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# Mariner Photography of Mars and Aerial Photography of Earth: Some Analogies

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Tentative characterizations of several Mariner 6 and 7 Martian surface features, made by the senior author in the absence of previous knowledge about Mars, are presented. The ridges in 7N17 are interpreted as a glacial moraine; barchane or parabolic sand dunes are identified in 6N5; and thermokarst collapse features, possibly produced in permafrost by Martian geothermal activity, are proposed in 6N8 and 6N14, in agreement with the suggestion of Sharp *et al.* (1971).

In the absence of a deductive physical theory of surface topographic characteristics, the geological and meteorological interpretation of surface features on the planet Mars as observed by Mariner spacecraft depends heavily on analogy with known terrestrial features. Not only is such an analogical approach useful; it is difficult to see what alternatives exist. Nevertheless it is clear that analogical approaches may lack uniqueness, and that there may be a significant difference in the interpretation depending upon the experience of the analyst with varieties of terrestrial geomorphology. An important and careful analysis of features in noncratered terrains observed in the Mariner 6 and 7 photography has recently been published by Sharp *et al.* (1971a, 1971b), a group with strong geological experience. Nevertheless it seems desirable to have an independent assessement of some of the vexing Martian surface features by an individual with a strong background in aerial photographic analysis of terrestrial land forms. Accordingly the senior author of this report was invited to examine a set of high contrast-enhancement photographs obtained by Mariner 6 and 7. The present paper represents his interpretations, as connected to present knowledge of Mars by the other authors. In each of the following three cases information supporting the senior author's interpretation has been provided by the other two authors, but we stress that the original interpretation was made in the absence of the supporting information. For example, the identification of the curvilinear features in 7N17 as a glacial moraine was made in the absence of *a priori* knowledge that this was a photograph of a polar region.

## Mariner Photograph 7N17: Glacial Moraine

This photograph (Fig. 1) strikingly illustrates a distinction between two regions. The region at lower right is a province of transported materials of sufficient depth to mask an ancient landscape similar to that shown towards upper left which is marked by craters and other generated topography. Since it is extremely unlikely that the province in lower right could have been fortuitiously preserved from impacts and similar events, the conclusion that a relatively recent covering has buried ancient terrain at lower right

FIG. 1. This is a reproduction of 7N17. A sketch diagram of this region as well as approximate scales are given in Fig. 5 of the paper by Sharp *et al.* (1971b). The contrast between the smooth topography of the lower right hand corner and the rest of the photograph is quite evident. The geometric distortion is severe, but this picture covers approximately 1380km horizontally, and 1180km vertically. The picture is not photometrically corrected; the entire area is frost-covered. Note the two provinces, and the suggestion of a great thickness of covering material.

seems inescapable. While topographic control of winds on Mars is to be expected in the presence of large elevation differences (Sagan, Veverka, and Gierasch, 1971), there is no evidence of a significant elevation difference along the boundary between buried and unburied terrain in Fig. 1. Under these circumstances the boundary appears to be too definite to be attributable to aeolian erosion of the covering material. On Earth, loess, as opposed to dune sand, can mask large areas in this manner, but the transition from a deep cover to a shallow cover, or no cover, is never as sharp as in this photograph. Sharpness of the boundary between the two provinces as well as the appreciable thickness of the covering material are consistent with a glacial origin for the covering material. The covering material could be frozen $CO_2$ and $H_2O$ interlayered with, or covered by, wind-blown dust.

Glacial action is also strongly suggested by the moraine-like arrangement of ridges towards in the lower right of Fig. 1. These are shown at a larger scale in Fig. 2. The lamination suggests an extensive ridge system similar to the lobate and interlobate moraines. The general compactness and maximum size of the ridges in terminal moraine segments is very similar to what is seen here, as is the tendency for the ridges to become more widely spaced and smaller in size as the margin segments. We see the erratic and complex offshoots typical of forces exerted by ice, but unlike those

FIG. 2. A closeup of the south polar region taken from 7N17. The ridges are about 2–5km wide, and extend for several hundred km. Typical separations between ridges are about 10–30km. The geographical south pole is located approximately halfway between the second and third reseau dots (counting from the left) in the second line of reseau dots from the bottom of the frame. Note the wrap-around lobe, suggesting flow around a topographic high.

exerted by more readily deflected forces such as winds.

