NASA

Technical Memorandum 80279

(NASA-TM-80279) PSEUDOCRATERS ON MARS N79-31126
(NASA) 18 p HC A02/MF A01 CSCL 03B

Unclas
G3/91 36073

Pseudocraters on Mars

H. Frey, B. L. Lowry, and S. A. Chase

JULY 1979

National Aeronautics and
Space Administration

Goddard Space Flight Center
Greenbelt, Maryland 20771

PSEUDOCRATERS ON MARS

Herbert Frey[+], Barbara L. Lowry[++] and Scott A. Chase

Geophysics Branch
NASA Goddard Space Flight Center
Greenbelt, Maryland 20771

[+] also, Astronomy Program, University of Maryland, College Park, MD 20742
[++] also, Geology Program, Morehead State University, Morehead, KY 40351

ABSTRACT

In the Cydonia region of southern Acidalium Planitia are small, low-relief, apparently volcanic dome-like structures whose size, morphology and general occurrence suggest they are martian analogs of terrestrial pseudocraters, a type of phreatic eruption. Average base diameters are about 800 meters which is somewhat larger than typical Icelandic examples. All the domes have summit pits; elongate domes generally have elongate summit pits or, in extreme cases, double pits. The greatest concentration of these domes is in a region of subdued fractured plains which may be old volcanic flows. Pseudocraters on the Earth are produced when lava flows over water-logged ground. On Mars surface or subsurface ice was the likely medium that produced the steam eruptions resulting in cratered dome-like structures on the lava surfaces.

INTRODUCTION

Much attention has been directed to the large martian volcanic constructs in Tharsis and elsewhere. Impressive as these are, their distribution is highly localized on major topographic highs in the martian crust. There are smaller central volcanic structures on Mars whose distribution is more general. Some of these were described by West (1974) who found probable martian analogs of cinder cones in Mariner 9 imagery in a variety of locations. We have studied one of these locations in more detail and observed a previously unreported volcanic landform (Chase and Frey, 1978; Frey et al., 1979), independently observed by Allen (1979). The size, morphology and general occurrence of these structures suggests to us that they are martian analogs of terrestrial pseudocraters produced by the interaction of lava flows with water or ice. Allen (1979) arrived at the same conclusion. Hodges (1978) inferred a somewhat similar origin for unusual ring structures within the Columbia Plateau basalts and suggested that more specific analogs of Icelandic pseudocraters might occur on Mars.

CYDONIA VOLCANIC STRUCTURES

The area studied lies near the Cydonia Mensae in southern Acidalium Planitia between 0° and 15°W longitude, 37° to 42°N latitude. Figure 1 is a Viking I mosaic (211-5557) of the region, provided by the National Space Science Data Center of Goddard Space Flight Center. The area is immediately south of that studied by Guest et al. (1977). Many of the units described by those authors occur within the region studied here, and where possible we have followed the same mapping conventions.

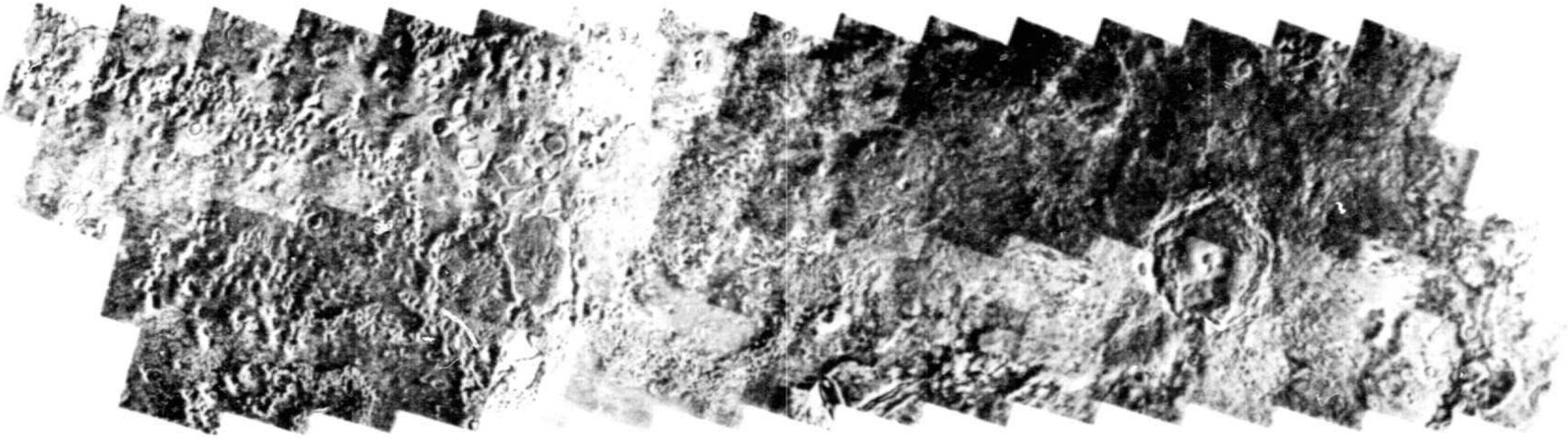


Figure 1

The eastern half of the region is dominated by the 100 km wide Bamberg impact crater. This is superimposed on mottled, sparsely cratered plains. The western half, which we investigated in detail, consists of dissected plateau and mesa materials, knobby terrain of two distinctly different scales, smooth, fractured and "subdued" fractured plains (see Guest et al., 1977). Figure 2a shows this half of the region in more detail. A geologic map of this area is shown in Figure 2b. The large plateau at the eastern edge of the picture is some 1200 km^2 in area. To the north are smaller mesas (m) and large, irregular knobs. The plateau material itself may represent a cover or mantle which has been stripped from regions further to the west and north (Guest et al., 1977). The knobby terrain may be dissected plateau material,

We have designated as "k_1" the dissected plateau material immediately to the west, east and southeast of the large plateau. Although probably related to the knobby terrain (k), the characteristic scale of the positive relief features is strikingly smaller than the larger knobs north and northwest of the plateau. The geologic map (Figure 2b) shows these units.

Northwest of the large plateau a narrow curving range of knobby materials divides fractured plains to the north from smooth plains to the south, near the center of Figure 2. Rampart craters exist on both units. Another less coherent outcrop of knobby terrain separates smooth plains from subdued fractured plains further south.

