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Nature and Origin of Intercrater Plains on Mars

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This paper presents the results of an investigation of the morphologic characteristics of the plains which separate the craters in the heavily cratered regions of Mars. These intercrater plains appear to be composed of stratified consolidated and unconsolidated materials, probably loose debris blankets and volcanic flows. The topmost layer of the plains unit varies from location to location. An older, cratered surface may be partly exposed where the kilometers-thick plains unit is locally incised and eroded. The association of chaotic terrain, fretted terrain and major channels with the plains suggests that the volatile(s) presumed to be necessary to produce these erosional landforms may have been present among the plains materials. It is speculated that the unconsolidated material is impact-generated debris and eolian deposits, suggesting an early atmosphere conducive to material transport and possibly flowing liquids.

Introduction

Craters on Mars have been studied since first revealed in the Mariner 4 photographs transmitted to Earth in 1965. Although initial studies emphasized the many lunar-like aspects of the martian crater population, the deficiency of smaller craters and attendant variations in size-frequency diagrams suggested non-lunar processes had acted on the craters. Mariners 6 and 7 returned more and better data on martian craters and clearly showed not only that the surface was unsaturated with large craters (i.e., on the order of 50-km diameter), but that there was less than an equilibrium population (i.e., a surface where crater erosion is dependent on the impact of smaller objects). This suggested large-scale degradation independent of specific process. Initially, it was proposed that the degradation reflected post-cratering atmospheric processes (Murray *et al.*, 1971). However, Chapman *et al.*, (1969) reported crater morphologies which suggested that the degradation of the craters occurred in part <u>during</u> the epoch of crater formation. Subsequent studies of Mariners 6, 7 and 9 photographs support this suggestion (Soderblom *et el.,* 1974; Chapman, 1974; Arvidson, 1974).

It is proposed here that the relatively smooth, crater-deficient areas within the cratered terrains on Mars (denoted intercrater plains, Fig. 1) are constituted of ancient stratified consolidated and unconsolidated materials, including large amounts of volatiles. They are among the oldest terrane units presently visible on Mars. An atmosphere significantly denser than the present one probably existed during their formation.

This paper will present observational evidence which bears on the above proposals for the nature and origin of the intercrater plains. After discussion of the evidence cited in support of previous views, further morphologic features of the plains will be examined to document the diversity of plains-forming materials and processes. In the discussion section, the set of speculative proposals will be developed.

Current Hypotheses

Three processes have been proposed to create and distribute the material of the intercrater plains (Fig. 1). One is that the materials represent impact-generated debris distributed by ballistics and by fluidized "base-surge" phenomena (Chapman *et al.*, 1969; Cintala *et al.*, 1975). Another specifies large-scale atmospheric redistribution of impact debris and weathering products (Chapman *et al.*, 1969; Murray *et al.*, 1971). The third involves the formation of large volcanic plains similar to those in the younger terrains of the northern hemisphere of Mars (Wilhelms, 1974). All three alternatives involve deposition rather than erosion, the former being a far more likely process to produce the observed sharp contacts, visible layering, and equal floor elevations inside and outside of craters (Wilhelms, 1974).

There are two main hypotheses for the formation of the intercrater plains: 1) that they are eolian, or 2) that they are volcanic. Used in this context, eolian refers to any process of transport above the surface; thus, the first two of the previously mentioned processes fall within this genetic category.

The first hypothesis proposed was that of eolian origin.

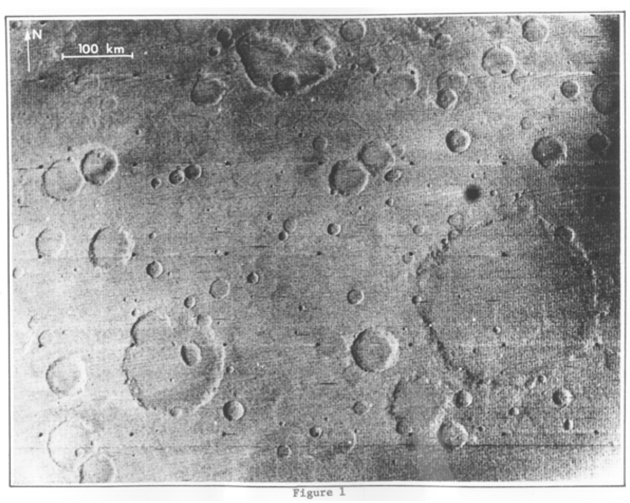


Figure 1: Low Resolution View of Intercrater Plains on Mars. Mariner 6 wide angle photograph of Mars showing a large expanse of cratered terrain in Deucalionis Regio. The large crater, Flaugergues, is located near 17°S, 340°W and is about 200 km in diameter. Note the essentially smooth, featureless texture of the intercrater surface (Photo 6N21).

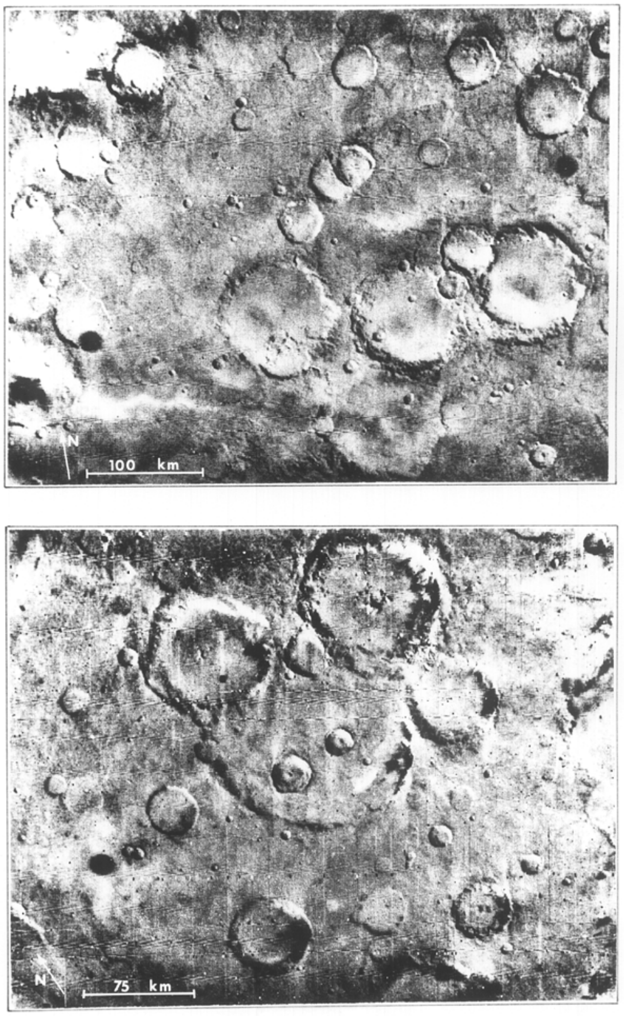


Figure 2A

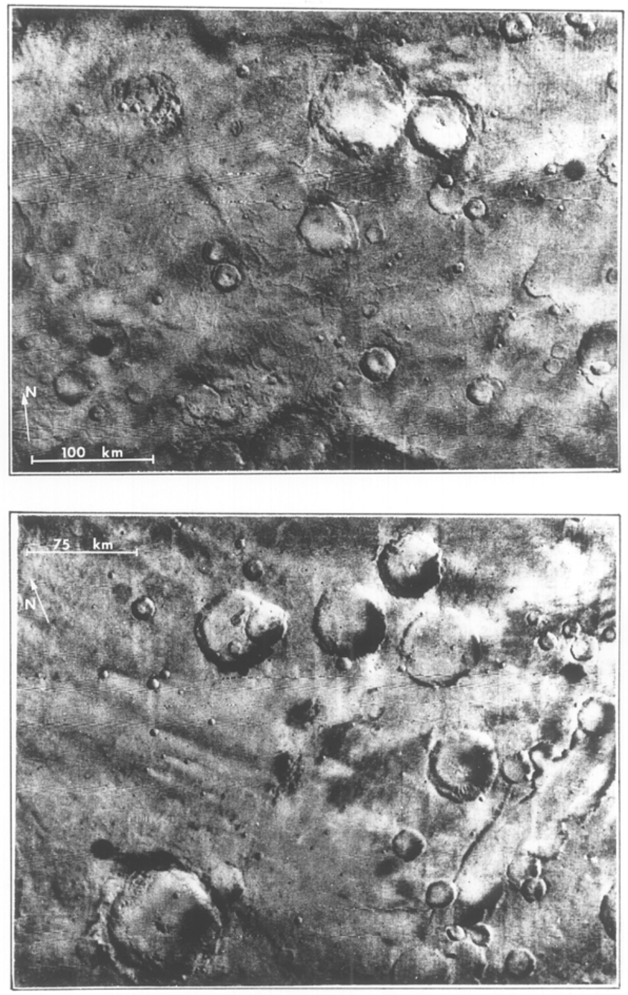


Figure 2B

Figure 2: Craters of the Heavily Cratered Terrain on Mars. 2A: Two Mariner 9 A-frames illustrating the various morphologies of large craters in heavily cratered regions on Mars. Note the many subtle states of crater degradation. It has been suggested that the degradation of the large craters occurred concurrently with their formation (Chapman et al., 1969; Soderblom et al., 1974)(Top, DAS 6859268: centered 7.6°N, 321°W; Bottom, DAS 6858498: centered 24.8°S, 357°W). 2B: Two more Mariner 9 A-frames, showing craters in a variety of degradational states. (Top, DAS 6931298, 8.95°N, 311°W; Bottom, DAS 6930598: 18.3°S, 321°W).

Leighton *et al.* (1967) and later Murray *et al.* (1971) cite the smooth plains, degraded large craters and pristine small craters as evidence of a post-large crater, pre-small crater erosional or depositional period involving widespread lateral transport of material. Chapman *et al.* (1969) cite evidence of a range of degradational states for the large craters to place the modification at a time commensurate with crater formation. The evidence in these early works was in most cases circumstantial, and only with the planetwide coverage of Mariner 9 were good examples found to support the interpretations (Soderblom *et al.*, 1974; Arvidson, 1974). Figure 2 shows regions of cratered terrain with a range of crater degradation portrayed. Regional differences have been attributed to more recent blanketing, exhumation, and erosional phenomena sufficient to significantly modify smaller craters, but to have had only a modest effect on the larger craters. While this is not specific evidence for an “atmospheric” origin, it suggests deposition of relatively unconsolidated debris associated with an ancient period of martian history.

The second alternative, proposed by Wilhelms (1974), is that the plains are predominantly volcanic. The evidence he cites is straightforward: similarity of features within the plains unit with comparable lunar features. Two categories of evidence are presented — the flooding of craters near the margins of large, youthful volcanic plains and the presence of lunar-like ridges. Figure 3 shows a wide-angle view of the margin of the Chryse Planita with uplands immediately south (14°N, 50°W). Features such as flow fronts (Fig. 4) and ridges (Fig. 5) suggest a volcanic origin similar to lunar maria for Chryse and other lightly-cratered plains. The transition between these plains and the uplands shows partially filled and remnant “ghost” craters similar to those filled by the lunar mare basalts. Since these features are also seen deep within the cratered terrains as manifestations of the intercrater plains/craters ensemble, an argument can be made for similar genesis (i.e., older volcanic units).

More evidence is shown in the ridges seen throughout the intercrater plains. Although not ubiquitous, these ridges are abundant enough to rank as a major landform of the plains. Figure 5 shows some examples. Ascribed to volcanic processes by lunar analogy (Wilhelms, 1974), it is important to note that the similarity is to lunar highland ridges, rather than to mare ridges, and that the “ridges” are one-sided scarps. Figure 5 compares lunar mare and highland ridges with

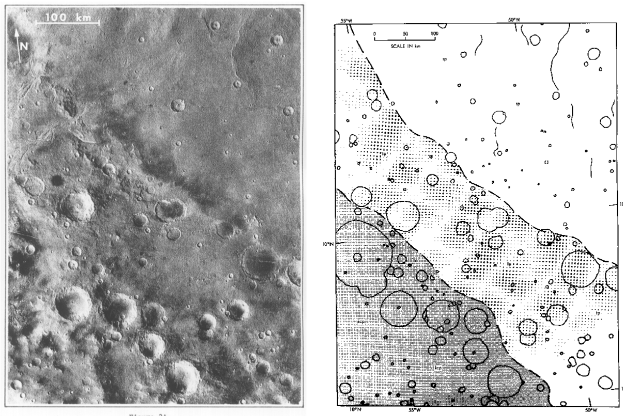


Figure 3A Figure 3B

Figure 3: Boundary between Smooth Plains and Intercrater Plains. 3A: Photomosaic of Mariner 9 A-frames showing the boundary between the Chryse Planitia and a region of cratered terrain near 14°N, 50°W. Note the buried and subdued craters in the zone between the smooth plains (upper right) and the intercrater plains (lower left). Note also the mare-like ridge in the smooth plains terrain (DAS 7543168, 7543238). 3B: Sketch map of smooth plains/cratered terrain (intercrater plain boundary, showing smooth plains (sp), intercrater plains (icp = heavy tone) and a transitional plains zone (tp = light tone). Similar relationships seen within the cratered terrain are cited by Wilhelms (1974) as evidence for a volcanic origin for the intercrater plains.