Despite the decline in definition towards the terminator, some interesting details can be discerned in the ridge system (Fig. 2). First, there is the distinct looping back of several of the ridges, again a characteristic of moraine arrangements on Earth. A map of a representative terrestrial moraine region is shown in Fig. 3. Here, individual moraines 2–20km in width and about 250km in length, produced in the Great Lakes region during the Wisconsin Glaciation, can be seen. The separation between ridges in Fig. 3 is of the order of a few ridge widths. By comparison the ridges in 7N17 are 2 to 5km wide, extend several hundred km, and have characteristic interridge separations of 10–30km. Thus not only the form, but also the absolute dimensions, of the 7N17 ridges are consistent with characteristic terrestrial moraines

In addition, the tight reverse curve in the front ridges may be due to the ridges being wrapped around topographic highs. As indicated in the caption to Fig. 2, these features are very close to the actual Martian south pole.

It is possible that large quantities of carbon dioxide ice can accumulate in the polar regions of Mars. At any given moment in the precessional cycle of Mars at least one of the poles is likely to be the site of a "permanent" polar cap. The situation reverses every 25 000 years—about half the precessional period (cf. Leighton and Murray, 1966). At the present time it is the north pole of Mars which exhibits a "permanent" polar cap; the north polar cap maintains a sizable extent even during northern summer.

The movement of glaciers is usually considered (see, e.g., Embleton and King, 1967) to consist of two components: (a) internal deformation, or "creep," and (b) basal sliding. Cold glaciers do not exhibit