Within the knobby terrain at $11^{o}W$, $40^{o}N$ are steep-sided conical structures with summit craters. Examples are shown in Figure 3. Many are circular in plan; others are elliptical. One such feature is over 8 km long and 3-4 km wide with a 1 km wide crater at its summit. The structure is roughly 700 m

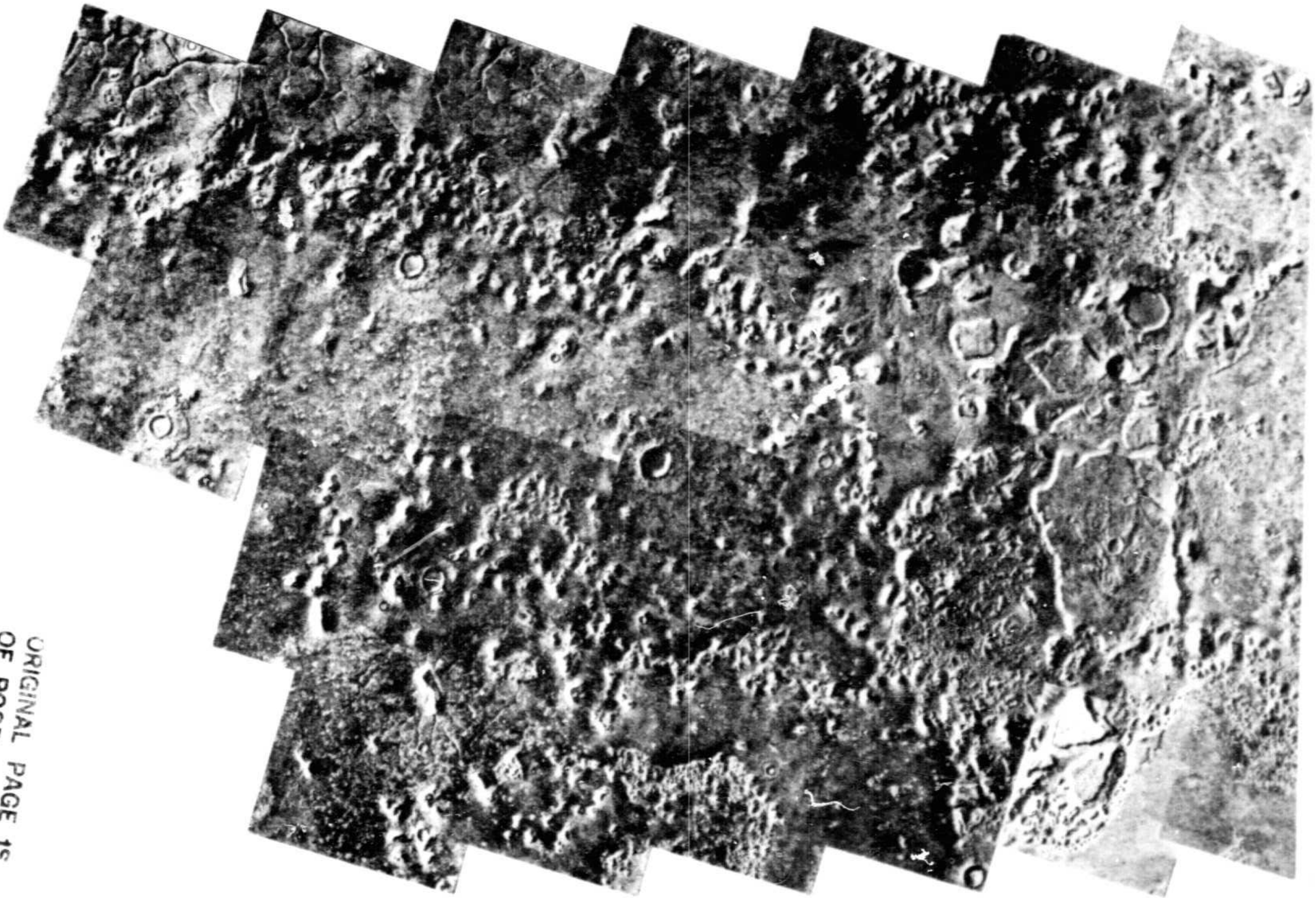
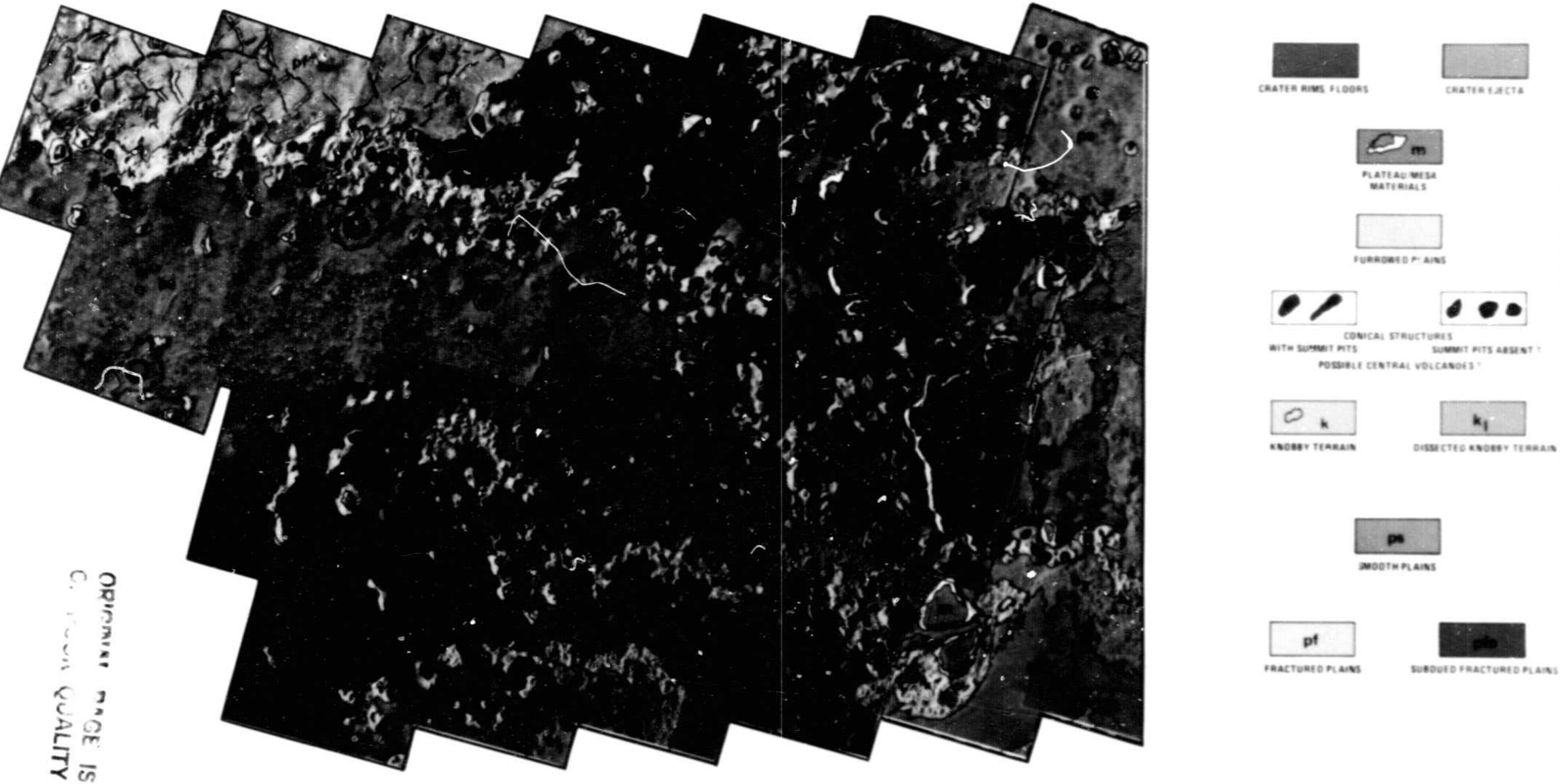