"ridges" of the martian smooth plains and intercrater plains. It is clear that the escarpments of the intercrater plains are indeed more like those of the lunar highlands, whose origin is still uncertain (Hodges, 1973; Howard and Muehlberger, 1973; Scott, 1973; Mattingly *et al.*, 1973; Young *et al.*, 1973). They also resemble the recently discovered escarpments on Mercury (Murray *et al.*, 1974). The current explanations for the lunar highland escarpments center on thrust faults or flow fronts, although neither origin can explain all the data. Of course, one process and subsequent ridge-form on one planet may not necessarily be applicable to another planet, but the detailed similarity is suggestive.

Wilhelms has chosen to separate two distinct types of intercrater plains: the "plateau" plains and the plains of the heavily cratered terrain. He apparently distinguishes the two primarily on the basis of crater frequencies, although the cratering statistics of Soderblom *et el.* (1974) and Mutch (personal communication, 1974) do not seem to indicate any great differences. On the qualitative observation of somewhat fewer craters and on the apparent burial and embayment of a moderate number of the larger craters, Wilhelms places the plateau plains intermediate in age between the heavily cratered terrain and the old, crater-deficient volcanic plains of the Lunae Planum.

All discussions of origin of intercrater plains have included disclaimers indicating the complexity of the problem and implying that more than one process was at work. Both Wilhelms (1974) and Soderblom *et el.* (1974) mention eolian, volcanic and fluvitile processes among others. In lieu of specific evidence which might exclude one of the alternatives, a complex history would seem reasonable. In the following sections, other features of the intercrater plains are-examined for such evidence.

Morphologies of the Intercrater Plains Surface features

As discussed initially by Murray *et al.* (1971), the surface of the intercrater plains at low resolution is essentially smooth and featureless. At higher resolution, however, a number of landforms can be seen. Some of these are associated with

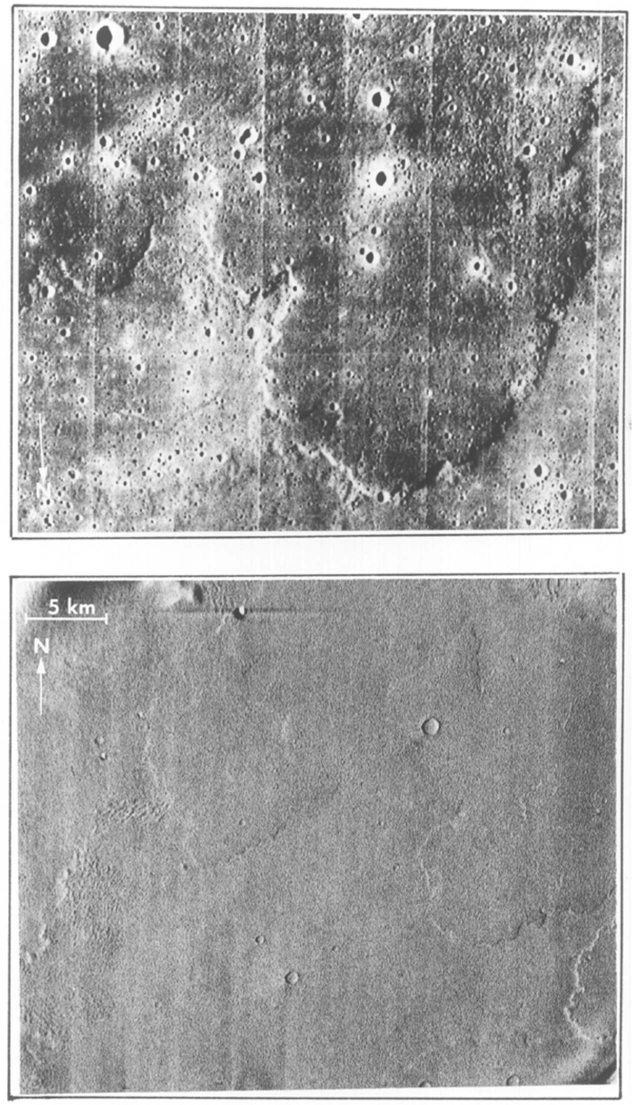


Figure 4

Figure 4: Flow Fronts on the Moon and Mars. Photographs of flow fronts on the Moon (top) and Mars (bottom) are presented here at the same scale. The poor contrast of the Mars frame is probably the result of unfavorable viewing conditions (solar elevation angle = 47° as opposed to the lunar example, 17°). Features such as these demonstrate the likelihood of volcanic plains formation on Mars. Although no clearly discernible fronts are seen in the intercrater plains, the large range in relative ages of identifiable volcanic plains suggests volcanic processes may have been active during the formation of the intercrater plains. (Top: Lunar Orbiter V M161, centered at 32.7°N, 22°W; Bottom: Mariner 9 frame DAS 6966613, located near 17°S, 136°W).

ephemeral, possibly polar-derived debris mantles (Soderblom *et al.*, 1973), while others appear to be more deeply rooted. In general, the regions between craters are characterized by low, rolling topography, becoming hummocky in regions. Small craters are abundant, especially in swarms of associated secondaries. In some regions, many of the larger craters (~20 km) have smooth, steep, convex-appearing interior walls and no ejecta, while in other nearby regions, the morphology changes to rough, blocky slumping interior walls and extensive ejecta blankets (Fig. 6).

These differences appear to represent not only latitudinal variations (as might be expected for blanketing by polar-derived debris blankets (Soderblom *et al.*, 1973, 1974), but also

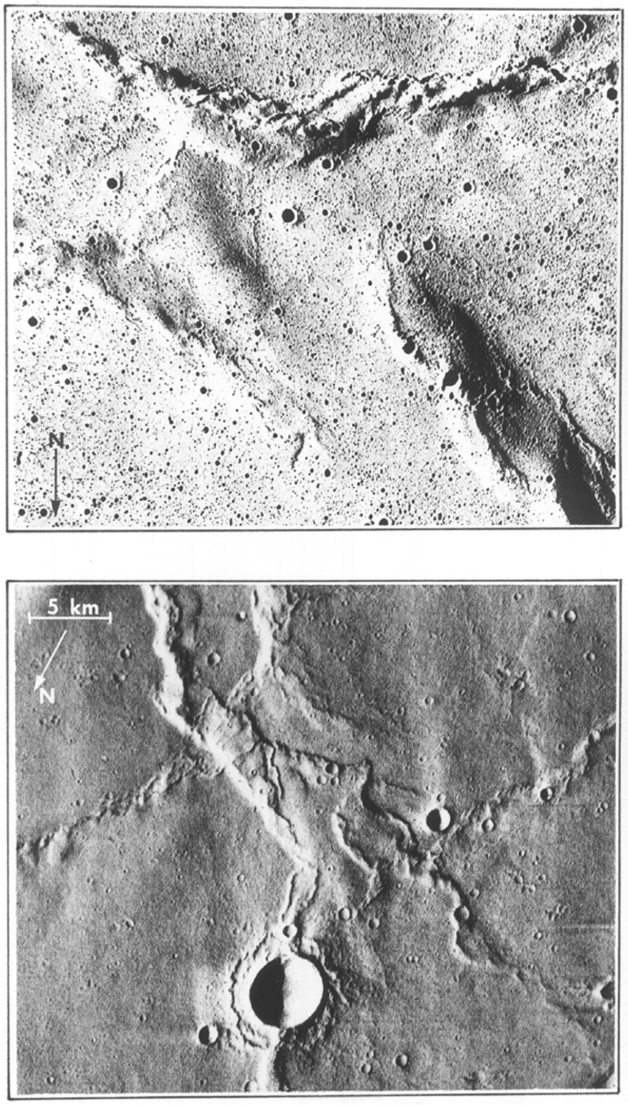


Figure 5(I)

Figure 5A: Mare ridges on the Moon (top) compared with smooth plains ridges on Mars (bottom), presented at the same scale. The general similarity in form suggests similar genesis, probably volcanic (Top: Apollo 17 metric camera M0454, enlargement of frame centered near 19.5°N, 20.3°E, with a sun elevation angle of 5°; Bottom: Mariner 9 B-frame DAS 12901348 centered at 23.2°8,244°W, sun elevation 20°).

longitudinal variations (perhaps in the materials in which the impacts occurred). In equatorial regions, where numerous lineations which resemble gullies mark the surface, the texture of the intercrater plains becomes quite rough (Fig. 7). Irregular features of positive and negative relief and discontinuous albedo markings create a surface of confusing complexity. No diagnostic traits indicative of materials or processes are clearly visible, and few features can be traced any great distance.

Perhaps more outstanding than the surface of the intercrater plains are the indications of the subsurface as revealed through erosional processes which have penetrated into the unit. The geographically limited formation of the chaotic, fretted and troughed terrains (Sharp, 1973a,b) and channels (Sharp and Malin, 1975) within the intercratered plains has revealed important information about the materials of the plains unit and about the erosional processes. It is this new information which bears most directly on the nature and origin of the intercrater plains.

Fretted terrain

Fretted terrain occurs in localized regions along the margin between cratered "uplands" and uncratered "lowlands" on Mars. A complete description of the features of fretted terrain can be found in Sharp (1973b). Two features are of particular interest to the present discussion. The first concerns the mode of transport of debris developed by the fretting process and the second involves the limitation of vertical incision of the intercrater plains unit. Figure 8a shows the development of fretted "channels" within the intercrater areas. At high resolution (Fig. 8b) the fretting process can be seen to have removed crater-filling material along its course but to have left untouched terrain immediately adjacent to the channel. Portions of small craters intercepted by the channels are still intact while other parts have been completely removed. This can be attributed to the resistance to erosion of the crater rims (possibly the result of shock lithification), to the gentleness of the fretting process, and to the ease of removal the debris produced by fretting. It is inferred that the materials into which the erosion occurred were essentially unconsolidated.

In most cases, floors of fretted channels exceed in depth floors of adjacent craters (Fig. 9), while craters integrated with the channels have concordant floors. This uniform depth of erosion appears throughout the intercrater plains, as has been noted by several Mariner 9 investigators (Sharp, 1973b; L. A. Soderblom and D. Wenner, personal communication, 1973), and will be shown elsewhere in this work in association with other erosional terrains.

Chaotic terrain

Chaotic terrain is confined primarily to a region within ±15° of the equator between 0° and 60°W, an area informally called the "Chryse Trough" because of its topographic form (a broad depression, trending roughly north-south and paralleling the Tharsis Ridge). Sharp (1973b) defines chaotic terrain as regions with "rough floor topography featuring a haphazard jumble of large angular blocks" with "arc-shaped slump blocks on [the] bounding escarpments." Although some areas of chaotic terrain are irregular in shape, others are clearly circular and craterlike. Some are in fact contained within craters (Fig. 10).

As noted previously in the fretted terrain, the erosion of the chaotic terrain appears to have three main attributes: 1) material was effectively removed from the chaotic regions with little effect on the surrounding terrain; 2) chaos developed to a depth greater than that represented by the floors of large craters; and 3) integrated regions of chaotic terrain and channels have concordant floors (Fig. 10). Material removal may have been less complete or effective than in fretted regions, a point indicated by the gradation from smooth channel floors to the rough, jumbled positive floor topography of the chaos. The restricted vertical development suggests that the erosional processes are effective to a limited depth. It is again inferred that the materials were only slightly consolidated, although the irregular blocks and the gradational transition from the smooth intercrater plain to the degenerated landform may imply more consolidated capping materials.

