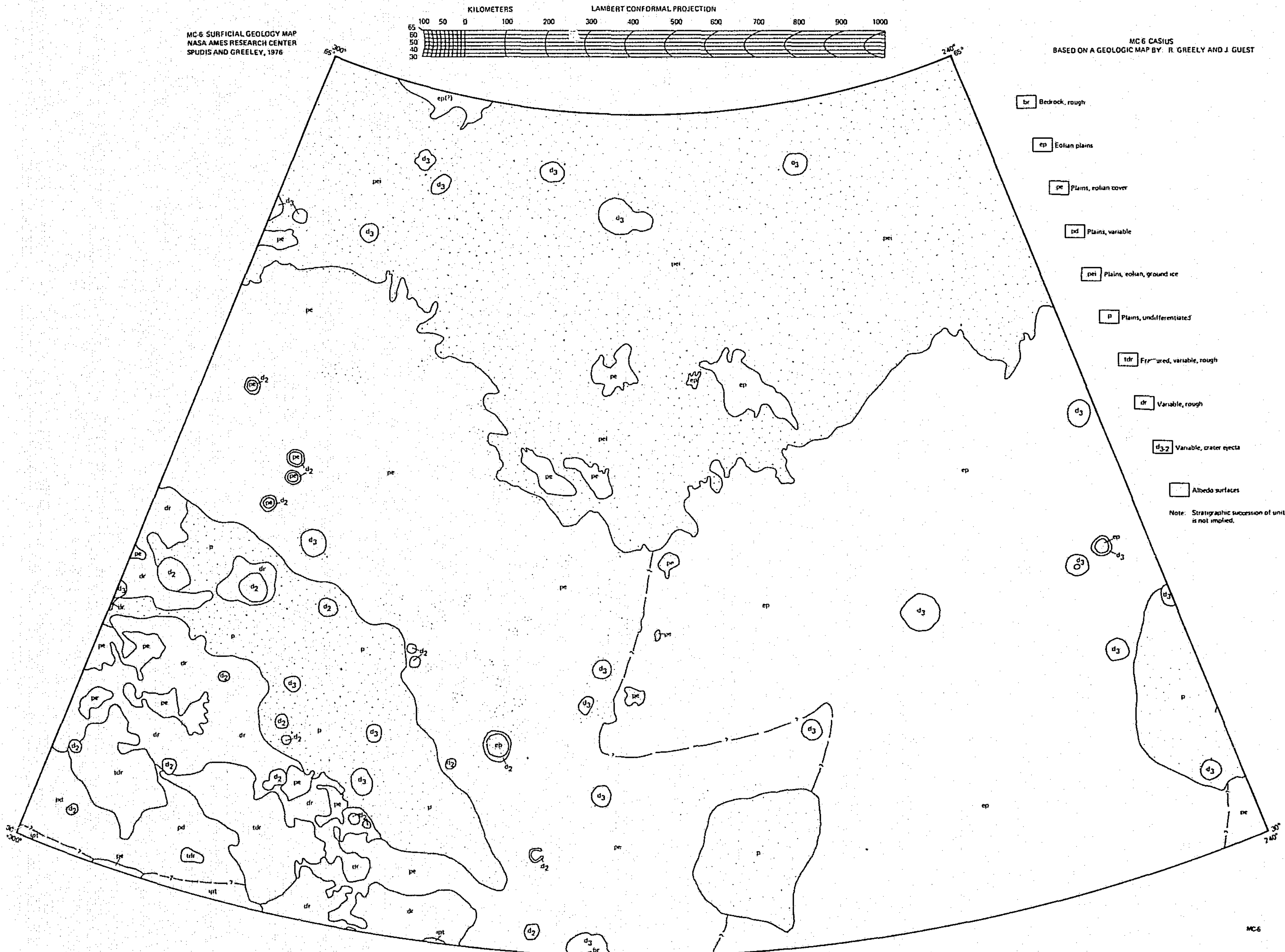
MC-3 ARCADIA
BASED ON A GEOLOGIC MAP BY: D. SCOTT & M. CARR

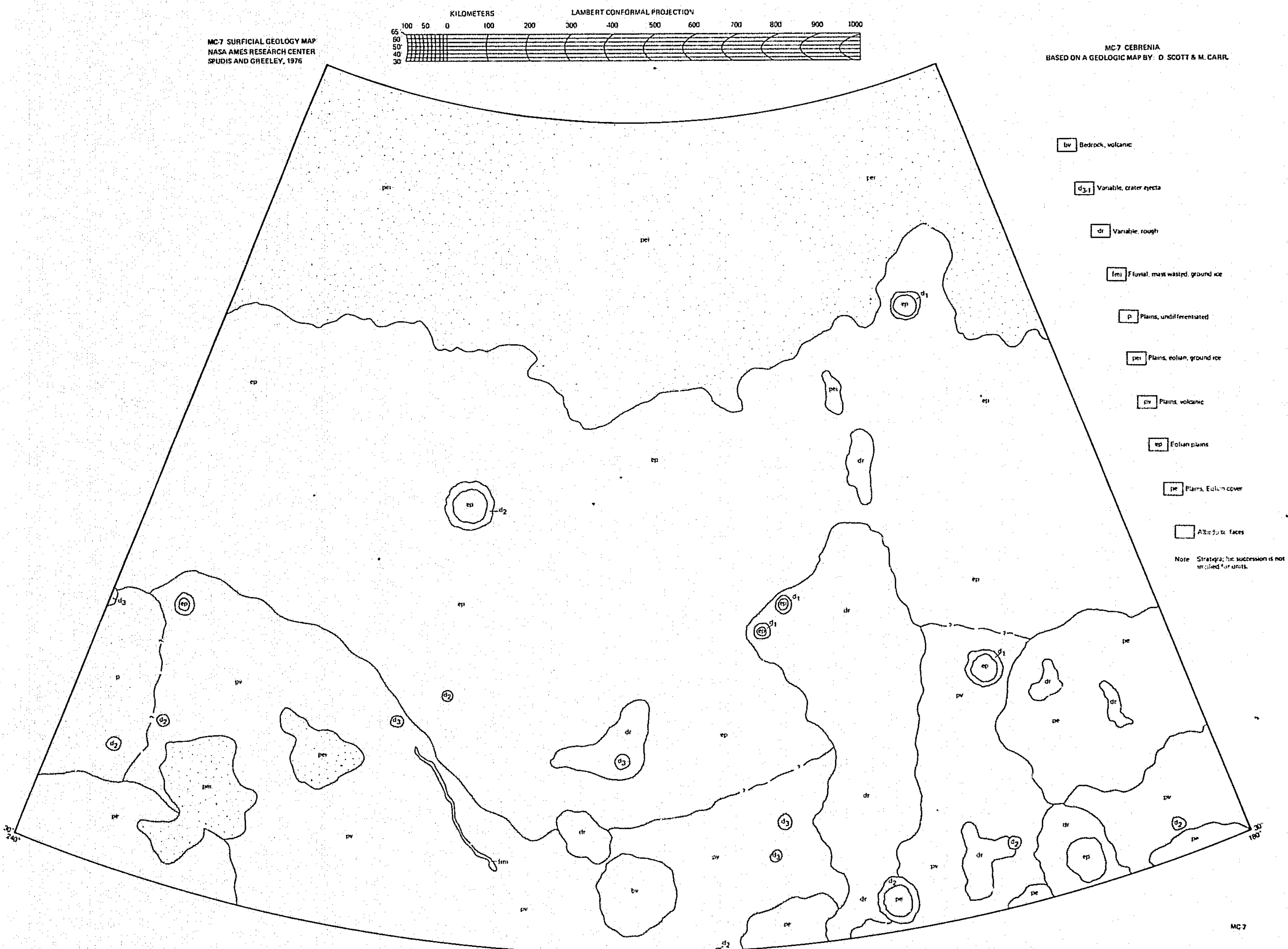




NASA AMES RESEARCH CENTER
SPUDIS AND GREELEY, 1976
MC-4 SURFICIAL GEOLOGY MAP
KILOMETERS
LAMBERT CONFORMAL PROJECTION
MC-4 MARE ACIDALIUM
BASED ON A GEOLOGIC MAP BY: D. SCOTT & M. CARR
pei Plains, eolian, ground ice
pde Plains, variable, eolian cover
pe Plains, eolian cover
pv Plains, volcanic
pvi Plains, volcanic, ground ice
fmi Fluvial, mass wasted, ground ice
ipd Ground ice, Plains, variable
dr Variable, rough
$d_{4\text{-}1}$ Variable, crater ejecta
Albedo surfaces
Note: Stratigraphic succession is not implied for units.
MC-4


NASA AMES RESEARCH CENTER
SPUDIS AND GREELEY, 1976
MC-5 SURFICIAL GEOLOGY MAP
KILOMETERS
LAMBERT CONFORMAL PROJECTION
100 50 0 100 200 300 400 500 600 700 800 900 1000
MC-5 ISMENIUS LACUS
BASED ON A GEOLOGIC MAP BY: B. LUCCHITTA
pe Plains, eolian cover
pv Plains, volcanic
pd Plains, variable
pvd Plains, volcanic, variable
pei Plains, eolian, ground ice
fmi Fluvial, mass wasted, ground ice
d Variable, cratered
dr Variable, rough
d4-1 Variable, crater ejecta
Albedo surfaces
Note: Stratigraphic succession of units is not implied.
MC-5

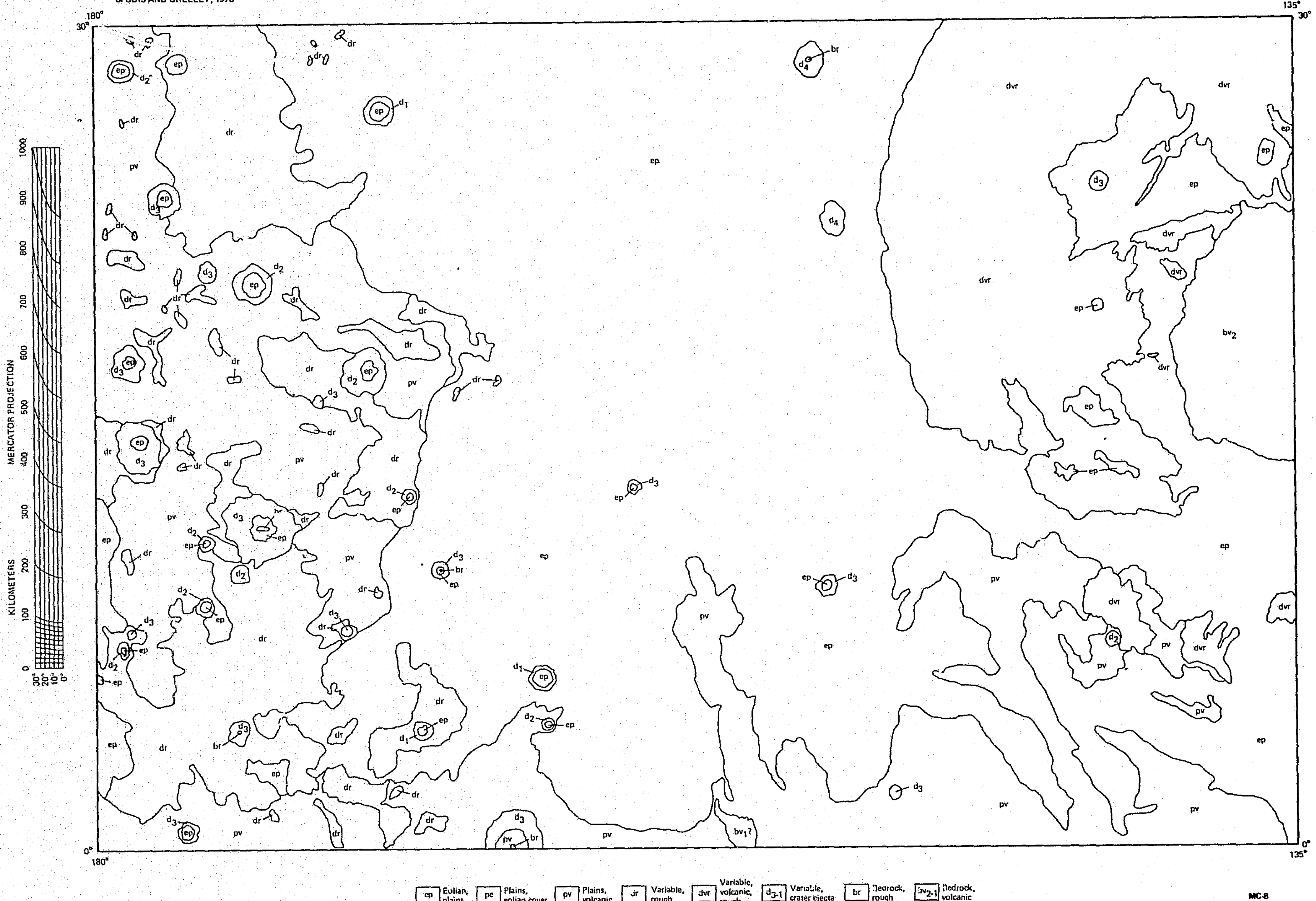

KILOMETERS
LAMBERT CONFORMAL PROJECTION
MC-6 SURFICIAL GEOLOGY MAP
NASA AMES RESEARCH CENTER
SPUDIS AND GREELEY, 1976
MC 6 CASIUS
BASED ON A GEOLOGIC MAP BY: R. GREELY AND J. GUEST
br Bedrock, rough
ep Eolian plains
pe Plains, eolian cover
pd Plains, variable
pei Plains, eolian, ground ice
p Plains, undifferentiated
tdr Fra~~ured, variable, rough
dr Variable, rough
d3-2 Variable, crater ejecta
Albedo surfaces
Note: Stratigraphic succession of units is not implied.
MC-6