Figure 2a


dpf
CRATER RIMS FLOORS
CRATER EJECTA
m
PLATEAU/MESA MATERIALS
FURROWED PLAINS
CONICAL STRUCTURES
WITH SUMMIT PITS
SUMMIT PITS ABSENT ?
POSSIBLE CENTRAL VOLCANOES ?
k
KNOBBY TERRAIN
k_1
DISSECTED KNOBBY TERRAIN
ps
SMOOTH PLAINS
pf
FRACTURED PLAINS
pfs
SUBDUED FRACTURED PLAINS

high (based on shadow measurements) and its steep sides are apparently fissured. The conical structures near the western margin of Figure 4 are distinguished not only by their summit pits but also by their symmetry when compared to the more irregular knobs with which they occur. West (1974) described similar features in Cydonia and elsewhere; her interpretation that they are cinder cones is adopted here. Other examples of possible volcanic cones are indicated in Figure 2b. In general they are closely associated with the knobby terrain although rare isolated examples do occur in the fratured plains to the north in Figure 2. A possible breached cone is shown in Figure 4.

Of particular interest is the widespread occurrence of small, mound-like domes within the smooth and fractured plains west of 10^{0} longitude. Several scattered examples of these can be seen in the western half of Figure 3, where smooth plains (ps) occur. Many more of these structures are located further west in both fractured plains (pf, Figure 5) and in smooth plains to the south (Figures 5, 6). The greatest number occur in subdued fractured plains (pfs) to the extreme southwest of the study area (Figure 7). The features are remarkable for their number, over 900 have been observed in this area (Chase and Frey, 1978). Generally they are circular in plan, but elliptical forms do occur (Figure 6). Most are less than 1 km across but basal diameters range from 0.5 to 1.5 km (the average of a large sample is 800 m). Smaller examples may exist but would be hard to recognize at the available resolution. The domes apparently have low relief, as they do not cast appreciable shadows. All have summit pits or craters which lack sharply defined rims. Pit diameters range from 0.25 to 0.45 km and are generally about 40% the diameter of the dome. Elongate domes have elongate pits which in extreme examples become double craters (Figures 5, 6).