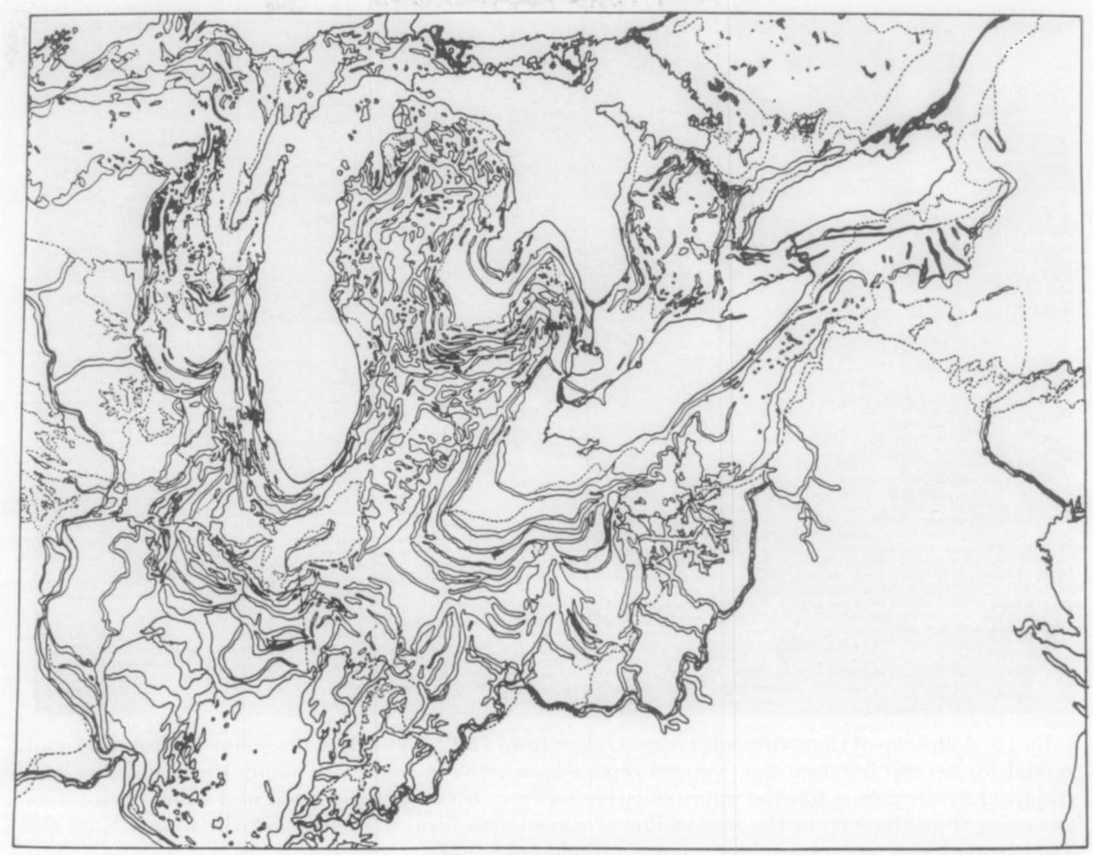

FIG. 3. Map of glacial moraines in the Great Lakes Region taken from "The Glacial Map of North America" (1945). Typical moraine spacing is ~10 miles; while widths are usually 2–5 miles. Moraine lengths of 100–200 miles are not uncommon.

basal sliding, since they are frozen to the bedrock, but there may be severe shearing in the basal ice layer. Thus cold glaciers on Earth may not be as effective in eroding bedrock by abrasion as are glaciers nearer to the freezing point of water. Because of the form of the phase diagram for frozen $CO_2$, we might expect internal deformation but not basal sliding in Martian glaciers if they are composed of dry ice. Temporary glaciation at the northern polar cap of Mars is to be expected under present conditions. By the same reasoning the south polar region of Mars has emerged from its ice age about as recently as north temperate latitudes on the Earth have. It is in this region that we expect to see the effects of glaciation, and it is possible that even today permanent ice remains near the south pole.

## MARINER PHOTOGRAPH 6N5: DUNES

Figure 4 shows a portion of Mariner photograph 6N5. There is a striking series of crescent-shaped features in the western (left) half of the photograph, the most conspicuous of which lies at approximately +52°W, +4°N in Xanthe—approximately in the region of the chaotic terrain noted by Sharp *et al.* (1971a). The geometric distortion on this photograph is severe; the distance between reseau marks is very approximately 230–330km. Thus the width of the main feature is ~100km and its length is ~300km. The main crescent-shaped feature is oriented about 30°E of N: smaller crescent-shaped features in the area have very similar orientation.

These features are strongly reminiscent

FIG. 4. A portion of 6N5. Note the numerous crescent-shaped features on the left hand side of the photograph, as well as the elongated feature in the upper middle part. The tip of the most conspicuous crescent-shaped feature lies at approximately (+52°W, +4°N). Due to severe geometric distortion, the scale is not linear; however the approximate distance between the reseau dots is 300km. Note that all the crescents point about 30° right of the vertical. There are several apparent scarps in the photograph, with higher albedo material seemingly piled up along them.

of terrestrial sand dunes. Dune groups on the Earth may cover thousands of square km, and the collective shape of an array of dunes remarkably often takes on the overall shape of the individual dune, particularly in the case of barchane dunes. The largest barchane dune area known is in Egypt and is about 150km wide and ~800km long; that is, somewhat larger than the dimensions of the dune system identified in 6N5. The width of the barchane belt in the Libyan desert is, according to Bagnold (1960), about 12km, but is at least 300km long. Such barchane belts are composed of individual crescent-shaped barchane dunes which, on Earth, have characteristic heights of several tens of meters. According to Holm (1960) individual crescent-shaped dunes in the Arabian Peninsula may be 2–5km long, and 200m high. Barchane dunes are to be distinguished from linear seif dunes which lack the characteristic crescent shape and which have been proposed previously by Gifford (1964) in an attempt to explain possible canals. Barchane dunes are also to be distinguished from parabolic or U-shaped dunes, which have a somewhat similar morphology. The principal difference between the two is that the tips of barchane dunes point leeward while the tips of parabolic dunes point windward (see, e.g., Viorst, 1967). The barchane and parabolic dunes both appear in desert regions subject to moderate winds. But the parabolic dunes result from stabilization, produced either by vegetation or by topography.

