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MARTIAN POLAR GEOLOGICAL STUDIES

FINAL REPORT

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Submitted by

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MARTIAN POLAR GEOLOGICAL STUIDES

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FINAL REPORT

Multiple arcs of rugged mountains and adjacent plains in the south polar region of Mars have many of the characteristics of a lunar basin and mare, in particular Mare Imbrium. The martian feature is interpreted to have originated in the same way as its lunar analog - by volcanic flooding of a large impact basin. The final report documents the key data and the methodology that leads to this conclusion.

MARTIAN POLAR GEOLOGICAL STUDIES

Studies of the South Polar Smooth Plains

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A. INTRODUCTION

The new Mars discovered by the television cameras of Mariner 9 in 1971 is dominated by a region of massive volcanic shield structures that had not been photographed at close range during earlier missions to the planet. Shield structures are not the only features of apparent volcanic origin. Almost the entire northern hemisphere of the planet is characterized by smooth plains pocked with isolated small impact craters and interrupted by shallow flow fronts and other features indicative of vulcanism. The northern volcanic plains are mantled by eolian materials in some areas and adjoin the ancient cratered uplands of Mars in an equatorial belt of highly variegated transitional features.

The most striking physiographic features of the moon are the dark lunar maria seen against the backdrop of the bright cratered uplands. Since a superficial mantle of eolian materials has extensively modified the primary tonal differences between different regions of Mars, it is not surprising that the gross martian surface markings do not resemble those on the moon. In particular, most of the larger basins that are seen on Mars appear light against a darker background in contrast to the relative appearance of lunar mare basins and highlands. However, on more thorough morphological analysis, and with the evaluation of elevation and gravity data, it is found that while martian basin structures bear resemblances to those of the moon (Wilhelms 1973), there are some important differences also. For example, Hellas, the largest martian basin, has a negative gravity anomaly whereas the flooded circular mare basins of the moon all have positive anomalies

In addition, the Hellas basin is still extremely deep even though it appears to be accumulating eolian materials. There are some indications of vulcanism associated with the Hellas basin to the northeast of the rim but none to suggest the massive basin filling volcanic processes that appear to have prevailed on the moon. The Argyre basin, 2000 km west of Hellas, seems to be similar in this respect. Basins on the margins of the old heavily cratered continental crust such as Libya are partly filled and modified by plains materials. It is not clear whether these plains materials are volcanic formed in response to basin formation or whether they originated for entirely different reasons as part of the general flooding of the northern hemisphere.

Near the south polar area of Mars an arc of rugged mountains identifies a basin structure (Fig. 1, Sharp 1971, Wilhelms 1973). Plains materials in the vicinity of this basin have been identified and classified as complex glacioeolian deposits (Murray et al 1972). These deposits have a significant post depositional impact crater population and have been pitted and partially stripped by erosional processes. These plains areas have been subdivided into areas of pitted terrain and etched terrain--the latter referring to areas where the stripping has gone to completion (Sharp 1973). The deposits that underlie the plains have also been subdivided into homogeneous and structured varieties (Sharp 1973). It has been suggested that both plains units are related genetically to the layered eolian deposits that stratigraphically overlie them (Murray et al 1972, Sharp 1973ab, . This article is concerned with an alternative explanation, that the plains are analogs of lunar maria, and explores the implications of this hypothesis.

B. TERRAINS AND ROCK UNITS OF THE SOUTH POLAR REGION

Murray et al (1973) recognized three major terrain types in the south polar region of Mars distinguished by the types of land form that were developed upon them: cratered terrain, pitted plains and laminated terrain. Further scrutiny of these terrains revealed that they were developed in rock units of quite different nature and age and contact relationships were clearly recognized (Figure 1). The oldest rock unit, the cratered unit, was believed to date from very early in the history of the planet at which time its surface was indented with large impact craters typically 50 to 150 km in diameter. This primordial landscape had evidently been modified by billions of years of exposure to the martian surface environment. Erosion and redeposition had produced a softly undulating landscape of ancient crater forms with rims varying greatly in relief The distribution of this ancient cratered terrain is designated ct in Figure 1).