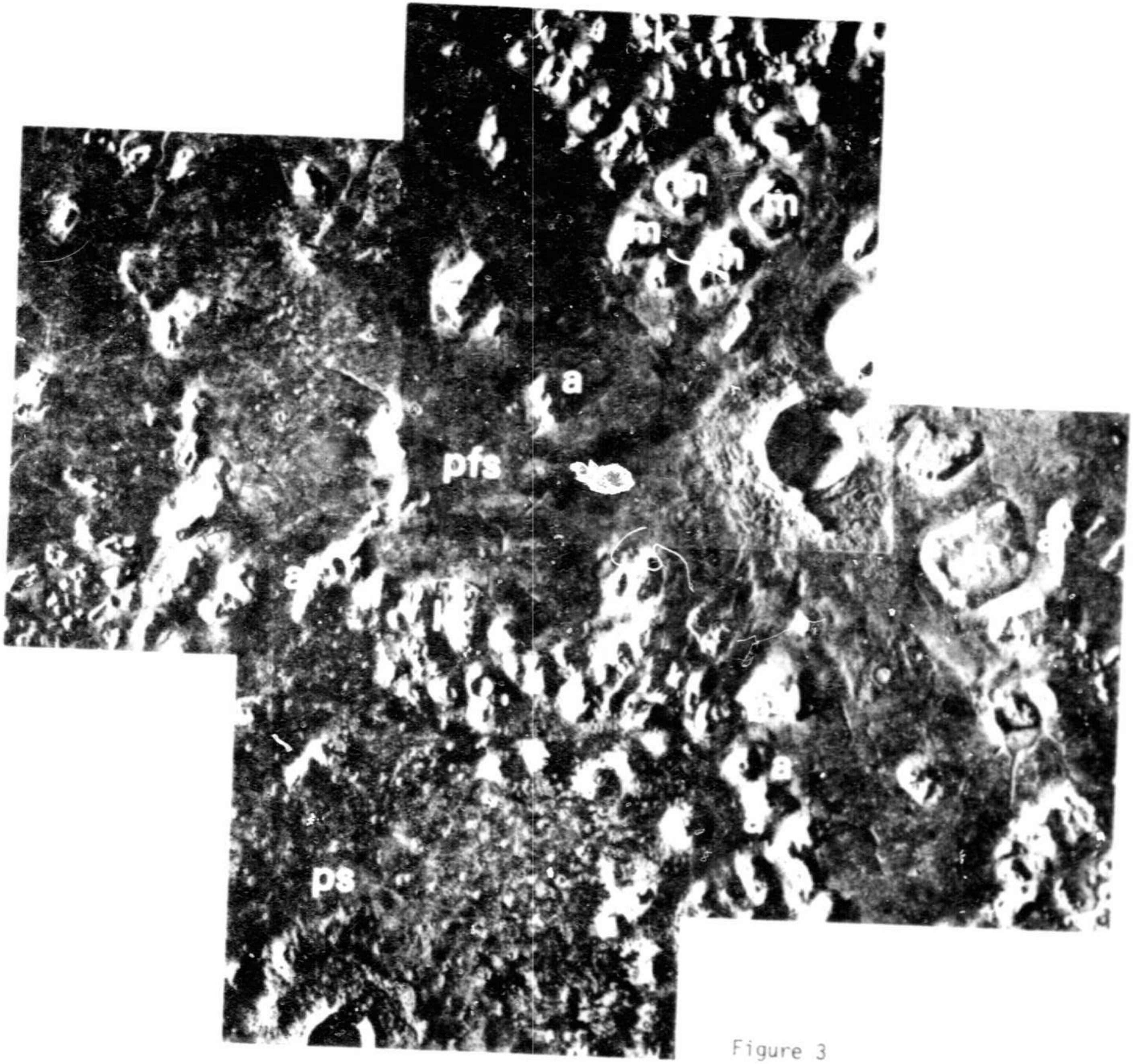


Figure 3

Figure 4

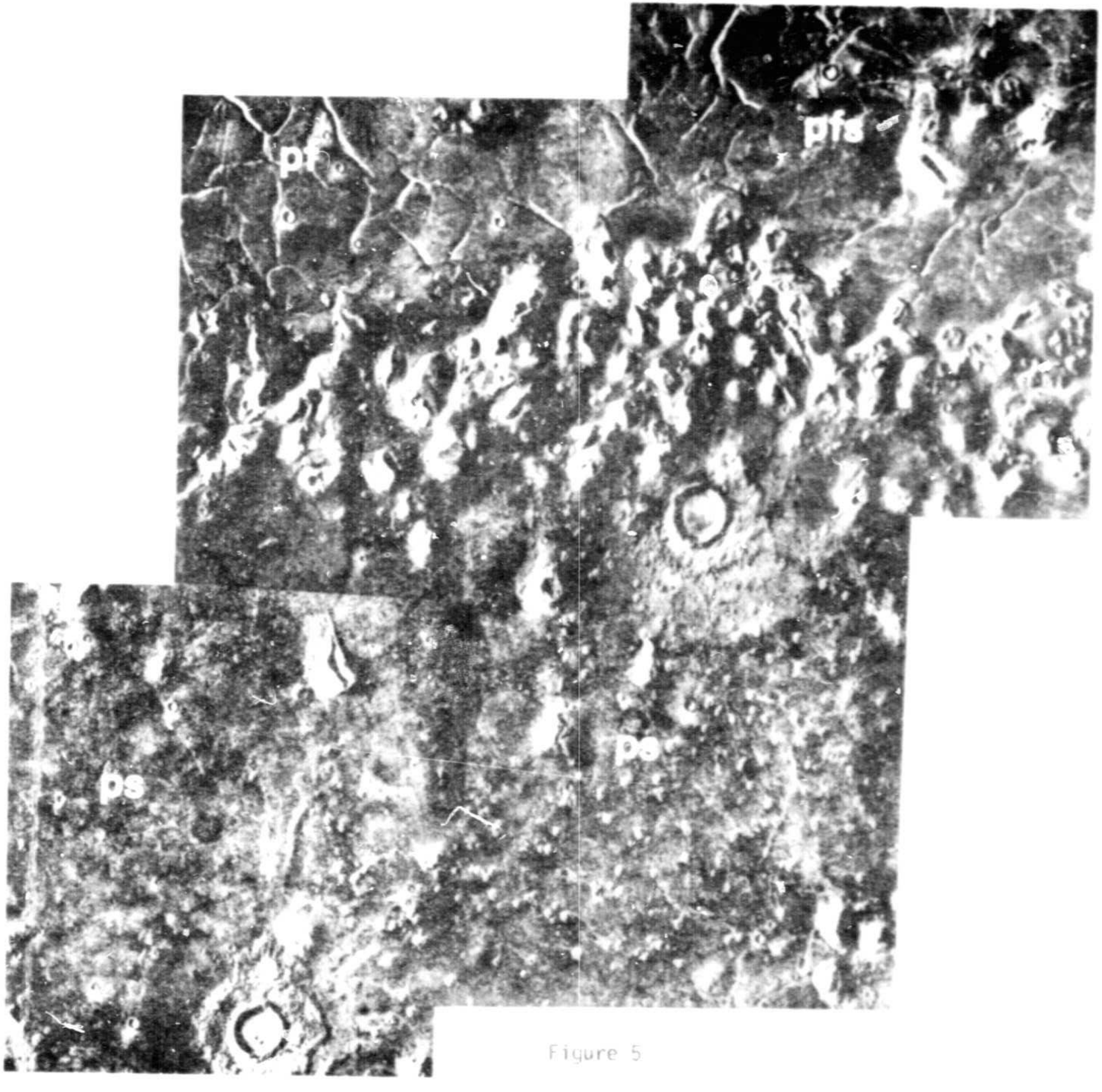


Figure 5

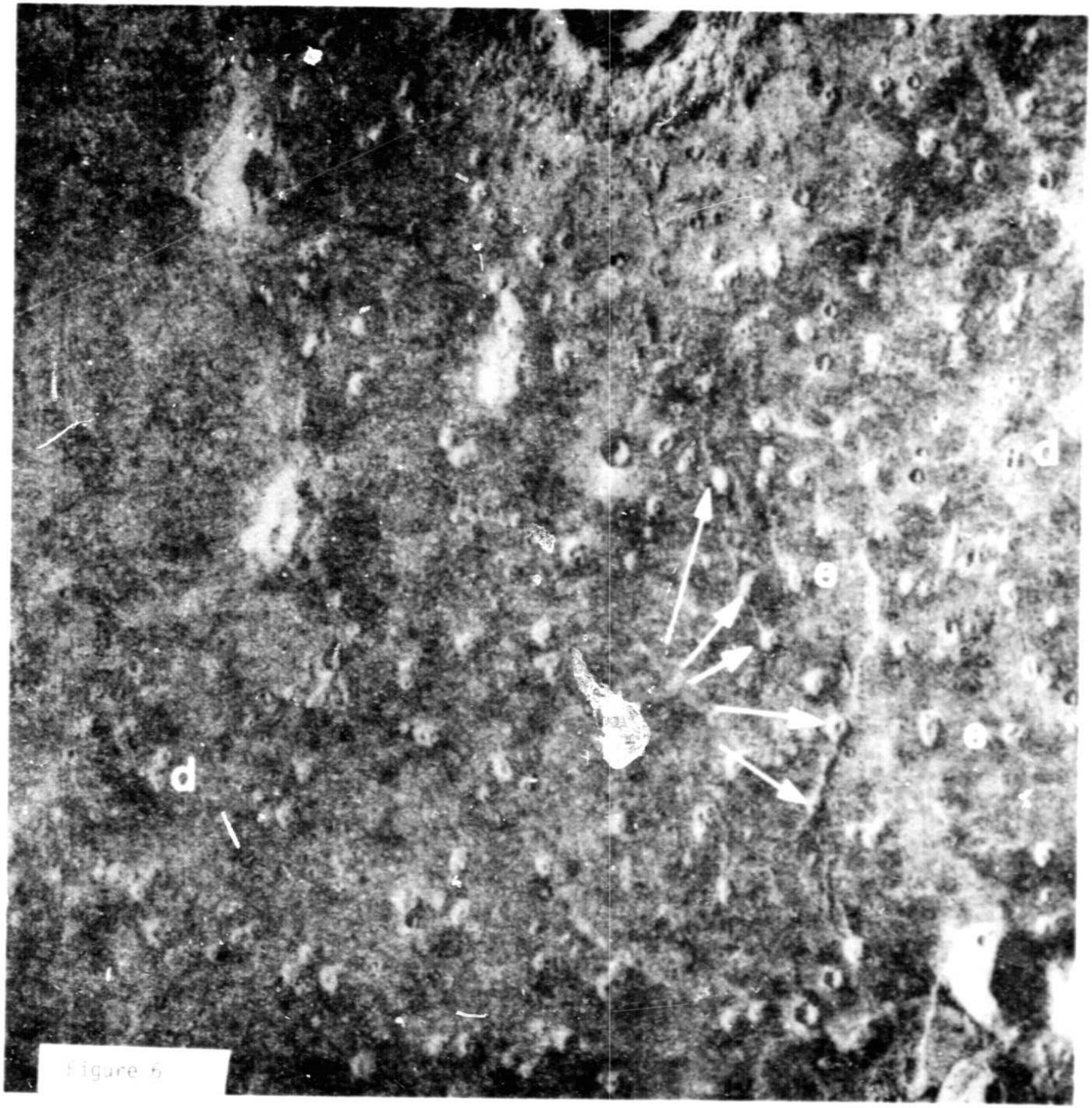


Figure 6

The distribution of the domes is not uniform across the region. They are most abundant in the southwestern corner of the area, in a region of subdued fractured plains (Figures 7, 8). They are also common in the central portion of the area where smooth plains occur (Figure 2; see Figure 5). Figure 5 shows how the distribution changes from smooth plains to fractured plains to the north. These two plains units are separated by an expanse of knobby terrain, across which the number of small domes decreases sharply from smooth to fractured plains. Likewise the number of domes decreases to the east as subdued fractured plains merge through dissected knobby terrain (k_1) into smooth plains (Figure 7). There is an extensive outcrop of smooth plains where domes are nearly absent in the area just west of the large plateau. No domes occur in plateau or mesa materials, and few occur in the knobby terrain itself.

Domes similar to those described here can be seen in Figure 4 of Guest et al. (1977), and to a lesser extent in their Figure 6. Those authors did not draw attention to these features, however.

NATURE OF THE CYDONIA DOMES

The low relief, morphology and especially the distribution of these small martian domes suggest they may be analogs of terrestrial pseudocraters, a specialized type of phreatic eruption cone recognized in Iceland (Thorarinsson, 1953; see also Fielder and Wilson, 1975, Figure 7.11). Allen (1979) arrived at the same conclusion based on his study of this region and field-work among Icelandic examples. On the Earth phreatic eruptions occur when magma comes into contact with water. Pseudocraters are a surface structure produced when