Channels attributed to fluidal action

Some of the most intriguing features on the martian surface are the large sinuous channels, and the most controversial problem associated with the channels is that of their ori-

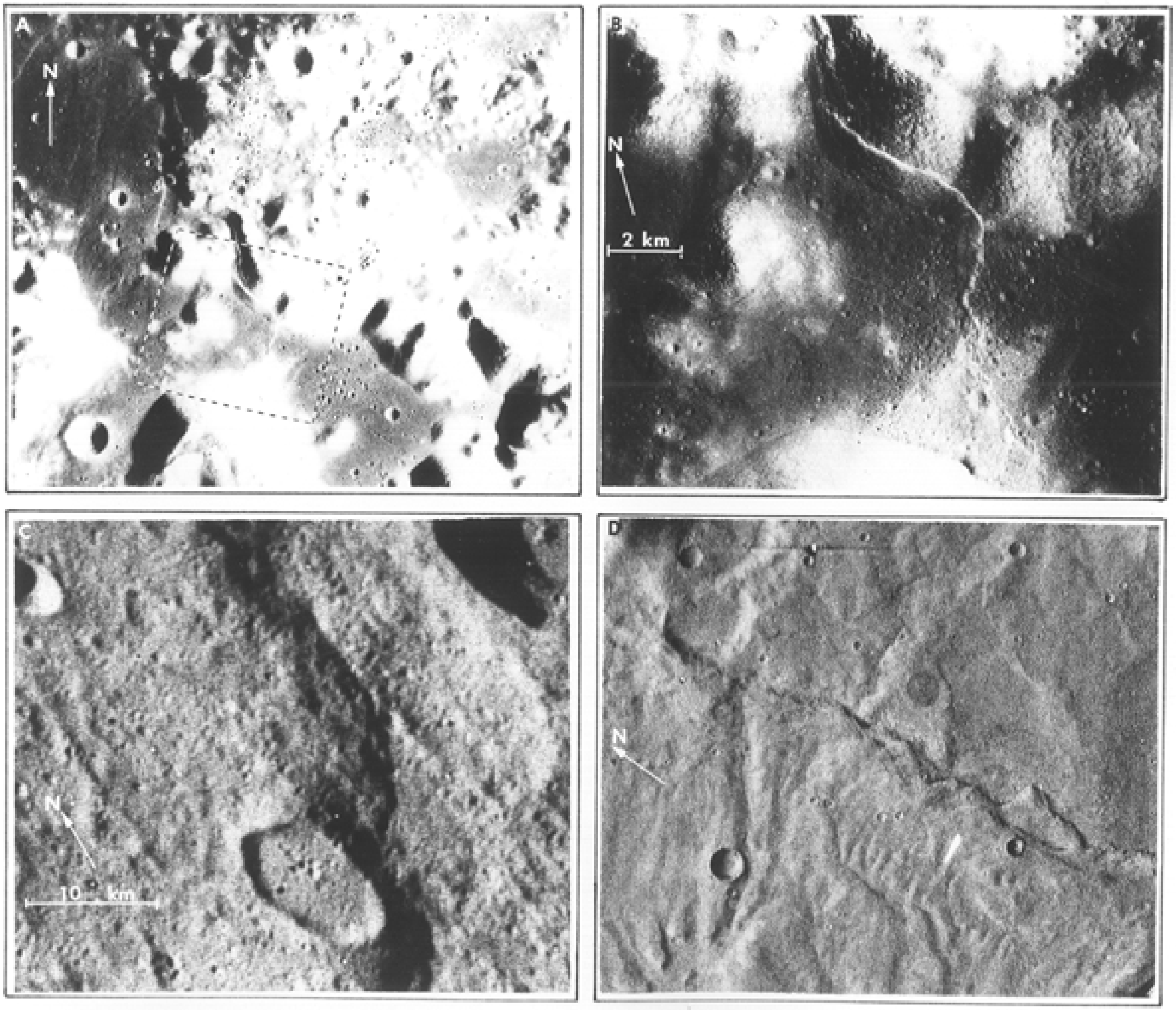


Figure 5(II)

Figure 5B: Lunar highland (A), mercurian intercrater plains (C) and martian intercrater plains (D) escarpments, shown at same scale. B shows lunar example enlarged by a factor of 3 (see inset). These features are distinctly different from those of Figure 5(I) and most likely reflect different genetic processes. Lunar example (Lincoln-Lee Scarp, Apollo 17 landing site) has been interpreted by several lunar scientists (Howard and Muehlberger, 1973) as the result of faulting, as has the mercurian scarp (Discovery Scarp, Murray et al., 1974). A similar origin may apply to the martian scarps. (A: Apollo 17 M0793; B: AS17-150-23006; C: FDS528884 (Mariner 10) D: DAS 8009123 (Mariner 9)).

gin. Although several alternatives have been proposed (Schumm, 1974; Carr, 1974), the favored origin is that of fluid erosion (Milton, 1973; Baker and Milton, 1974; Sharp and Malin, 1975). Channels of this nature are almost entirely restricted to the cratered terrain/intercrater plains, and provide yet another means of probing the subsurface of the plains.

Baker and Milton (1974) have developed a case for the origin of some channels by catastrophic floods, as have Sharp and Malin (1975). The best example of such a channel is Mangala. The morphological similarity to the channeled scablands in Washington State, formed by the catastrophic release of the ice-dammed Pleistocene Lake Missoula (Bretz, 1923; 1969), is striking. The scablands developed in two types of materials: the Palouse loess deposit and the basalts of the Columbia Plateau which were covered by the loess. The massive floods stripped away the loess to form wide channels, and incised into the bedrock floors of these scabland channels as deep as 200 m.

Figure 11a shows a portion of the Mangala channel suggestive of catastrophic flooding. Two features within this photograph bear directly on the materials of the plains unit. First, note that the craters on unchanneled terrain are subdued and appear blanketed while those on channel deposits are more pristine in form. This suggests at least a superficial mantle of loose material has been eroded. Second, note the stripped and scoured appearance along the margin and in large isolated patches, and the smooth channel floor. This suggests the patchy removal of a blanket of loose debris and incision into a more resistant material. Further downstream, a braided section of channel may represent in part unconsolidated channel deposits eroded during the terminal stages of the flood (Fig. lib). Similar features are seen within the Ares channel.

In these cases, while the process of removal appears to have been more violent than in the fretted or chaotic regions, evidence is strong for at least some unconsolidated fine ma-

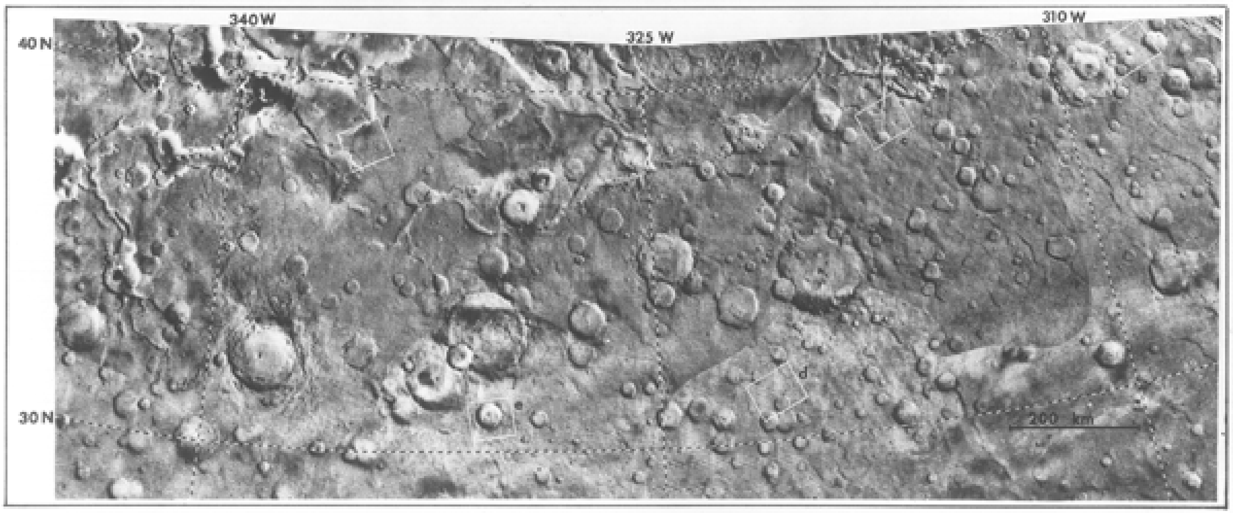


Figure 6A

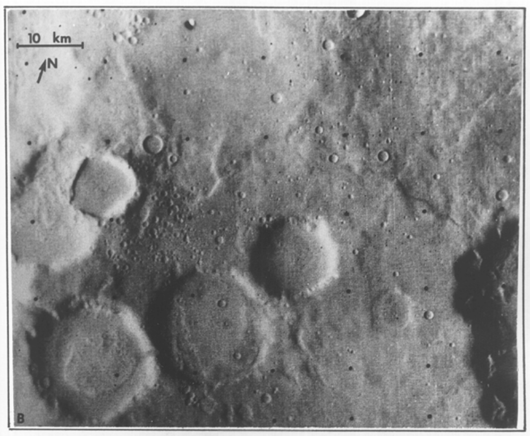


Figure 6B

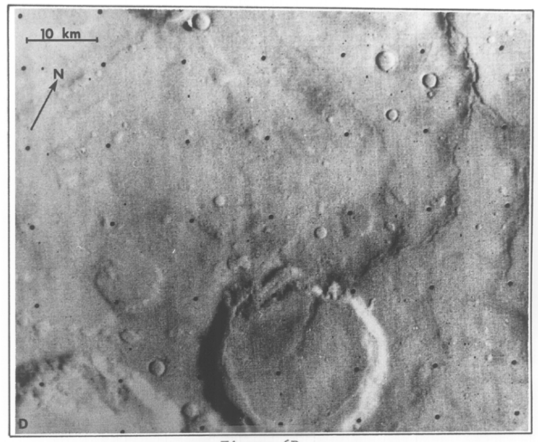


Figure 6D

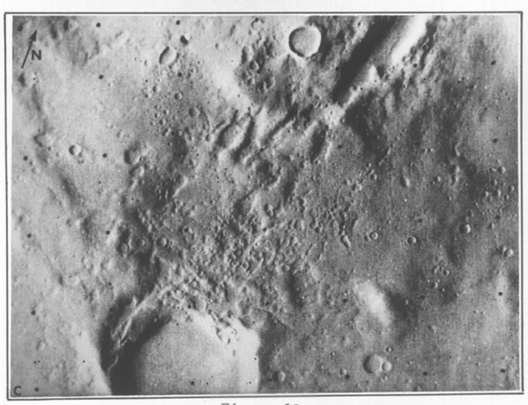


Figure 6C

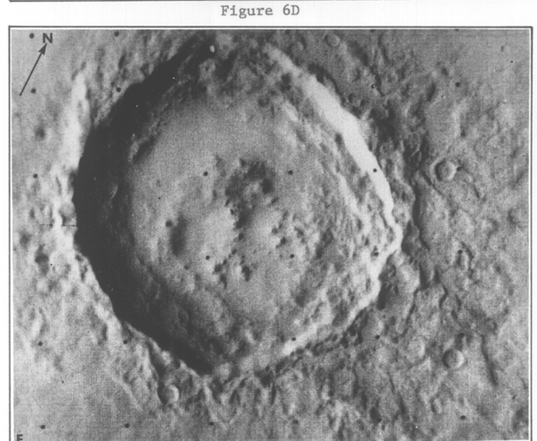
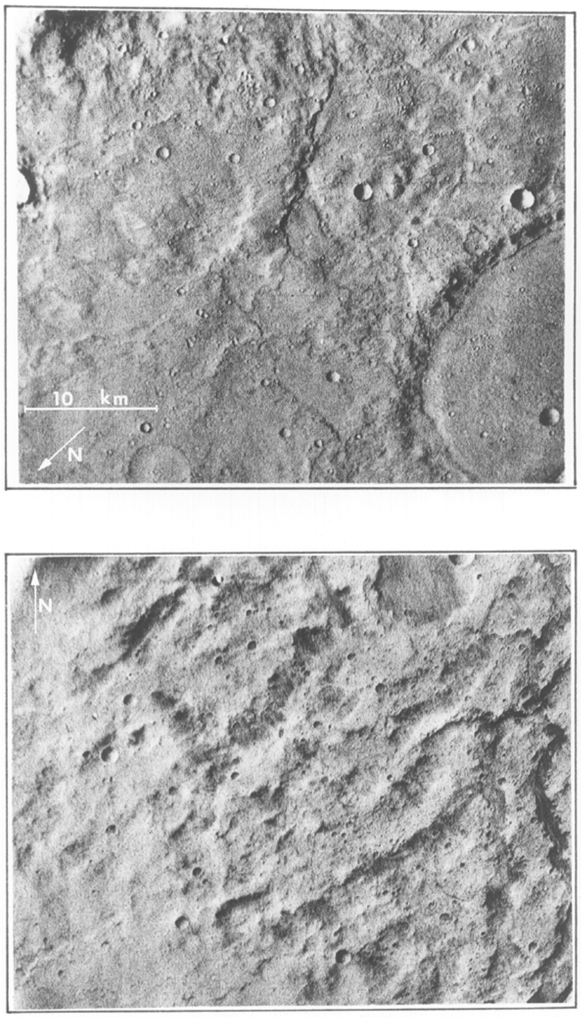