To distinguish between the two possibilities, barchane or parabolic, it is useful to examine known wind motions in this area. de Vaucouleurs (1954) mentions two major cloud motion events in this region. The first occurred between 9 and 12 July, 1922 at $\eta = 279$–$281°$, that is, during Northern autumn. The average cloud velocity was 18–36 km/hr in a direction about 30°W of North. The second case occurred between 25 and 29 May 1937 at $\eta = 241$–$243°$, that is, during late Northern summer. The average cloud velocity was ~10 km/hr in a direction about 45°E of North. Thus in both cases that a major cloud system has been observed to move through this area, the cloud motion was northerly; that is, the winds were from the South. This would suggest that the horns of the crescents in 6N5 point upwind, implying that the dunes are parabolic rather than barchane and therefore are stabilized (i.e., the movement of fine particles occurs in the center of the crescents and the tips of the crescents are immobilized). In this case a very important question arises about what stabilizes parabolic dunes on Mars. If the dunes are barchane with horns pointing downwind, we must conclude that both cloud motions discussed by de Vaucouleurs are not representative of the mean wind motion in this area. Hook-shaped dunes tend to have their long arm pointing downwind. (Bagnold, 1960; Holm, 1960). Such a dune may appear at left center of Fig. 4. If so, barchane dunes are implied.

The prominent dune on the left and others nearby show a consistent tendency towards a sharp border on the Northern (top) edge and a vaguer less well-defined inner boundary. This is associated with the direction of net progress of the dunes and is independent of the identification as barchane or parabolic. The complex dune pattern in the upper center is also a common shape generated by nonuniform topography. Elsewhere in this photograph vague suggestions of sand accumulation are seen: a possible fault scarp appears entering the area along the right margin. As this trends downward and changes orientation towards