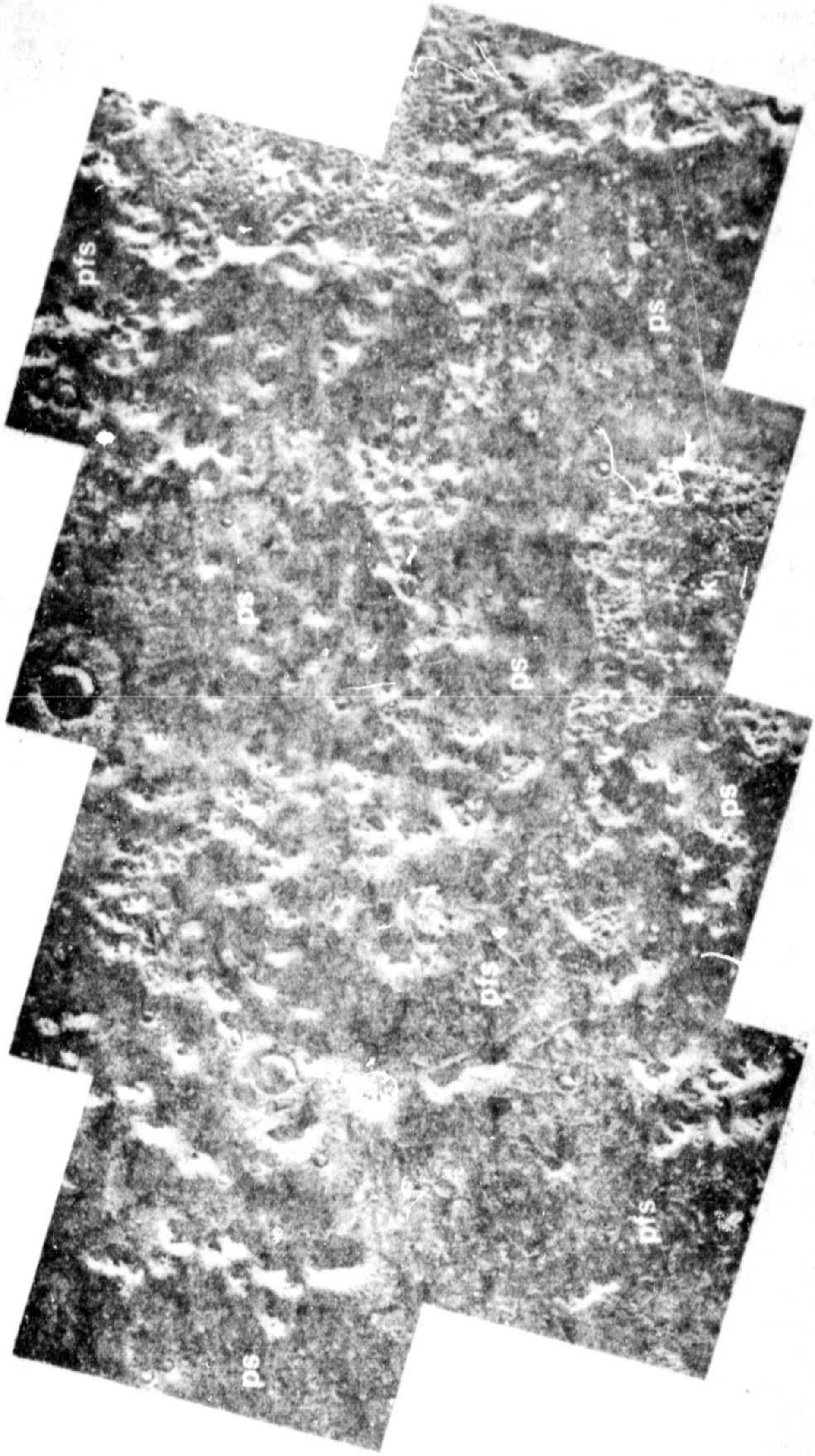


Figure 7

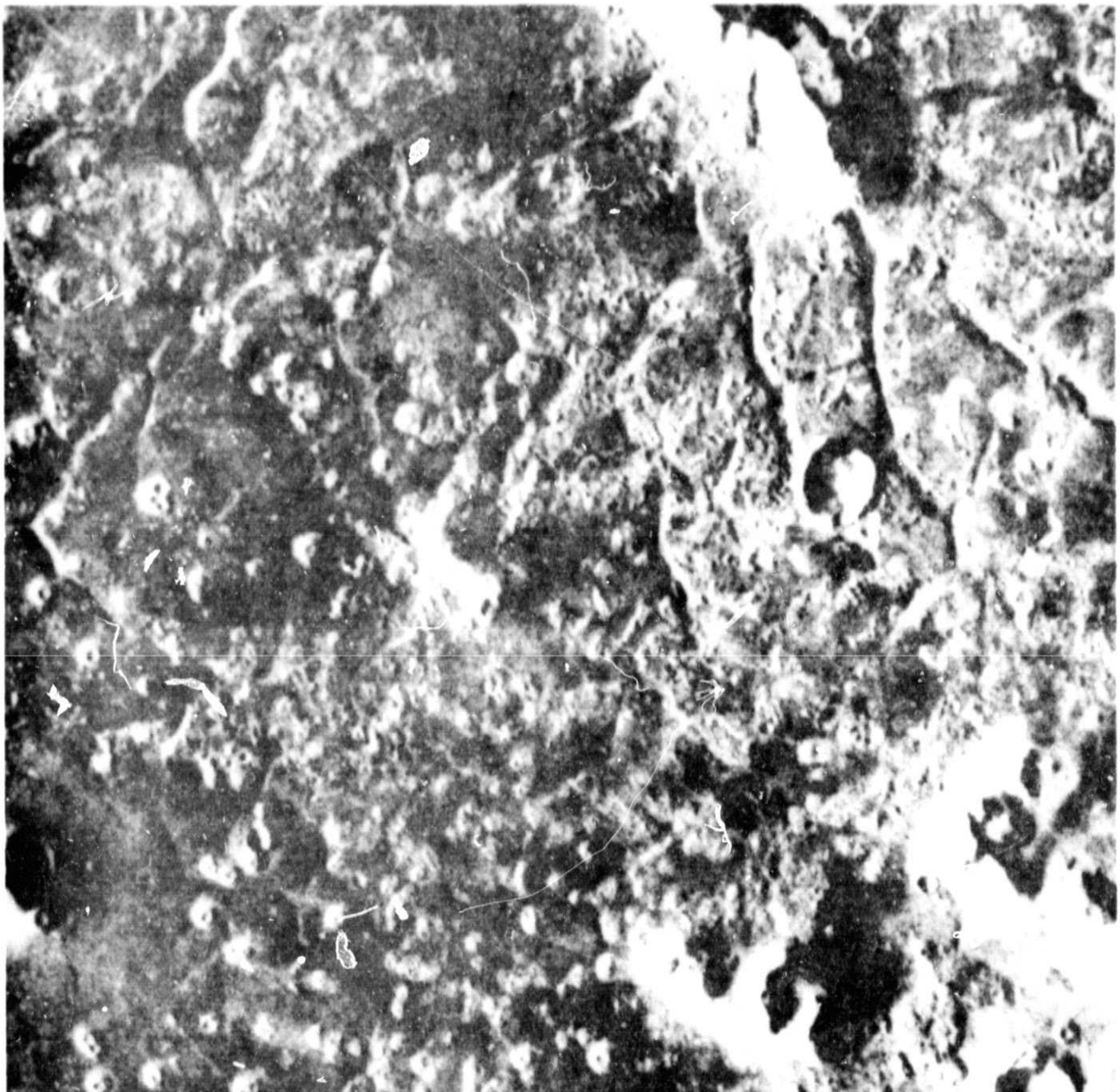


Figure 8

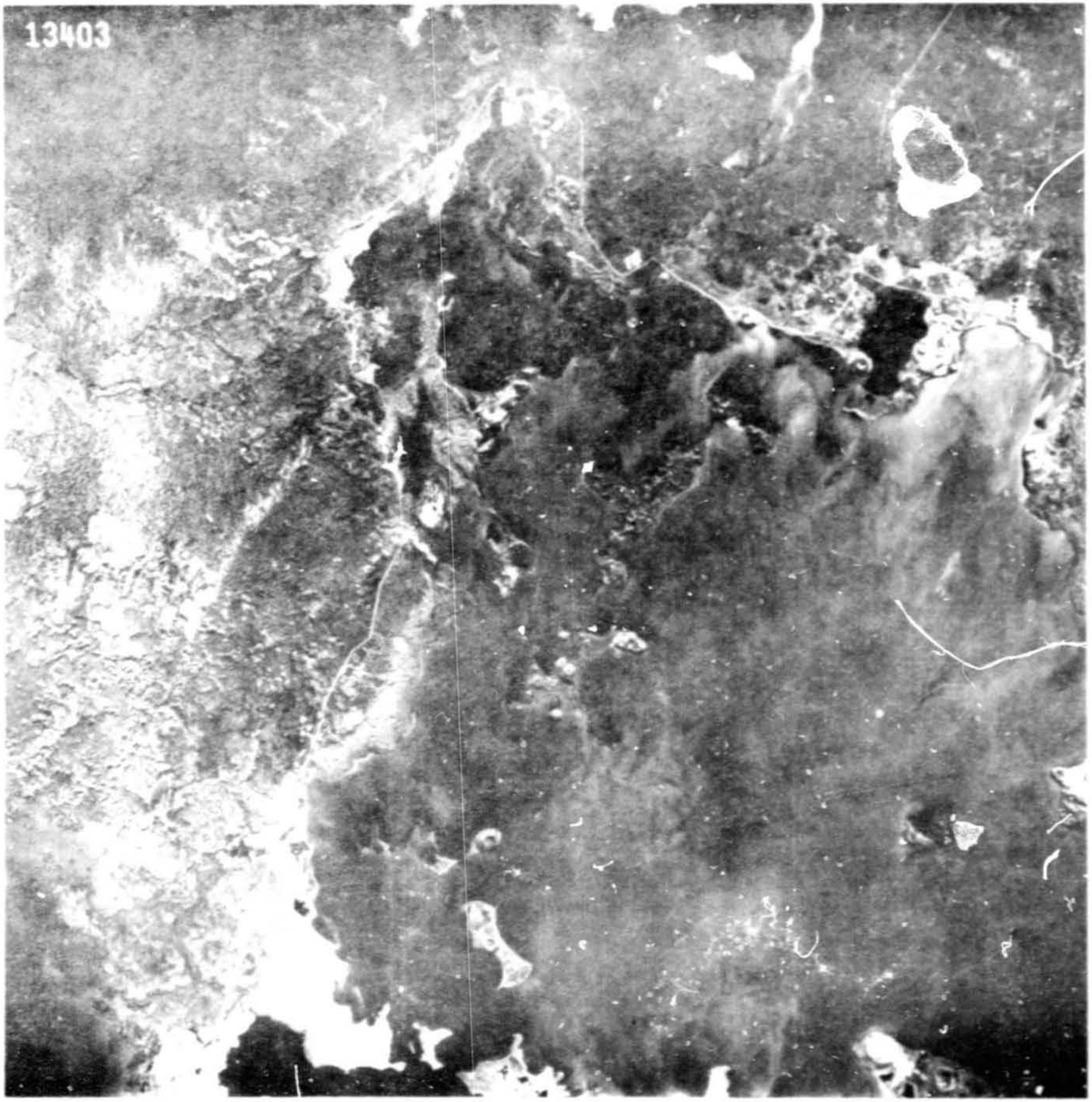


Figure 9

lava flows over water or water-logged ground. Steam explosions result in closely spaced conical structures of pyroclastics and spatter, generally less than 100 m across. Larger examples are known, however; Thorarinsson (1953) reports diameters up to 320 m. The summit pits are generally large, 40-50% the width of the base of the cone. Typical heights are a few tens of meters. Numerous examples of Icelandic pseudocraters from the Lake Myvatn region are shown in Figure 9.

The morphological similarity between the pseudocraters in Figure 9 and the domes in Figures 6 and 8 is striking. Circular and elongate domes appear on both planets. Summit pits are large compared with the base width of the cones. The major difference between the martian domes in Cydonia and the pseudocraters in Iceland is the relatively large size of the former. The smallest diameter we measured for the Cydonia features was 500 m, but unrecognized smaller examples may well exist. In fact phreatic eruptions on Mars might be expected to generally produce larger structures than corresponding explosions on the Earth, due to the lower gravitational potential of the smaller planet. The typical basal diameter we found for the martian features is ~800 m, some 2.5 times greater than the large diameter pseudocraters in Iceland. This is consistent with inverse gravity scaling for Mars, whose gravitational acceleration is only 40% that of the Earth.

Within the areas they occur, the martian domes show little evidence for structural association. One possible exception may be seen in Figure 6 where a half dozen domes occur along a ridge-like feature. This is the only example we could find of possible structural relation. Although generally closely spaced, the domes are widely distributed in smooth and fractured plains (see above). In Figure 8 the mounds display no particular affinity for the fractures which occur in this region. The same is true in Figure 5. By contrast the proposed cinder cones seen in Figure 3 and elsewhere are generally strongly grouped in the knobby terrain. The widely scattered distribution of the small domes may be the strongest evidence that they are phreatic eruption cones and not other types of volcanic structures. For example, Wood (1979) has suggested these small Cydonia domes are cinder cones, based on measurements of their basal diameters and the diameters of their summit pits. He finds that the Cydonia structures have dimensions similar to terrestrial cones, but has neglected the possibility that differences in gravitational fields could produce martian pseudocraters 2-3 times larger than Icelandic analogs. Wood (1979) also argues that the spatial density of the martian cones is less than that of pseudocraters in Lake Myvatn in Iceland. Figure 8 shows that the density of the Cydonia domes is extremely high, especially if any of the barely resolved positive features between the cones are also pseudocraters. Comparison of Figure 8 with Figure 9 shows both fields are densely but randomly populated, in keeping with the steam explosion origin of these structures.

Carr et al. (1977) raised the possibility that structures similar to these domes might be highly modified impact craters (see their Figure 25). In Figure 8 small impact craters are intermixed with the domes; the morphology of the impact structures is quite distinct. The Cydonia domes are positive, mound-like features, sometimes extremely elongate, with rimless summit craters. The impact structures in this region display a sharpness of rim and lack of positive relief that clearly distinguishes them from the proposed pseudocraters.