MC-7 SURFICIAL GEOLOGY MAP
NASA AMES RESEARCH CENTER
SPUDIS AND GREELEY, 1976
KILOMETERS
LAMBERT CONFORMAL PROJECTION
100 50 0 100 200 300 400 500 600 700 800 900 1000
65 60 50 40 30
MC-7 CEBRENIA
BASED ON A GEOLOGIC MAP BY: D. SCOTT & M. CARR
bv Bedrock, volcanic
d_{3-1} Variable, crater ejecta
dr Variable, rough
fmi Fluvial, mass wasted, ground ice
p Plains, undifferentiated
pei Plains, eolian, ground ice
pv Plains, volcanic
ep Eolian plains
pe Plains, Eolian cover
MC-7

MC-8 SURFICIAL GEOLOGY MAP

NASA AMES RESEARCH CENTER
SPUDIS AND GREELEY, 1976

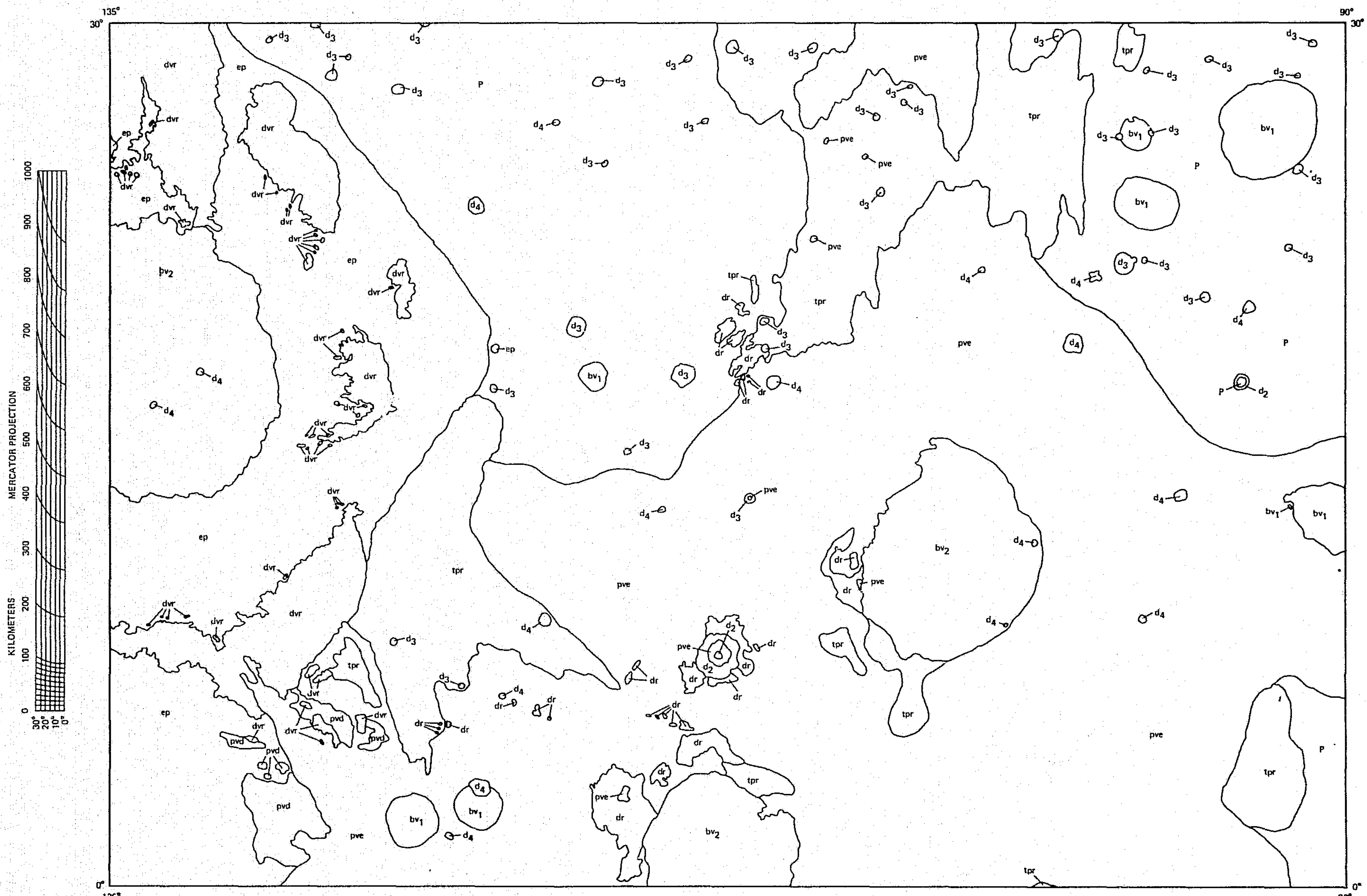
MC-8 AMAZONIS
BASED ON A GEOLOGIC MAP BY: S. DWORNIK & E. MORRIS



NASA AMES RESEARCH CENTER
SPUDIS AND GREELEY, 1976

MC-9 SURFICIAL GEOLOGY MAP

MC-9 THARSIS
BASED ON A GEOLOGIC MAP BY: M. CARR



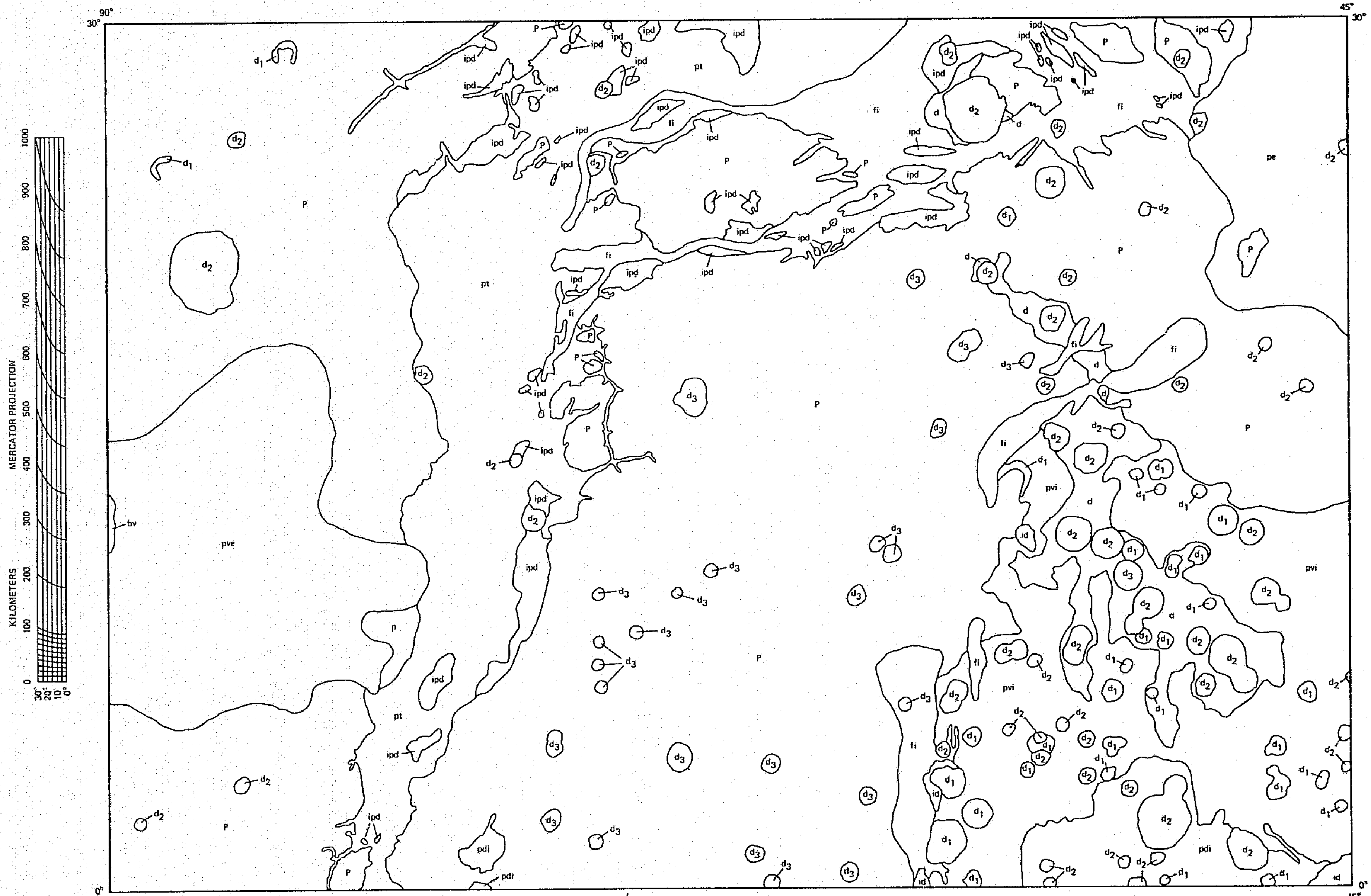
bv2-1 Bedrock, volcanic | ep Eolian plains | pve Plains, volcanic eolian cover | pvd Plains, volcanic variable | p Plains, undifferentiated | tpr Fractured plains, rough | d4-2 Variable, crater ejecta | dr Variable, rough | dvr Variable, rough volcanic

MC-9

NASA AMES RESEARCH CENTER
SPUDIS AND GREELEY, 1976

MC-10 SURFICIAL GEOLOGY MAP

MC-10 LUNAE PALUS
BASED ON A GEOLOGIC MAP BY: D. MILTON



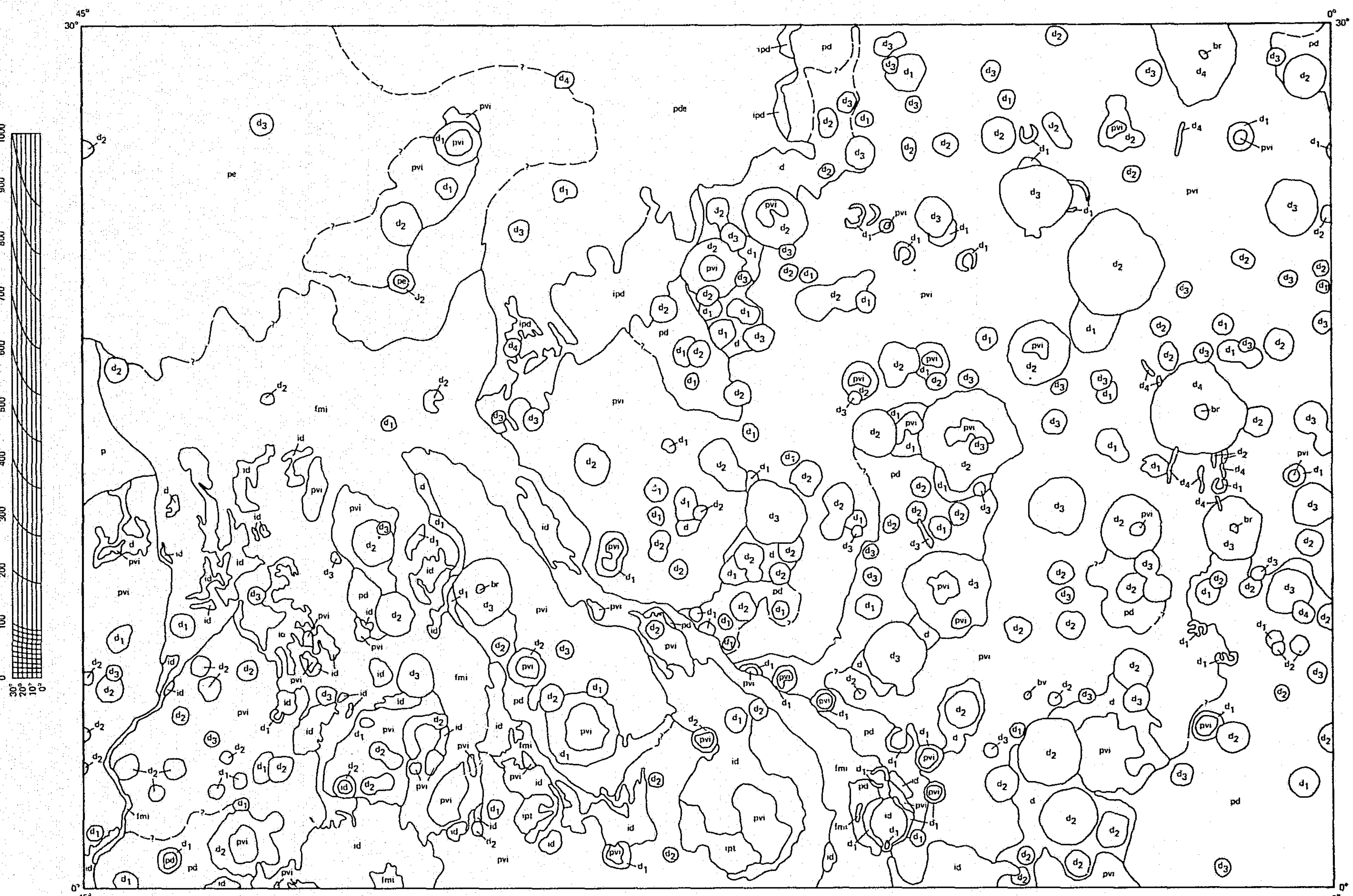
pe	Plains, eolian cover	pve	Plains, volcanic, eolian	pvi	Plains, volcanic, ground ice
pt	Plains, fractured	pdi	Plains, variable, ground ice	p	Plains, undifferentiated
id	Ground ice, variable	ipd	Ground ice, plains, variable	fi	Fluvial, ground ice
d	Variable, cratered	d_{3-1}	Variable, crater ejecta	bv	Bedrock, volcanic