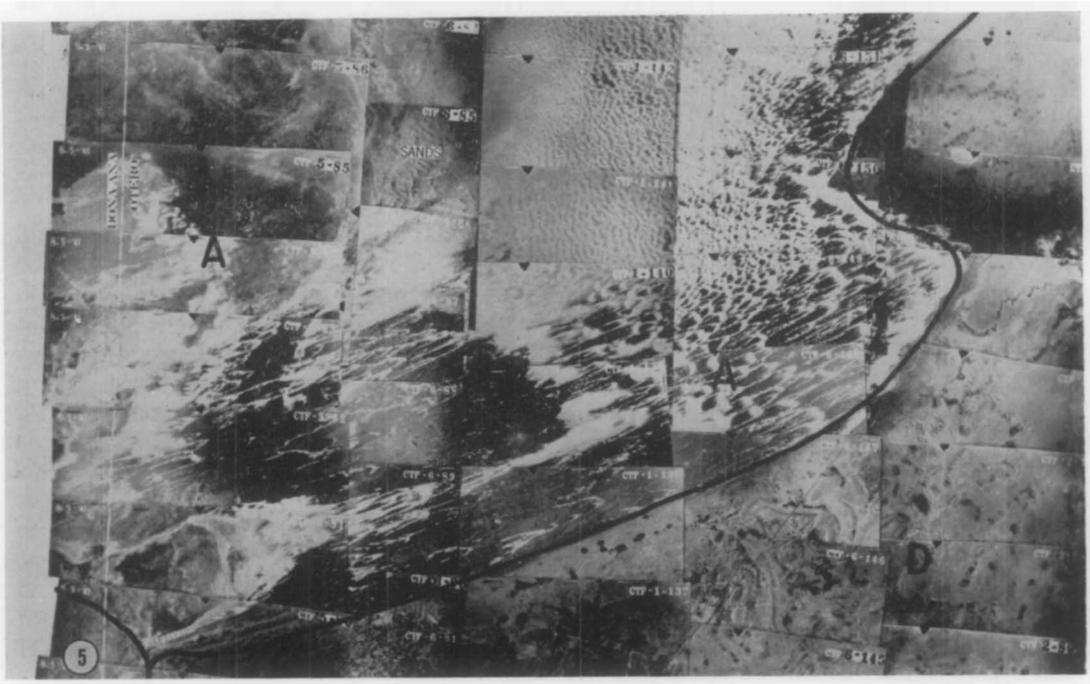


FIG. 5. Photographic mosaic of the Otero district of New Mexico showing numerous aligned crescent-shaped dunes. Note the sharp boundary between the dune-covered terrain and the sand-free surrounding area. (A = gypsum salts; D = calcareous shales.)


FIG. 6. An enlargement of the area covered by CT-147, CT-148, and CT-149 in the preceding mosaic. Note the resemblance between the dunes in this photograph and the crescent-shaped features in Fig. 4. Also note the similarity between the structure of the sand dune edge where it meets the surrounding sand-free area and the longitudinal feature in the upper middle part of Fig. 4.

the south-western corner of the picture, it seems to afford shelter from the wind and thereby permits fine particles to settle in the lee of the scarp, forming a broad smooth area of relatively high reflectivity. This is a common occurrence in many deserts. An aerial photographic mosaic of crescent-shaped dunes in the Otero district of New Mexico is shown in Fig. 5; an enlargement of a portion of this area is displayed in Fig. 6. The existence of coordination of small dunes making up large dune groups is especially striking.

On Earth crescent-shaped dunes form transverse to the wind direction and are characteristically found where wind velocities are at most moderate and where vegetation may be common (see Fig. 5). In contrast, sief, or long longitudinal dunes, form parallel to the wind direction, and are characteristically found where the winds are strong and where vegetation is sparse. Both types of dunes probably exist on Mars. It is important to look for them in the Mariner Mars '71 photography, since among other things they are excellent indicators of mean wind directions provided they are controlled by winds and not by topography (as sand piling up along a ridge). In particular, the dune region of 6N5 should be examined at high resolution from the Mariner Mars '71 Orbiter.