Figure 6E

Figure 6: Variations in Crater Morphology within the Intercrater Plains Regions. **6A**: Mariner 9 A-frame photomosaic showing areas photographed by B-camera. Frames rectified to Lambert Conformal projection. Note that frames b,c, and f are at approximately the same latitude, as are d and e. Instead of a latitudinal variation as seen by Soderblom et al. (1973) elsewhere on Mars, a longitudinal variation is suggested: steep, convex-appearing interior unterraced walls and little indication of ejecta blankets (b,c, and d) east of about 325°W (Type 1), and shallow, blocky, terraced interior walls and pronounced ejects blanket (e,f and Figure 8B) west of that longitude (Type 2). Although differences in crater size may be responsible for the morphologic differences, this seems unlikely, since only craters large enough to display the cited morphologic features are compared. The longitudinal variation suggested by the data may imply differences in the materials of the innercrater plains. **6B**: Mariner 9 high resolution frame DAS 8263014, showing Type 1 crater morphology at 38°N, 307°W. Note the large number of small craters, probably secondaries formed by ejects from a large fresh crater not shown in this photograph. **6C**: Mariner 9 high resolution frame DAS 8191054, showing Type 1 morphology at 38°N, 316°W (photo same scale as B). Note small craters (secondaries?) and fretted channel at upper right. **6D**: Mariner 9 high resolution frame DAS 8190914, showing Type 1 morphology at 30°N, 321°W. Note the escarpment at right that appears to traverse the crater wall and floor at bottom. **6E**: Mariner 9 high resolution frame DAS 8118948 showing terraced crater morphology (Type 2) at 30°N, 330°W (photo same scale as D). **6F:** Mariner 9 high resolution frame DAS 8047198 showing terraced morphology (Type 2) at 38°N, 334°W. Note extensive ejecta blanket and fretted channel at left.



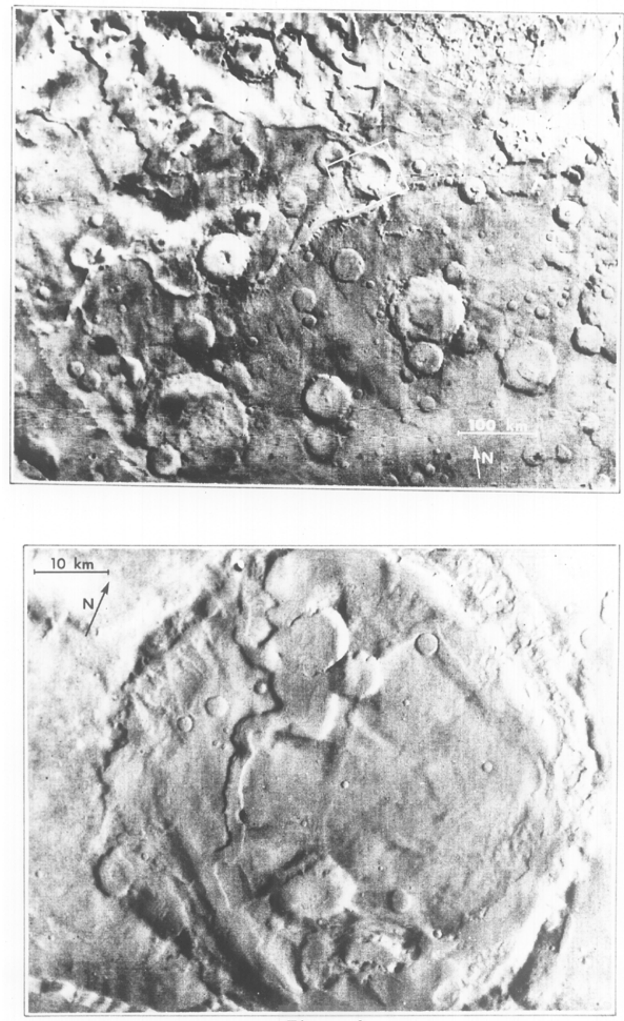


Figure 7

Figure 7: High Resolution Photographs of Intercrater Plains in the Equatorial Region of Mars. Two Mariner 9 B-frames showing the complex nature of the morphology of the intercrater plains in the martian equatorial regions. Escarpments, ridges, isolated hills, channellike forms, and wave-like hummocks combine with craters and crater deposits to form a confusing pattern of topographic forms (Top: DAS 11620145, 16°S, 331°W; Bottom: DAS 8909609, 7.4°S, 245°W).

Figure 8

Figure 8: Fretted Channels and Craters: Relationship to Intercrater Plains. Top: Mariner 9 A-frame DAS 8119058 (36°N, 326°W) showing location of high resolution: B-frame on fretted channel. Bottom: Mariner 9 B-frame DAS 8119093 showing terraced morphology (see Fig. 6) at 38°N, 326°W. Note the three main attributes of the process of fretting of the materials of the intercrater plains: 1) portions of crater rims survive the removal of surrounding material; 2) the fretting appears sharply defined (i.e., shows little effect immediately adjacent to the fretted area); and 3) a uniform depth of channel development.

terial being a constituent of the intercrater plains.

Layers within the plains

Layering of subsurface materials is seen in several places within the cratered hemisphere of Mars. In most cases, the visibility of the layers is marginal, the four following examples being representative of the range in perceptibility of the features.

The best and most obvious occurrence of layered material outside of the polar layered deposit occurs within the Ganges Chasma of the Valles Marineris (Fig. 12). Rising above the interior floor of the 750-km long, 170-kmwide and 2-km deep chasm is a mesa-like island of layered material which is about 2-km thick (D. Dzurisin, personal communication, 1974). The summit of the layered mesa is essentially level with the surface of the intercrater plain into which the chasm is formed. It is possible that these layered materials are not representative of the intercrater plains unit in which the chasm has formed, since the walls of Ganges Chasma do not show the abundant layering seen in the intratrough mesa. The layered material of the mesa would then most likely represent a post-chasm deposit which has subsequently been partly removed. Since the layered deposit is as thick as the plains unit, it is difficult to imagine processes that could essentially fill the chasm to its brim, and then remove the material. It seems more likely that the visible layers in the mesa represent some inhomogeneity within the plains material, which is evidenced by the differences from the wall layering. The nearly complete removal and the appearance of slope gullies which head in “weeping layers” suggests a loosely consolidated material possibly rich in volatiles (Sharp and Malin, 1975).

Elsewhere in the Valles Marineris, layers are seen within the wall formations (Fig. 13). A distinct dark unit seems to cap the sequence, consistent with the smooth plain surface being a later volcanic material covering the older, intercrater plains unit. Mare-like ridges on the plains immediately north (Lunae Planum) and south (Syria, Sinai Planitia) reinforce

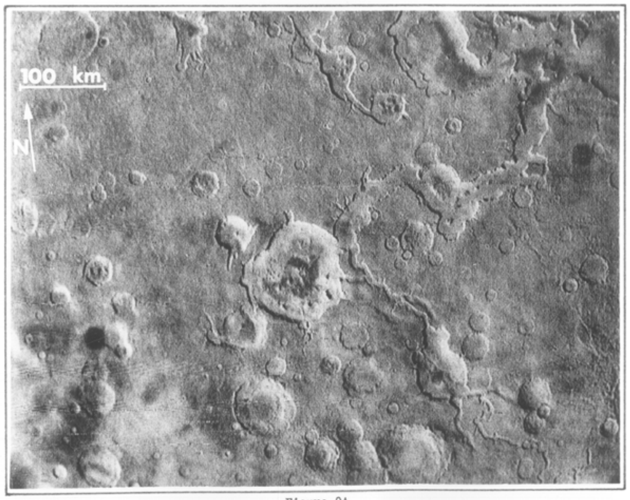


Figure 9A

Figure 9: Fretted Channels and the Intercrater Plains. **9A**: Mariner 9 A-frame DAS 7975208 centered at 36°N, 345°W. This figure illustrates the three points shown in Figure 8 at a larger scale, and adds one more: that the fretting process proceeds to a greater depth than the floors of the craters of the plains. Note the integration of craters by both tangential and head-on encounters. **9B**: Mariner 9 B-frame mosaic (DAS 9378189, 10650904, and 10650974) showing a portion of the fretted channel shown in Figure 9A. Note the concordant floor joining the fretted crater to the channel (middle left). Note, too, the resistant crater rims within the fretted channel (far right).

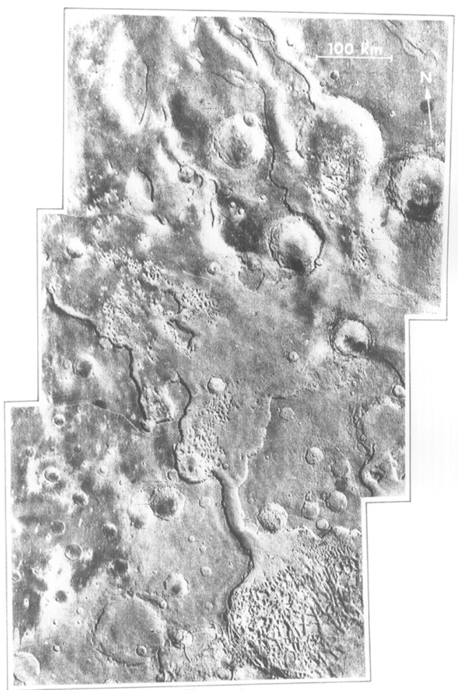


Figure 10

Figure 10: Chaotic Terrain and the Intercrater Plains. These Mariner 9 photographs (DAS 7686808, 7686878 and 7686948) show the major aspects of the process of chaos formation within intercrater plains. Note: 1) the deterioration often appears confined initially to craters; 2) the effective removal of material in some regions, and the residue which survives in other regions; 3) the uniform appearance of channel and chaotic terrain depth; 4) that crater floors lie above the floors of the channels; and 5) the sharp boundaries between plains affected by chaotic terrain formation and those that are not. As in the case of fretted terrain, these observations suggest the effective removal of an essentially unconsolidated material, perhaps overlain by a more competent rock unit capable of resisting at least in part the erosion associated with chaos formation.