The laminated terrains of the south polar region are developed in the youngest blanket which has been termed the layered deposits. The terraced and banded appearance of the terrain gave rise to the descriptive term laminated and resulted in the inference that this part of Mars is underlain by layered deposits (Murray et al 1973, Cutts 1973). The area covered by layered deposits (Fig. 1) includes the location of the south polar ice cap.

Intermediate stratigraphically between the cratered unit and layered deposits is the pitted plains unit. It is the characteristics of this unit and the impact basin that are associated with it that will now be considered.

C. THE SOUTH POLAR BASIN

A conspicuous physiographic feature of the south polar regions is a rugged mountainous arc extending from near 78°S, 230°W to 80°S, 315°W (Fig. 1a and 2). It is characterized by cuspate segments oriented towards the center of the arc, multiple crater scalloping and a relatively smooth planar surface on its southern concave side. To the north, several prominent linear groupings of impact craters can be recognized. The mountain arc forms almost a semicircle. Where it terminates near 80°W, 315°W, it has apparently undergone burial by plains materials; at the other end of the arc the nature of the terminus is not easily deduced.

The existence of this mountainous arc as revealed in Mariner 7 pictures suggested to Sharp et al (1971) that this was the site of a large impact basin. Wilhelms (1973), in his detailed analysis of impact basins on Mars, corroborated this view but did not examine the south polar basin in detail. Quantitative data on elevation differences recently obtained from both Mariner 9 ultraviolet spectrometer data and television stereo images (Dzurisin and Blasius, 1974) confirms that a depression correlates with the interior of the mountain ring and its floor is, on average, 2 km below the surrounding terrain.

D. PITTED PLAINS UNIT

1. General Description

What appears to be a continuous deposit of rock materials similar in nature and essentially contemporaneous in origin occupies the northern part of the south polar basin and a vast irregular area ranging from 300°W westward to 115°W and from 85°S to near 60°S. Over most of the perimeter of this pitted plains unit, it overlies cratered terrain; poleward of 80°S it is mantled by polar layered deposits.

The pitted plains unit is characterized by a flat plains-like surface sparsely indented by impact craters and distinctive pits and hollows. In certain areas, the process of pitting has been so extensive that growth and coalescence of depressed areas has led to stripping of the plains unit from substantial areas of terrain (Sharp 1973). These stripped areas are mapped as pitted and etched terrain (pet) in Fig. 1. The diverse kinds of pits and the varieties of pitted and etched terrain are illustrated in Fig. 2. The character of the cliff faces forming the margins of pits and areas of pitted and etched terrain provides little evidence for layering in the pitted plains unit.

Sharp (1973) has suggested that the massive blankets of the pitted plains unit have at least two members. The younger of these, seemingly homogeneous and structureless, is estimated to range in thickness from about 400 meters at 80°-70°S to about 50 meters at 65°S. This structureless unit appears to rest unconformably on one or more still older massive blankets which exhibit linear, curving and intersecting structures. These structures have been etched out by erosion forming spectacular geometric patterns (Figure 2d). The pits indenting the homogeneous blanket are of various depths -- some extend entirely through the blanket exposing the underlying hummocky rock floor as in Figure 2c.

2. <u>Relationship to Mountainous Terrain</u>

As well as the areas of pitted and etched terrain which form islands within the perimeter of the pitted plains unit, there are also other important features within the pitted plains unit. Several areas of rugged terrain comprised of roughly conical peaks occur near 355°W, 82°S and are termed mountainous terrain (mt in Figure 1). The largest area of mountainous terrain adjoins a large impact crater approximately 80 km in diameter. The walls of this crater are neither completely circular nor symmetrically polygonal. Strong structural alignments appear to be reflected in the development of exceptional prominent ridges parallel to those parts of the crater rim nearest and farthest from the polar basin.