## Mariner Photographs 6N8 and 6N14: Thermokarst

Figures 7 and 8 show portions of Mariner 6 photographs 6N8 and 6N14

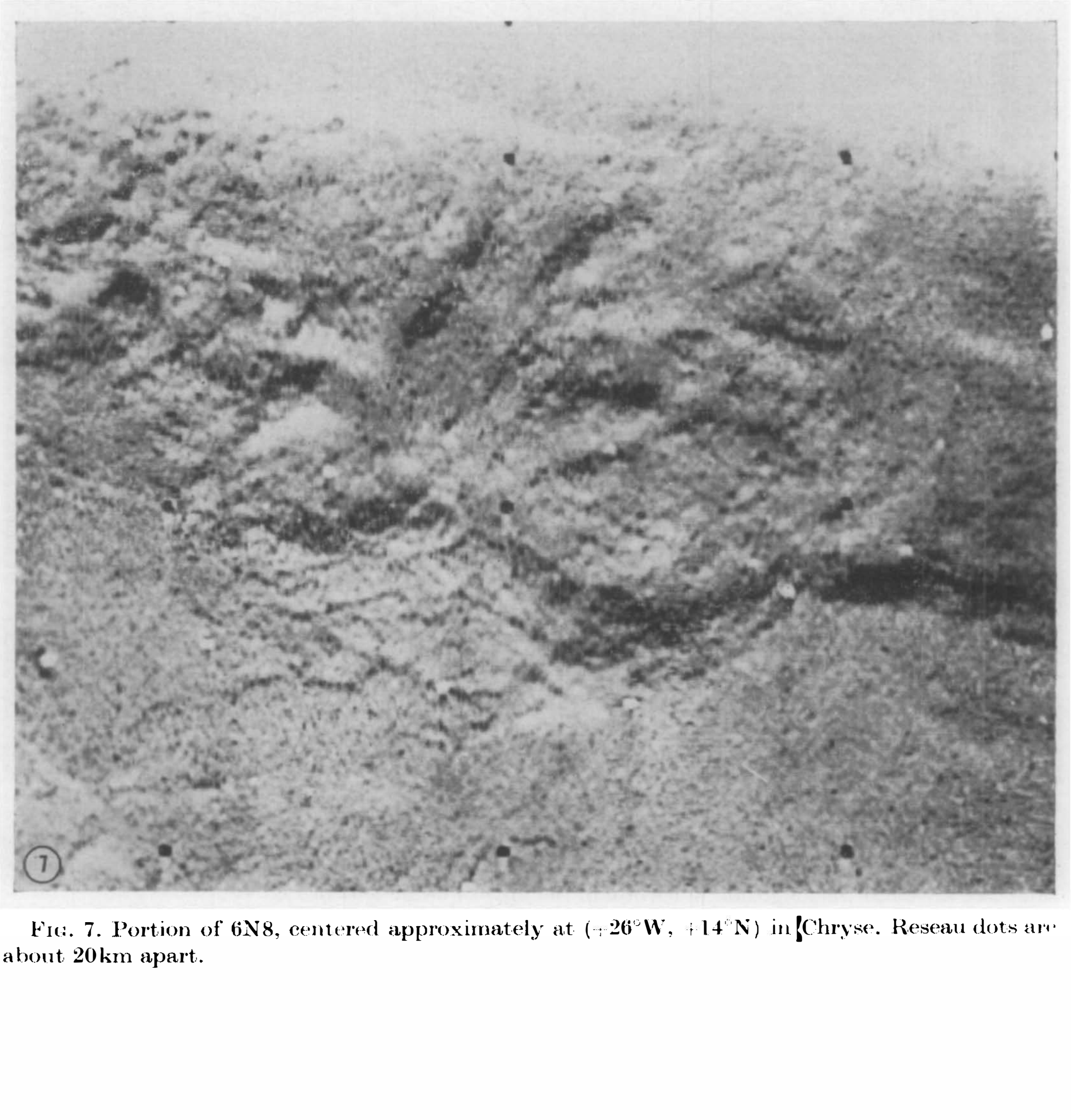


Fig. 7. Portion of 6N8, centered approximately at (+26°W, +14°N) in Chryse. Reseau dots are about 20 km apart.

