

# COMPARISON OF KNOBS ON MARS TO ISOLATED HILLS IN EOLIAN, FLUVIAL AND GLACIAL ENVIRONMENTS

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**Abstract.** Positive isolated features or knobs have been observed on Mars since Mariner 9 first photographed the planet in 1972. More recently, the Viking Orbiters photographed the surface at increased resolution. With the use of Viking photomosaics, a systematic search for knobs was completed. The knobs were characterized by length, width, geographic location, proximity to streaks and geologic surroundings. Similar isolated features on Earth eroded by fluvial, glacial, and eolian processes were studied and measured. Comparison of length-to-width ratios of Martian knobs to isolated hills on Earth indicate that the Martian knobs are most similar to the isolated hills formed in a hyper-arid environment. The terrestrial features were probably formed initially when solid rock was fractured, then wind erosion, starting at the fractures, continued to sweep away sediments leaving isolated hills. Such hills in fluvial and glacial environments have length-to-width ratios significantly higher than those of the Martian knobs. Other diagnostic features associated with such environments are absent in the case of the Martian knobs. Moreover, streaks, splotches, dunes and pitted and fluted rocks, all indicative of an eolian regime, are associated with the Martian knobs.

## 1. Introduction

Eolian erosion is an effective modifier of the Earth's surface as seen in many hyper-arid deserts, where wind is the primary resurfacing agent. Eolian modification of the Martian surface has been suggested by many authors through correlations between the terrestrial eolian features and similar patterns on Mars.

Both Mariner 9 (McCauley, 1973; and Cutts and Smith, 1973) and Viking 1 and 2 (Mutch *et al.*, 1976) images indicate the presence of a dominant eolian regime on Mars. Local and planet-wide dust storms show that extreme winds are present and of sufficient velocity to move sand-sized particles from one area to another. Streaks, splotches, dunes, yardangs, pitted and fluted rocks and even small drifts seen from the Viking 1 Lander are all indications of eolian activity.

Knobby material, rounded to subangular hills, on Mars is found planet-wide and is generally located along or near boundaries between plains and plateau units. The relationship between streaks and knobs, as well as craters, on Mars has been studied by Chaikin *et al.* (1981). Both knobs and craters affect the path of the wind, by acting as topographic impediments and deflecting it and, therefore, affect erosion and deposition of particulate material.

McCauley *et al.* (1979) have shown the effectiveness of wind erosion in the Western Desert of Egypt. Gifford *et al.* (1979) showed, through the use of remotely sensed data, the relationship of the wind regime to the orientation of dunes in the same desert. Thomas and Veverka (1979) similarly mapped wind streak orientations indicating the global wind regime on Mars (Figure 1).

In this study, we compare isolated hills on Mars to isolated hills in terrestrial eolian, fluvial, and glacial environments. The objective of this study is to evaluate the effectiveness of wind as a land modifier on Mars and to provide additional evidence for the consequences of eolian processes, as opposed to fluvial or glacial processes, in the reshaping of the Martian surface.

## 2. Previous work

The effect of wind as a modifier of the Earth's surface was initially documented by Bagnold (1941) in his treatise on the physics of sand movement by wind. Most of his observations were made in the Western Desert of Egypt where the free interplay of sand and wind has been allowed to continue for a long period of time (Bagnold, 1933).

Whitney (1978) noted that the wind behaves much the same way on all scales and established the role of vorticity in developing lineations by wind erosion. Vorticity plays a dominant and more direct role in shaping, sculpting, lineating, pitting and burnishing by its direct action upon surfaces. Furthermore, Mainguet and Callot (1978) showed how corrosion features shaped solely by the wind can be up to 100 km long.

El-Baz *et al.* (1979) showed the relationship of landforms to the wind regime, bedrock composition, sediment supply and topography in the Western Desert of Egypt. They compared these landforms to similar wind-formed features on Mars such as sand dunes, light and dark streaks, knob 'shadows' and yardangs.

McKee (1979) brought together a comprehensive investigation on types of dunes, global distribution of these dunes, the mechanics of their development and their relation to the wind regimes that formed them.

Chaikin *et al.* (1981) showed how changes in the outline and appearance of the Cerberus albedo feature on Mars can be explained by eolian redistribution and removal of bright material during major dust storms. El-Baz and Maxwell (1979) indicate similarities between wind-produced bright and dark colored streaks in southwest Egypt and similar streaks in the Cerberus region of Mars.

Breed (1977) compared dunes in the Hellespontus region of Mars to crescentic ridge-type dunes that are located in terrestrial sand seas. Mean length, mean width and wavelength were measured for all areas. Mean ratios in all sampled terrestrial dune fields were found to be similar to mean ratios in the Hellespontus dune region.

McCauley *et al.* (1977) have identified yardangs, wind sculpted features that resemble inverted boat hulls, in many desert regions. Ward (1979) has compared these features to similar sculpted features on Mars.