3. Domical Features

A number of domical constructs capped by craters appear near 70°S, 350°W (Figure 2j). These features are not conical in form but are characterized either by irregular slopes or by well defined ridges developed on the sloping sides of the domes. The domes appear to be confined to a very limited area of the pitted plains unit.

4. Sinuous Features

Sinuous ridges are also prominent characteristics of the pitted plains (Figure 2i). The more conspicuous of them have been mapped. Like the wrinkle ridges on the lunar maria (Schultz, 1975) and the sinuous ridges on the martian Chryse Planitia (Greeley, 1977) these features occupy plains surfaces and occur in systems following the same general trend. However, lunar and martian wrinkle ridges typically consist of narrow sinuous ridges on top of a broader rise. Also, the lunar wrinkle ridges and the Chryse Planitia features generally consist of a series of segments offset from one another. For these reasons there are evidently morphological differences between the south polar sinuous ridges and wrinkle ridges.

Histograms have been generated of the frequency of occurrence of the south polar sinuous ridges as a function of their length. Comparable data on the lunar wrinkle ridges and the plains of Chryse Planitia will be collected during next years' program.

5. Impact Craters

Impact craters are present on the south polar pitted plains and the population is comparable to that on the lunar maria and the plains of Chryse Planitia. Many of the impact craters within the plains exhibit central peaks. Histograms contrasting the populations of craters with and without central peaks on the south polar plains with those on the surrounding upland have been generated.

E. INTERPRETATIONS

1. Origin of South Polar Basin

Those workers who have recognized the existence of a semi-circular mountain ring near the south pole of Mars have either implicitly assumed it was of impact origin (Sharp, 1971; Dzurisin and Blasius, 1974) or stated that it was an impact structure without presenting a detailed case for that interpretation (Wilhelms, 1973). Our analysis substantiates this conclusion by those earlier workers. The specific evidence that supports this conclusion includes:

1) Pang and Hord (1973) have obtained ultraviolet elevation maps indicating the existence of major depression coincident with the inferred basin location.

2) The location and orientation of mountainous terrain patches (mt) suggests that they might be large clods of ejecta from the basin or uplifted tectonic blocks.

3) Fractures, ridges and crater chains can be identified in the region surrounding the inferred location whose subradial geometric relationship suggests that they might be a consequence of a basin forming impact.

4) The unevenness of the large crater population on the older cratered plains near the basin - some areas are apparently devoid of large

crat... ghost craters are common and the rims of many large craters are heavily degraded - is consistent with the uneven ejecta deposition that may accompany an oblique basin forming impact. (Unless a significant change in the pole direction has occurred it seems most likely that a basin forming impact at this latitude would have been oblique).

Despite this positive evidence for an impact origin there are no indications of multiple ring structures such as those that characterize lunar basins and the quality of gravity field data is far too poor to learn anything about this feature although gravity data obtained from the Viking II spacecraft may change this situation if the mission lasts for long enough for the periapsis to reach moderate southern latitudes.

2. Origin of the South Polar Plains

Just Prior to the Apollo landings it was widely believed that most of the flat or slightly undulating surfaces on the moon with a generally smooth aspect including the maria and the bright plains had been surfaced by vulcanism. The visit of the Apollo 14 astronauts to the Fra Mauro formation and the observations of the Apollo 16 astronauts at the Descartes site indicated that highland vulcanism, if it had occurred at all, was limited in its occurrence and was certainly not responsible for the formation of plains units.

The Mariner 10 observations of the floor of the Caloris basin (Caloris Planitia) on Mercury has lead to considerable controversy over the role of volcanism in the formation of the plains filling impact basins. Strom, et al., (1975) have used stratigraphic, volumetric and albedo considerations to argue that the majority of smooth plains on Mercury were produced by volcanism which occurred at the close of a period of heavy bombardment. Wilhelms (1973) has challenged this evidence, however, and contends that an impact origin is more plausible for the mercurian plains. Plains formation after an impact might occur in the 'base surge' regime that accompanies large impacts where large scale vaporization of rock takes place or as molten rock (impact melt) settles back into the transient impact cavity. Some workers have interpreted the light plains on the floor of the lunar orientale basin as solidified impact melt or a mixture of impact melt and unmelted clasts (Howard, et al., 1974; Head, 1974; Moore, et al., 1974).

