Chapter 17

ANALOGS OF MARTIAN EOLIAN FEATURES IN THE WESTERN DESERT OF EGYPT

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ABSTRACT

Dark, streamlined streaks observed in orbital images of the Western Desert of Egypt are similar in scale and form to crater- and knob-related streaks on the martian surface. In Egypt, dark streaks form in the lee of topographic highs, ranging in size from small hills a few meters across, to the 60 km wide Uweinat massif. On the surface of Mars, streaks may be either lighter or darker in tone than the surrounding plains. Individual streaks occur primarily in the lee of craters, although in the Cerberus region, several light-toned streaks occur in the lee of irregular knobs, similar to those in southwestern Egypt. Knob- and crater-related wind streaks on both Earth and Mars owe their characteristic patterns to the local deviation of wind around topographic barriers. Knob streaks on both planets most often display a convergent pattern, whereas crater streaks on Mars are more often divergent. Field investigation in southwestern Egypt indicates that the characteristic shape of wind streaks is a function of the transport and deposition of material surrounding the streak rather than erosion or deposition in the lee of the obstacle.

In addition to these landform analogies visible at orbital altitudes, many near-surface features in the Western Desert are similar to those seen in Viking lander images from the surface of Chryse Planitia on Mars. Sand drifts and small dunes are present in both deserts, as are pitted and faceted rocks that occur in both non-vesicular basalt and in sandstones. Evidence of wind pitting and erosion in the Western Desert suggests that rocks in the Viking 1 landing site may not necessarily consist of vesicular basalt, but may owe their surficial features to wind erosion.

INTRODUCTION

Wind-dominated landforms are the most abundant features throughout northern Africa and particularly in the Western Desert of Egypt. Although the major eolian landforms of the Sahara were known well before the advent of orbital data, photographs from the Gemini through the Apollo-Soyuz missions, and images from Landsat satellites allow comparison of these features on an interplanetary basis. In

1972, when the Mariner 9 spacecraft returned images of the surface of Mars, it became clear that eolian activity was the most dominant process on the martian surface. One of the first clear indications of this fact was the presence of wind-produced bright and dark streaks extending from many craters.

Both bright- and dark-toned wind streaks occur in the Western Desert. Bright streaks are composed of sand dunes and dune belts, sand sheets, and lag deposits of light-colored bedrock, whereas dark-toned streaks are predominantly local lag fragments and desert pavement (El-Baz and Maxwell, 1979a). As seen from orbit, the dark streaks in the Western Desert are present in the lee of topographic obstacles to the predominant northerly wind flow, and create streamlined patterns similar to those in the lee of craters and knobs on Mars.

As a result of the 1978 investigation of the Western Desert, however, it was found that geomorphic features on a much smaller scale are also analogous to several of those seen in Viking Lander 1 and 2 images of the surface of Mars. In addition to the eolian drifts that are a commonplace occurrence in the Western Desert, numerous pitted and fluted rocks of differing lithologies are present on the desert surface. Similarities of these eolian pitted rocks to those on the martian surface have been described by McCauley and others (1979a).

Consequently, the scale-independent resemblance of both Egyptian and martian landforms suggests that the Western Desert, with its present-day hyperarid climate, provides one of the closest terrestrial analogs for the study of martian geomorphic processes. The purpose of this study is to present detailed comparisons of dimensional parameters for both martian and Egyptian wind streaks and to discuss their inferences for the origin of martian streaks. Based on our field observations of surface materials in the Western Desert, it is also possible to speculate on the origin of martian eolian features seen in Viking lander images.

REGIONAL SETTING

In the Western Desert, knobs of protruding bedrock and associated wind streaks form an irregular line between the Kharga depression and the Gilf Kebir plateau. Bedrock exposures are composed of highly resistant, Fe-rich sandstones and conglomerates of the Nubia series, although east of the Bir Tarfawi region, the protruding knobs consist of outcrops of the Tawel granite (see Dardir, Chapter 7). The linear nature of the Nubia sandstone outcrops is created by the gently northward dipping attitude of the beds, which have been partially submerged by sand driven from the north. It is possible that these linear outcrops mark the positions of low cliffs retreating northward, now represented by isolated hills that create the streak patterns seen from orbit. The location of streaks measured for this study is shown in Figure 17.1.