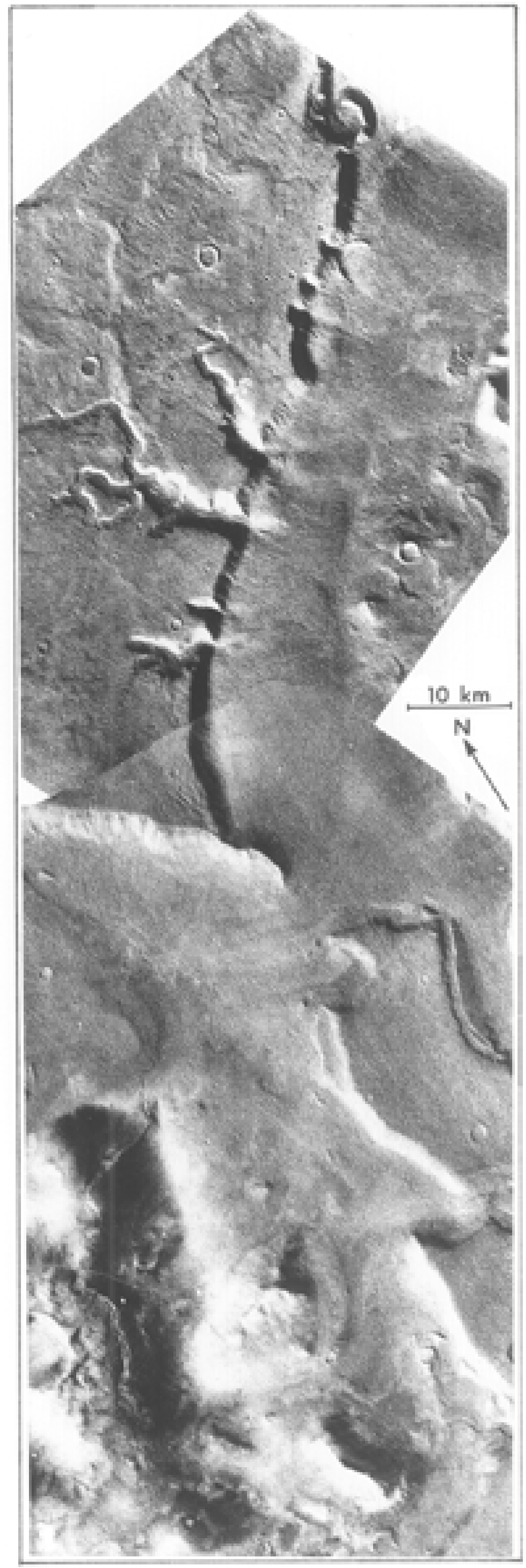


Figure 9B

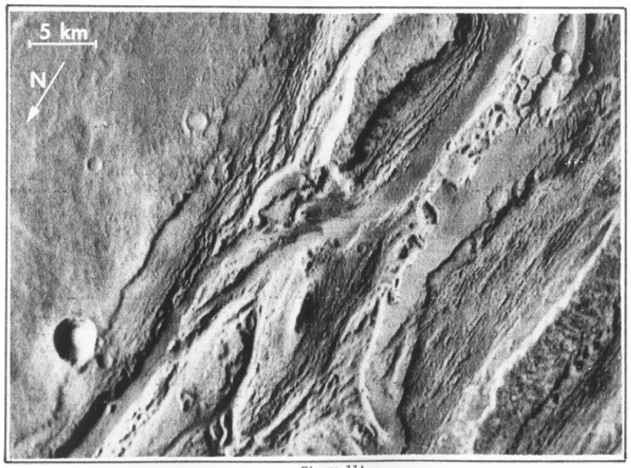


Figure 11A

Figure 11: High Resolution Photographs of Mangala Vallis (5°S, 151°W). **11A**: Mariner 9 B-camera frame DAS 12499650, illustrates two interesting features which bear on the type of materials in the intercrater plains. Note the two small, subdued craters on the plains in the upper left portion of the frame, and compare these with the two similarly sized craters superposed on the channel formations in the upper right portion of the picture. The difference in morphology suggests a blanket covers the craters on the plain but not those on the channel. The second feature concerns the overall morphology of the channel, which is reminiscent of channeled scablands formed in Washington State, where loose material covered basalt bedrock. These two observations suggest the intercrater plains consist in part of loose material covering more resistant material. **11B**: Mariner 9 B-frame (DAS 9628649) shows a portion of Mangala which is downslope from the first region. A most interesting feature of this region is the possible existence of layering or vertical structure evidenced in the terracing of some of the small “islands” and in the resistant knobs which top these “islands”. **11C**: Sketch Map of Figure 11B, indicating position of contourlike layering. Diagonal tone indicates pre-existing surface; light tone indicates deepest channel incision. X marks denote resistant knobs.

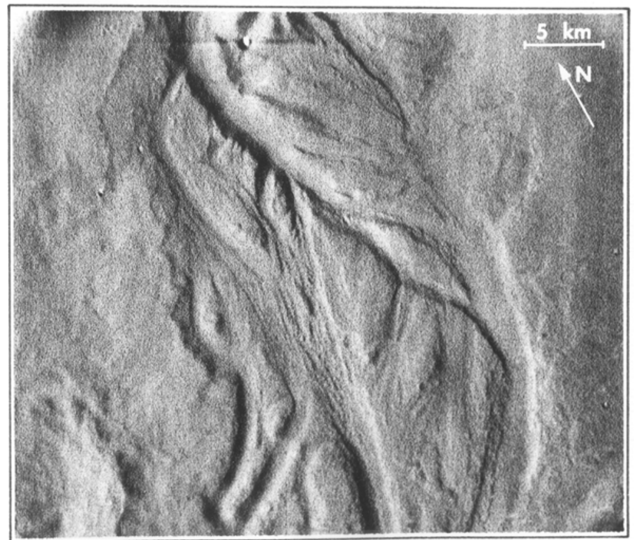


Figure 11B

Figure 11C

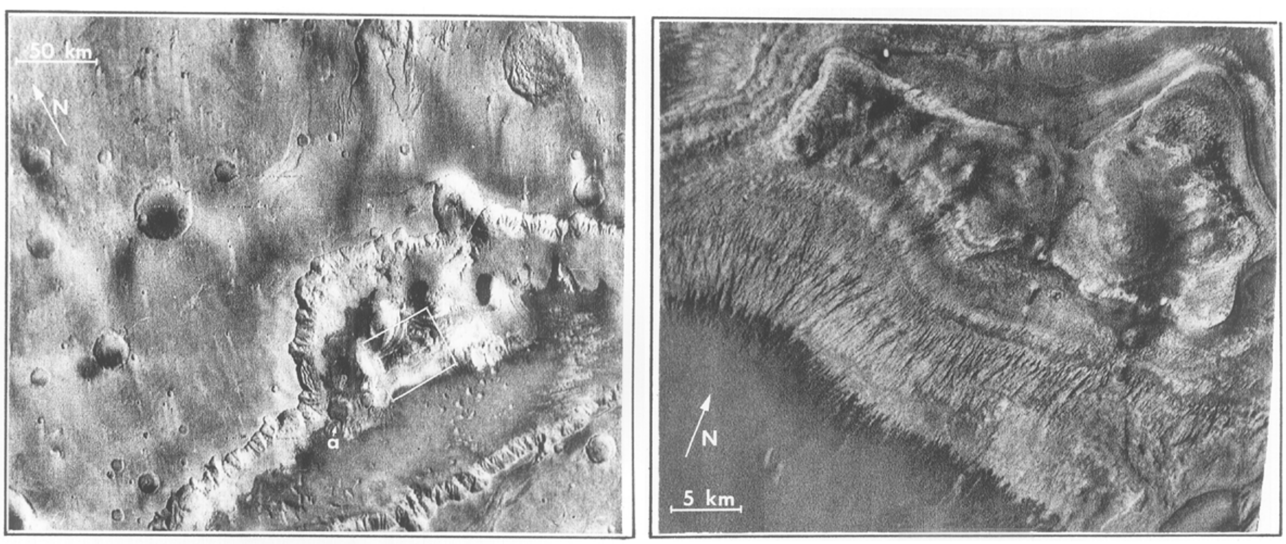


Figure 12

Figure 12: Layering in the Intercrater Plains: Ganges Chasma (6°S,50°W). Top: Mariner 9 A-frame (DAS 7614498) showing layered deposit within Ganges Chasma. Note: 1) dark trough floor material possibly showing through “windows” in layered material north and east of B-frame rectangle; 2) lightcolored hills rising above dark floor material, similar to layered material albedo; and 3) crater-like form west of layered mesa, indicated by “a”. Bottom: High resolution B-frame (DAS 9017619), showing the intra-trough mesa about 2 km high, whose summit is essentially level with the plain in which the trough formed.

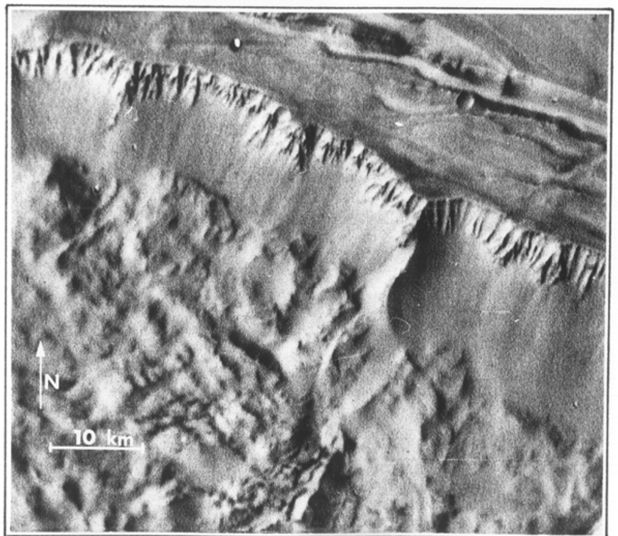


Figure 13A

Figure 13B

Figure 13C

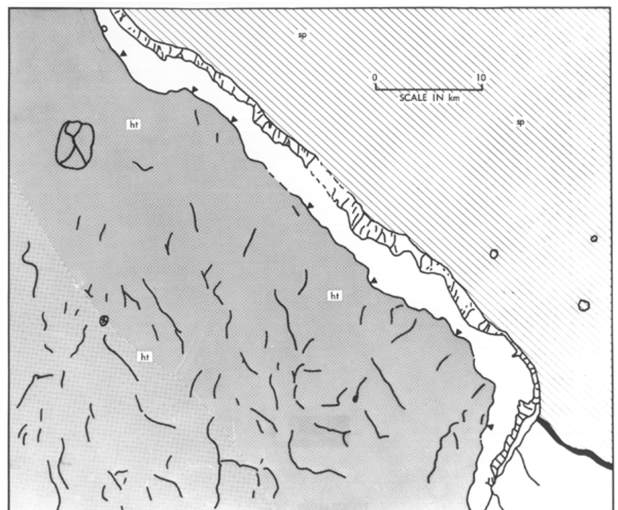


Figure 13D

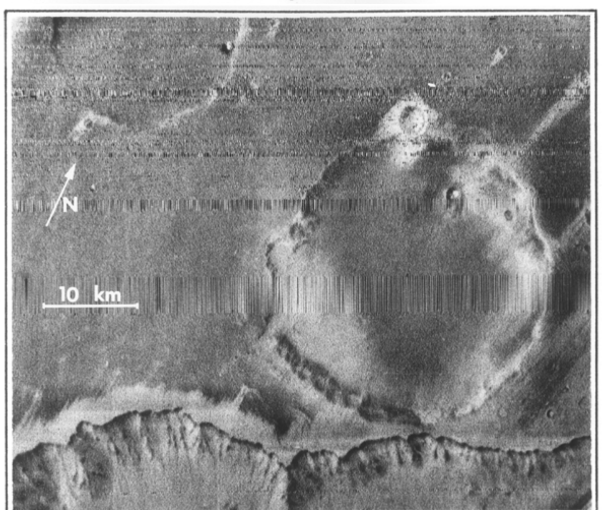


Figure 13E

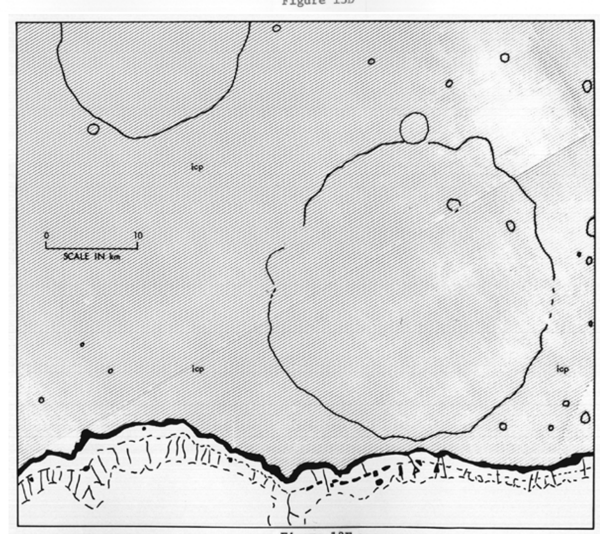


Figure 13F

Figure 13: Layering in the Intercrater Plains: Valles Marineris. Six Mariner 9 high-resolution B-frames illustrate the range in visibility of layers within the walls of the Valles Marineris. Each photograph is accompanied by a sketch showing the features identified as layering. In each case, the upper level plains surface is indicated by diagonal lines and an abbreviation (sp=smooth plain; icp=intercrater plain), and the lower level surface is indicated by a medium tone and abbreviation (ht=hilly terrain; cf=canyon floor). Featureless wall materials, possibly talus slopes, are left unmarked. Ridges and craters are marked, as are the ridges defining chutes near the brink of the walls. Figure 13A & B: DAS: 7398723 (7.5°S, 78°W); Figure 13C & D:DAS: 10132999 (6.7°S, 87°W); Figure 13E & F:DAS: 10492729 (1.5°N, 45°W); Figure 13G & H:DAS: 7614463 (8.6°N, 50°W); Figure 13I & J: DAS: 7326758 (7.3°N, 87°W); Figure 13K & L:DAS: 10204674 (6.6°N, 85°W)