A third mode of origin for plains units has been examined for the planet Mars by Chapman, 1969; Murray, et al., 1971 and Jones, et al., 1973. This is the eolian model where the planification of the surface is attributed to subaerial erosion or deposition. Such a process, associated with an early atmosphere, has also been discussed for the formation of intercrater plains on Mercury (Strom, 1975). Malin (1975) has recently reviewed the evidence for impact processes, volcanism and eolian planification in the intercrater plains of Mars.

With this information as background we shall reduce the question of the origin of the south polar plains to two separate questions: 1) were the plains formed by local mass wasting or by surface atmosphere interaction or were they formed as impact debris or by post impact mare-type vulcanism? 2) What was the precise mechanism of formation?

We feel that the surface atmsophere interaction model for the origin of the polar plains can be confidently rejected. We come to this conclusion on the following grounds:

a) The plains do represent the surface of a deposit and not the consequence of planification of an ancient cratered terrain. This is evidenced by the windows in the deposits into the underlying surface.

b) The thickness of this deposit (defined as the depth of the windows) varies substantially across the polar region and appears to be strongly controlled by topography. In this respect, the deposit is unlike the layered deposits where the inferred thickness of the deposit was remarkably uniform. The distribution of this airfall sediment is not limited to lowlands.

c) Sinuous ridge features on the plains must imply volcanic or tectonic activity at the time of plains formation or after. If the plains were eolian this requires an unreasonable complexity of hypothesized origin for the ridges.

d) Structured and non-structured plains have no simple origin on the eolian model.

e) Domical features have no simple origin on the plains model.

f) Proximity to an impact structure exists which is an important prerequisite for alternative modes of origin.

Whereas the impact and volcanic origins for the polar plains do not suffer from all the objections above, it is not easy to reach a distinction between impact and volcanic models using this evidence.

At this time we prefer the volcanic model as:

a) It can more readily account for the largest volumes of plains deposits both inside and outside the basin.

b) The embayment relationships between the high standing topography and the plains are more suggestive of flooding from beneath and adjacent rather than under a rain of molten debris.

c) The few cratered domes that exist although not closely resembling lunar maria features, nevertheless, are most easily explained as late-stage extrusions of a viscous lava. The alternative explanation of these features as clods of impact melt is not satisfactory as there are just three isolated examples of these features and no accompanying hummocky plains.

d) The reticulate pattern of ridges in the so called 'Inca-city' is strong evidence of extrusion of lava into subsurface fractures. Even if this were true it does not, of course, demonstrate that large scale extrusion of lavas occurred. However, it would suggest that melting occurred at modest depths beneath the plains.

e) The sinuous ridges that occur on the plains, although morphologically different, resemble in pattern and distribution ridges in the lunar maria which are known to be of volcanic origin.

E. SUMMARY AND CONCLUSIONS

A study of south polar geological features using Mariner 9 imagery suggests that a semicircular escarpment extending from $81^{\circ}S$, $310^{\circ}W$ to $82^{\circ}S$, $220^{\circ}W$ is an impact basin. The plains that are intimately associated with this feature are considered not to be of eolian origin as previous workers have considered. Although origin as a combination of impact melt and ejected base surge debris cannot be excluded, a volcanic origin similar to that postulated for the origin of the lunar maria is preferred.

FIGURE CAPTIONS

1. (ab) Photomosaic of and sketch map of the south polar region 90°S - 65°S. Areas occupied by major terrains and significant physiographic features are identified. The inferred locations for the rims of craters and basins which have been buried or otherwise obliterated are identified by dashed lines. The very fine lines indicate ridge alignments on the pitted plains and structural patterns within the pitted or etched areas of the pitted plains unit.

2. (a) Cratered terrain (ct). In this location the craters appear eroded and stripped (DAS 7792258).