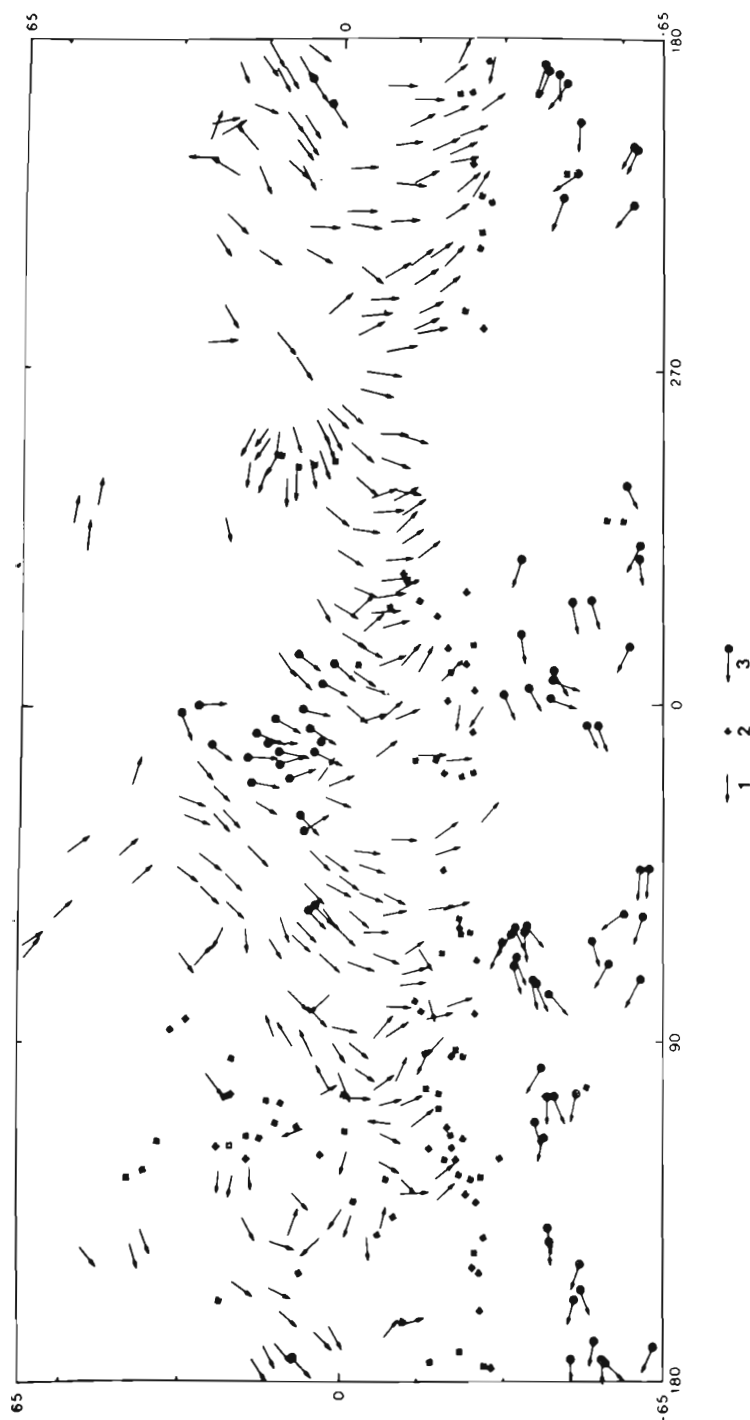


Fig. 1. Global pattern of wind streaks: 1. bright, 2. dark, and 3. spotch-related streaks (after Thomas and Veverka, 1979, p. 163).

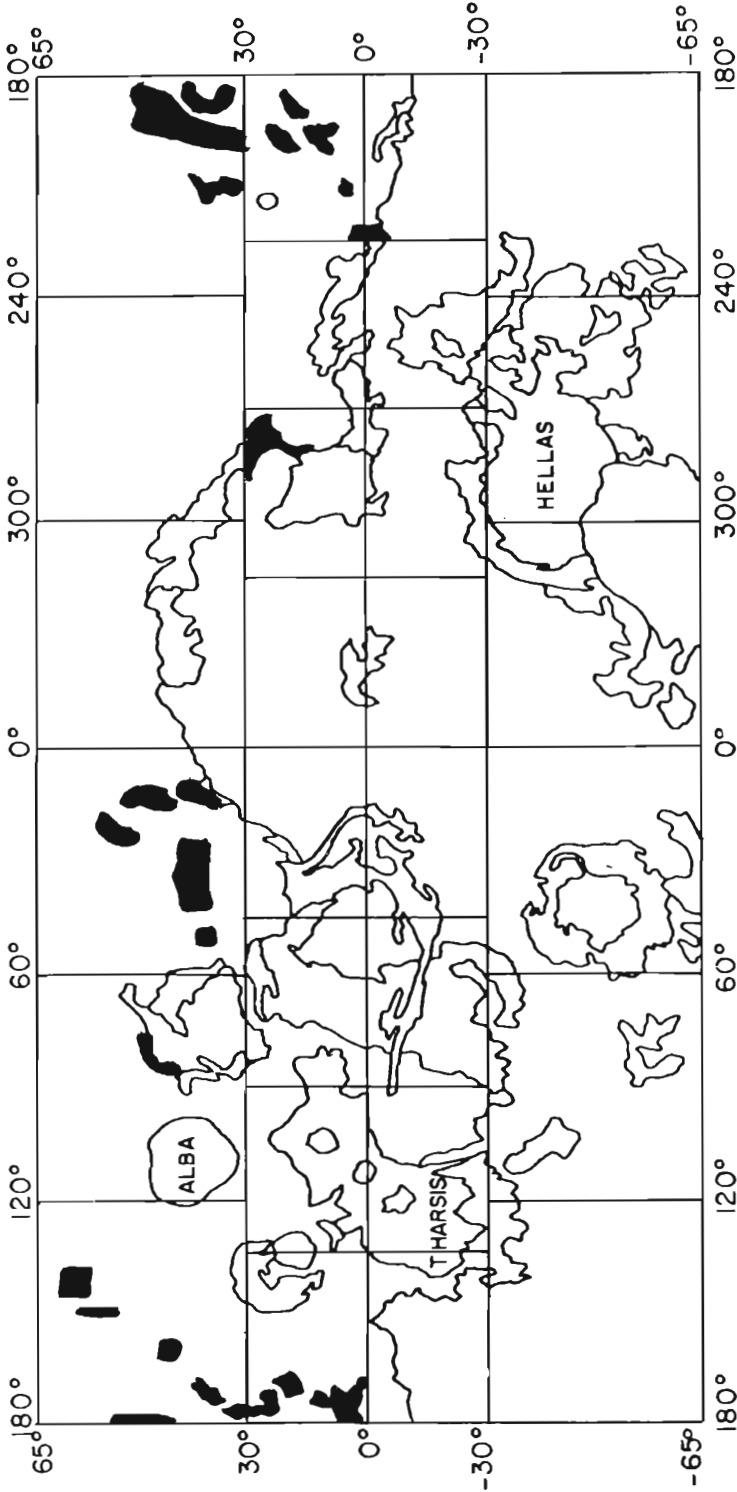


Fig. 2. Location of characterized knobs on Mars.



The above examples show that the wind is a potent agent of reshaping surface features on both Earth and Mars.

### 3. Methods

Viking 1 and 2 images were systematically studied for positive isolated features, i.e., knobs. These features were subsequently digitized from U.S. Geological Survey photomosaics at 1 : 2 000 000 scale by length (long axis) and width (perpendicular to length at widest point). These mosaics cover the Diacria (MC-2), Arcadia (MC-3), Mare Acidalium (MC-4), Cebrenia (MC-7), Amazonis (MC-8), Syrtis Major (MC-13), Elysium (MC-15), and Aeolis (MC-23) regions of Mars (Figure 2). The knobs were characterized by length, width, geographic location, proximity to streaks as seen on the photomosaics, and geologic surroundings.

Positive isolated features on Earth eroded by a fluvial, glacial or eolian process were located and digitized by length and width. Aerial photographs of parts of Puerto Rico, New York State, and Egypt and previous morphometric studies of Washington, Arizona, Ireland, England, and the Piedmont region of Virginia, North Carolina and South Carolina were used for data compilation, each being characteristic of one of the above processes.

Areas were selected where knobs are of sufficient size so the limits of resolution would not affect their interpretability.