In several areas on Mars, wind streaks have formed in the lee of irregular positive features as well as craters. Streaks may form behind groups or rows of knobs as well as behind isolated hills.

Figure 17.1 Landsat mosaic of Egypt showing location of wind streaks used for comparison with martian streaks. Arrows indicate the locations of streaks investigated during 1978 field trip: A) Qaret El-Maiyit, a granitic hill approximately 1 km across, and B) Uweinat Mountain, a 60 km wide mountain composed of granite and syenite.

Knob-related streaks are well-developed in the Cerberus region of Mars (15°N, 200°W), where the knobs consist of roughly equidimensional faceted appearing hills that occur on a smooth plains unit of probable volcanic origin (Fig. 17.2). Comparisons of Mariner 9 and Viking images of this region have shown that subtle changes in the patterns of dark and light streaks have occurred in the 5 years between the two missions (Chaikin and others, 1980). With this evidence of surficial erosion and deposition, and the presence of knob-related streaks, Cerberus provides a suitable location for comparison with the wind streaks of the Western Desert.

WIND STREAKS

Comparison of Scale

For comparison of the scale of wind streaks on both planets, measurements of knob widths and streak lengths were made from enlarged Viking images and Landsat images placed in an opaque projector. Knob widths were measured perpendicular to the streak direction, and in the case of martian craters, rim crest diameter was measured. Streak lengths were measured from the downwind edge of the knob or crater to

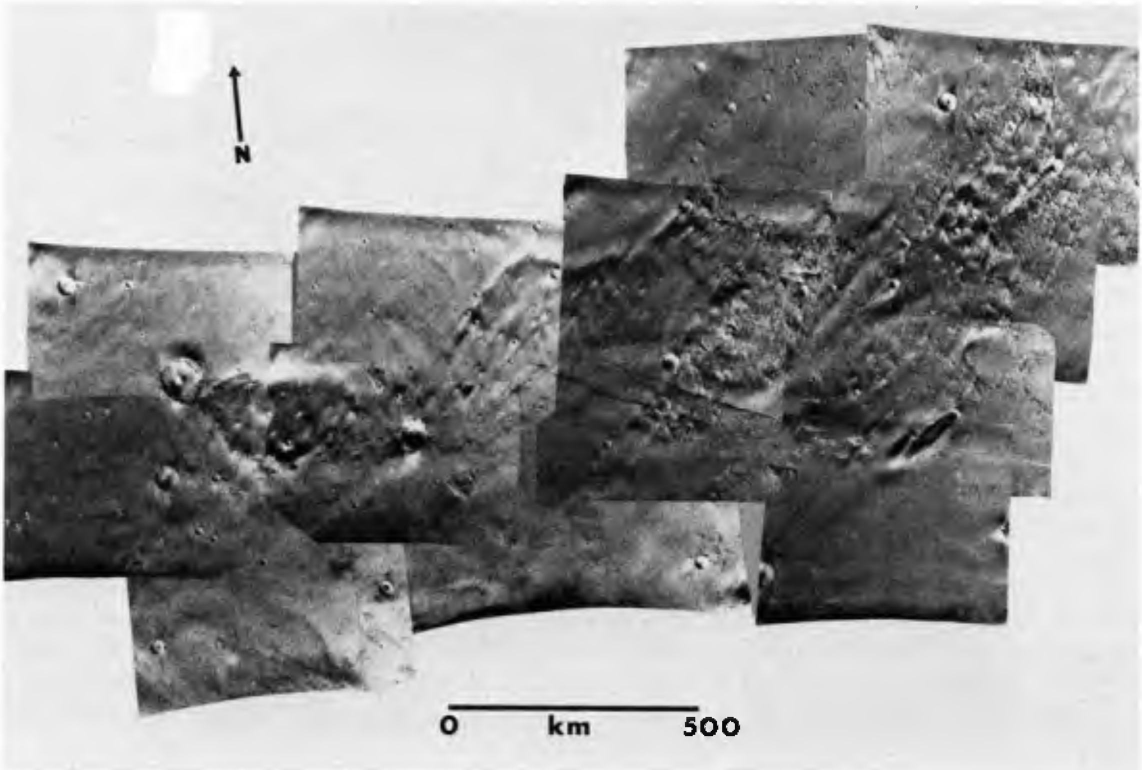

Figure 17.2 Mariner 9 mosaic of the Cerberus region of Mars showing dark- and light-toned streaks. Note dark crater streak in lower right, and the numerous light streaks within the dark albedo feature.