MC-10

NASA AMES RESEARCH CENTER
- SPUDIS AND GREELEY, 1976

MC-11 SURFICIAL GEOLOGY MAP

MC-11 OXIA PALUS
BASED ON A GEOLOGICAL MAP BY: D. WILHELMS

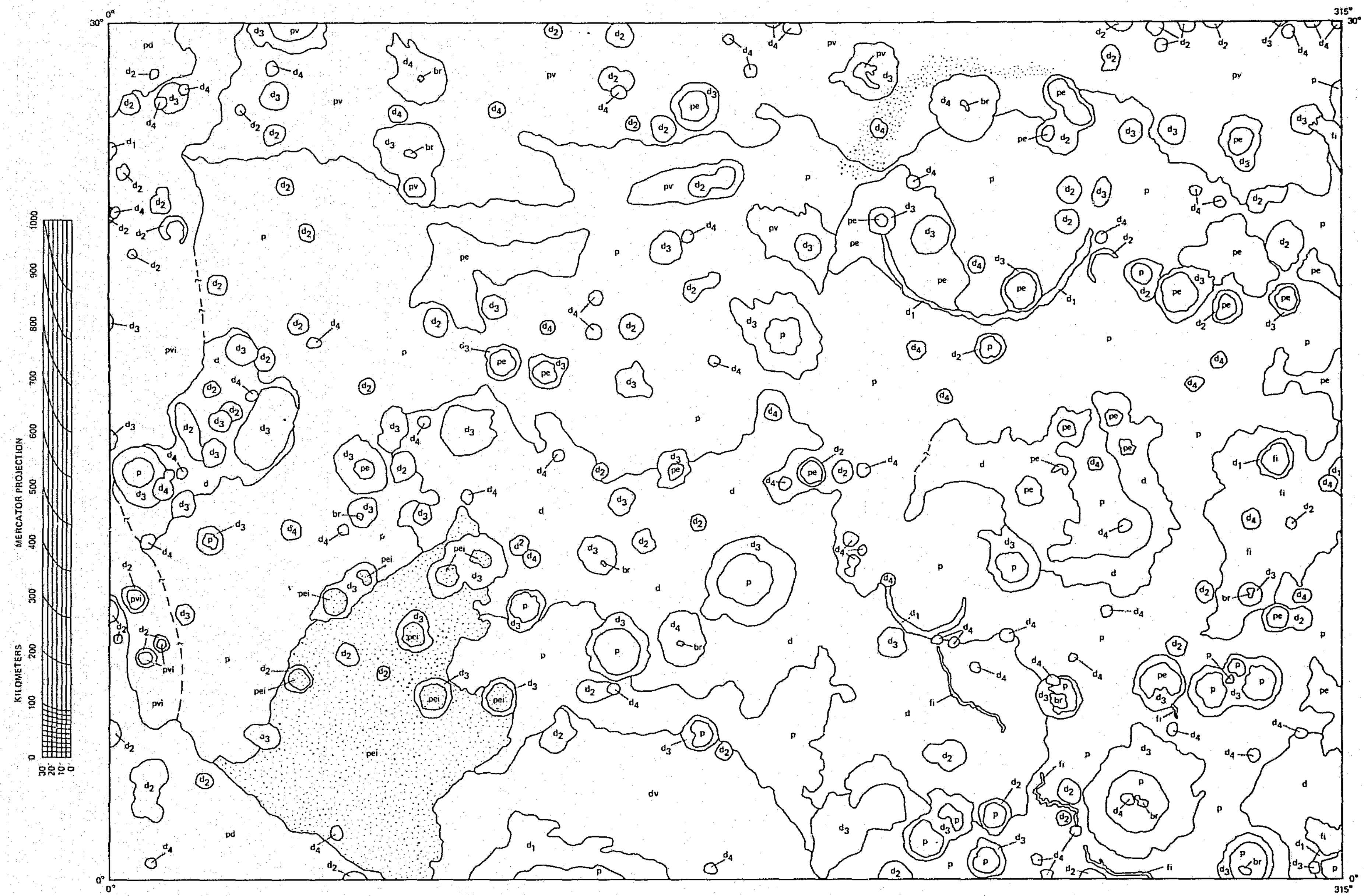


pe: Plains, eolian cover	pde: Plains, variable, eolian cover	id: Ground ice, variable	fmi: Fluvial, mass wasted ground ice	p: Plains, undifferentiated	pd: Plains, variable	pvi: Plains, volcanic, ground ice	ipd: Ground ice, plains, variable	d4-1: Variable, crater ejecta	d: Variable, cratered	br: Bedrock, rough	bv: Bedrock, volcanic	ipt: Ground ice, plains, fractured	MC-11

NASA AMES RESEARCH CENTER
SPUDIS AND GREELEY, 1976

MC 12 SURFICIAL GEOLOGY MAP

MC-12 ARABIA
BASED ON A GEOLOGIC MAP BY: J. KING



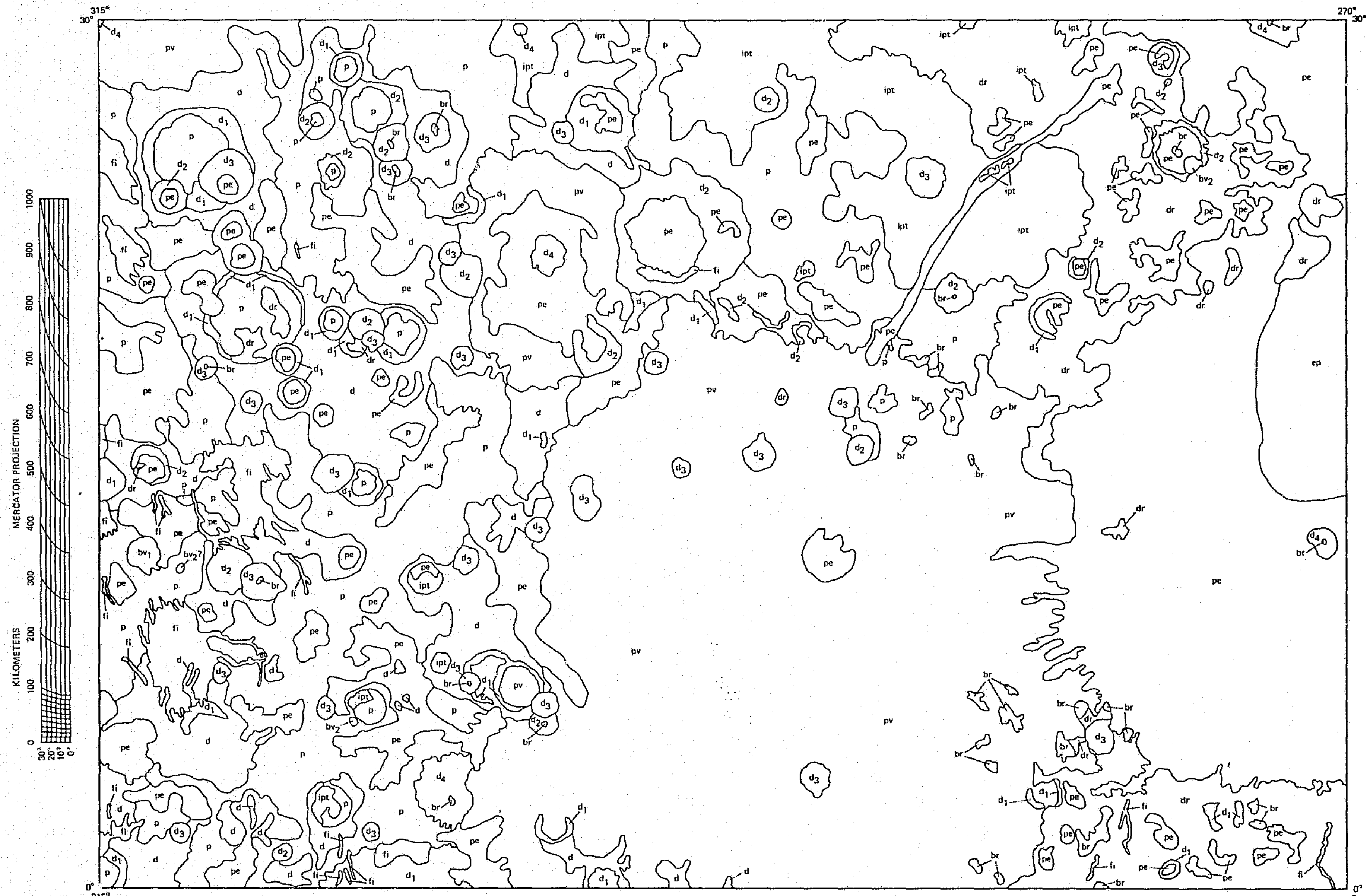
br	bedrock, rough
pe	plains, eolian cover
p	plains, undifferentiated
pd	plains, variable
pvi	plains, volcanic, ground ice
pv	plains, volcanic
pei	plains, eolian, ground ice
fi	fluvial, ground ice
dv	variable, volcanic
d	variable, cratered
d4-1	Variable, crater ejecta
(dotted)	Albedo surfaces

MC-12

NASA AMES RESEARCH CENTER
SPUDIS AND GREELEY, 1976

MC-13 SURFICIAL GEOLOGY MAP
10 JUNE, 1976

MC-13 SYRTIS MAJOR
BASED ON A GEOLOGIC MAP BY: MEYER & GROLIER



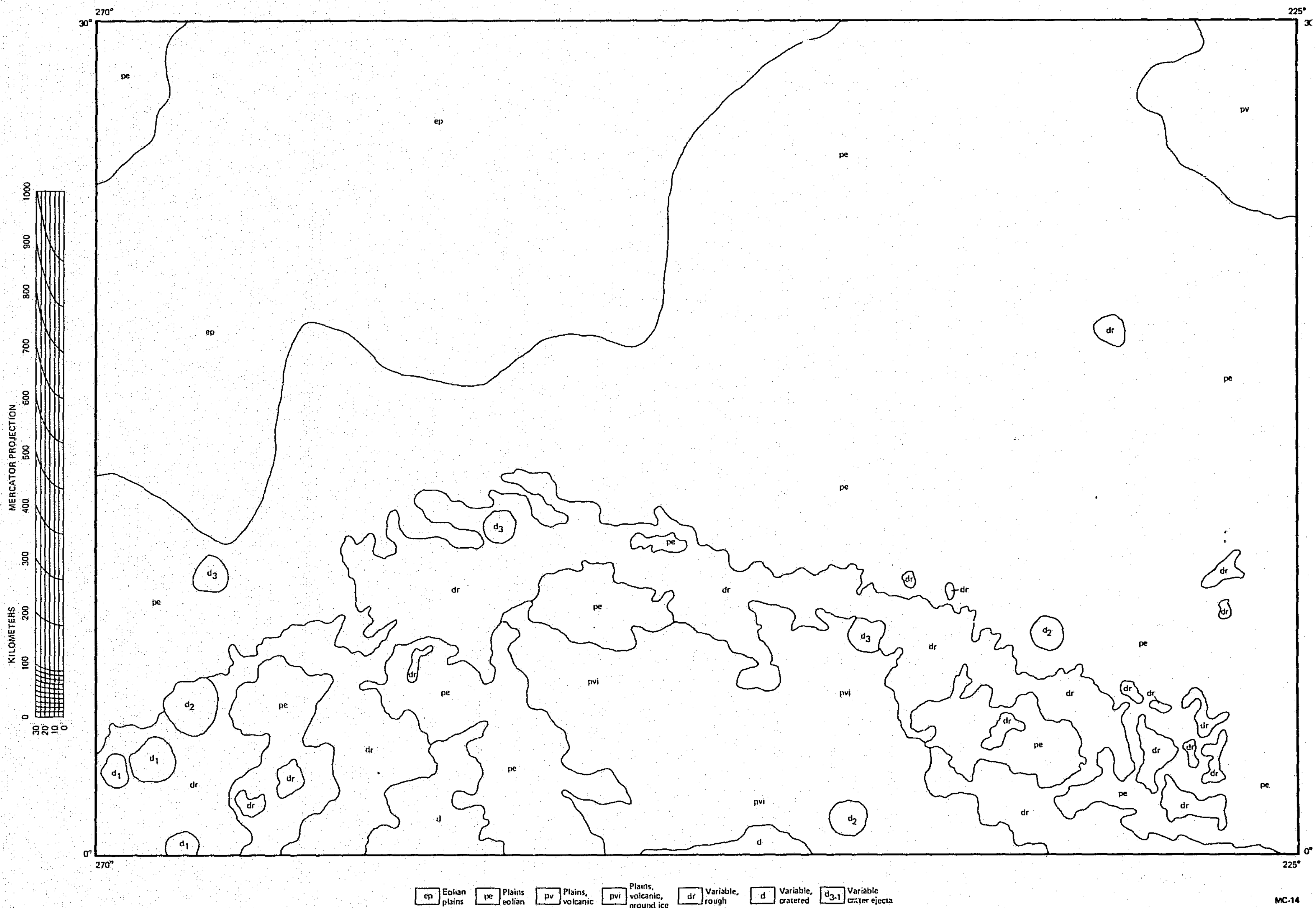
(blank)	Albedo surface
ep	Eolian plains
pe	Plains, eolian
pv	Plains, volcanic
p	Plains undifferentiated
ipt	Ground ice, plains, fractured
fi	Fluvial, ground ice
dr	Variable, rough
d	Variable, cratered
br	Bedrock, rough
bv	Bedrock, volcanic
d_{4-1}	Variable, crater ejecta