(b) Cratered terrain (ct). Here the crater rims are muted as if sedimentary infilling has taken place (DAS 8727884).

(c) A smooth extra-marginal upland (pp) surrounds pits penetrating the entire thickness of the homogeneous blanket (hundreds of meters) exposing a hummocky substrate (DAS 8763864).

(d) Erosion reveals part of the structured 'blanket' consisting of a set of orthogonal ridges in a 'waffle' pattern informally known as the 'Inca city'.(DAS 8044398).

(e) Area near 65°S, 322°W where the blankets are much thinner than in 2(c) and where pit formation is so extensive that the terrain has been termed 'etched' (Sharp (1973)). Lineations of the surface of the upland veneer may express the direction of an eroding prevailing wind (Paper II).

Ridges in the hummocky substrate are not as consistent in direction and may be stucturally controlled (DAS 6245608).

(f) Terraced slopes of laminated terrain indicate the erosion of layered deposits (DAS 8080238).

(g) Area of mountainous terrain (DAS 8620224).

(h) Rim of south polar impact basin (DAS 7864148).

(i) Ridges of the unmodified pitted plains unit (DAS 9375034).

(j) A crater capped cone on the pitted plains unit (DAS 8404134).

(k) Lunar mare ridges (Lunar Orbiter).

(l) Marius Hills complex (Lunar Orbiter).

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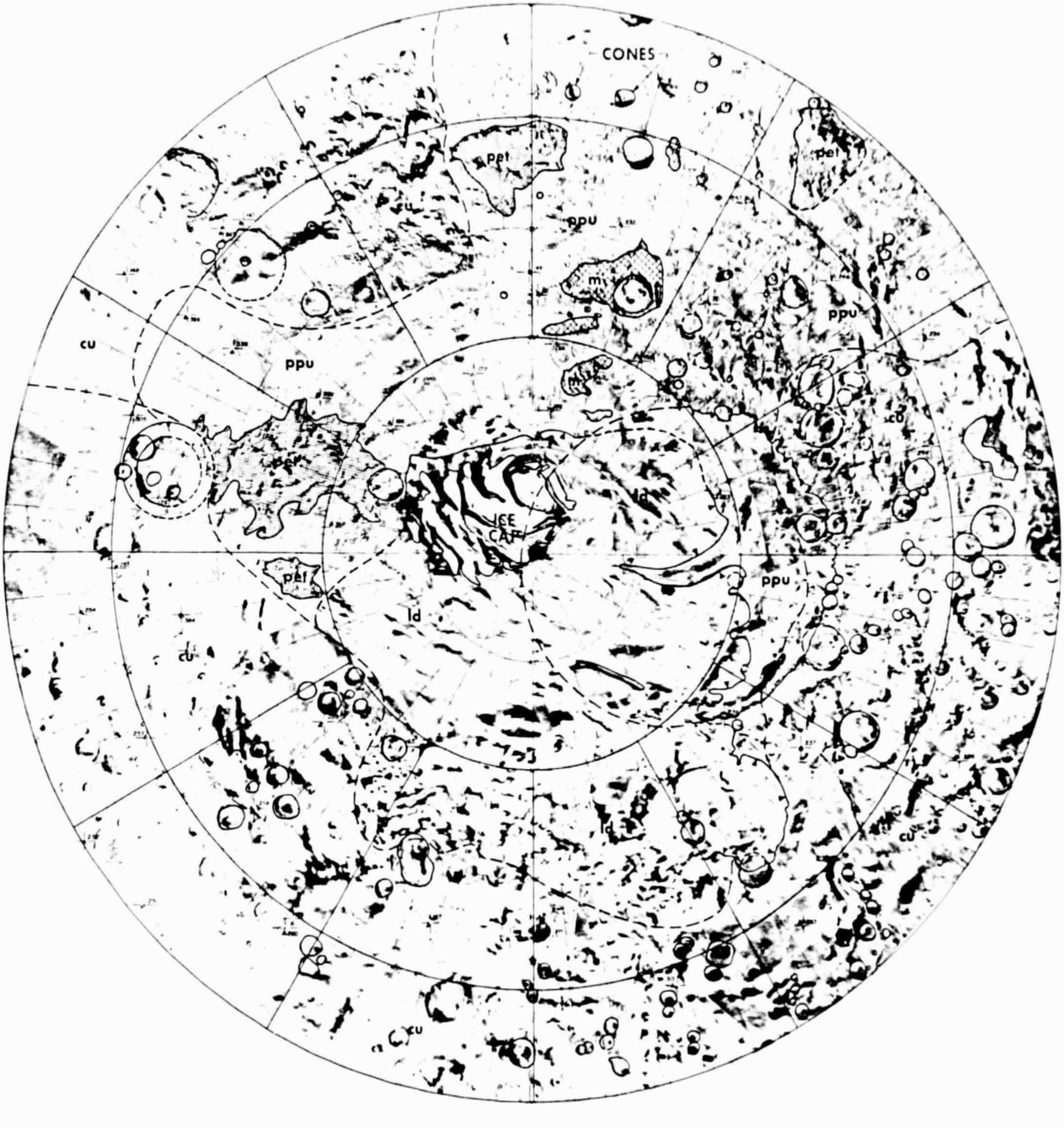