the tip of the streak. If the streak had a ragged downwind edge, as with some divergent streaks, an average length was measured, this being necessarily a subjective measurement. Both the knob widths and streak lengths of Egyptian and martian wind streaks are within the same scale. Knob widths seen from orbit range from 1 to 25 km, although most knobs in the Western Desert occur between 2 and 7 km. Streak lengths range from 5 to 75 km, although most cluster at lengths of 5 to 25 km (Fig. 17.3). The scale and overall form of knob streaks on both planets are similar to those of crater-related streaks on Mars, which are shown in Figure 17.3 for comparison. The average streak length/knob width ratio for Egyptian streaks is 4.8, and for martian knob streaks is 3.0, consistent with the range of crater streak parameters noted by Arvidson (1974). Because of these similarities between knob- and crater-related streaks, we believe that any implications resulting from our study of knob streaks in the Western Desert may apply equally well to the formation of both knob and crater streaks on Mars.

Streak Patterns

In addition to the similar scale of wind streaks, the patterns of knobs protruding through smooth, plain surfaces is also similar on both planets. This suggests that the local geologic setting may be

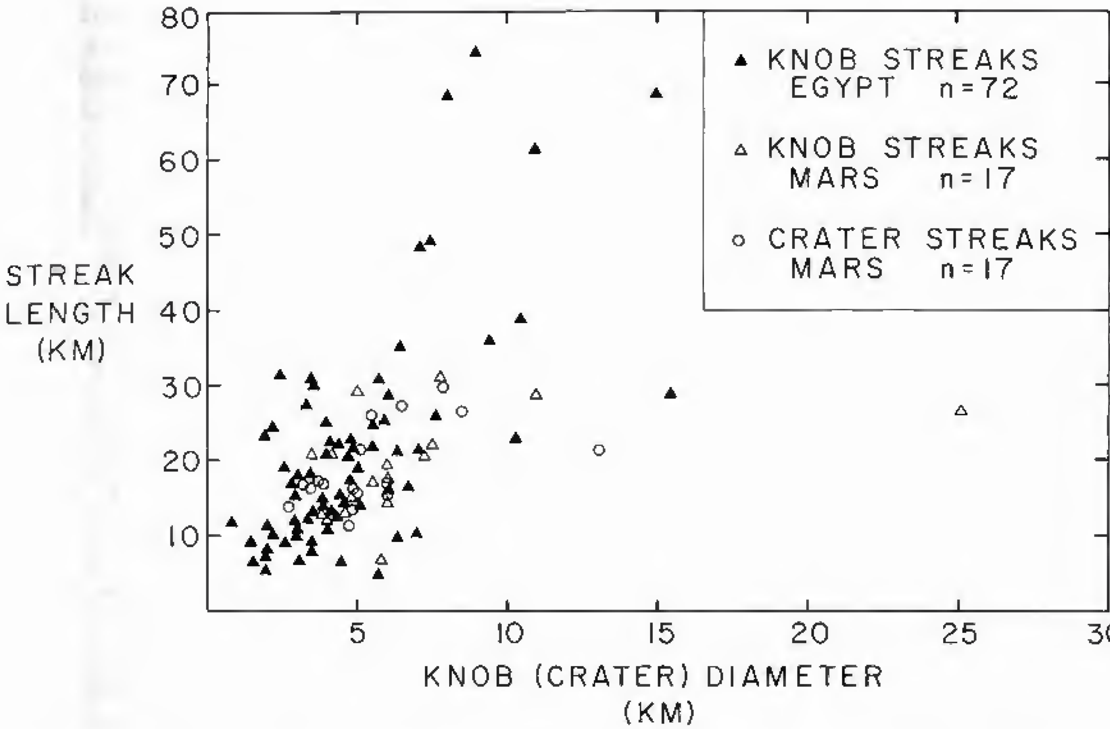

Figure 17.3 Scatter diagram of knob width versus streak length for both Egyptian streaks in the Western Desert, and knob and crater streaks in the Cerberus region of Mars. Both Egyptian and martian streaks occur at the same scale, although some of the larger Egyptian streaks (particularly Uweinat) are longer than those in the Cerberus region.