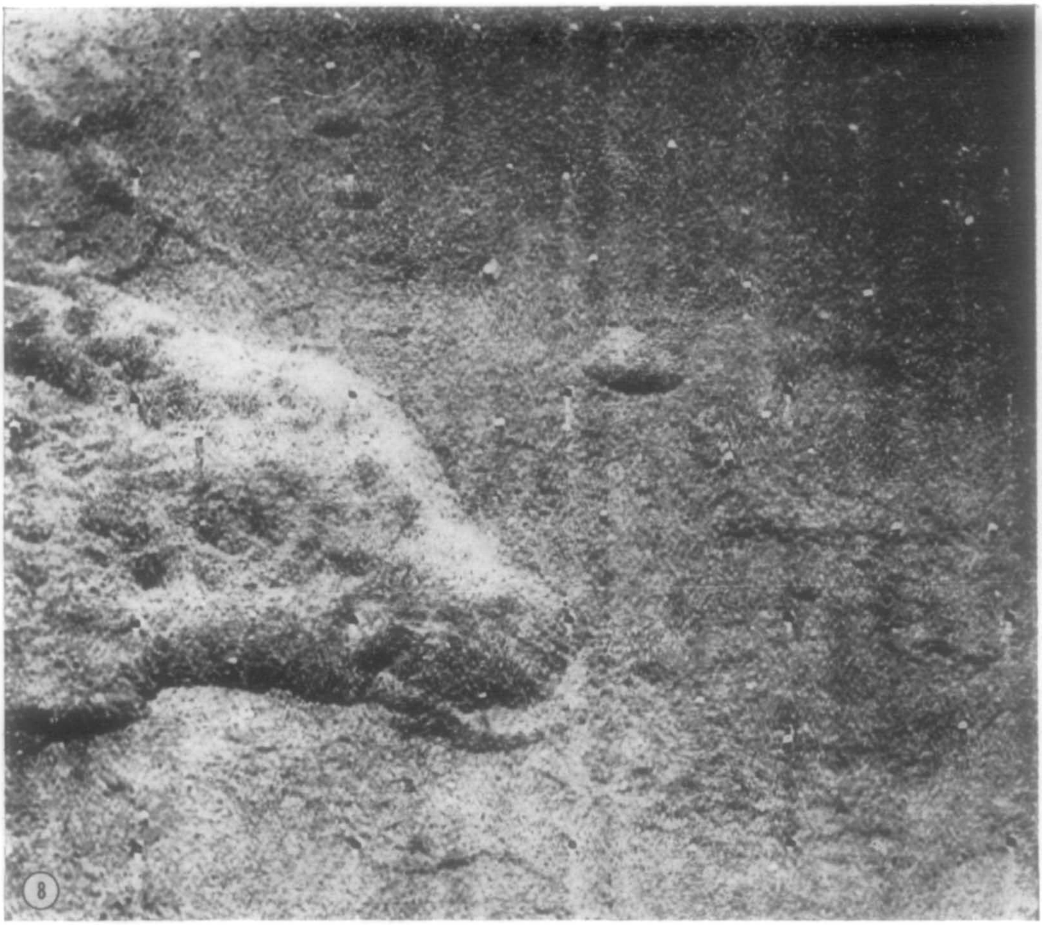

FIG. 8. Portion of 6N14 centered approximately at (+37°W, +12°N) in Chryse. Reseau dots are about 30 km apart horizontally, and 20 km apart vertically.

which suggest regions of progressive collapse of the Martian surface caused by the removal of subsurface support. This suggestion was made by the senior author independently of similar suggestions made by Sharp *et al.* (1971a). 6N8 strongly suggests that the local surface materials are unconsolidated along a structurally controlled course. Such features have been called chaotic terrain by Sharp *et al.* (1971a).

The chaotic terrain seen in 6N8 (Fig. 7) has the typical uncontrolled margin of thermokarst—which is produced by the thawing of perenially frozen ground (permafrost) in terrestrial polar regions. Thawing proceeds progressively outwards from the original locale of thawing, and can be initiated by any disturbance of the surface that exposes the permafrost to a heat source. Figures 9 and 10 illustrate thermokarst chaotic terrain on Baffin Island, and in Alaska, respectively. The scales are of course very much smaller than for the Martian pictures but the essential process responsible is probably scale-independent.

In 6N8 the curving edge of the slumping material should be noted. The roughly circular boundary suggests that an impact may have initiated the collapse seen in Fig. 7. On the other hand in 6N14 we see strong marginal control similar to that found in the edge failures of basaltic flows. This is particularly evident in the

FIG. 9. Thermokarst collapse features on Baffin Island. Approximate scale = 15 meters. The collapse feature is ~2m deep.

southwestern margin where large segments are tearing away, slumping, sliding or drifting down toward the central chaotic area. Similarly headward progress is indicated by a crescent-shaped failure in the center of the feature. It appears that the lower portion of the crescent has slumped to a greater degree than the upper portion, and that the entire failure zone is necking down and following a channel pattern that continues upward on a curvilinear trend. The remarkably strong control exhibited on a segment of the upper left edge of the chaotic zone is well aligned with a pronounced lineament that extends to the lower left corner of the photograph. This has the typical appearance of fracture in a bedrock surface, manifesting itself as a straight scarp with a failure providing locally atypical control, along short sections of valley walls.