LEGEND

CRATERS

CENTRAL PEAKED CRATERS

ROUNDED ESCARPMENT CARET POINTS DOWNHILL

ld LAYERED DEPOSITS

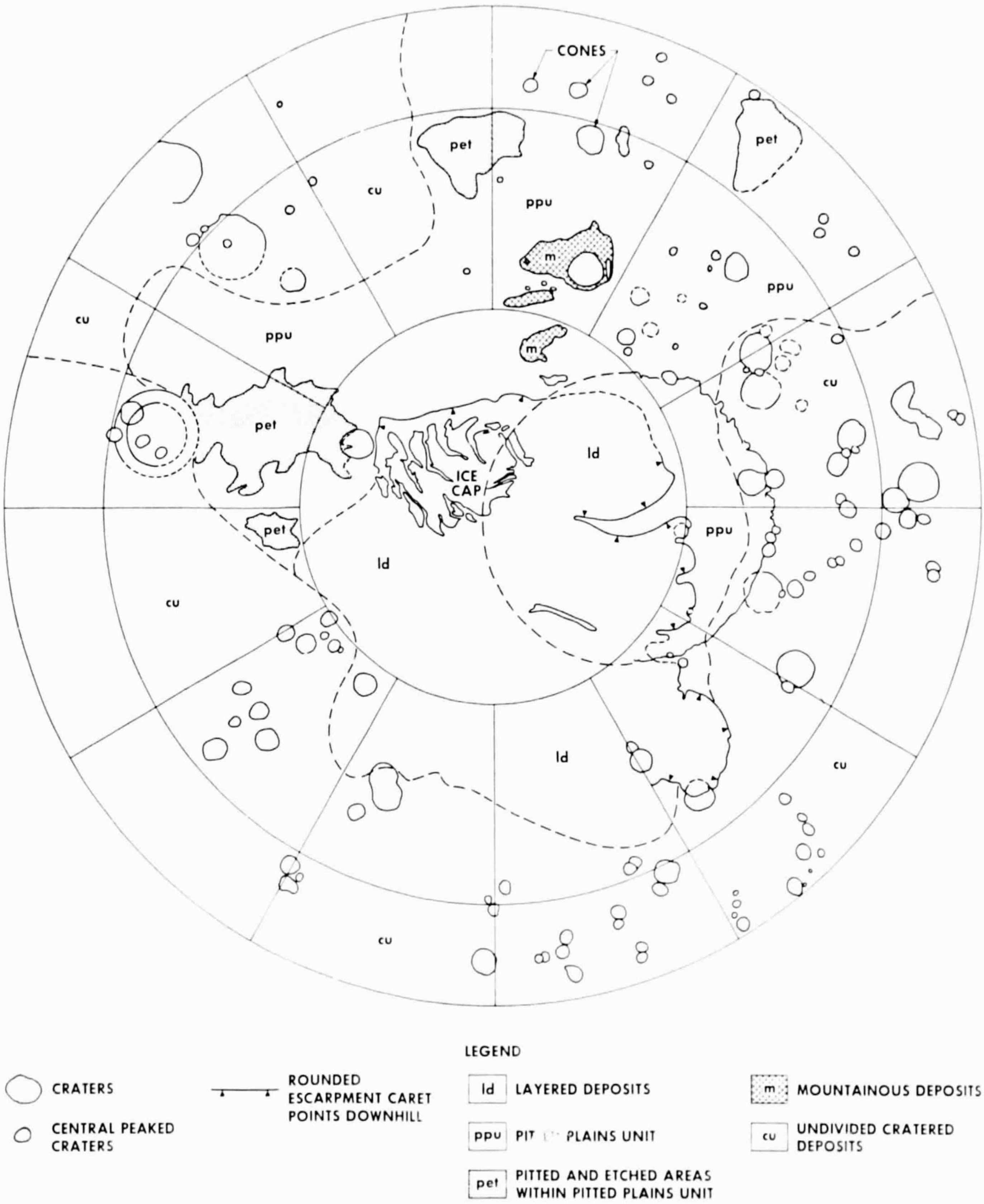
ppu PITTED PLAINS UNIT

pet PITTED AND ETCHED AREAS WITHIN PITTED PLAINS UNIT

m MOUNTAINOUS DEPOSITS

cu UNDIVIDED CRATERED DEPOSITS