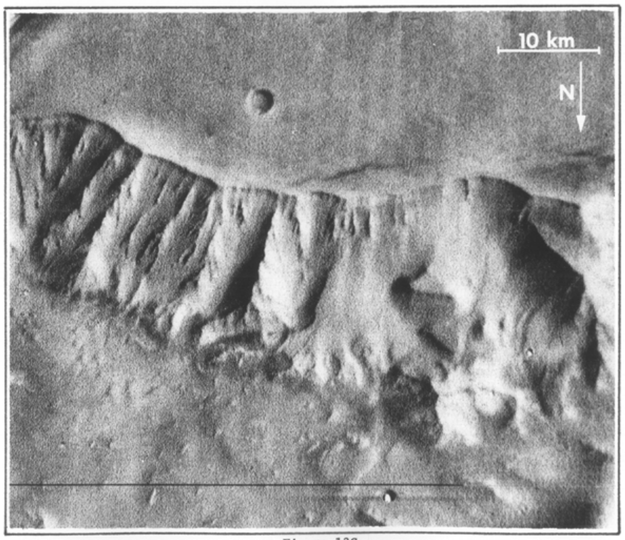


Figure 13G

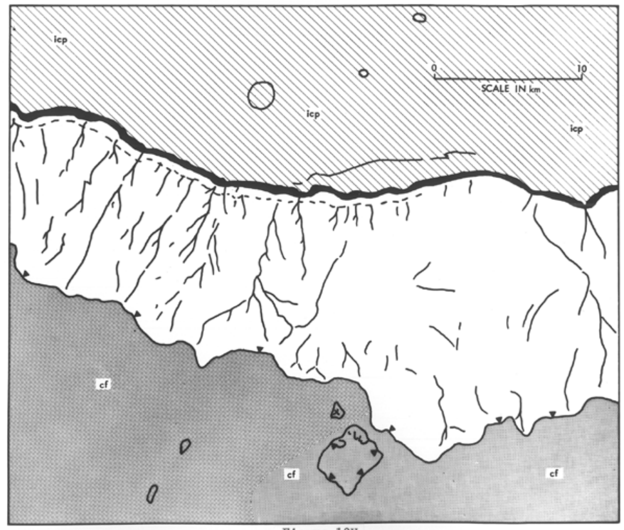


Figure 13H

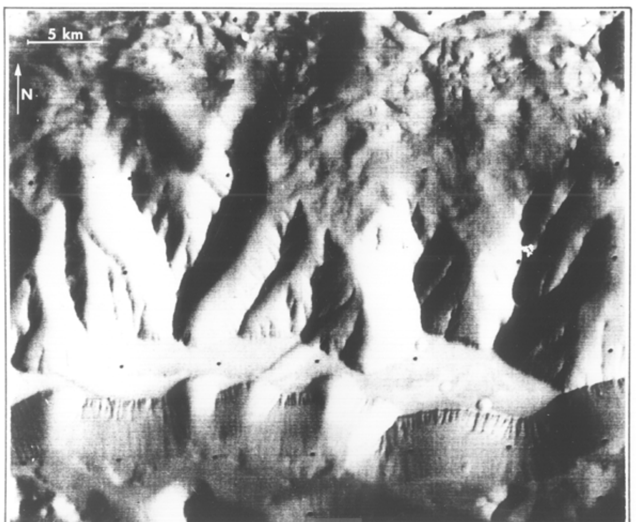


Figure 13I

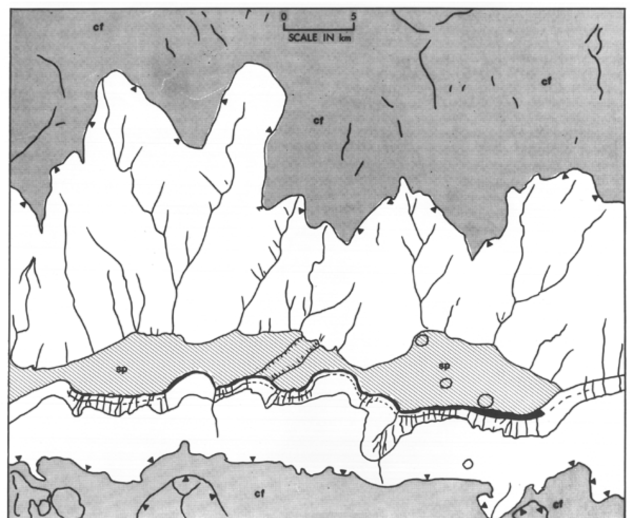


Figure 13J

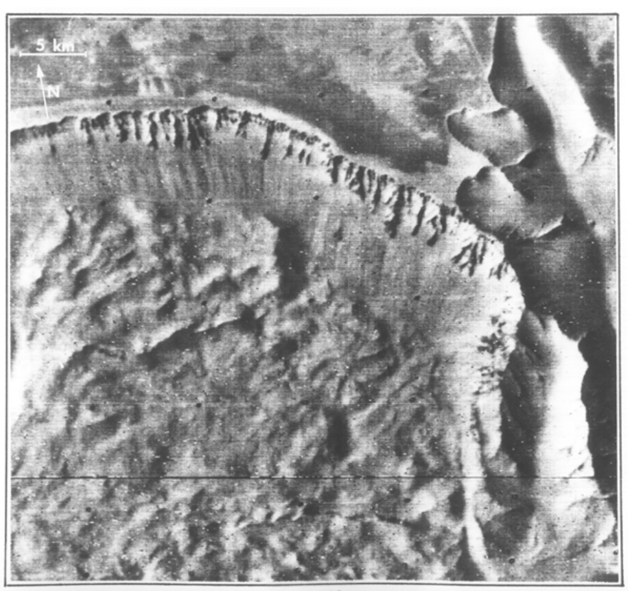


Figure 13K

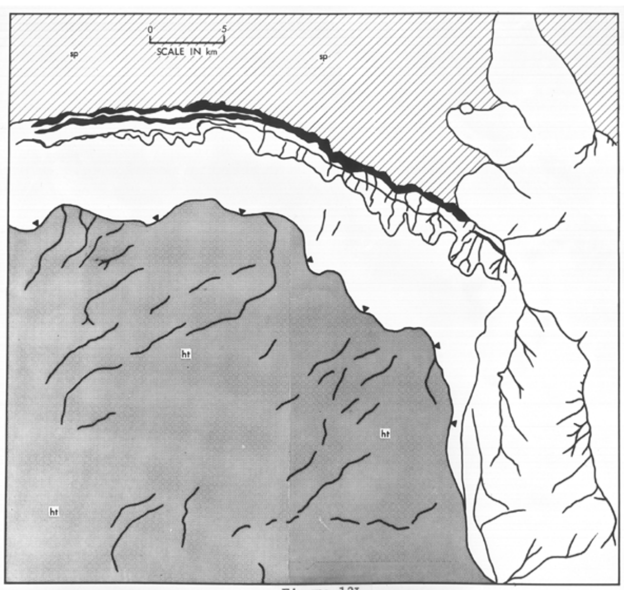


Figure 13L

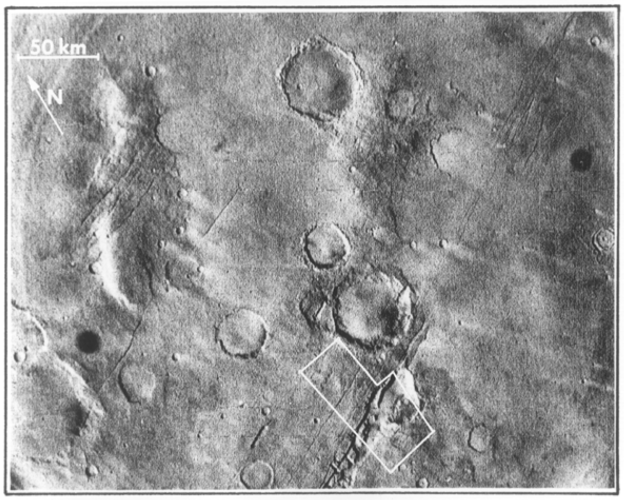


Figure 14A

Figure 14: Layering in the Intercrater Plains: Memnonia Fossae (24°S, 140°w). **14A**: Mariner 9 A-frame (DAS 6966508) showing location of B-frame mosaic. **14** B: Mariner 9 B-frame mosaic (DAS 9772004, 9772074, and 9772144) showing possible resistant, dark material outcropping beneath lighter material (ridge at center) and over light material on right (south) side of major graben. Note the sequence of flows and faulting on left side of graben. **14C**: Sketch map of area shown in Figure 14B.