important in controlling both the placement and morphometric characteristics of streaks. In the Western Desert, the pattern of exposure of dark material is controlled by the locations of numerous light-colored longitudinal dunes that have migrated southward (El-Baz, 1977; p. 77). Composite streaks are generally much smaller, and average 9 km long. In contrast to large streaks (such as that in the lee of Uweinat), smaller ones form in response to local bedrock outcrop patterns, and are affected more by local wind directions than by the regional wind regime. For example, composite streaks north of Uweinat deviate to the east and west around the mountain. As is the case with individual large streaks, light-colored sand deposits surround the dark material (local desert pavement?) of the composite streaks, resulting in an irregular pattern.

Streak Form

For comparisons of streak form, Mars streaks were measured from enlarged Viking Orbiter images of the Cerberus region at a scale of 1:425,000. Martian crater and knob streaks range up to 36 km in length and 17 km in width, and the maximum area of 179 knob streaks is 450 km^2, whereas that of 62 crater streaks is 342 km^2. Because of the less distinct outline of the larger Egyptian streaks, only smaller streaks were used for shape comparison. The 239 knob streaks in southwestern Egypt, outlined at a scale of 1:200,000 from Landsat false color images range up to 21 km^2 in area, and are up to 12 km long and 5 km wide.

A plot of the maximum width and length of martian crater and knob streaks, and Egyptian knob streaks (Fig. 17.4) indicates that all three streak types follow the same general curve, although the degree of scatter increases from crater to knob streaks. Knob streaks in the southwestern corner of Egypt exhibit the greatest scatter ($r = 0.618$), but are generally narrower than their martian counterparts. The relatively small width of the Egyptian streaks is also indicated by a plot of streak length versus total area. As shown in Figure 17.5, the total area of distinct Egyptian streaks is much less than that of martian streaks. In both places, however, the range of values is similar for streaks less than about 50 km^2 in area.

In order to compare the degree of streamlining for streaks on both planets, we have chosen a dimensionless shape parameter (K) used by Chorley (1959) to analyze the shape of drumlins, and more recently by Baker (1978a) for loess islands in the channeled scablands of Washington. The value of K indicates the deviation of the observed form from that of a circle:

$$K = \frac{l^2 \pi}{4 A} \quad (1)$$

in which l is the length of the form, and A is the area. Thus, a circle would have a value of $K = 1$. For streamlined forms in the channeled scablands, Baker (1978a, p. 92) found that K varies between 2 and 5, and may be related to the calculated Reynolds number for maximum scabland flood flows.

For crater streaks on Mars, values of K range from 0.6 to 4, and can be correlated with the length of the streak (Fig. 17.6); the longer the streak, the greater degree of streamlining. Although this relationship holds for knob streaks on both planets, there is a significant difference in the slope of the regression curve between martian and Egyptian knob streaks. Values of K for the Egyptian streaks range from 0.3 to 9, and exhibit a higher degree of streamlining than do martian crater or knob streaks. The relatively high values of K associated with the Egyptian streaks are most likely a function of the near-surface transport of material, and the unidirectional wind flow. Among the larger streaks visible in the Western Desert, parallel types are the dominant form. Many of the larger dark streaks have a constant width and extend for as much as 140 km before grading into the surrounding brighter sand. Thus, deposition of material from martian duststorms, and variability of wind direction are likely causes for the lower values of K exhibited by martian streaks.