MC-13

NASA AMES RESEARCH CENTER
SPUDIS AND GREELEY, 1976

MC-14 SURFICIAL GEOLOGY MAP

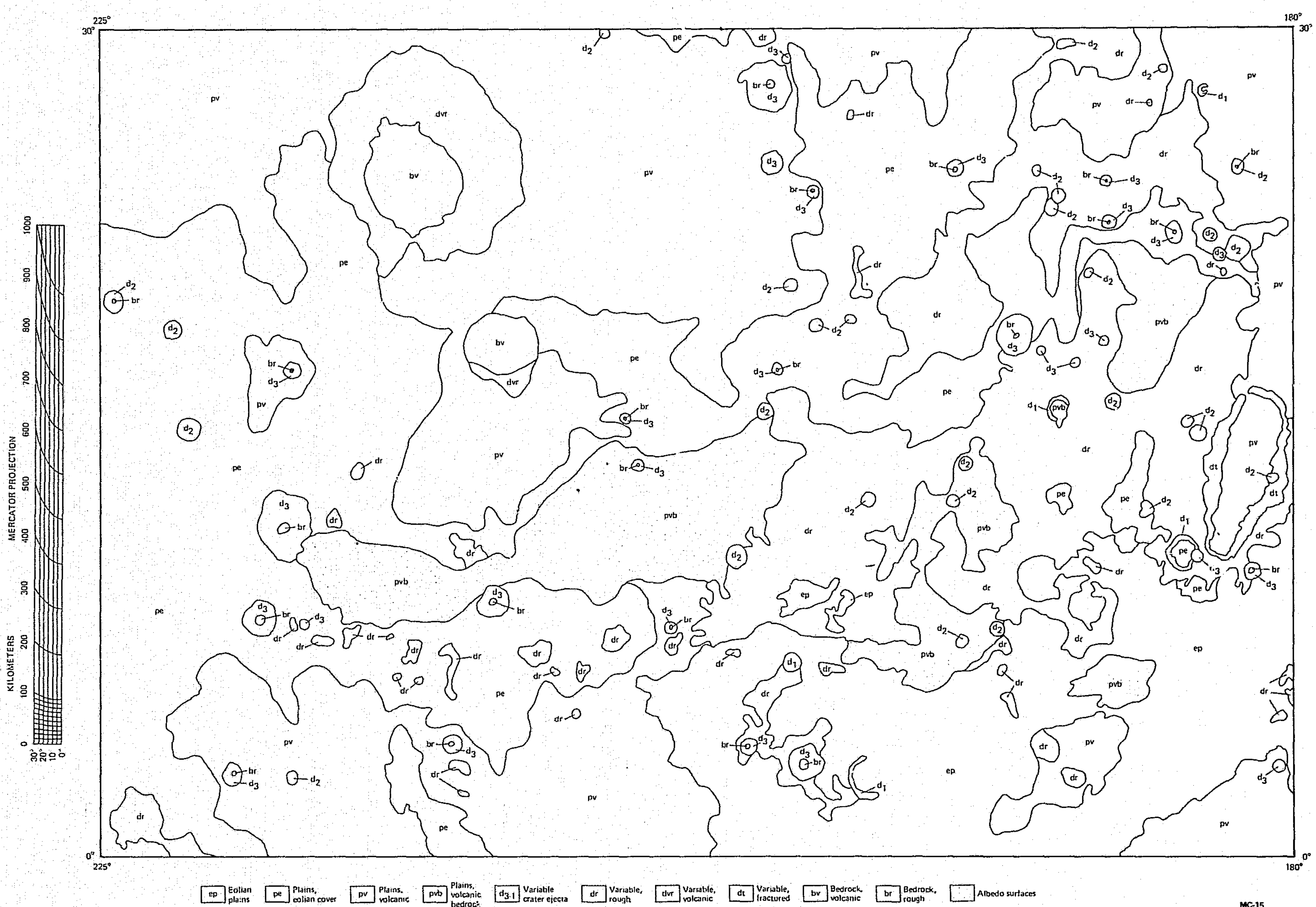
MC-14 AMENTHES
BASED ON A GEOLOGIC MAP BY: D. STUART-ALEXANDER



NASA AMES RESEARCH CENTER
SPUDIS AND GREELEY, 1976

MC-15 SURFICIAL GEOLOGY MAP

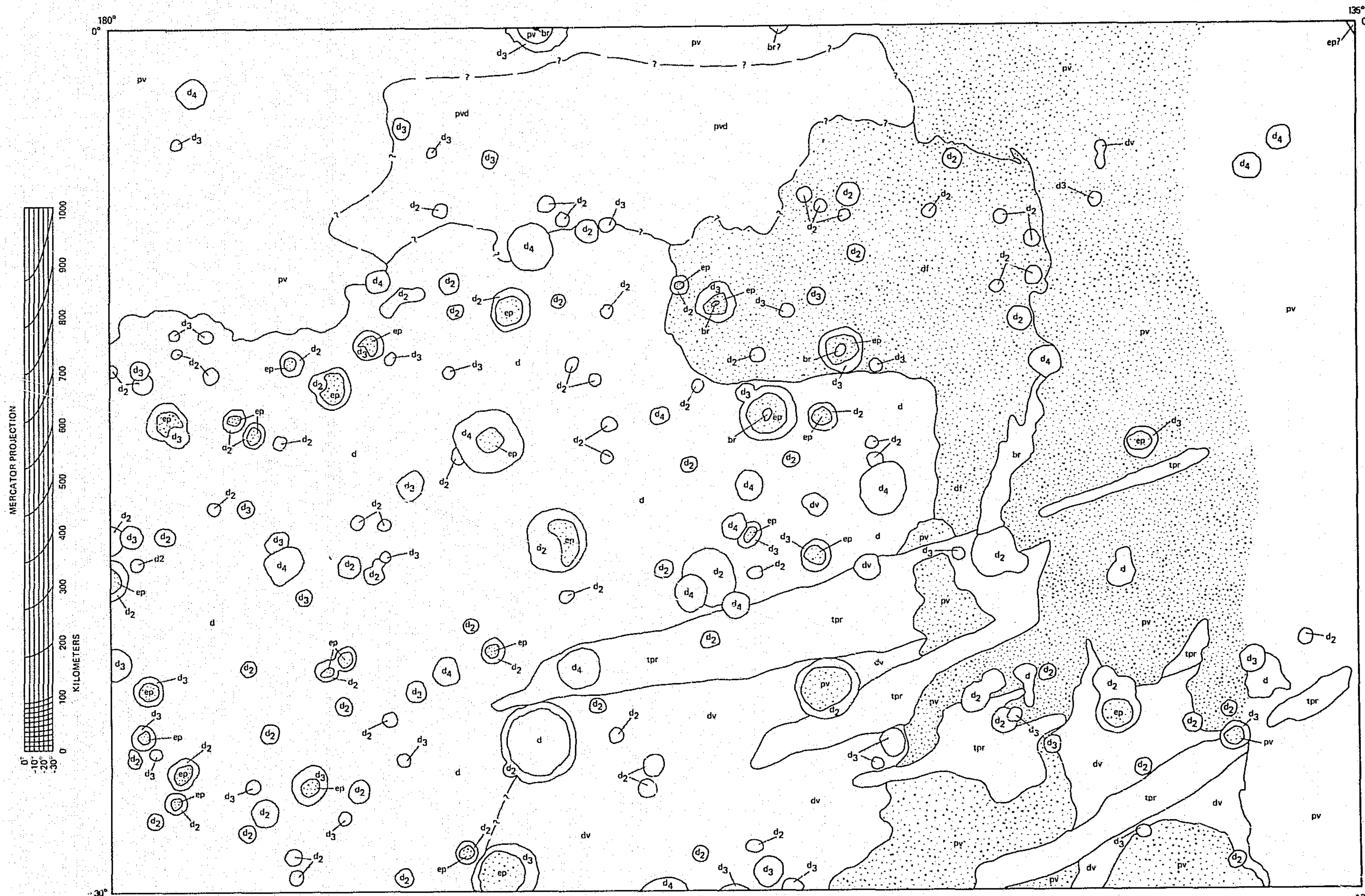
MC-15 ELYSIUM
BASED ON A GEOLOGIC MAP BY: J. ALLINGHAM & D. SCOTT



NASA AMES RESEARCH CENTER
SPUDIS AND GREELEY, 1976

MC-16 SURFICIAL GEOLOGY MAP

MC-16 MEMNONIA
BASED ON A GEOLOGIC MAP BY: T. MUTCH



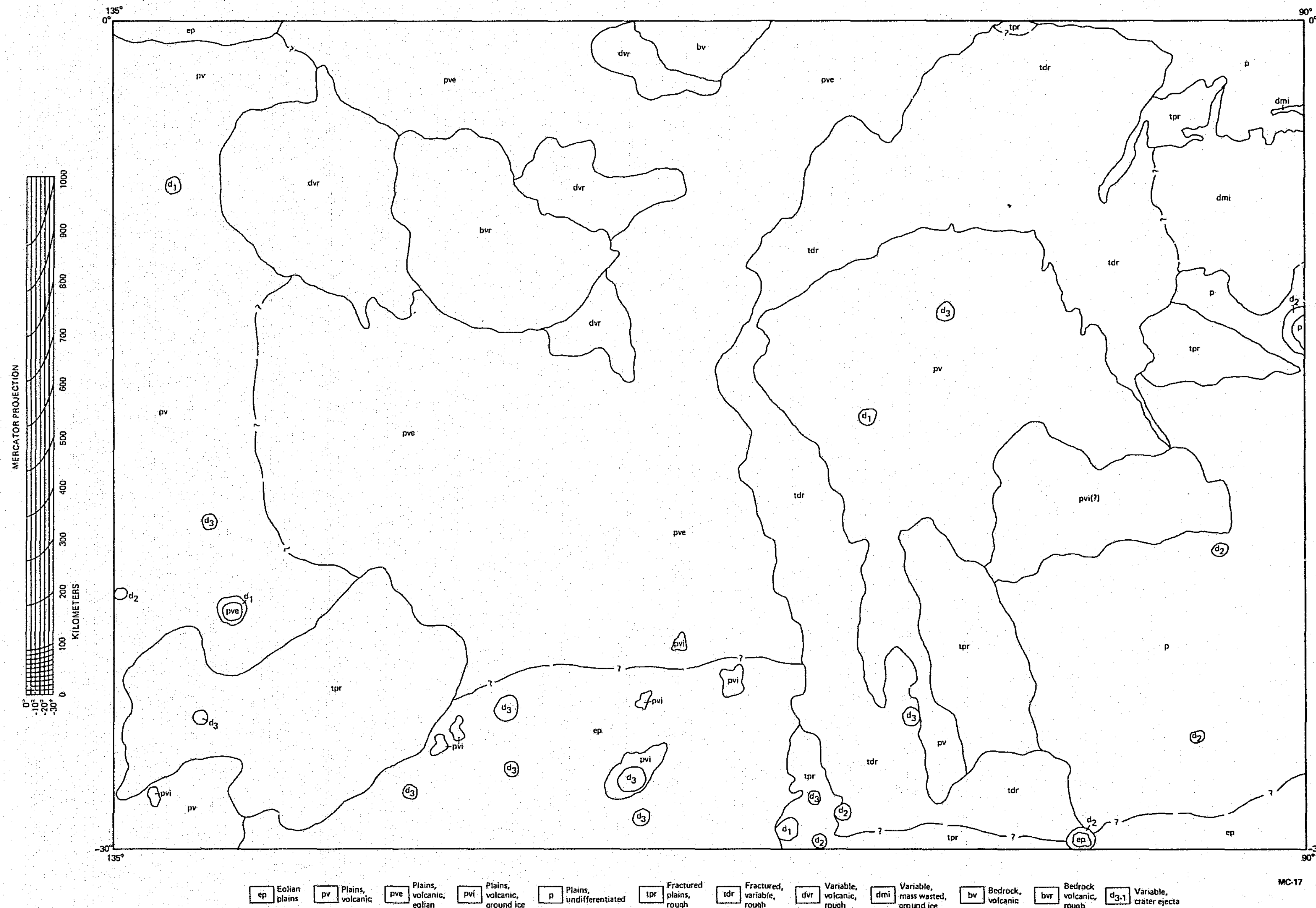
ep	Eolian plains	pv	Plains, volcanic	pvd	Plains, volcanic, variable	tpr	Fractured plains, rough	d	Variable, cratered	dv	Variable, volcanic	df	Variable, fluvial	d4-2	Variable crater ejecta	br	Bedrock, rough	⁚⁚	Albedo surfaces