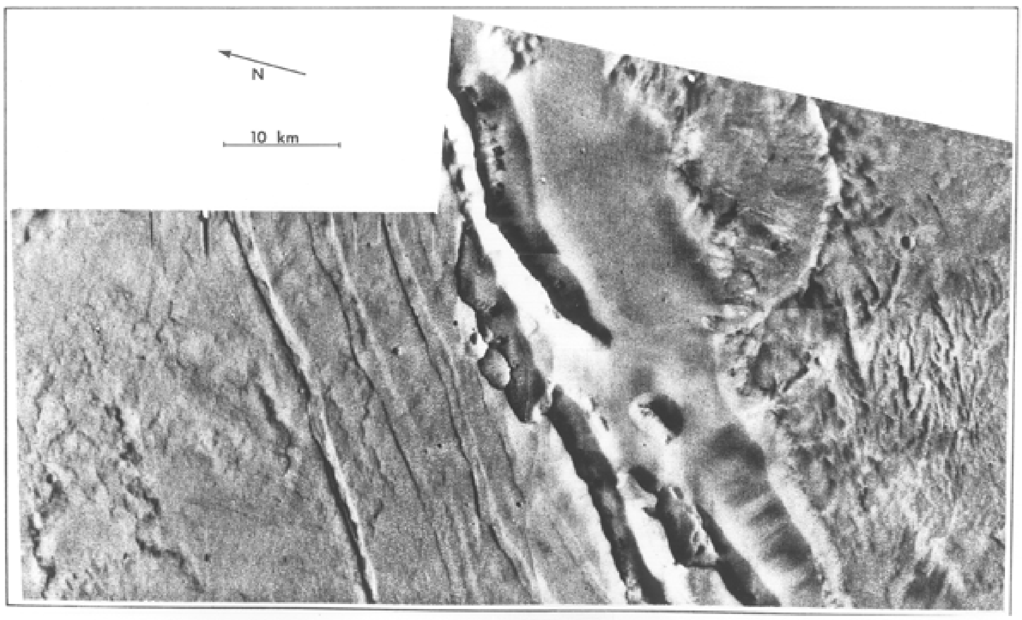


Figure 14B

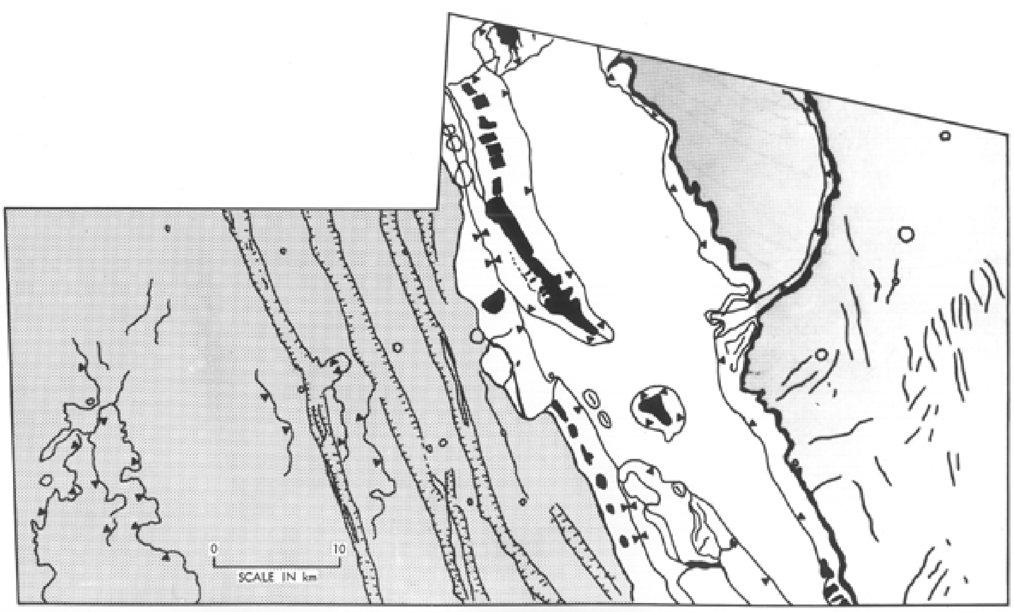


Figure 14C

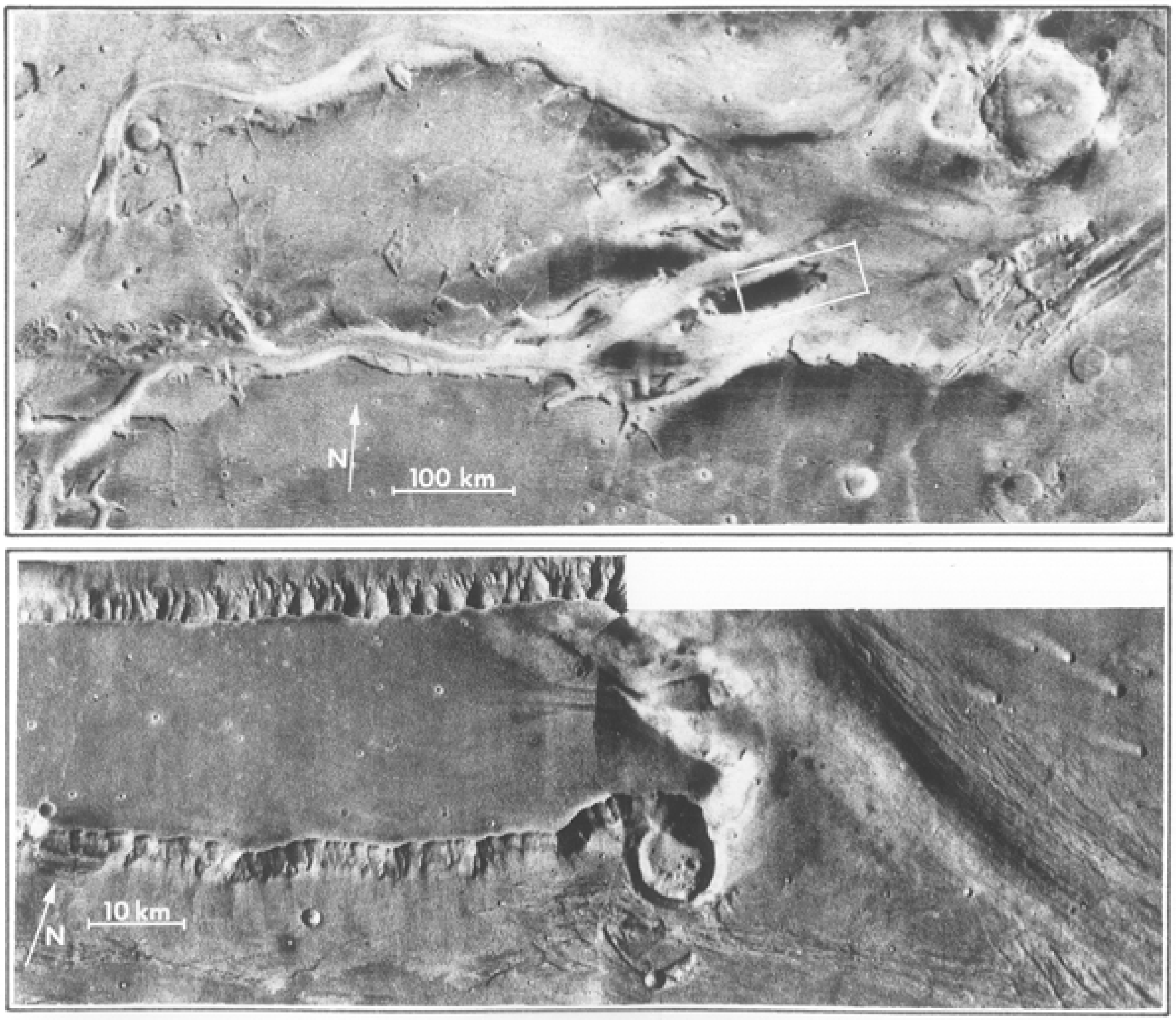


Figure 15A

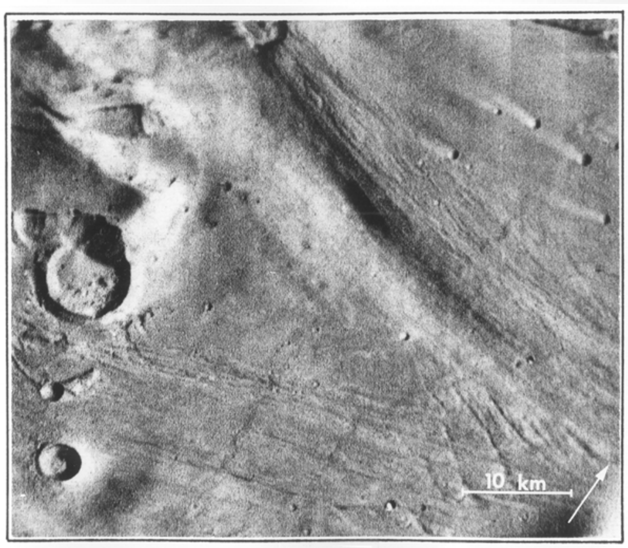


Figure 15B

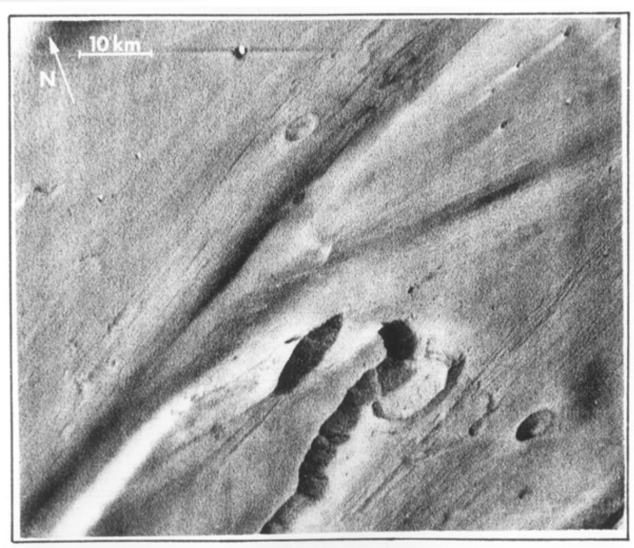


Figure 15C

Figure 15: Crater Exhumation and the Intercrater Plains: Kasai Vallis (24°N, 61°S). **15A**: Top: Mariner 9 A-frame mosaic (DAS 7399738, 7471698) showing location of B-frame mosaic within Kasai channel. Bottom: Mariner 9 B-frame mosaic (DAS 10277409, 12866208) showing 8-km crater being exhumed from beneath the 3-km cliff of the intra-channel "island". Note preservation of crater. (Illumination in lefthand photo is from left; in righthand photo it is from the right). **15B**: Mariner 9 B-frame (DAS 12866208) showing detail of buried crater. **15C**: Mariner 9 B-frame (DAS 8945729) showing oblique view of partially buried crater.

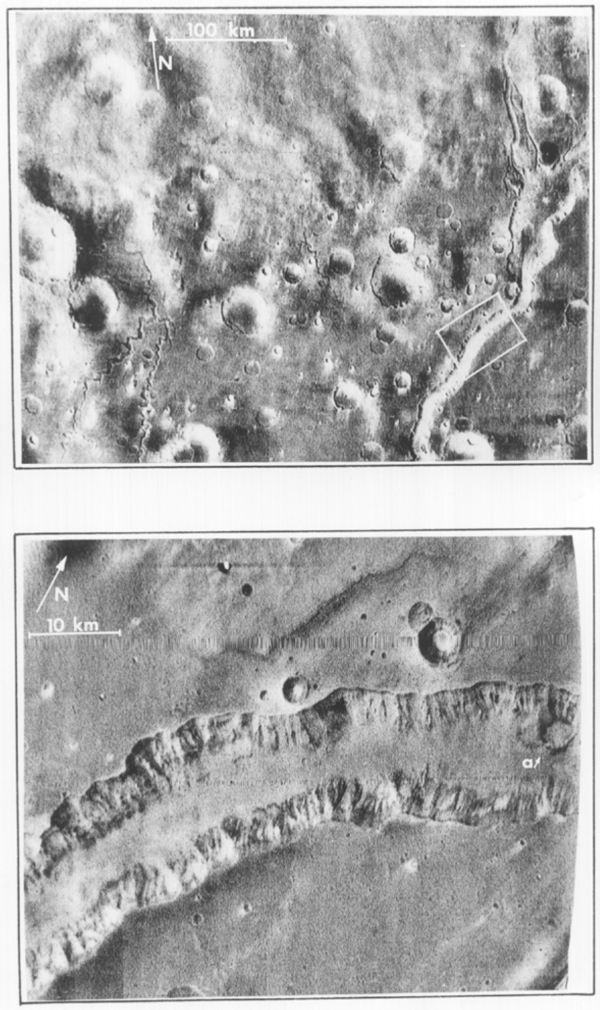


Figure 16

Figure 16: Crater Exhumation and the Intercrater Plains: Shalbatana Vallis (7°N, 40°W). Top: Mariner 9 A-frame (DAS 7614988) showing location of high-resolution B-frame within Shalbatana channel. Bottom: Mariner 9 B-frame (DAB 10492799) showing a craterlike form about 4 km in diameter being exhumed from beneath the layered wall of the Shalbatana channel (a). Sharp and Malin (1975) expressed concern in interpreting this channel as fluvial, because of the small source to channel volume ratio. This concern seems justified, since fluvial erosion would have probably destroyed the crater.

this impression. In the walls of the canyons, beneath the sharp, darker brink, broad bands of alternating light and dark albedo (relative albedos — the absolute differences may be quite small) suggest layering, as do the differences in outcrop expression which occur downslope. Such layering is seen in several widely separated locales extending over the entire length of the Marineris system, some 3000 km. The layered materials may not be entirely members of the intercrater plains unit, but since the eastern end of the Valles are within the intercrater plains unit, while the mid and western regions are within smoother, younger plains units, a laterally gradational change consistent with the burial of the intercrater plains by younger volcanics is suggested.

Nearly halfway around the planet, at 26°S, 140°W near the Sirenum Fossae, where a smoother volcanic plain "laps" onto older intercrater plains, a graben has cut into the materials (Fig. 14). Dark and light strata are seen within the walls and on "islands" within the graben. The surface to the northwest reveals a number of low, lobate escarpments (probably lava flow fronts) which cover and are cut by a series of small horst and graben which parallel the main tectonic feature. To the southeast, a similar plain surrounds a highly textured region of much lower albedo. It is suggested here that the dark stratum and this one dark surface region are older material which has been covered by lighter plains units.

Finally, in the braided region of the Mangala channel, slight, very faint lineations with contour-like configuration (Fig. 11) may indicate layering within that region of intercrater plains. Note particularly the "resistant" knobs located on several "islands".

Exhumation of cratered surface and lower level boundary of inter-crater plains

Perhaps the most dramatic evidence for the nature of the intercrater plains unit is shown in Figure 15. It shows an "island" within the gigantic channel Kasai, approximately 3-4 km high, whose surface is at the same relative elevation as the Lunae Planum plateau plains into which the channel is cut. Note the crater being exhumed from beneath the retreating cliff of the island. Although Baker and Milton (1974) attribute this channel to catastrophic flooding, the remarkable state of preservation of not only the crater's wall, but of its interior features attests to the gentle character of the exhumation and erosional processes. This preservation also suggests that the 3-km thick deposit neither affected the crater during accumulation nor during the period prior to erosion. As noted by Baker and Milton, the walls of Kasai and of this particular island show stratification nearly identical to that seen in other regions. This suggests a connection between this otherwise isolated feature and the greater area of intercrater plains.

There are several other examples of crater exhumation within the intercrater plains, although the Kasai crater is by far the best. One is within the channel Shalbatana and is shown in Figure 16. This craterlike form is less distinct and perhaps more eroded than the Kasai crater. Although Sharp and Malin (1975) classified Shalbatana as an outflow channel of flood origin, their difficulty in explaining a channel volume/source volume ratio of unity caused them to propose a polygenetic origin. A complex origin does in fact seem to be more reasonable in light of the Shalbatana crater.

Another example is a crater-like form, seen only at low resolution, on the floor of Ganges Chasma (Fig. 12). Its light rim deposits stand above the dark floor material of Ganges but is some 1.5 km beneath the rim of the chasm. It cannot be conclusively demonstrated that this feature was once overlain by materials as represented by either the walls or layered deposits, but this conclusion seems plausible in light of the close areal proximity and textural similarity to other features more clearly related to the intercrater plains unit.

A final observation concerning the cratered surfaces being exhumed from beneath the intercrater plains is the possible existence of a delineating stratum near the base of the unit. The dark floor of the Ganges Chasma occurs at an elevation of from 0 to -1 km relative to the 6.1 mbar pressure surface (Christensen, 1975). A similar dark unit is seen throughout the Valles Marineris whenever the floor reaches a depth of 0 to -1 km. As the surface of the plains into which the Valles have developed rises in altitude westward, the depth of incision increases, occasionally reaching but not penetrating below a dark unit at 0 to -1 km (Fig. 17). Eventually, the increase in surface elevation exceeds the increase in canyon depth and only patchy dark features are seen on the floor.