### 4. Results

#### 4.1. MARS DATA

The Diacria Quadrangle (MC-2) contains knobs in the smooth and mottled plains units. The knobs are disseminated throughout the north-central part of the quadrangle (Figure 3a) between 140 °W and 160 °W and are relatively small. Their average length and width is 4.87 and 3.69 km respectively, with a length-to-width ratio of 1.35 : 1. There is an area of knobby terrain in the southwest section of the quadrangle (Figure 3b) that extends to the Elysium volcanic province. These knobs are surrounded by plains material and form a rugged upland terrain (Scott and Allingham, 1976). They are slightly larger and have an average length of 6.2 km and width of 4.6 km, with a length-to-width ratio of 1.32 : 1. Streaks are not associated with knobs in the quadrangle and structural control of the land forms is more subdued or absent in the north, although becoming more apparent in the southwest where the central plains rise toward Elysium Mons.

The Arcadia Quadrangle (MC-3) has small knobs disseminated throughout the northern section. Along 50 °N latitude, in the northeast section of Arcadia, large isolated knobs are present at the northwest edge of the Tempe Plateau in the etched-upland material (Figure 3c). Structural trends, such as ridges, faults, and structural alignments, are prominent and oriented northeast-southwest. The knobs are oriented

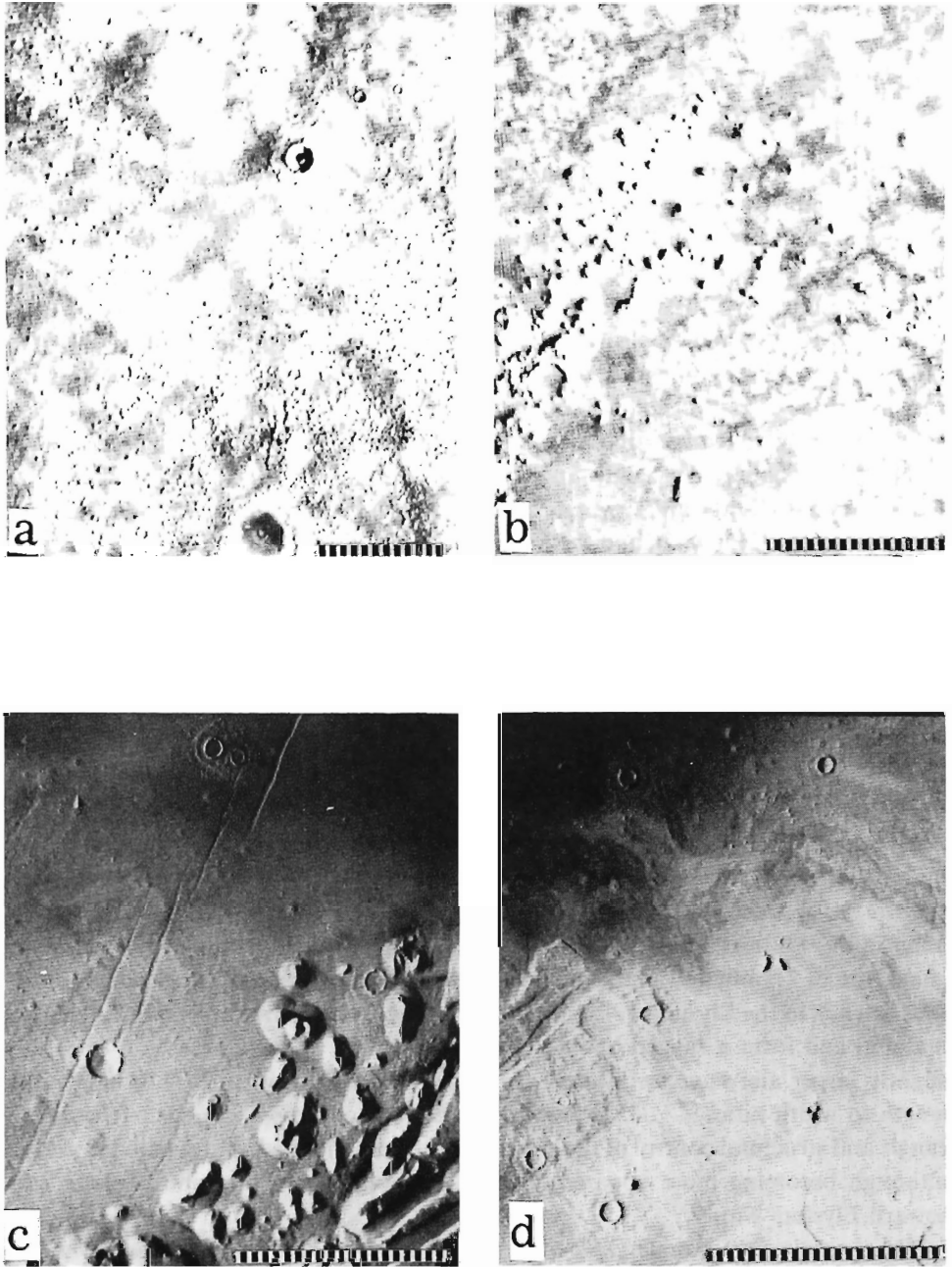


Fig. 3. (a) Disseminated knobs in the north-central region of the Diacria Quad., Viking image 815A05. (b) Knobs in the southwest region of the Diacria Quad., Viking image 776B53. (c) Large isolated knobs at the northwest edge of the Tempe Plateau in the Arcadia Quad., Viking image 701B92. (d) Isolated knobs in the northwest section of Mare Acidalium, Viking image 704B15. The scale bars are each 100 km.

similar to the structural trends and streaks are absent. The knobs in this region have an average length of 13.22 km and width of 8.82 km, with a length-to-width ratio of 1.50:1.

In the northwest section of Mare Acidalium (MC-4), located at 52°N, 53°W, there are a few isolated knobs (Figure 3d). These are at the northeast end of the fractured and channeled plains material. Their average length and width is 7.62 and 6.25 km respectively, with a length-to-width ratio of 1.24:1. In the northeast section of Mare Acidalium, knobs are present in the mottled plains material, with an average length of 5.4 km and width of 3.6 km (Figure 4a). Their length-to-width ratio is 1.50:1. In the southeast section of Mare Acidalium, knobs are disseminated throughout the plains material. Their average length is 4.6 km and width is 3.6 km, with a length-to-width ratio of 1.26:1. Located at 40°N, 10°W, are some knobs in the dissected plateau material that are closely spaced and slightly larger (Figure 4b). Their average length is 5.8 km and width is 4.2 km, with a length-to-width ratio of 1.42:1. In the south-central section of Mare Acidalium, the knobs are scattered and small in size, with an average length of 4.90 km and width of 3.4 km (Figure 4c). Their length-to-width ratio is 1.43:1. Wind streaks indicate a southeast to east-southeast direction in the north section of the quadrangle and south-southeast direction in the south section of the quadrangle.

The Cebrenia Quadrangle (MC-7) contains knobs at the northern edge of Phelegra Montes, an uplifted area, and in the surrounding hilly terrain (Figure 4d). Their average length and width in the northwest is 8.12 and 6.25 km respectively, with a length-to-width ratio of 1.30:1. In the southeast, their average length is 6.89 km and width is 4.86 km, with a length-to-width ratio of 1.42:1 (Figure 5a). In the south-central section, scattered, smaller knobs occur in the hummocky plains material, characterized by its small closely spaced rounded hills of low relief, with an average length and width of 5.2 and 3.6 km respectively (Figure 5b). Their length-to-width ratio is 1.45:1. Streaks are absent.