MC-16

NASA AMES RESEARCH CENTER
SPUDIS AND GREELEY, 1976

MC-17 SURFICIAL GEOLOGY MAP

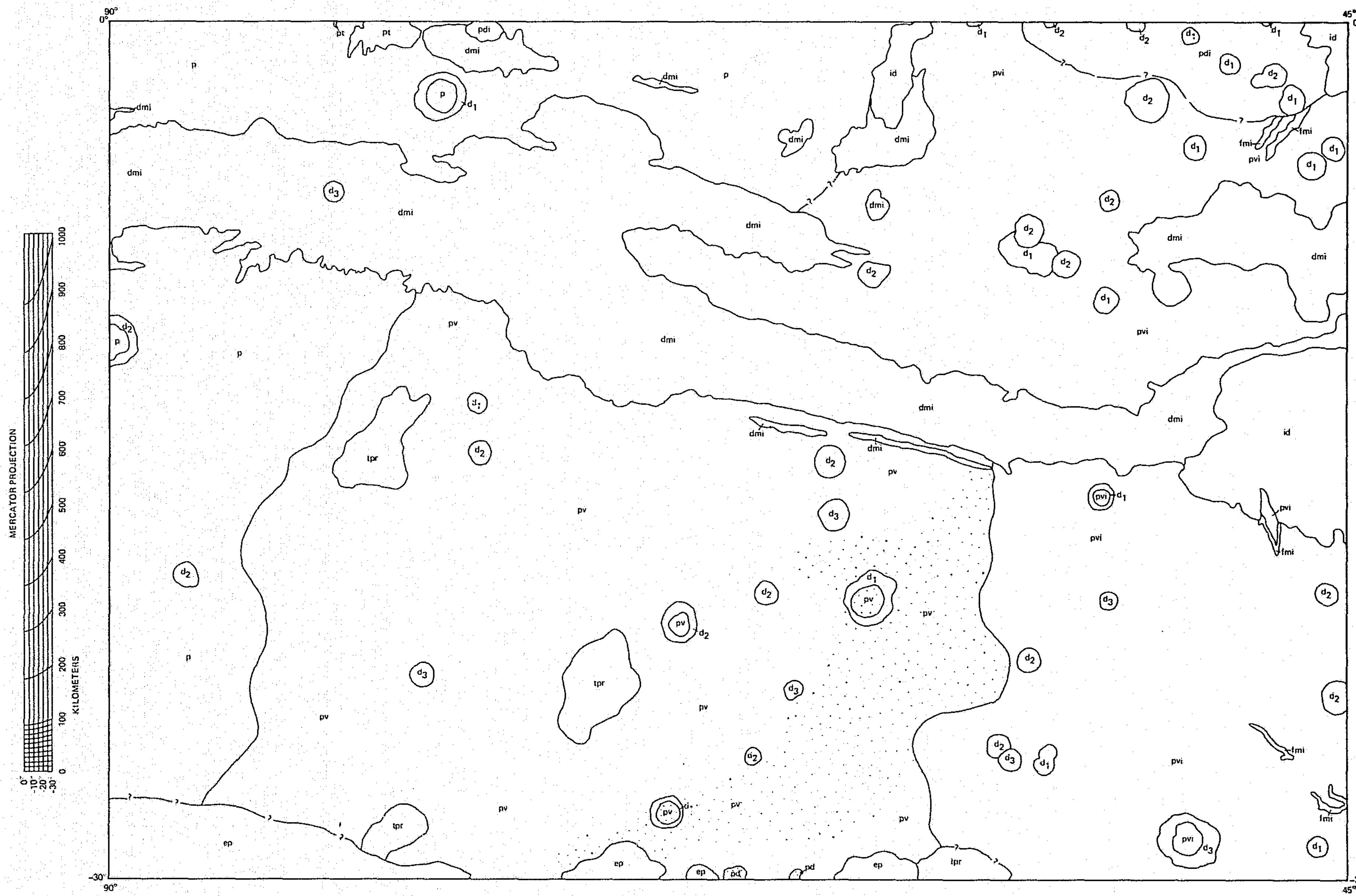
MC-17 PHOENICIS LACUS
BASED ON A GEOLOGIC MAP BY: D. SCOTT & M. CARR



NASA AMES RESEARCH CENTER
SPUDIS AND GREELEY, 1976

MC-18 SURFICIAL GEOLOGY MAP

MC-18 COPRATES
BASED ON A GEOLOGIC MAP BY: D. SCOTT & M. CARR



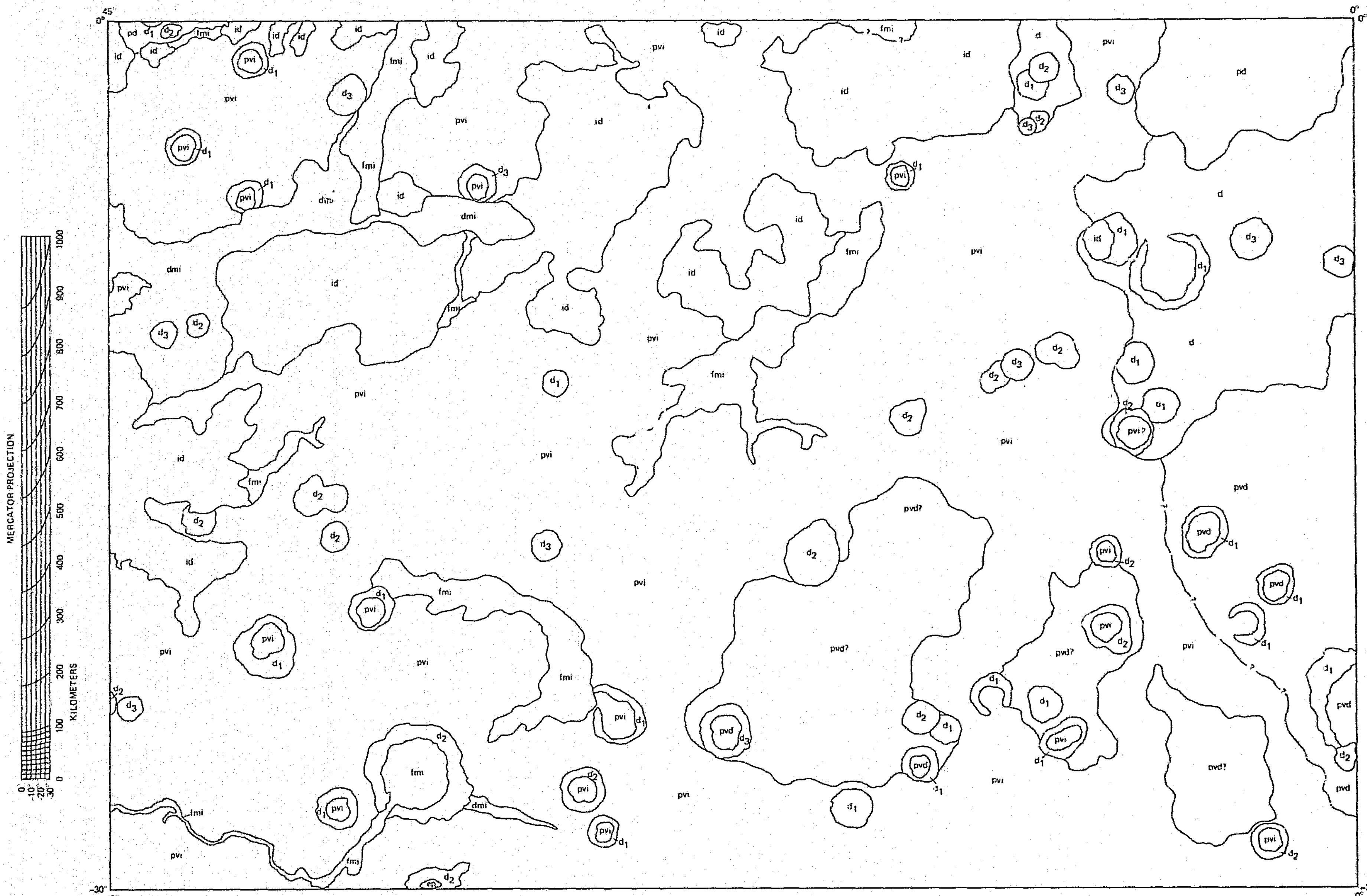
· ·	Albedo surfaces
ep	Eolian plains
pv	Plains, volcanic
pvi	Plains, volcanic, ground ice
pd	Plains, variable
p	Plains, undifferentiated
pdi	Plains variable, ground ice
pt	Plains, fractured
fmi	Fluvial, mass wasted, ground ice
id	Ground ice, variable
tpr	Fractured plains, rough
dmi	Variable mass wasted, ground ice
d_{3-1}	Variable, crater ejecta

MC-18

NASA AMES RESEARCH CENTER
SPUDIS AND GREELEY, 1976

MC-19 SURFICIAL GEOLOGY MAP

MC-19 MARGARITIFER SINUS
BASED ON A GEOLOGIC MAP BY: R. S. SAUNDERS



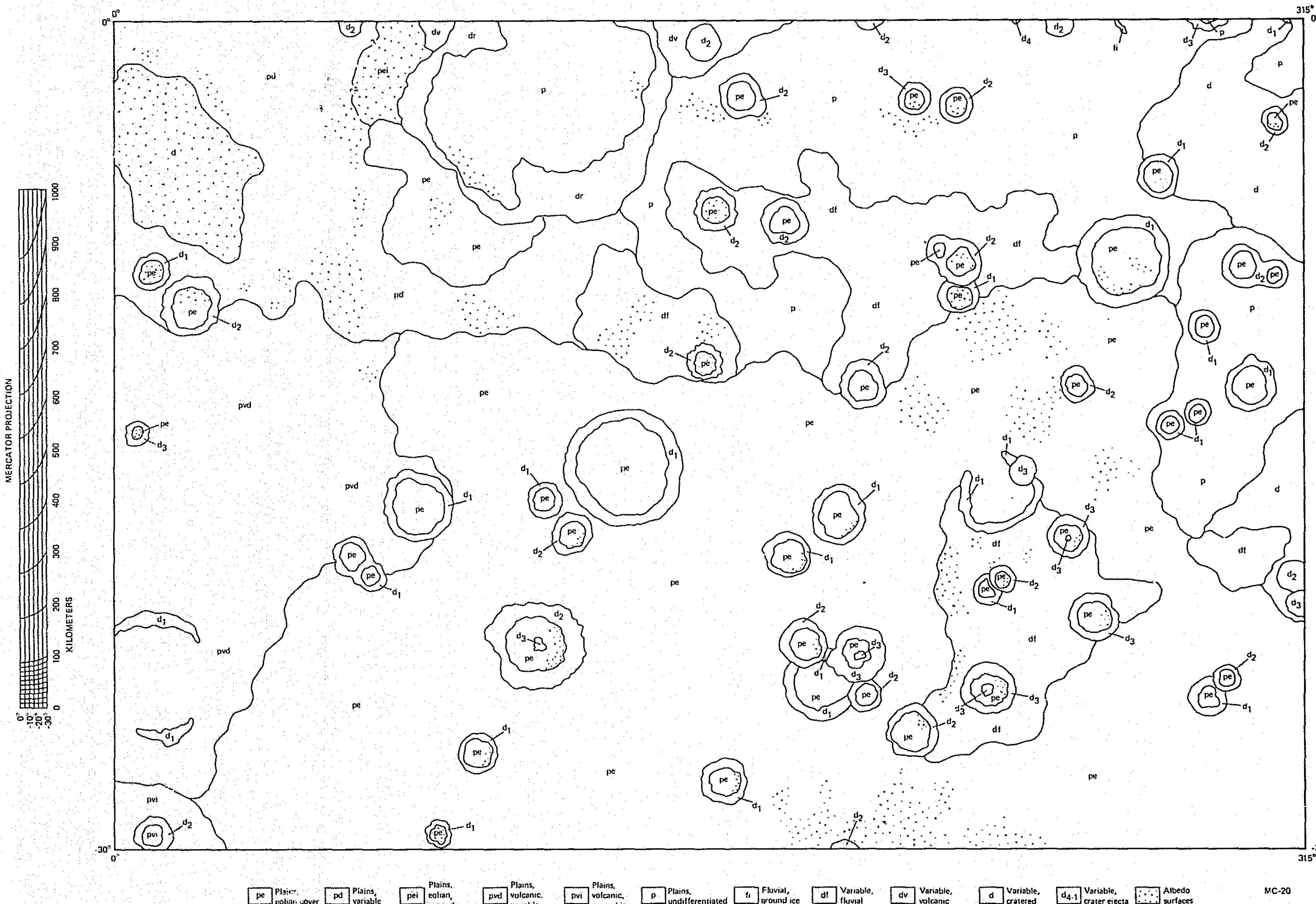
ep Eolian plains	pvi Plains volcanic, ground ice	pvd Plains volcanic, variable	pd Plains, variable	id Ground ice, variable	fmi Fluvial, mass wasted, ground ice	d Variable, cratered	dmi Variable mass wasted, ground ice	d_{3-1} Variable, crater ejecta	