FIGURE 1(a)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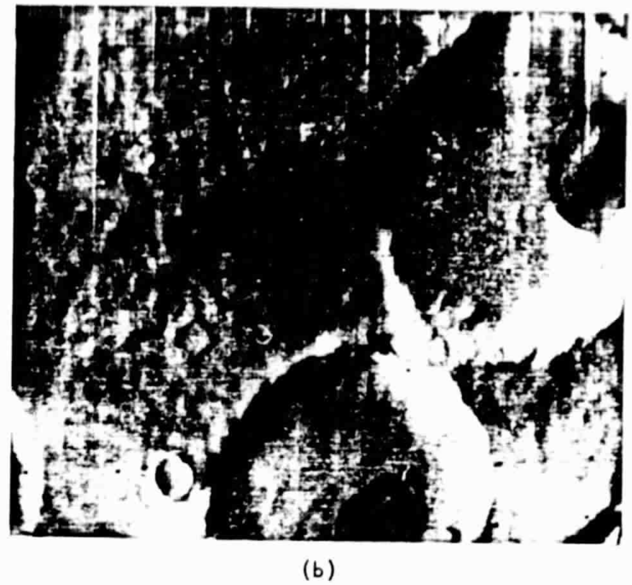
ld LAYERED DEPOSITS
ppu PIT PLAINS UNIT
pet PITTED AND ETCHED AREAS WITHIN PITTED PLAINS UNIT
m MOUNTAINOUS DEPOSITS
cu UNDIVIDED CRATERED DEPOSITS

Figure 1(b)

(a)



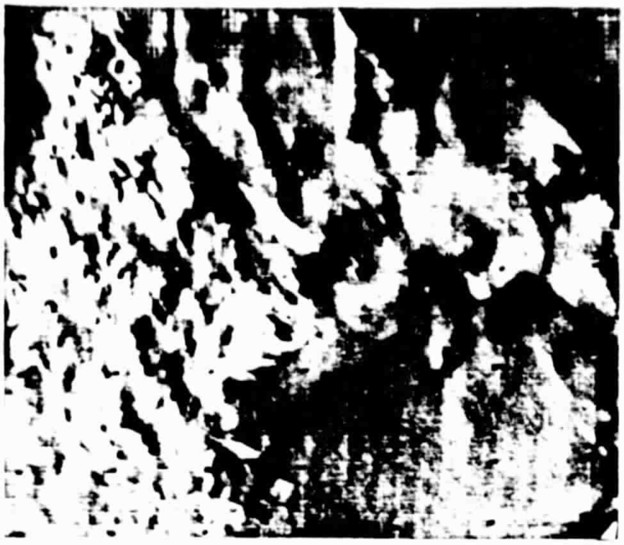
(b)