In the Amazonis Quadrangle (MC-8), knobs are located in the western section of the quadrangle from 165°W to 180°W (Figures 5c and d). Their average length is 6.9 km and width is 4.8 km, with a length-to-width ratio of 1.42:1 in the northwest and an average length of 5.3 km and width of 3.6 km, with a length-to-width ratio of 1.47:1 in the southwest. Streaks are abundant in the area and indicate a southwest wind direction. Structural relief increases toward the plains-highland boundary. Linear escarpments have a southerly orientation. The knobs are oriented south to southwest.

In the Syrtis Major Quadrangle (MC-13), knobs occur at the northern end of the furrowed plains, located at the plains-highland boundary (Figure 6a). Their average length is 6.93 km and width is 4.83 km, with a length-to-width ratio of 1.43:1. Streaks are not present. Structural trends are to the northeast, and the knobs are oriented north to northeast. In this area, the cratered plains grade into the furrowed plains, which grade northeastward into the knobby material.

In the Elysium Quadrangle (MC-15), knobs occur in a highly cratered and rugged

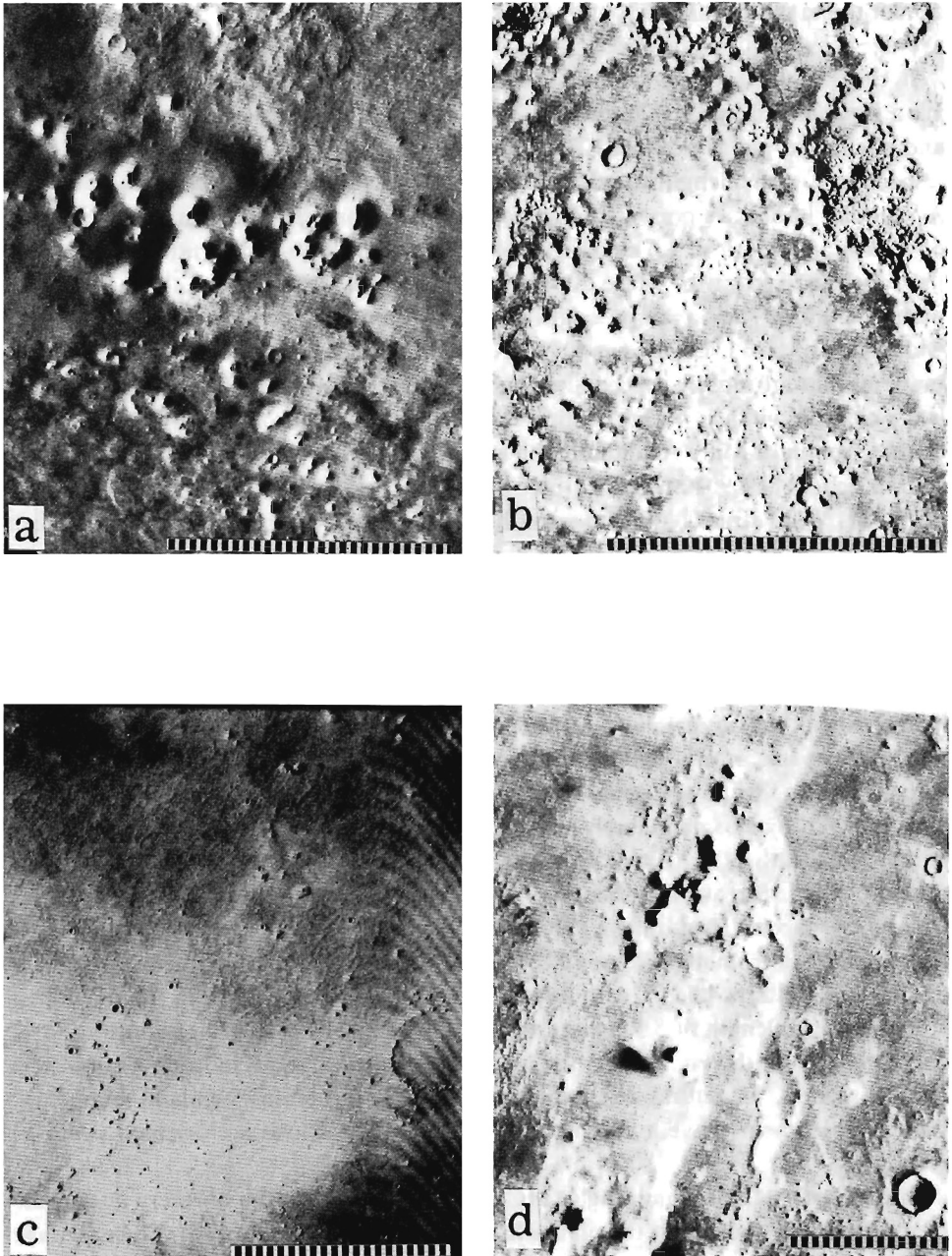


Fig. 4. (a) Isolated knobs in the northeast section of Mare Acidalium, Viking image 673B06. (b) Isolated knobs in the southeast section of Mare Acidalium, Viking image 561A26. (c) Isolated knobs in the south-central section of Mare Acidalium, Viking image 670B66. (d) Knobs at the northern edge of Phelegra Montes, Viking image 810A32. The scale bars are each 100 km.