MC-19

NASA AMES RESEARCH CENTER
SPUDIS AND GREELEY, 1976

MC-20 SURFICIAL GEOLOGY MAP

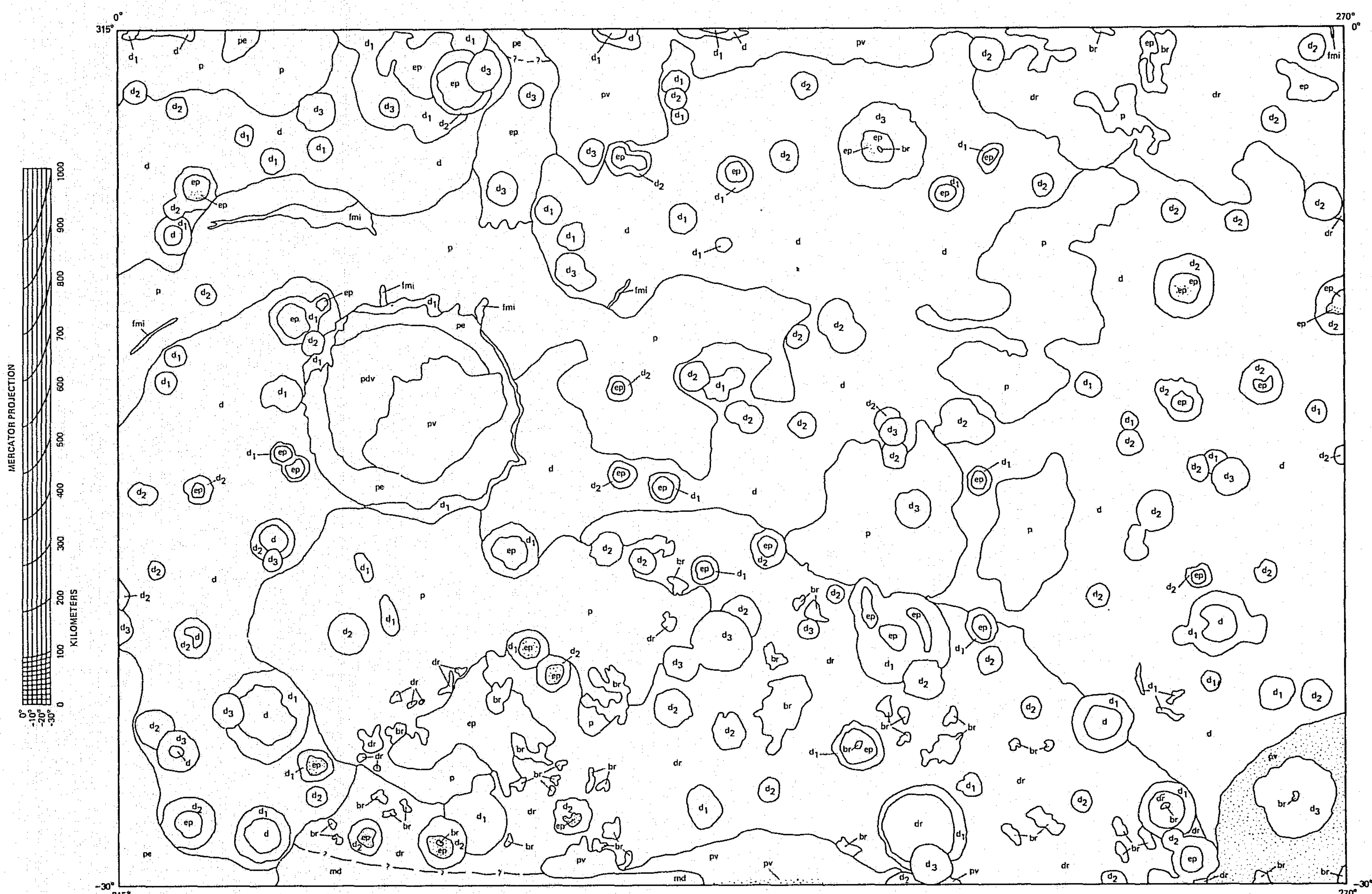
MC-20 SINUS SABAEUS
BASED ON A GEOLOGIC MAP BY: D. SCOTT AND M. CARR



NASA AMES RESEARCH CENTER
SPUDIS AND GREELEY, 1976

MC-21 SURFICIAL GEOLOGY MAP

MC-21 IAPYGIA
BASED ON A GEOLOGIC MAP BY: G. SCHABER



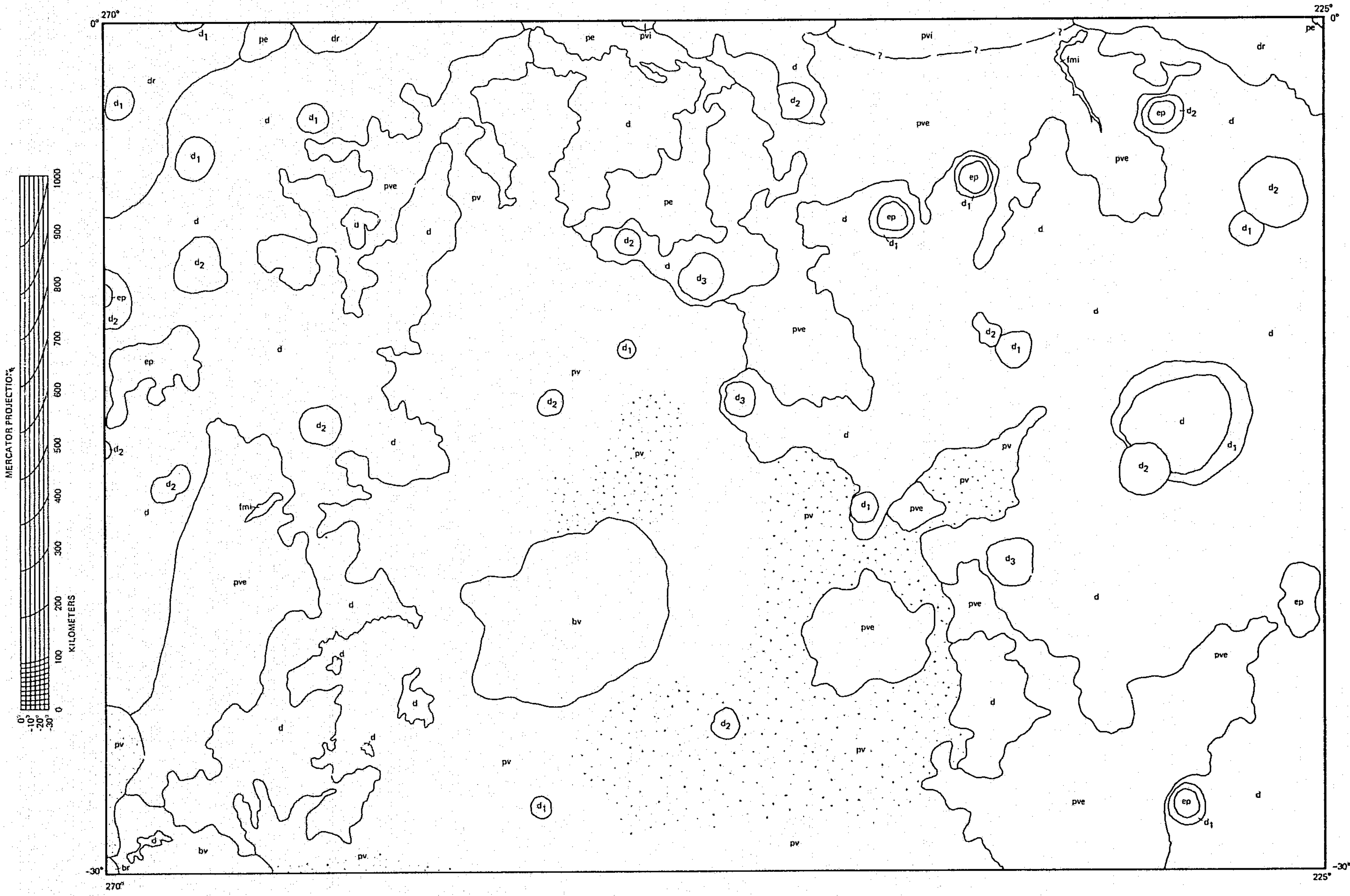
ep	eolian plains
pv	plains, volcanic
p	plains, undifferentiated
pdv	plains, variable, volcanic
pe	Plains, eolian cover
md	mass wasted, variable
fmi	fluvial, mass wasted, ground ice
d	variable, cratered
dr	variable, rough
br	bedrock, rough
d3-1	variable, crater ejecta
(stippled)	albedo surfaces

MC-21

NASA AMES RESEARCH CENTER
SPUDIS AND GREELEY, 1976

MC-22 SURFICIAL GEOLOGY MAP

MC-22 MARE TYRRHENUM
BASED ON A GEOLOGIC MAP BY: E. KING



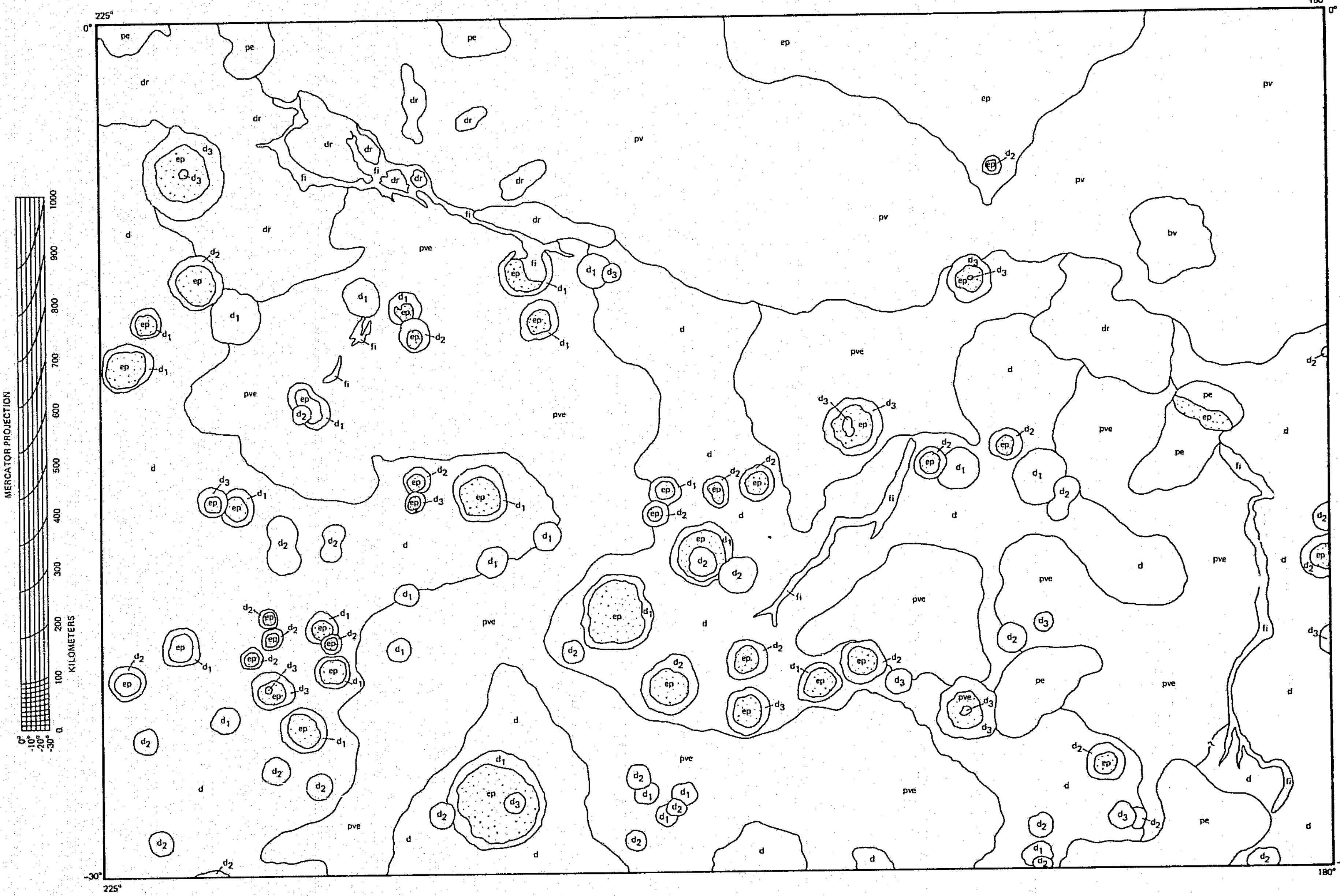
MC-22

pe	Plains eolian
ep	Eolian plains
pv	Plains, volcanic
	Albedo surfaces
pve	Plains, volcanic, eolian
pvi	Plains, volcanic, ground ice
fmi	Fluvial, mass wasted, ground ice
dr	Variable, rough
d	Variable, cratered
$d_{3\text{-}1}$	Variable, crater ejecta
bv	Bedrock, volcanic