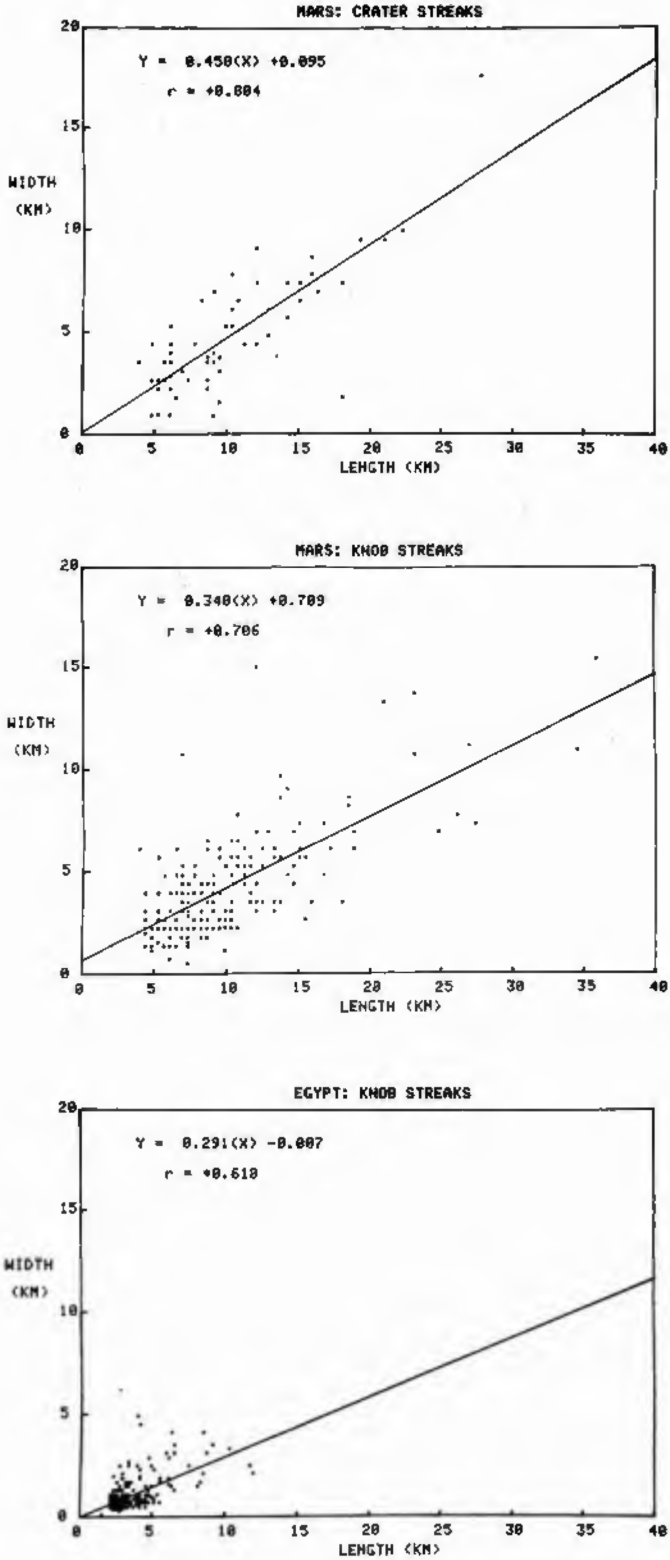

Figure 17.4 Width versus length for martian and Egyptian wind streaks. The distinct knob streaks in Egypt are smaller than their martian counterparts, but follow a similar size relationship.