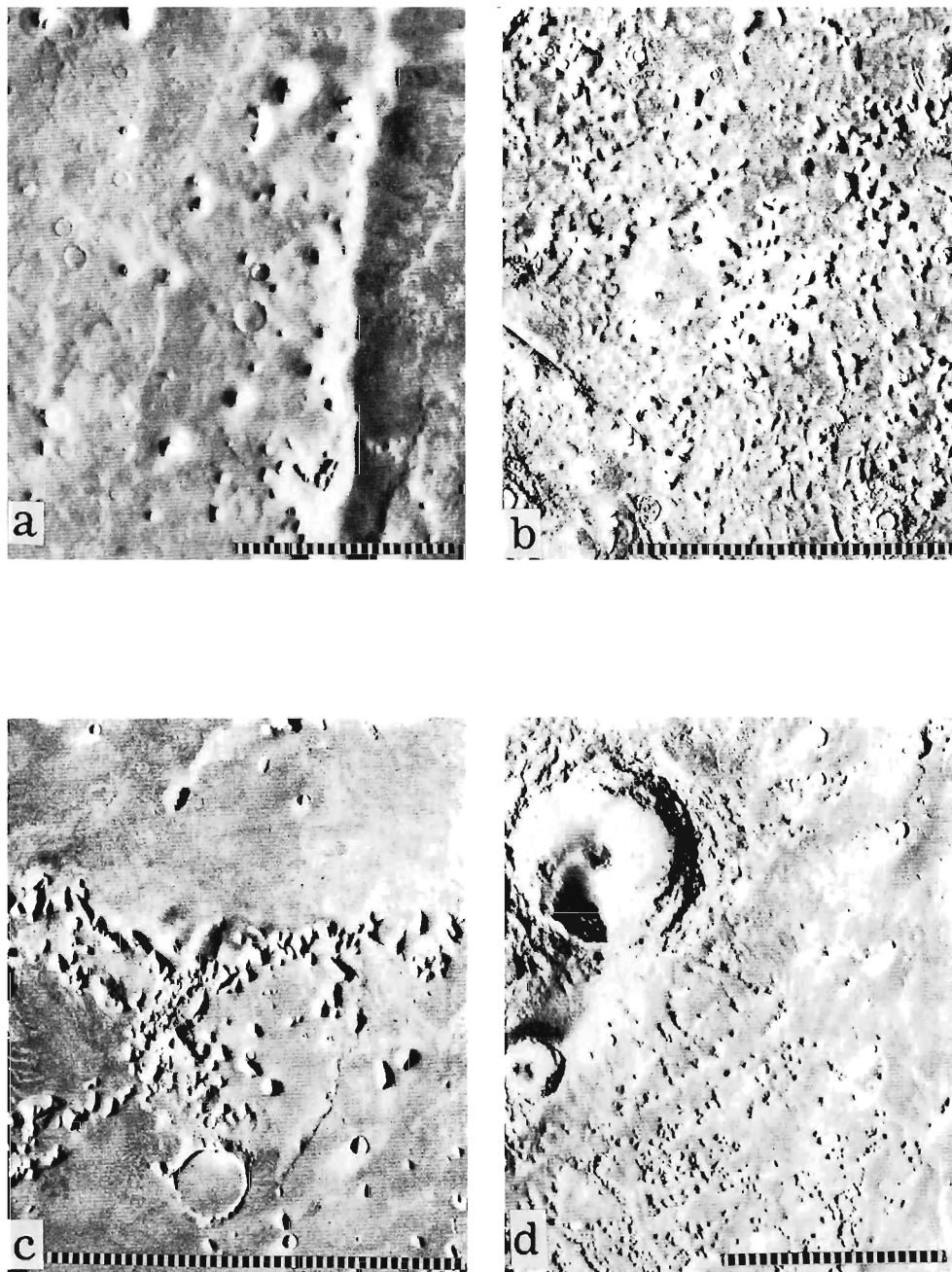


Fig. 5. (a) Knobs in the southeast section of the Cebrenia Quad., Viking image 846A31. (b) Knobs in the south-central section of the Cebrenia Quad., Viking image 541A13. (c) Knobs in the northwest section of the Amazonis Quad., Viking image 583A80. (d) Knobs in the southwest section of the Amazonis Quad., Viking image 848A21. The scale bars are each 100 km.

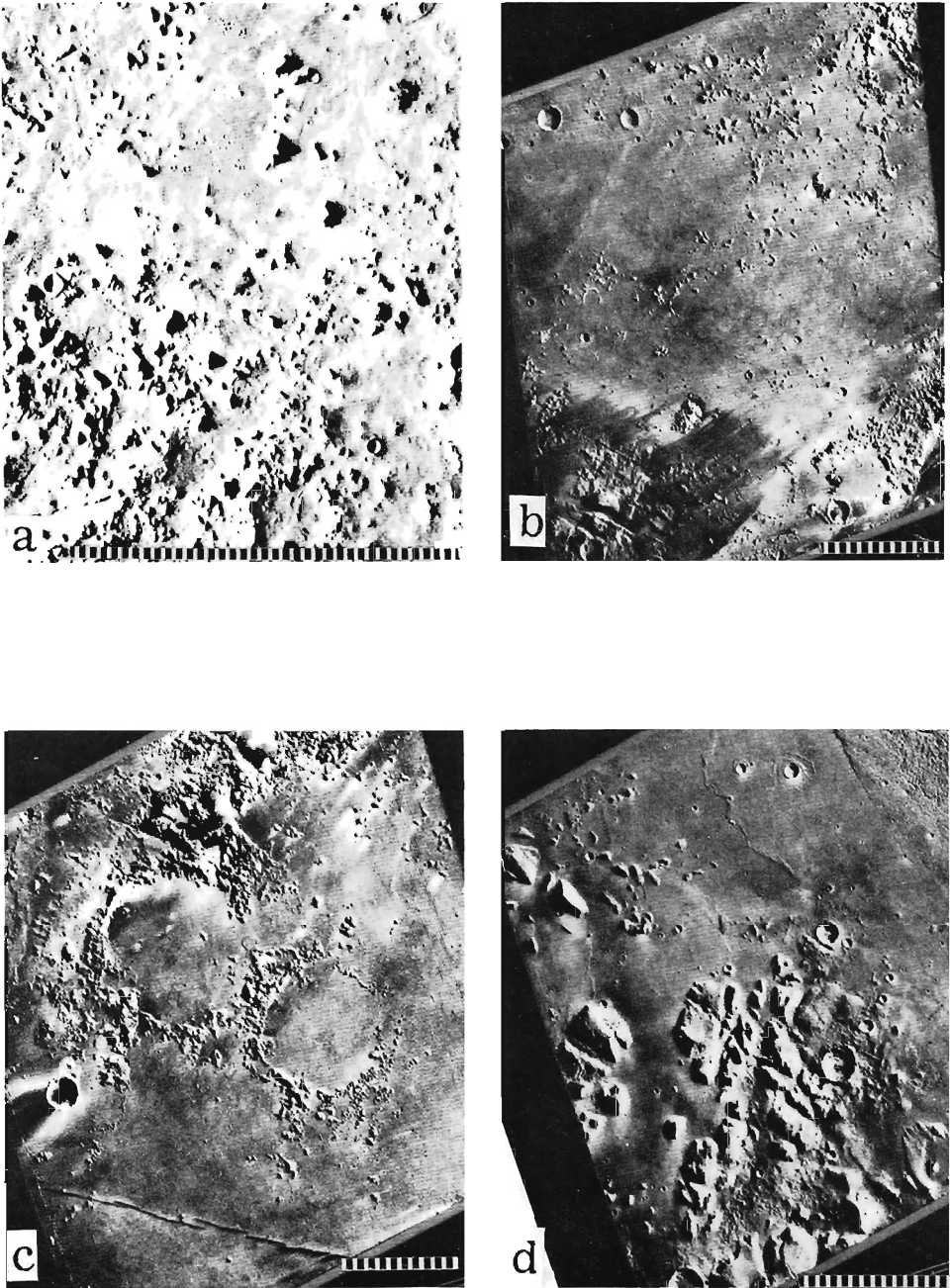


Fig. 6. (a) Knobs present near the plains-highland boundary in the Syrtis Major Quad., Viking image 534A53, (b) Knobs in the northeast, Viking image 672A64, (c) southeast, Viking image 672A84, (d) southwest, Viking image 631A06 of the Elysium Quadrangle. The scale bars are each 100 km.