(c)

(d)

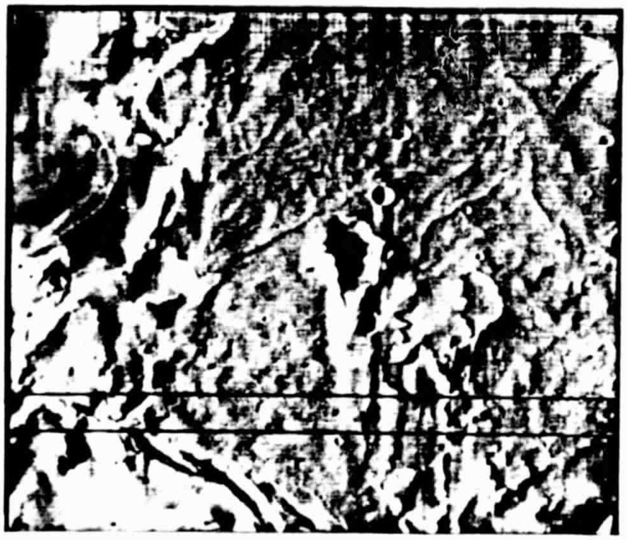
(e)

(f)



(g)

(h)



(i)

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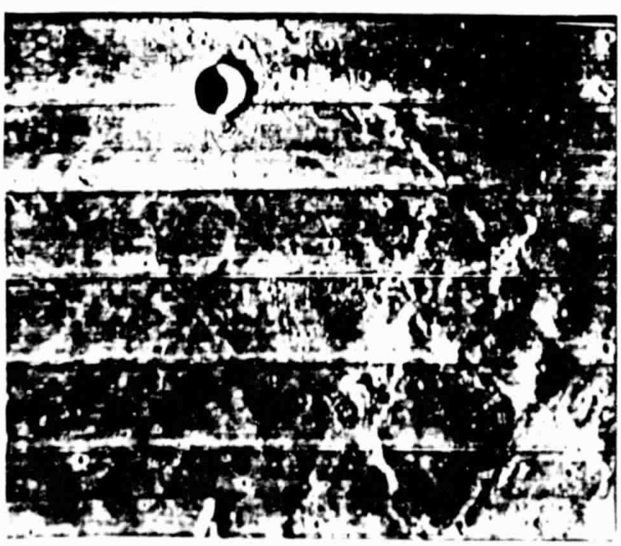

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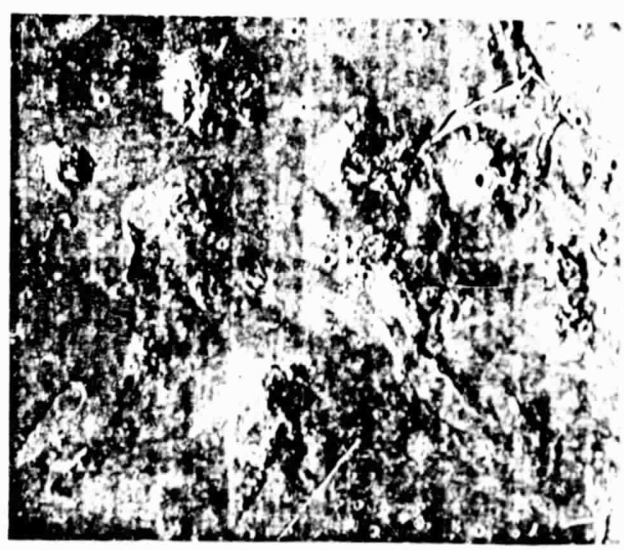

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