Terrestrial pingoes, produced by pressure-induced doming of ice-rich ground, can appear morphologically similar to pseudocraters. On the Earth pingo base diameters can be comparable to small pseudocraters but typical terrestrial pingoes are an order of magnitude smaller than the Cydonia domes (Wood, 1979). Furthermore it is unlikely that gravitational effects will lead to larger martian pingoes than those found on the Earth, as would be expected for explosive volcanics on Mars.

DISCUSSION

Phreatic eruptions on Earth occur where magma comes into contact with water. Pseudocraters, as described by Thorarinsson (1953), form when lava flows over water or water-logged ground. Similar structures should result when lava flows over ice or ice-rich ground, which is a more likely case for Mars. Allen (1979) has shown that the energetics of the steam explosion for the lava-ice contact require that the ice be close to the surface.

The association of the domes with fractured plains (especially in the southwest of the study area) supports this conclusion. Carr et al. (1976) suggested that polygonal fractures similar to those here and to the north (Guest et al., 1977) are due to permafrost (see Carr and Schaber, 1977). Allen (1979) described numerous positive relief, ridge-like and flat-topped structures in this area and elsewhere as moberg ridges and table mountains, formed by the penetration of lava into a layer of ice. Flow fronts visible in smooth and fractured plains as well as the ridge shown in Figure 6 support a volcanic nature for many of the plains units described here. Given the apparent evidence for both lava and ice, the area is a likely one for the formation of pseudocraters.

The relation of the proposed pseudocraters to the other structures and geologic units of this region is not clear. The greatest density of the domes occurs within the extreme southwest of the area (Figure 7, extreme left; Figure 2, lower left), mapped as subdued fractured plains. Subdued fractured plains also occur to the northeast of the knobby terrain (Figure 3), near flat-topped structures of plateau and mesa materials (Figure 2b). There are fundamental differences between these regions: the fractures in the southwest (the area of high dome density) are narrow and generally radial or concentric about a proposed moberg ridge (Allen, 1979). To the northeast the fractures are much less numerous, much less distinct, and generally display a much less obvious association with positive-relief features which do outcrop in the vicinity. The fractures appear extremely subdued, as though obscured or blanketed (Guest et al., 1977). If this area is mantled by deposits more than 100 m thick, most pseudocraters would be obscured if they did exist. The fractures to the northwest (Figure 2, Figure 5) are much more distinct. A small number of domes occur in this area, but almost none in the subdued fractured plains to the northeast (Figure 4).

Similar fractured and subdued fractured plains, containing scattered examples of the dome-like structures, are found to the north (Guest et al., 1977; see their Figures 4 and 6). Those authors suggest that these plains predate the formation of the plateau and mesa materials, which may represent thick deposits now being stripped away to reveal the subdued fractured (partially stripped?) or fractured (completely stripped?) plains below. This suggests there may be extensive (fractured?) plains of pseudocraters below the mesa materials which are common in the eastern portion of the study area (Figure 2).