terrain that extends in an arc from the south-central part to the northeast part of the quadrangle. Southwest-trending streaks are present throughout and are concentrated in the Cerberus region. The major structural trends in the central and southeast section of the quadrangle are northwest. Many of the knobs are oriented in a similar direction, but some have a southwesterly orientation. Some faceted knobs have one face directed toward the prevailing wind. The average length and width of the knobs in the northeast is 7.02 and 4.47 km (Figure 6b), in the southeast, it is 5.71 and 3.88 km (Figure 6c), and, in the southwest, it is 6.28 and 4.11 km (Figure 6d). Their length-to-width ratio is 1.57 : 1, 1.47 : 1 and 1.53 : 1 respectively.

Knobs are present along the plains-highland boundary of the Aeolis Quadrangle (MC-23, Figure 7). These knobs are significantly larger. Their average length and width is 13.22 and 9.14 km respectively, with a length-to-width ratio of 1.45 : 1. These knobs are oriented in a northwest-southeast direction. The plains-highland boundary in this area is marked by northwest trending linear escarpments, and streaks are absent.

Table I is a summary of the results presented above.

TABLE I  
Morphometric data on Martian knobs

Area	Mean length (km)	Mean width (km)	Length/width	n
MC-2 N	4.87	3.69	1.35 : 1	29
MC-2 SW	6.20	4.60	1.32 : 1	70
MC-3 NE	13.22	8.82	1.50 : 1	56
MC-4 NW	7.62	6.25	1.24 : 1	4
MC-4 NE	5.40	3.60	1.50 : 1	30
MC-4 CE	5.80	4.20	1.42 : 1	15
MC-4 SE	4.60	3.60	1.26 : 1	33
MC-4 SC	4.90	3.40	1.43 : 1	41
MC-7 NE	8.12	6.25	1.30 : 1	26
MC-7 SE	6.89	4.86	1.42 : 1	70
MC-7 SC	5.20	3.60	1.45 : 1	18
MC-8 NW	6.90	4.80	1.42 : 1	58
MC-8 SW	5.30	3.60	1.47 : 1	17
MC-13 NE	6.93	4.83	1.43 : 1	9
MC-15 NE	7.02	4.47	1.57 : 1	58
MC-15 SE	5.71	3.88	1.47 : 1	49
MC-15 SW	6.28	4.11	1.53 : 1	19
MC-23 NW	13.22	9.14	1.45 : 1	10

#### 4.2. TERRESTRIAL DATA

Eight regions were used to gather morphometric data of positive isolated features. The results of the digitized data analysis based on aerial photography and previous morphometric studies are shown in Table II. The Farafrá Depression and an area of central Arizona represent regions containing isolated features eroded in an eolian environment. Regions in Ireland, England, and the United States contain isolated



Fig. 7. Knobs present near the plains-highland boundary of the Aeolis Quad., Viking image 631A06. The scale bar is 100 km.

TABLE II  
Morphometric data on terrestrial isolated features

Area	Mean length	Mean width	length/width	Geological environment	<i>n</i>
Farafra	203 m	138 m	1.47 : 1	Eolian	75
New York	11.87 km	4.24 km	2.80 : 1	Glacial	25
Puerto Rico	120 m	84 m	1.43 : 1	Fluvial	63
Piedmonts	15.20 km	8.40 km	1.92 : 1	Fluvial	350
Arizona	3.98 km	2.74 km	1.50 : 1	Eolian	105
Washington	NA	NA	3 : 1	Fluvial	NA
Ireland	NA	NA	2 : 1	Glacial	NA
England	NA	NA	3 : 1	Glacial	NA
U.S.A.	NA	NA	2.4 : 1 to 3.4 : 1	Glacial	NA

NA – Not Available

features that were eroded in a glacial environment. Sections of Washington State and Puerto Rico exhibit isolated features eroded in a fluvial environment.

The Farafra Depression, located in the west-central part of the Western Desert of Egypt, is bounded by three scarps creating a roughly triangular shape. Manent and El-Baz (1980) showed how the wind is channeled between the two scarps forcing the dunes to parallel the mean orientation of the scarps (Figure 8). The scarps themselves



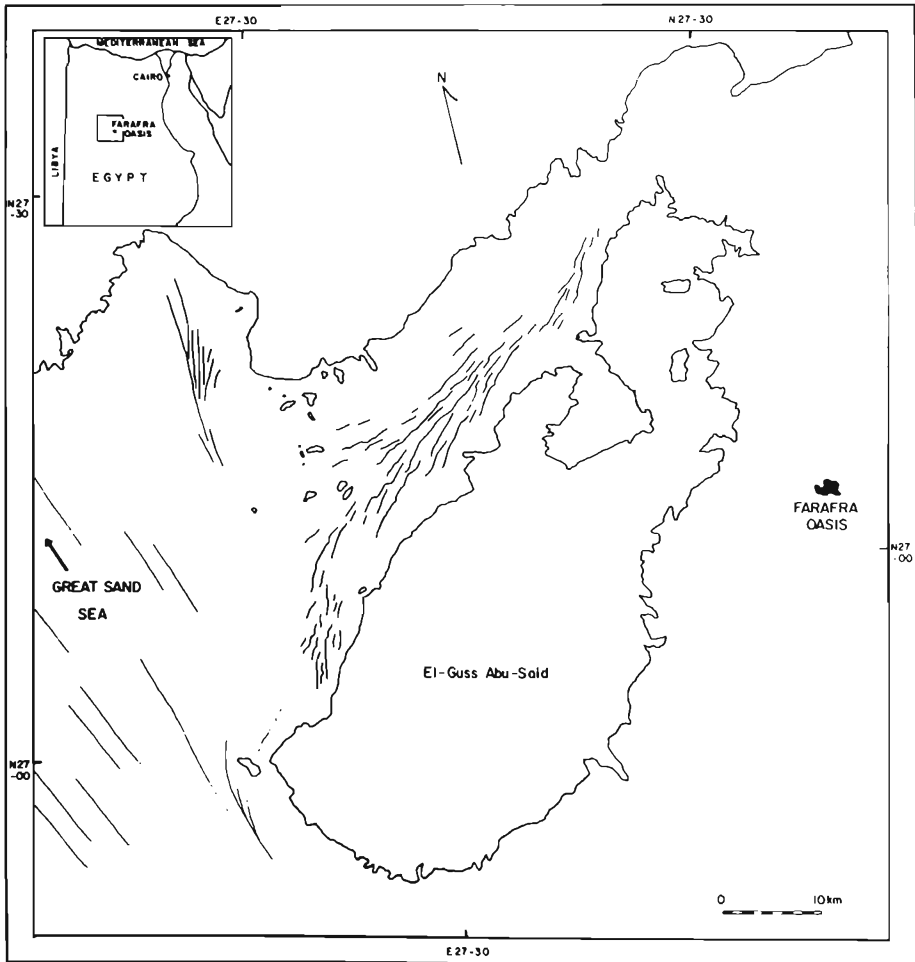


Fig. 8. Dunes oriented parallel to resulting direction of two scarps near the Farafra oasis, Western Desert of Egypt (after Manent and El-Baz 1980, p. 298).