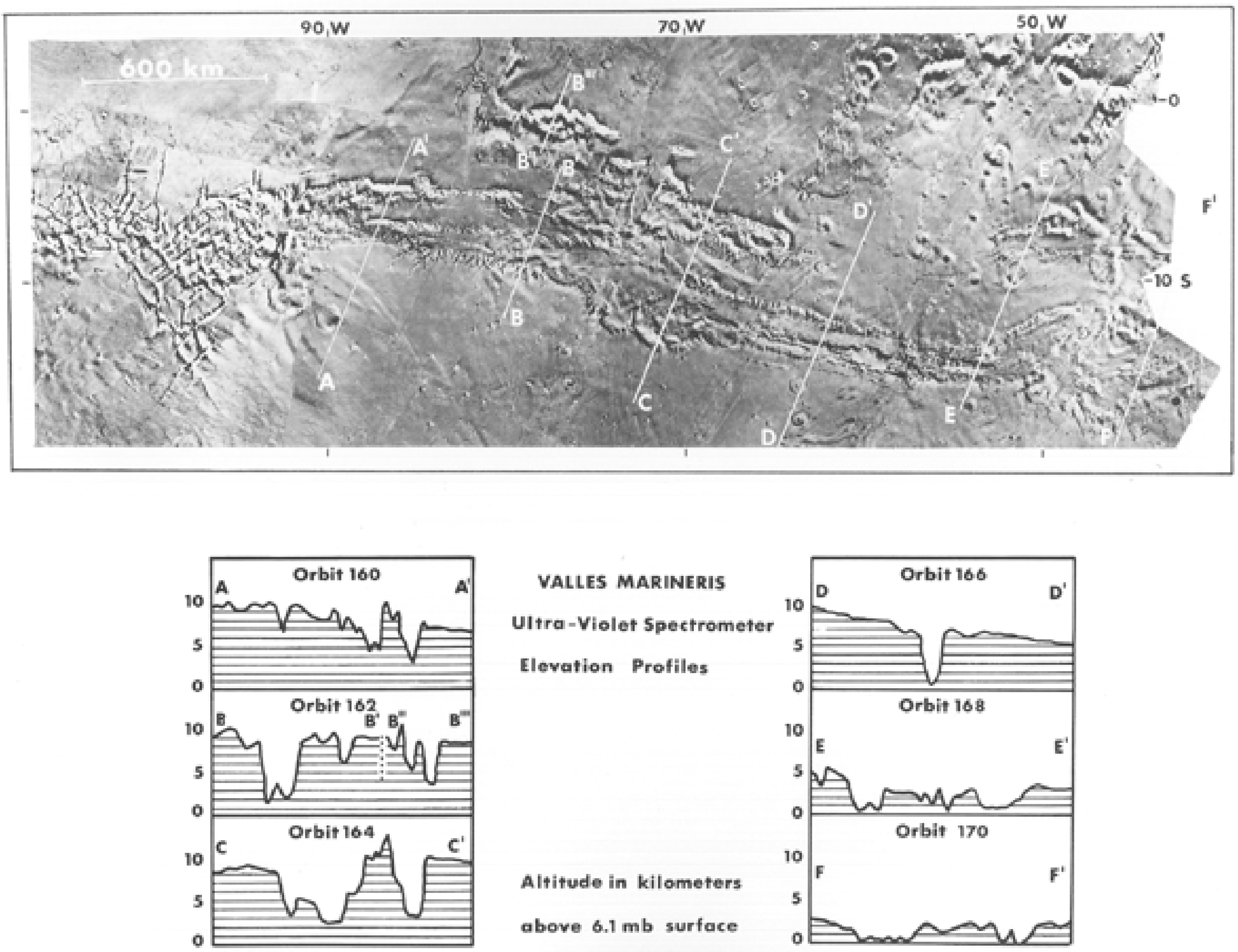


Figure 17

Figure 17: Elevation Profiles of the Valles Marineris. Ultraviolet spectrometer altitude profile for the Valles Marineris are shown here with ground tracks plotted on a photomosaic of the chasms. Note particularly in the eastern portion of the Valles Marineris that the depth of formation does not appear to exceed the zero kilometer elevation level and that the depth increases at roughly the same rate that the surface elevation increases. Only in the western portion of the Valles does the elevation increase become greater than the increasing depth. Wherever the canyon depth reaches about 0 km, the floor appears dark. In the east this is seen in many places, but as the floor elevation increases, only patches are seen of the low albedo material. It is possible that a dark base material underlies the material into which the Valles Marineris developed.

The westernmost depths are between the 2- to 6-km levels, and no dark patches are visible. The Kasai and Shalbatana craters also appear developed within the 0 to -1 km surface, although it does not appear dark.

Discussion

This section will consist of a set of summary statements and conclusions and a series of progressively more speculative interpretations. The former are strongly suggested by the data; the latter are plausible extrapolations. It should be clear that the speculations may present only one of a number of possible alternatives.

The following statements summarize the observations presented in the previous sections:

1. Large craters show significant diversity in degradation, but most tend to be very degraded.
2. Some regions of intercrater plains are extremely subdued, with “flooded” craters.
3. Escarpments are seen in both high and low resolution images that are reminiscent of both lunar highland and mercurian scarps.
4. The processes of fretted and chaotic terrain formation remove material from channeled regions with little effect on surrounding terrain.
5. Fretted and chaotic terrains develop to depths greater than the depths of large, flat-floored craters.
6. integrated regions of chaotic and fretted terrains have concordant floors.
7. A number of channels show evidence of stripping away of loose debris and scour of underlying resistant materials.
8. Several regions show subsurface layering.
9 A few craters are being exhumed from beneath thick deposits.

Two major conclusions can be derived from the observations presented above. First, that the landforms of the intercrater plains suggest a complex sequence of stratified units including both cohesive and relatively unconsolidated materials. Second, that the topmost unit varies from location to location across the surface of Mars. Both conclusions are independent of specific materials and processes which may be invoked to form the unit. They suggest that martian intercrater plains are more complex than many investigators

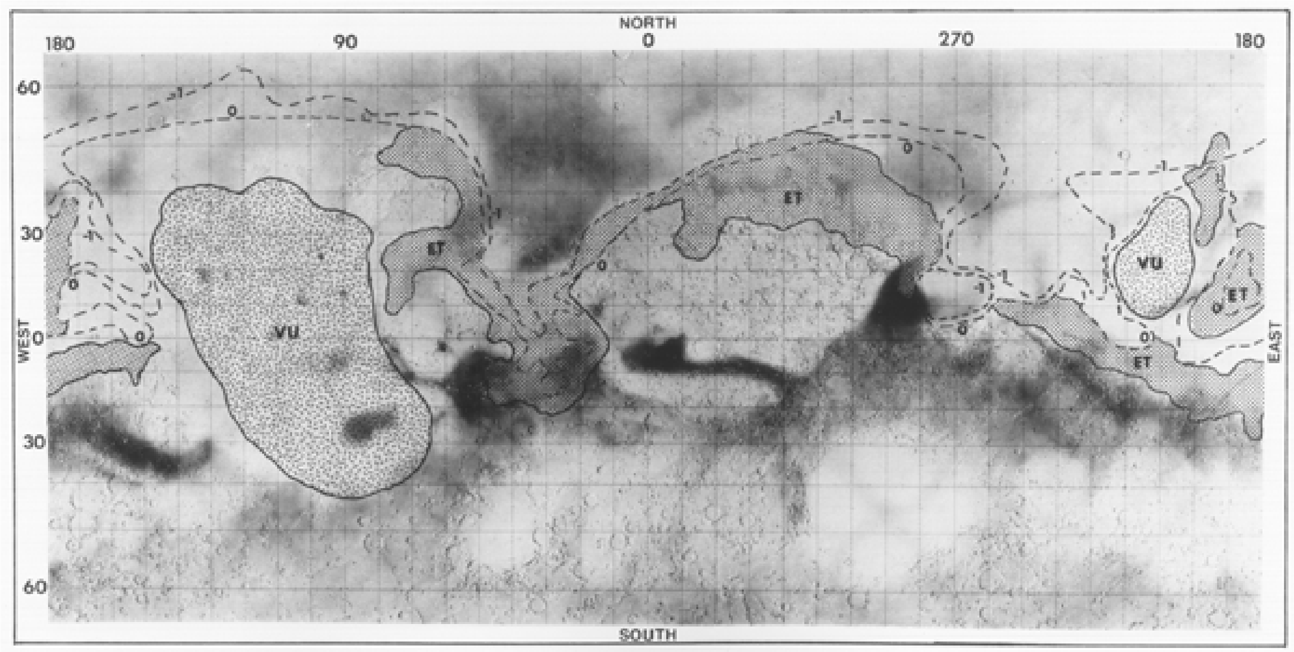


Figure 18

Figure 18: Map of 0 to -1 km Elevation Zone. This map shows the 0 to -1 km elevation zone determined from radar radio occultation, UVS and photogrammetry. Note that except in regions of volcanic activity (Tharsis and Elysium, denoted VU) the erosional zone (ET) between the cratered terrain/intercrater plain and smooth plains follows this contour interval. The speculation presented here is that the 0 to -1 km contour zone signifies the presence of a discontinuity in the structure of the martian lithosphere. Although this discontinuity may be environmentally controlled (e.g., presence of a phase change of water from solid to liquid), the emergence of a cratered surface from beneath the intercrater plain at roughly this elevation suggests that the discontinuity is a real surface having important stratigraphic relation.

have portrayed. Any planetwide stratigraphy must recognize that complexity.

The data and above conclusions seem relevant to four topical speculations: 1) the nature of the materials; 2) the nature of plains formation; 3) the relationship between chaotic, fretted, and channeled terrains; and 4) considerations of an ancient martian crust. The first two will be discussed together, since problems relating environmental processes and constituent materials are nearly inseparable.

The surface of Mars appears to have been continually modified prior to and during the portion of heavy bombardment recorded in the most cratered regions. The resurfacing continued after the bombardment ceased, although its nature appears to have changed dramatically. Surface ridges and resistant wall outcrops suggest competent rock units, while scoured channels, widespread weakly consolidated strata, subdued morphology, and the ease of erosion suggest loose debris blankets.

It is interesting to speculate that the enormous widths of the martian channels (relative to terrestrial examples) may be due to lateral erosion of looser, unconsolidated material along a more resistant bedrock. Volcanic plains seem to have formed throughout the period recorded by the intercrater plains unit and afterwards. The source and nature of the unconsolidated material, however, cannot be definitely established and appears to be unique to the intercrater plains. There seems to be too much loose debris too evenly distributed to be attributed to the cratering process alone. Thus an atmosphere appreciably greater than that presently observed on Mars, capable of transporting considerable material both in suspension and through saltation and traction, is probable. impact-generated debris (such as the lunar surface materials), weathering products, and volcanic ash are all probably constituent materials. Since the redistribution of this fine material appears to have terminated with the end of the heavy bombardment, it is necessary for Mars to have lost this early atmosphere at that time, through exospheric loss, surface recombination, or through some as yet unknown process.

Spatial and temporal development of chaotic and fretted terrains and channels within intercrater plains suggests that lithospheric volatiles believed necessary for their formation (Sharp, 1973b; Sharp and Malin, 1975) were supplied by the intercrater plains unit. These landscapes may reflect the temporary re-release of previously buried (or incorporated) atmospheric volatiles, or the release of juvenile volatiles. This suggests that the plains unit may be the residence for the ancient martian atmosphere, a possibility proposed in a different context by Fanale and Cannon (1971). This implies ancient and unique conditions for formation of these landforms, a conclusion similar to that arrived at through separate studies of channels (Malin, 1976; Sharp and Malin, 1975). Another point, the gentle nature of the erosion of fretted channels, suggests that this may be quite different from the channeling by catastrophic or longer-term flooding.

The final speculation concerns the observation of a 0 to -1.0 km "base level". Inspection of the planetary topographic model prepared by Christensen (1975) shows that, except in regions associated with volcano/tectonic uplift (Tharsis and Elysium), the 0 to -1 km zone delineates the boundary between the cratered uplands and uncratered lowlands (Fig. 18). The transitional landform between these regions (fretted terrain) occurs within 1 km or so of this contour. In the northern plains between the volcano/tectonic uplifts, knobby terrains reminiscent of fretted terrain lie just above the 0 to -1 km zone, suggesting a ridge of pre-existing older terrain, currently eroded, surrounded by younger volcanic plains.

Whether the altitude zone represents an environmental level (e.g., for permafrost, Sharp, 1973b; L. A. Soderblom and D. Wenner, personal communication, 1973), or an actual physical surface (as evidenced by craters) representing a discrete time-stratigraphic marker, is not apparent in the data presently available. However, it suggests the possibility of an ancient bedrock unit significantly older than the most cratered surface.

In summary, Mars appears to have had a complex early history, complete with significant atmospheric and some fluid erosion. Just as the polar layered deposits are believed to record the recent history of Mars (Cutts, 1973), so may the ancient layered deposits — the intercrater plains — record the most primitive history of Mars. Detailed studies of Martian stratigraphy in the distant future may be as intellectually rewarding as the studies of terrestrial stratigraphy are today.

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