NASA AMES RESEARCH CENTER
SPUDIS AND GREELEY, 1976

MC-23 SURFICIAL GEOLOGY MAP

MC-23 AEOLIS
BASED ON A GEOLOGIC MAP BY: D. SCOTT & M. CARR

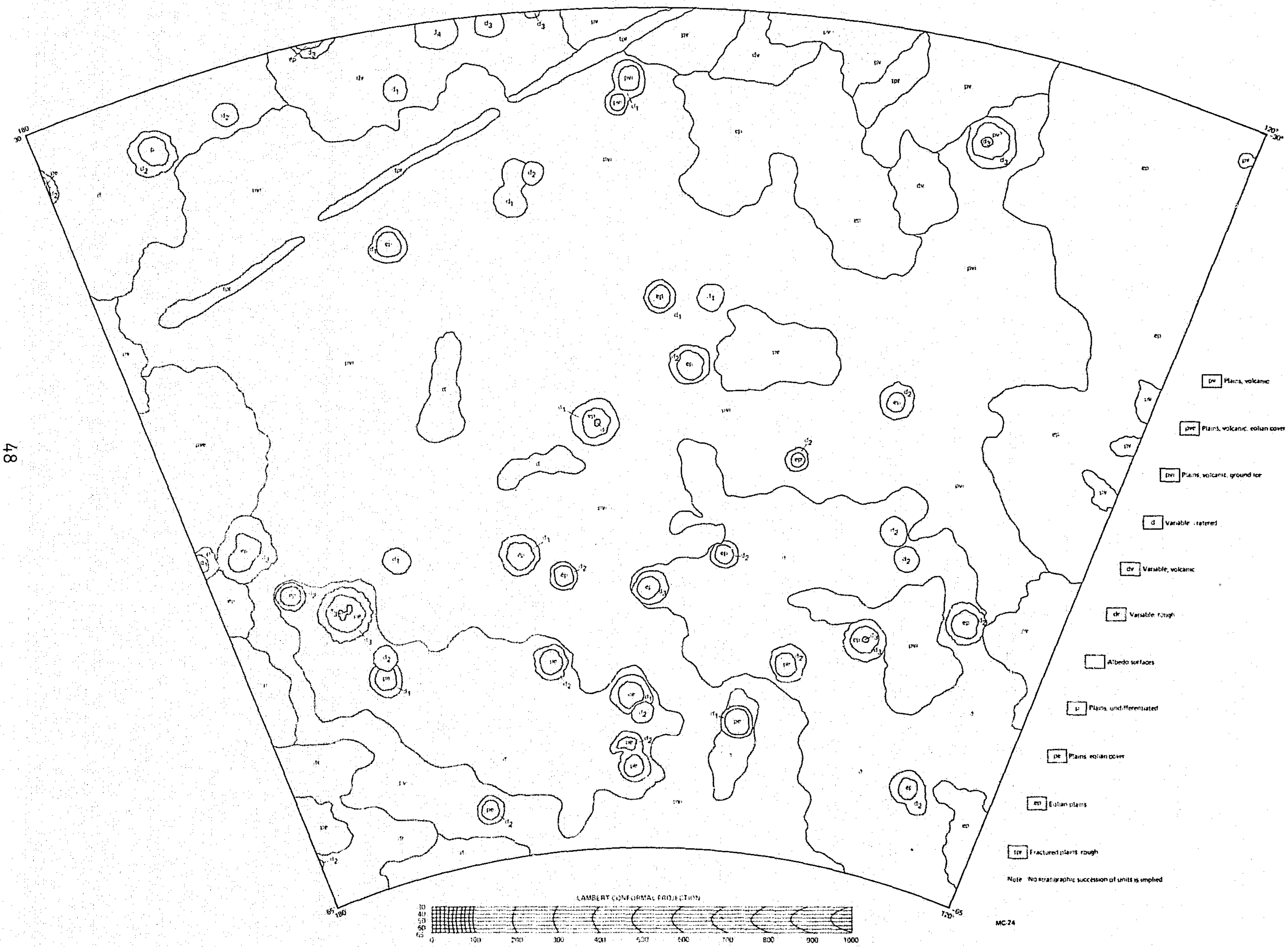


bv Bedrock, volcanic | ep Eolian plains | Albedo surfaces | pe Plains, eolian | pv Plains volcanic | pve Plains, volcanic, eolian cover | fi Fluvial, ground ice | dr Variable, rough | d Variable, cratered | d_{3-1} Variable, crater ejecta