were shaped by pluvial action. However, during dry climatic periods, such as within the past 5000 y, isolated hills have been shaped by eolian erosion (Figure 9). The width of these isolated hills range from 45 to 232 m and their length range from 73 to 412 m. Their length-to-width ratio is 1.47:1, with an average length of 203 m and width of 138 m. Approximately 20 km south of the above hills, yardangs in a field were measured ranging in length from 0.87 to 15.4 m and in width from 0.41 to 10.2 m. Their length-to-width ratio is 1.89:1, with an average length of 10.2 m and width of 5.4 m.

The Earth's surface can also be eroded by glacial erosion, which results from the presence or passage of a glacier. Many features, such as drumlins, kettles, and striation marks result from this type of erosion. Drumlins, in particular, are smooth

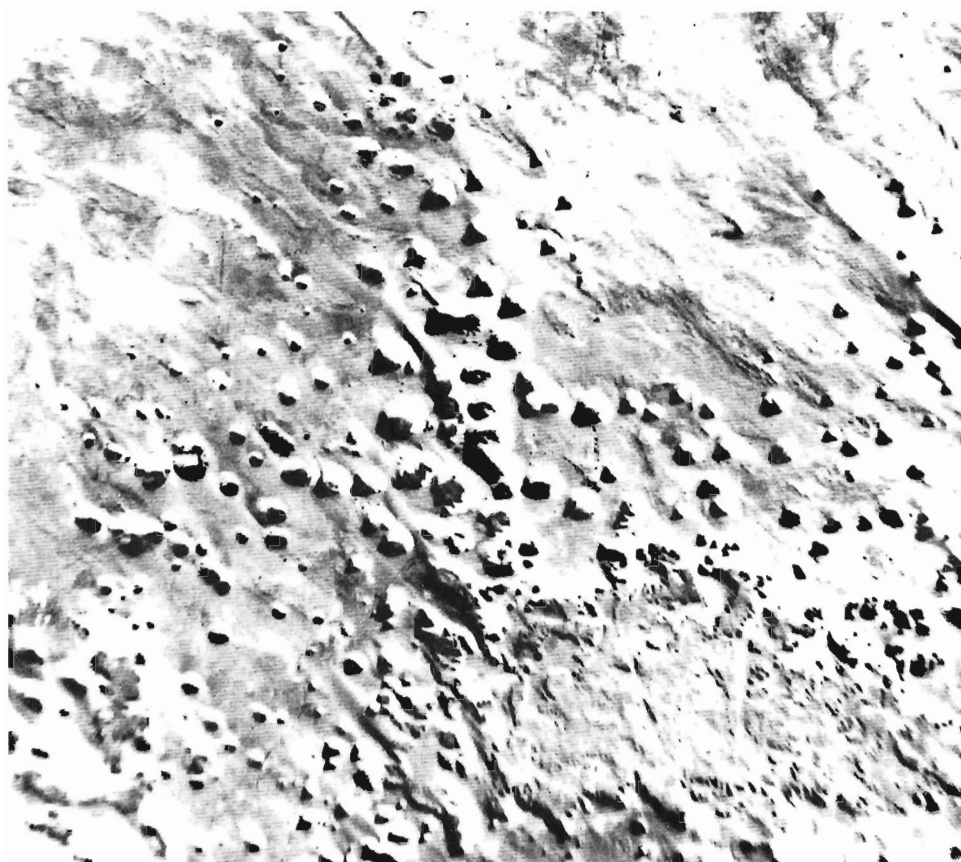


Fig. 9. Isolated hills located north of the Farafra oasis shaped by eolian erosion.

elliptical hills elongated in the direction of ice movement produced under flowing ice with a composition of rock and/or drift. Extensive morphometric analyses of these features have been performed (Chorley, 1959; Heindenreich, 1964; Reed, *et al.*, 1962; Smalley and Unwin, 1968; and Vernon, 1966). Length to width ratios of such features vary from 2 : 1 in County Down, Ireland (Vernon, 1966), to 3 : 1 in Northern England (Hollingsworth, 1931). Reed *et al.* (1962) found ratios of 2.4 : 1 to 3.4 : 1 typical in the United States. A field of drumlins in upstate New York have a length-to-width ratio of 2.8 : 1 (Manent and El-Baz, 1981) which agree with Reed's findings (see Figure 10). They range in length from 5.3 to 17.4 km and in width from 2 to 5.9 km. Their average length and width are 11.78 and 4.24 km respectively.

Large scaled erosional features in the Channeled Scabland of Washington have been extensively studied by Baker (1978). These features are streamlined residuals of basalt or loess and are formed in a fluvial environment. The scabland streamlined hills were morphometrically analyzed by statistical correlation and regression analysis and



Fig. 10. Hilly glacial terrain near Palmyra, New York.

found to be formed by a rapidly flowing fluid. Their length-to-length ratio measures their elongation, and there is little change in the length-to-width ratio being constant at 3 : 1 with increasing size.

Karst topography is formed over limestone, dolomite, or gypsum by solution and is characterized by closed depressions or sinkholes, caves and underground drainage. An area in Puerto Rico exhibits large isolated hills known as mogotes (Figure 11). These hills are residual masses and are associated with the karst topography of the region. The landscape is also modified by fluvial erosion during alternating wet and dry episodes. The mogotes rise from blanket sand deposits to heights between 50 to 250 m. These hills range in length from 53 to 254 m and in width from 36 to 157 m. Their length-to-width ratio is 1.43 : 1, with an average length and width of 120 and 84 m, respectively.