Not all of the proposed pseudocraters are found in fractured plains; the smooth plains in the central portion of the study area also contain these structures (Figures 2 and 5). These plains, as well as the fractured and subdued fractured plains, are apparently older than the plateau and mesa materials, based on numbers of small craters found on each unit. The Cydonia domes, therefore, seem to predate the period of deposition which produced the mesas. Beyond this it is difficult to determine the ages of these features because of the complex interrelationships of the units involved.

While the details of the relations of the proposed pseudocraters to the other geologic structures in Cydonia are not completely clear, their potential significance is obvious. Not only does the distribution of pseudocraters indicate the presence of volcanic flows, but more importantly shows the location of surface or near-surface ice on Mars. The appearance of other volcano-ice structures in the northern plains of Mars (Allen, 1979) suggests that pseudocraters may in fact exist outside the region studied here. Locating the past distribution of surface or near-surface ice on Mars has important implications for both the total volatile budget of Mars and perhaps for past climatic modeling of the planet.

CONCLUSIONS

Widely distributed, low-relief, dome-like features found in the Cydonia region of Acidalium Planitia are morphologically similar to terrestrial pseudocraters found in Iceland. Interaction of relatively thin lava flows with near-surface permafrost or ice may have produced steam explosions resulting in low mounds generally less than 1 km across. All of the martian structures have summit pits, but are generally larger than typical terrestrial examples. Their large size may be a result of the lower gravitational field in which explosions would occur on Mars.

The martian domes occur principally on smooth or fractured plains in association with other structures which seem to indicate volcano-ice interaction (table mountains, moberg ridges). These plains are stratigraphically lower and apparently of greater age than plateau and mesa terrain to the east. The location of pseudocraters on Mars is an important clue to mapping the past distribution of surface or near surface ice on that planet, and has implications for both the total volatile budget and past climatic conditions.

ACKNOWLEDGEMENTS

We are grateful to Carl Allen for useful discussions on the identification of pseudocraters and other volcano-ice structures in Cydonia, and for providing us with copies of portions of his thesis prior to its defense. We also thank Carroll Ann Hodges (USGS) and Chuck Wood (Smithsonian) for their support and ideas on phreatic eruptions. The detailed comments of two helpful reviewers is gratefully acknowledged. We are extremely grateful for excellent assistance from the National Space Science Data Center of Goddard Space Flight Center in obtaining the individual pictures used in this study. This work was supported by NASA Grant NGL 21-002-033.

REFERENCES

Allen, C.C., Volcano-ice interactions on the Earth and Mars, PH.D. Thesis, University of Arizona, 1979.

Carr, M.H., H. Masursky, W.A. Baum, K.R. Blasius, G.A. Briggs, J.A. Cutts, T. Duxbury, R. Greeley, J.E. Guest, B.A. Smith, L.A. Soderblom, J. Veverka and J.B. Wellman, Preliminary results from the Viking orbiter imaging experiment, Science, **193**, 766-776, 1976.

Carr, M.H., R. Greeley, K.R. Blasius, J.E. Guest and J.B. Murray, Some martian volcanic features as viewed from the Viking orbiters, J. Geophys. Res., **82**, 3985-4015, 1977.

Carr, M.H. and G.G. Schaber, Martian permafrost features, J. Geophys. Res., **82**, 4039-4054, 1977.

Chase, S.A. and H.V. Frey, Volcanic landforms in Cydonia, B.A.A.S., **10**, 57, 1978 (abstract).

Fielder, G. and L. Wilson, *Volcanoes of the Earth, Moon and Mars*, Elek Science, London, 1975.

Frey, H.V., S.A. Chase and B. Lowry, Phreatic eruptions on Mars, in *Lunar and Planet. Sci. X*, 400-401, 1979 (abstract).

Guest, J.E., P.S. Butterworth and R. Greeley, Geologic observations in the Cydonia region of Mars from Viking, J. Geophys. Res., **82**, 4111-4120, 1977.

Hodges, C.A., Basaltic ring structures of the Columbia Plateau, Geol. Soc. Am. Bull., **89**, 1281-1289, 1978.

Thorarinsson, S., The crater groups in Iceland, Bull. Volcanologique, Series 2, Tome 14, pp. 3-44, 1953.

West, M., Martian volcanism: additional observations and evidence for pyroclastic activity, Icarus, 21, pp. 1-11, 1974.

Wood, C.A., Monogenetic volcanoes of the terrestrial planets, submitted to Proceed. Tenth Lunar Planet. Sci. Conf., 1979.

FIGURE CAPTIONS

Figure 1: Viking I photomosaic 211-5557. The region shown includes the large crater Bamberg and stretches from about 0° to 15°W longitude, 38° to 41°N latitude in southeast Acidalium Planitia. North is at the top. Bamberg is approximately 100 km in diameter.

Figure 2: Detailed photomosaic and geologic map of study area. (a) Photomosaic of western one-third of the area shown in Figure 1. Note the large plateau near the right side of this Figure. See text for detailed descriptions. (b) Geologic map of study area. Two scales of knobby materials (k, k_1) are distinguished. See text for details.

Figure 3: Mosaic of Viking I images 70A07 to 70A10 showing knobby terrain (k) separating smooth plains (ps) from subdued fractured plains (pfs) and mesa materials (m). Note conical and elliptical structures ("a") which may be cinder cones. Small domes are abundant in the smooth plains in the lower left, but are scarce in the subdued fractured plains.

Figure 4: Enlargement of Viking I image 70A10 (lower right of Figure 3). Possible cinder cones ("a") and breached cone ("b") at left are part of the knobby terrain in Figure 3. Subdued fractured plains (pfs) seem emergent from a blanket continuous with the mesa materials (m) at upper right. Small domes appear in the extreme lower left of the picture.

Figure 5: Mosaic of Viking I images 70A02 to 70A05. Knobby terrain (k) divides fractured plains (pf) and subdued fractured plains (pfs) from smooth plains (ps). Numerous small, bright circular mounds with summit pits occur in the lower right portion of the Figure. Many fewer domes appear north of the knobby terrain.

Figure 6: Enlargement of Viking I image 70A04 (lower right of Figure 5). Note elongated domes ("e") and domes with double pit structure ("d"). Several domes appear to be aligned with a N-S trending ridge-like structure (arrows).

Figure 7: Mosaic of Viking I images 72A01 to 72A08. The mosaic forms the lower strip of Figure 2a. Domes are abundant in the western portion of the Figure and decrease in numbers where subdued fractured plains (pfs) merge with smooth plains (ps) to the east.

Figure 8: Enlargement of Viking I image 72A02 (lower left of Figure 7). The numerous domes on the left side of the picture show little affinity for the fractures near the ridge-like structure in the upper right (moberg ridge?).

Figure 9: Aircraft photo-image of pseudocraters near Lake Myvatn in Iceland. The largest domes are some 200 m across. (Courtesy of C.C. Allen).