The chaotic terrain of 6N14 does not suggest an impact origin. This appears to leave only the possibility of geothermal heating inducing the permafrost collapse. For this reason it is especially noteworthy that the area of Mars which showed the strongest thermal anomaly in the infrared radiometer scan (Neugebauer *et al.*, 1969; 1971) was precisely the region of 6N14. This may be an emissivity effect, but does suggest that this thermal anomaly is of internal origin and implies the existence of geothermal activity on Mars. Some models of the evolution of the Martian interior imply contemporary geothermal activity (Hanks and Anderson, 1969). Recently, Sharp *et al.* (1971a) have supported this interpretation of some Martian features.

One other consequence of the existence of thermokarst on Mars might be mentioned: the Viking lander is intended to maintain an ambient temperature of about 300°K even at night. In the terrestrial arctic such conditions are sufficient to induce severe permafrost removal and collapse (Fig. 10). Unless appropriate precautions are taken any heat-generating Mars lander may collapse into a thermokarst that it has itself produced. Such a fate is obviously undesirable for any lander having a lifetime of several months. Bias against such a fate can be provided by selecting a landing site in equatorial latitudes or in temperate latitudes at the end of summer. Under both circumstances temperatures of 280°K or so are common.


FIG. 10. Thermokarst collapse in Alaska. Approximate horizontal scale = 15 m. The collapse feature is ~3 m deep.

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## REFERENCES

BAGNOLD, R. A. (1960). "The Physics of Wind-blown Sand and Desert Dunes." Methuen, London.

DE VAUCOULEURS, G. (1954). "Physics of the Planet Mars." Faber and Faber, London.

EMBLETON, C., AND KING, C. A. M. (1967). "Glacial and Periglacial Geomorphology." Arnold, London.

GIFFORD, F. A. (1964). The Martian canals according to a purely aeolian hypothesis. *Icarus* **3**, 130–135.

HANKS, T. C., AND ANDERSON, D. L. (1969). The early thermal history of the Earth. *Phys. Earth Plant. Interiors* **2**, 19.

HOLM, D. A. (1960). Desert geomorphology in the Arabian Peninsula. *Science* **132**, 1369.

LEIGHTON, R. B., AND MURRAY, B. C. (1966). Behavior of carbon dioxide and other volatiles on Mars. *Science* **153**, 136.

NEUGEBAUER, G., MÜNCH, G., CHASE, S. C., HATZENBELER, H., MINER, E., AND SCHOFIELD, D. (1969). Mariner 1969: Preliminary results of the infrared radiometer experiment. *Science* **166**, 98.

NEUGEBAUER, G., MÜNCH, G. KIEFFER, H., CHASE, S. C., AND MINER, E.(1971). Mariner 1969 infrared radiometer results: Temperatures and thermal properties of the Martian surface. *Astron. J.*, in press.

SAGAN, C., VEVERKA, J., AND GIERASCH, P. (1971). Observational consequences of Martian wind regimes. *Icarus*, this issue.

SHARP, R. P., SODERBLOM, L. A., MURRAY, B. C., AND CUTTS, J. A. (1971a). The surface of Mars. 2. Uncratered terrain. *J. Geophys. Res.* **76**, 331.

SHARP, R. P., MURRAY, B. C., LEIGHTON, R. B., SODERBLOM, L. A., AND CUTTS, J. A. (1971b). The surface of Mars. 4. South Polar cap. *J. Geophys. Res.* **76**, 357.

VOIRST, J. (1967). "The Changing Earth." Bantam, N.Y.