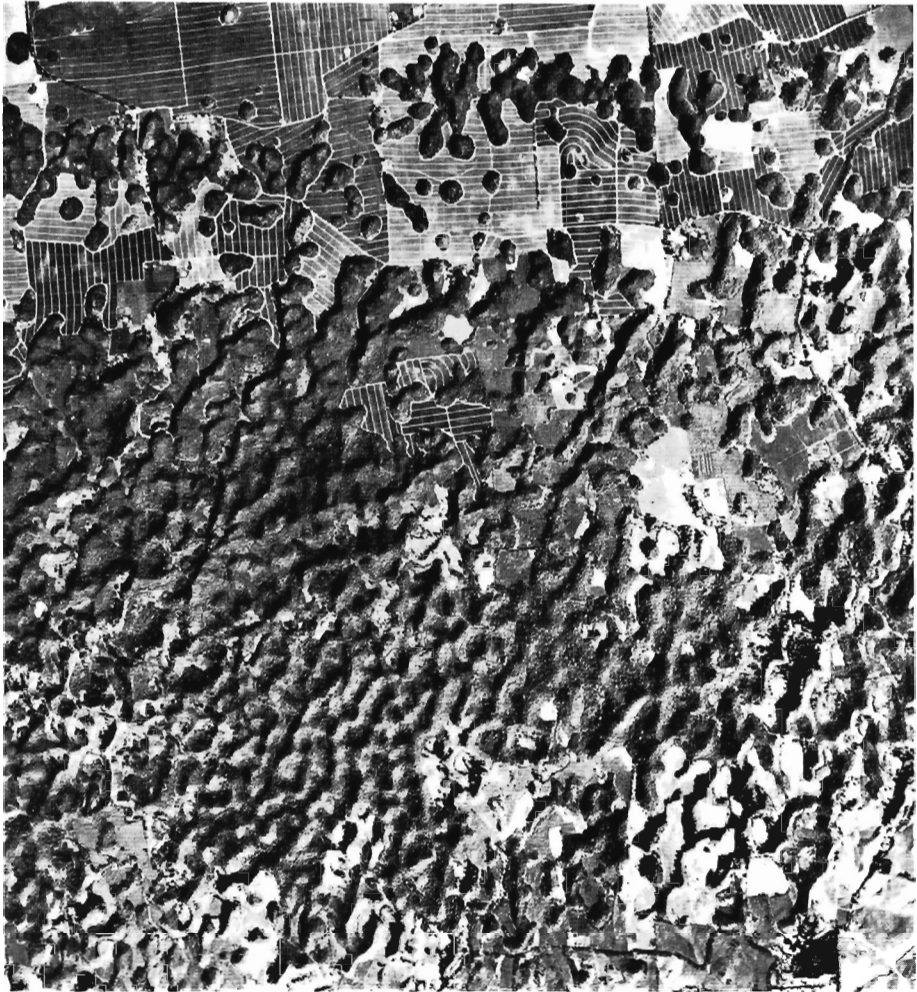


Fig. 11. Mogotes associated with karst topography in Puerto Rico.

Kesel (1972) studied the morphologic characteristics of inselbergs in a humid temperate and an arid environment. His study was limited to isolated hills in crystalline, igneous and metamorphic rocks located in the Piedmont of Virginia, North and South Carolina and in central Arizona.

In the piedmont region, the general northeastward trend of the inselbergs coincides with the strike of the lithologic and structural units of the bedrock. A secondary trend to the northwest is presumably related to the southeast direction of flow of the streams down the escarpment. The average length and width of the 350 inselbergs is 15.2 and 8.4 km respectively, with a length-to-width ratio of 1.92:1. In central Arizona, the general trend of the inselbergs varies between different mountain ranges. Jointing does

play a major role in determining the trend and shape of the remnants. The average length and width of seventy-nine isolated hills is 3.98 and 2.74 km respectively, with a length-to-width ratio of 1.50 : 1.

## 5. Discussion

Evidence for the reshaping of the Martian surface by glacial activity is scarce. Tapered forms may result from glacial activity, such as drumlins, but other associated diagnostic landforms of glacial activity have not been recognized on Mars. Also, length-to-width ratios of drumlins on Earth have been extensively studied and found to be approximately 3 : 1 (Chorley 1959). The length-to-width ratio of isolated hills on Mars is significantly lower, ranging from 1.24 : 1 to 1.57 : 1.

Allen (1980) compares Table Mountains in Iceland to isolated features on Mars. He states that Table Mountains are the subglacial equivalent of small shield volcanoes and suggests that isolated knobs in the Acidalia Planitia region are similar. However, ridges in the Acidalia region of Mars have the same trend (north-northwest) as the ridge system of the Tharsis region, and it is not likely that the ridges would have formed independent of the compressional stresses that formed the Tharsis Ridge system and be of subvolcanic origin (Watters, personal communication). It is widely accepted that the ridges are of compressional stresses (Wise *et al.*, 1979; Saunders and Gregory, 1980; and Watters and Maxwell, 1980), and that the plains material is of volcanic origin from the Tharsis region. However, if they were of subglacial origin, one would expect to see a ridge system associated with each subglacial volcano. Also, one would expect glacial features that result from large ice sheets that are required for the formation of Table Mountains.

Streamline erosional features in the channeled Scablands of Washington were compared to similar erosional forms in the Martian outflow channels in the Kasei Vallis region of Mars. Baker concluded that even though features on both planets are not identical, they are similar enough to have been formed by the same fluvial processes. Again, their length-to-width ratio of 3 : 1 is significantly larger than knobs on Mars.

In Puerto Rico, length-to-width ratios are similar to some area of Mars (Table I), but other diagnostic features associated with these residual masses such as sinkholes, caverns, and depressions are absent. Climatic indicators for this type of environment, now or previously, are also absent. Therefore, we conclude that knobs on Mars were not formed by fluvial action.

In the Western Desert of Egypt, general dune orientations change from north-northwest in the northern part to north-northeast in the southwest indicating the wind regime of the region. Many dunes are intimately associated with scarps that bound numerous depressions (El-Baz, 1979). This relationship is believed to result from the interaction between sand-carrying winds and scarps and other topographic features (Gifford *et al.*, 1979). Although their size is much smaller, the isolated hills in the

Farafra Depression in the Western Desert of Egypt are the most similar to the isolated hills on Mars based on length-to-width ratios, geologic surroundings and associated wind-related features. As shown by recent studies (Butzer and Hanson, 1968; Cook and Warren, 1973; Doehring, 1977; Glennie, 1970; and Mabbutt, 1977), prolonged wind erosion creates isolated hills; cliff retreat does not have to result from water erosion. These isolated hills were initially formed when solid rock fractured, thus providing the structural control. Wind then acted upon the rock by sweeping away the sediment in a preferred orientation (Figure 10). On Mars, it has been observed that, as one moves from high to equatorial latitudes, structural and other topographic influences, such as scarps, faults and craters, and the effect of wind, become more significant. Thus, the size of the hills initially is larger, and they get smaller as the process of eroding the knobs continues. Sagan *et al.* (1973) noted that at the equatorial latitudes the calculated winds are the strongest and steadiest. At higher latitudes, their magnitudes are less, and the direction varies during the diurnal cycle. Also, elevation differences and obstacles in the path of the wind increase the wind speed and, therefore, its erosive power. Thus, we conclude that the most likely process for the formation of knobs on Mars is the initial fracturing of solid rock, which is then acted upon by the wind sweeping away the sediment within the fractures and continuing until isolated hills are left behind similar to those in the Farafra Depression and central Arizona regions.

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