MC-23

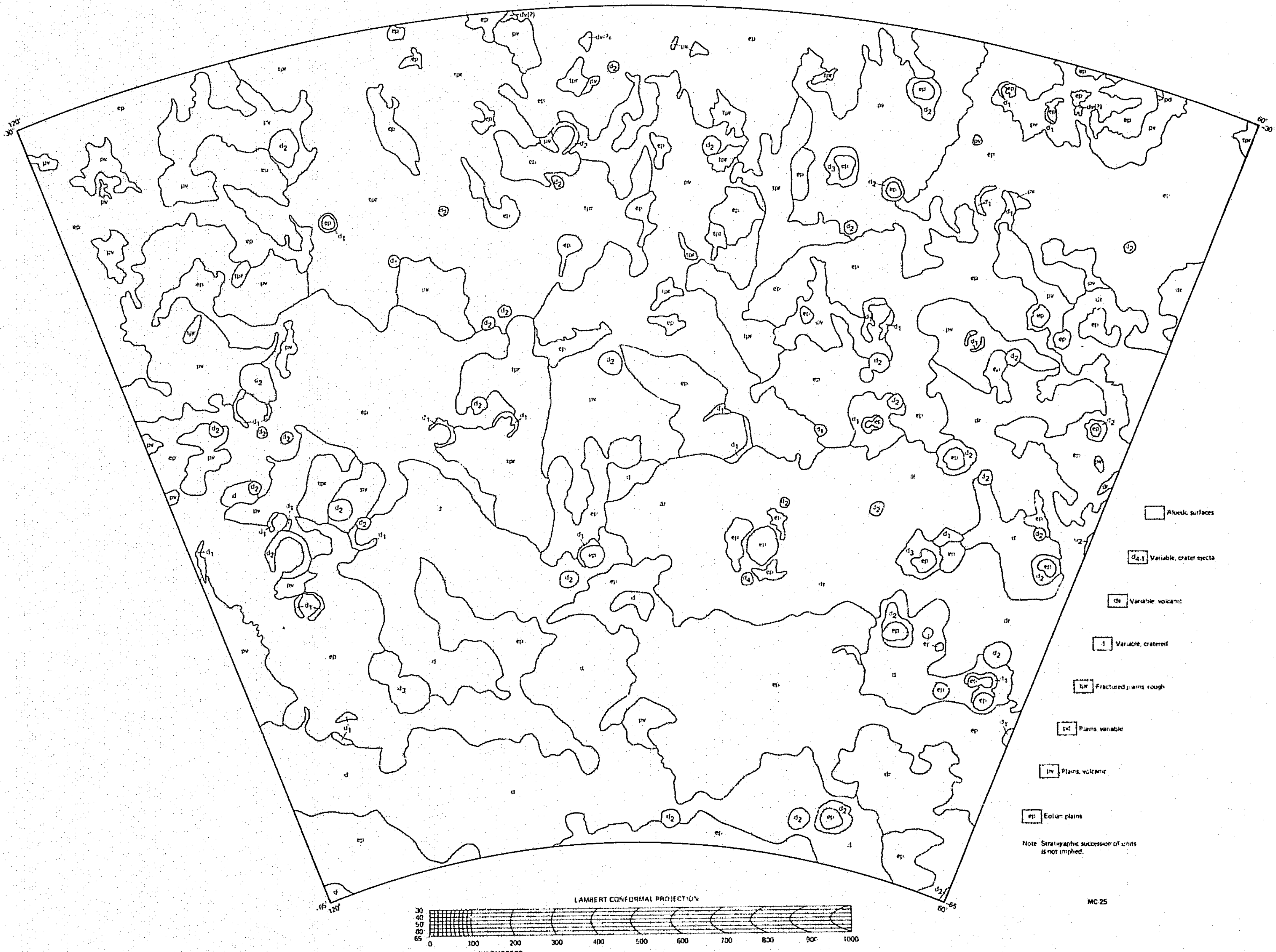
MC 24 SURFICIAL GEOLOGY MAP
NASA AMES RESEARCH CENTER
SPUDIS AND GREELEY, 1976

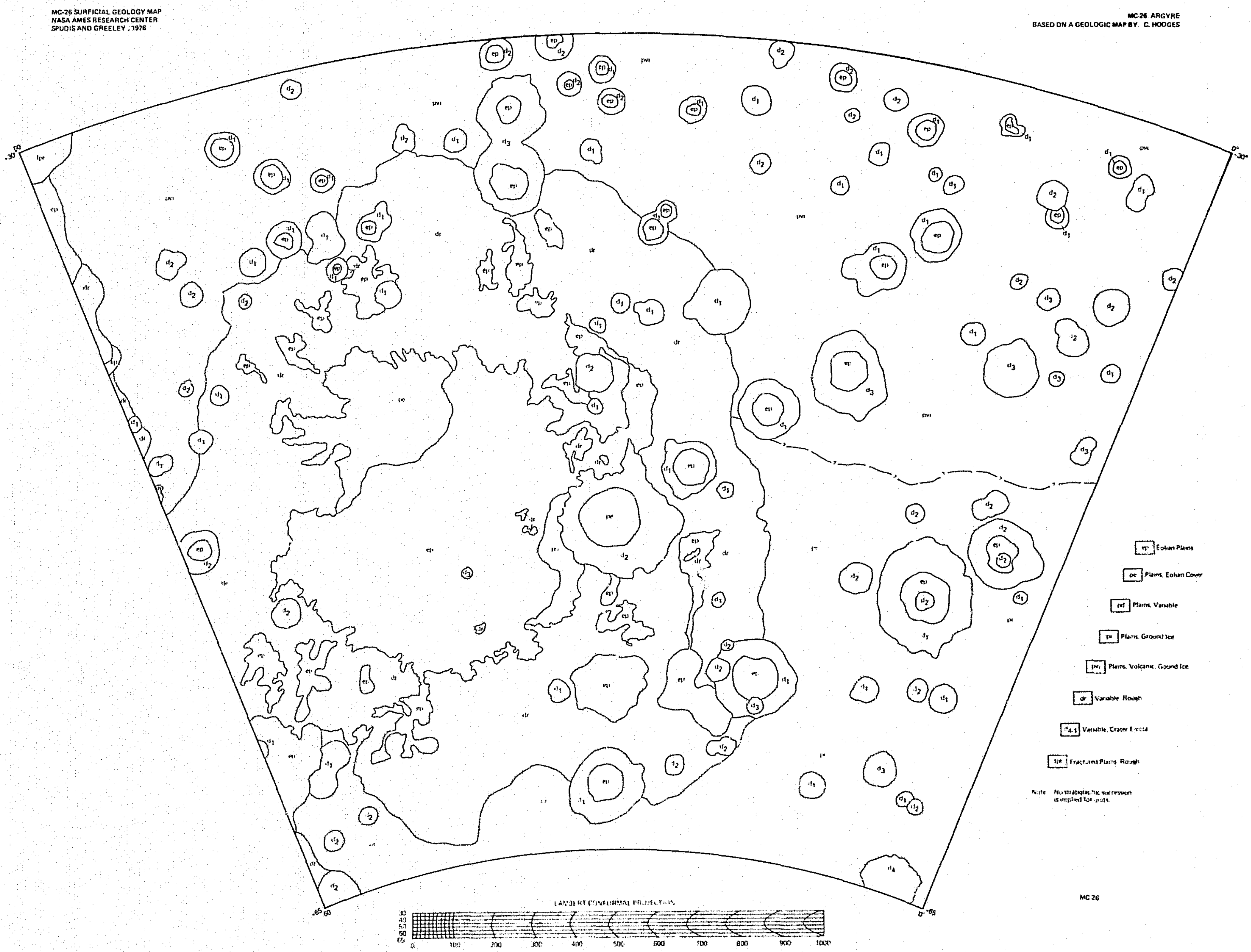
MC-24 PHAETHONTIS
BASED ON A GEOLOGIC MAP BY: D. SCOTT & M. CARR

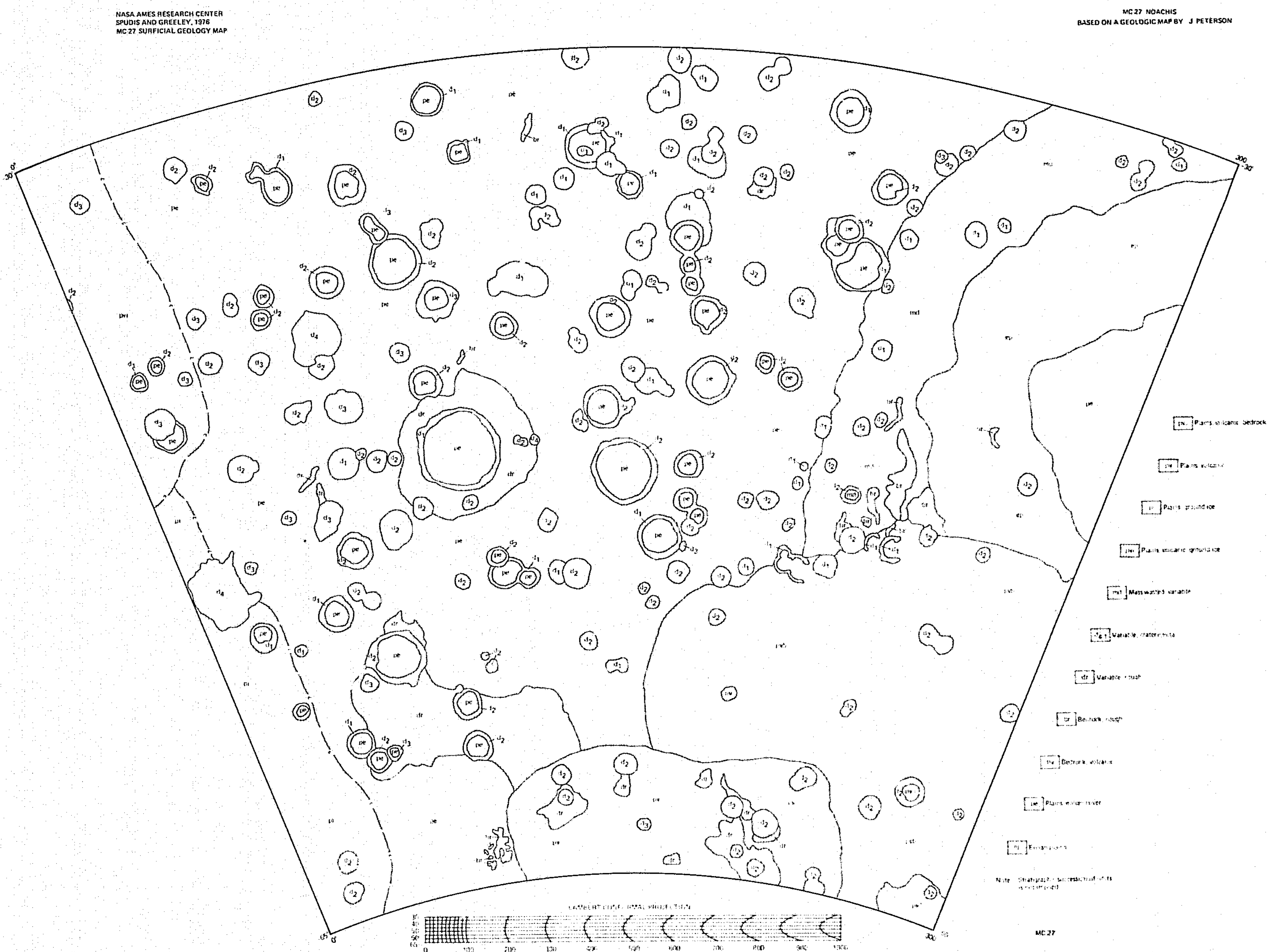


MC-25 SURFICIAL GEOLOGY MAP
NASA AMES RESEARCH CENTER
SPUDIS AND GREELEY, 1976

MC-25 THAUMASIA
BASED ON A GEOLOGIC MAP BY G. McGILL

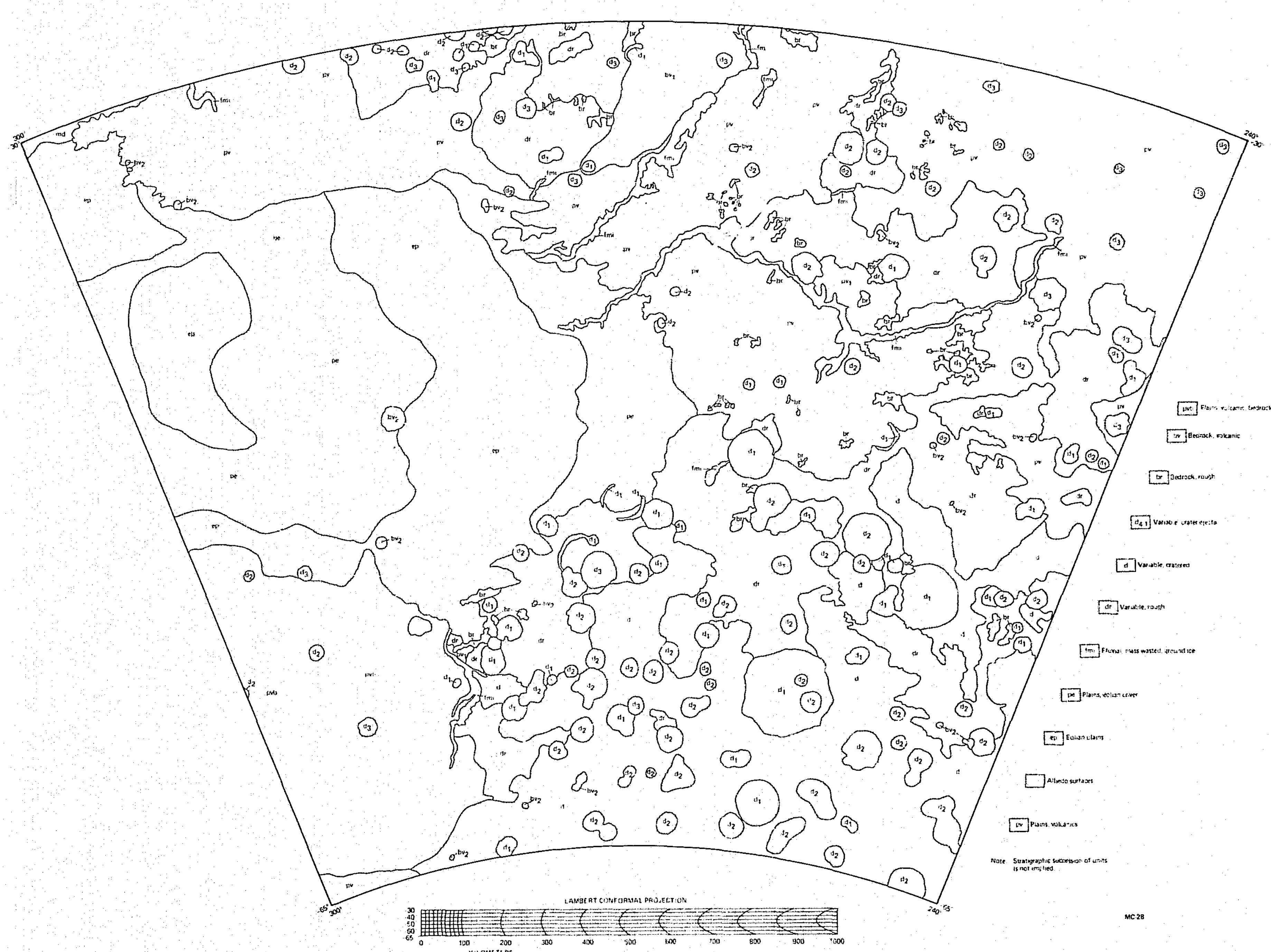



MC-26 SURFICIAL GEOLOGY MAP
NASA AMES RESEARCH CENTER
SPUDIS AND GREELEY , 1976
MC-26 ARGYRE
BASED ON A GEOLOGIC MAP BY C. HODGES
Eolian Plains
Plains, Eolian Cover
Plains, Variable
Plains, Ground Ice
Plains, Volcanic, Gound Ice
dr Variable Rough
Variable, Crater Ejecta
Fractured Plains Rough
LAMBERT CONFORMAL PROJECTION
0 100 200 300 400 500 600 700 800 900 1000
KILOMETERS
MC 26


NASA AMES RESEARCH CENTER
SPUDIS AND GREELEY, 1976
MC 27 SURFICIAL GEOLOGY MAP
MC 27 NOACHIS
BASED ON A GEOLOGIC MAP BY J PETERSON
Plains volcanic bedrock
Mass wasted variable
MC 27
KILOMETERS

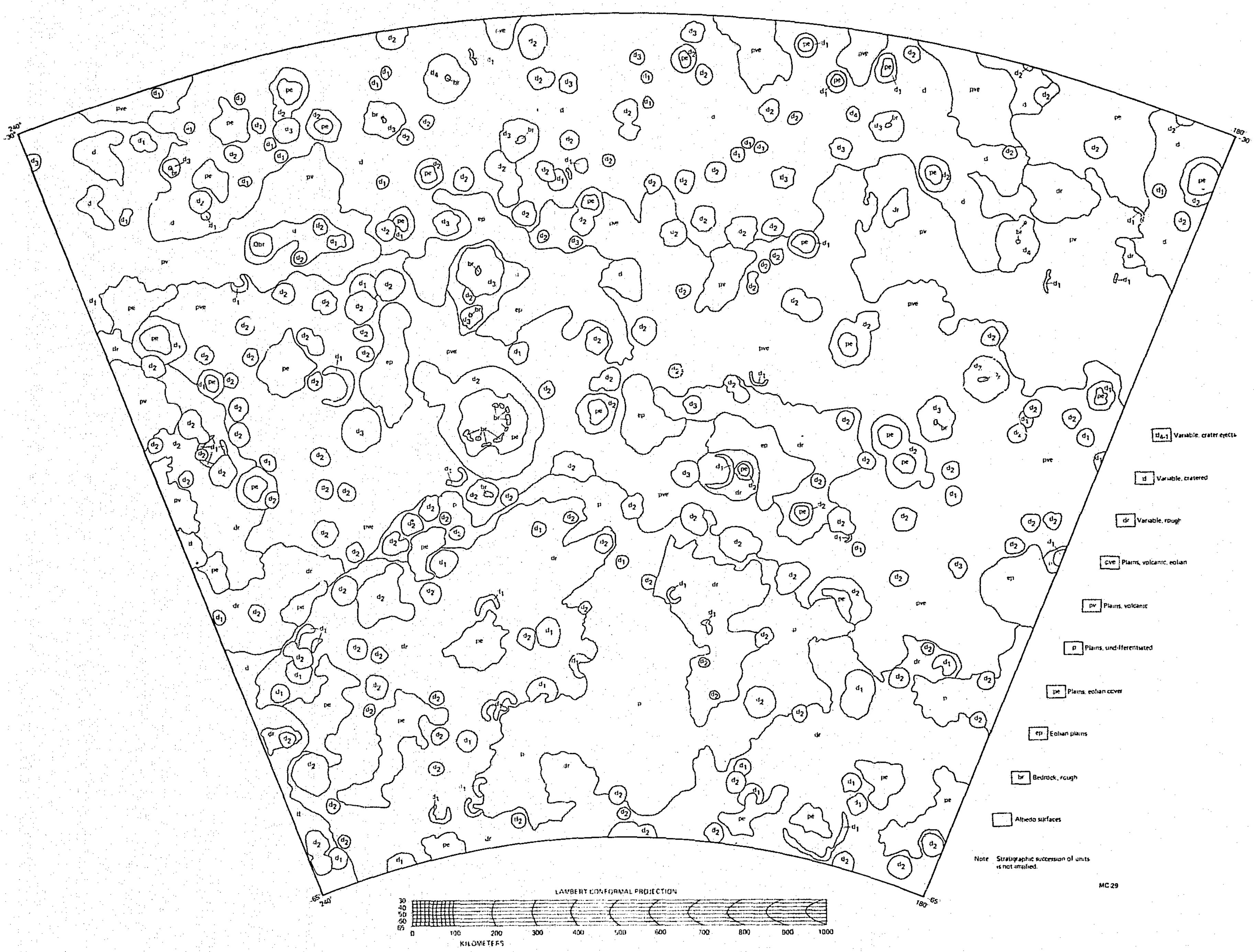
MC-28 SURFICIAL GEOLOGY MAP
NASA AMES RESEARCH CENTER
SPUDIS AND GREELEY, 1976

MC-28 HELLAS
BASED ON A GEOLOGIC MAP BY: D. POTTER



NASA AMES RESEARCH CENTER
SPUDIS AND GREELEY, 1976
MC-29 SURFICIAL GEOLOGY MAP

MC-29 ERIDANIA
BASED ON A GEOLOGIC MAP BY: R. DEHON



d4-1 Variable, crater ejecta
d Variable, cratered
dr Variable, rough
pve Plains, volcanic, eolian
pv Plains, volcanic
p Plains, undifferentiated
pe Plains, eolian cover
ep Eolian plains
br Bedrock, rough
Albedo surfaces

Note Stratigraphic succession of units is not implied.

MC 29

NASA AMES RESEARCH CENTER
SPUDIS AND GREELEY, 1978

MC 30 SURFICIAL GEOLOGY MAP

MC 30 MARE AUSTRALE
BASED ON A GEOLOGIC MAP BY L. SODERBLOM & C. CONDIT