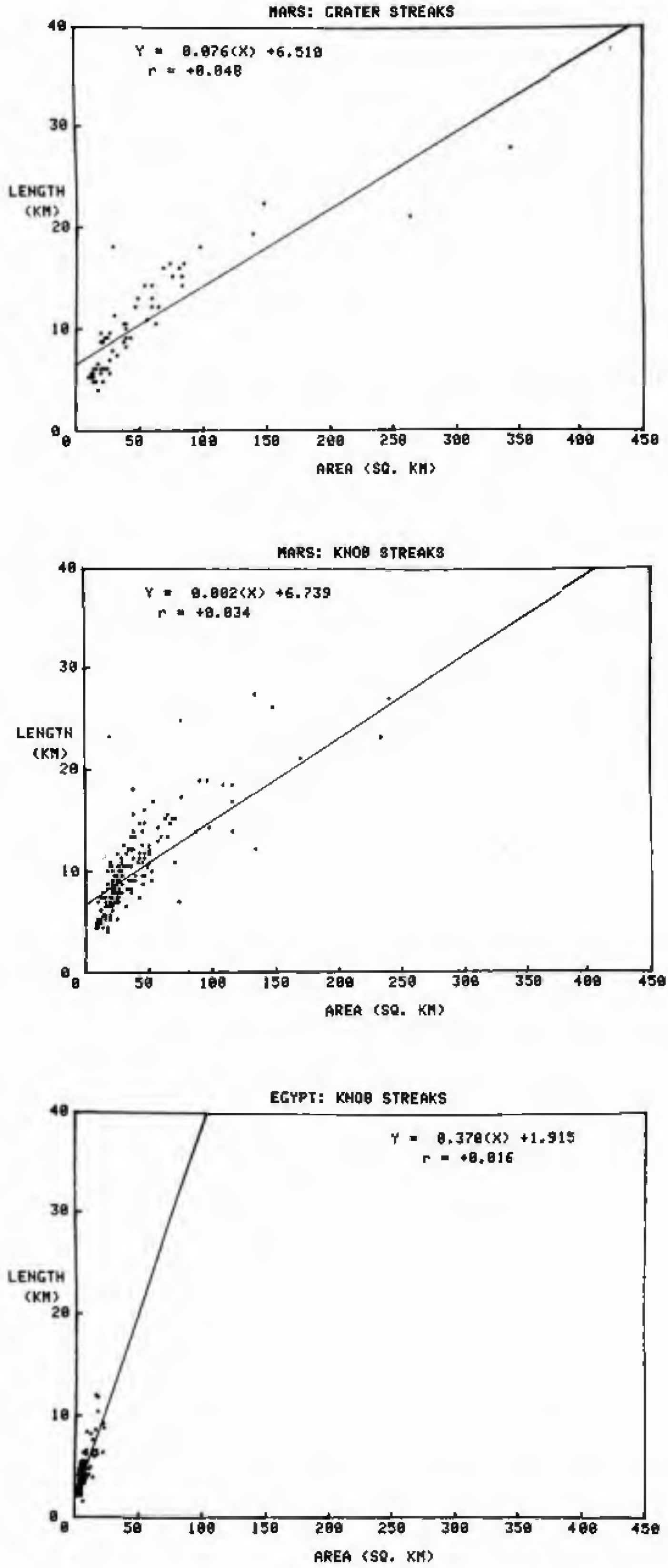

Figure 17.5 Length versus area for martian and Egyptian wind streaks.

Surface Characteristics

A combination of photogeologic evidence (Veverka, 1975; Veverka and others, 1978) and wind tunnel simulations with model craters (Greeley and others, 1974a) have been used as evidence that most dark streaks on Mars are erosional scars which change in response to the redistribution of the brighter material surrounding the streak. This method of change in streak form has recently been supported by observations of streaks in the Western Desert (El-Baz and Maxwell, 1979a). Bright streaks on Mars are most likely fine grained material deposited in the wind shadow in the lee of craters. These streaks may not be affected by the lower velocity winds that occur between the martian dust storms.

Both bright and dark streaks are present in the Western Desert; bright streaks are depositional and consist of sand accumulations in longitudinal dunes, relatively thin sand sheets, and coarse lag surfaces. Dark streaks are erosional products of mountains and hills and consist of irregular chips of rock.

The importance of local bedrock outcrops as a source of material for dark streaks in southwestern Egypt is demonstrated in the lee of Qaret El-Maiyit hill. This streak is composed of 5-7 mm size granitic pebbles eroded from the hill, and the dark surface is surrounded on both sides by a light-colored sand sheet. The surface of the streak itself is more than 1 m below the level of the surrounding sand sheet, thus providing a minimum estimate of the sand sheet thickness. Because of their large size, the dark pebbles of the streak are less likely to be moved due to the more frequent sand moving winds than are the finer particles of the sand sheet. Consequently, the shape of the dark streak will change mainly in response to the shifting of light-colored sand on both sides.

The area surrounding Ras El-Abd, a trachyte hill east of Gebel Uweinat typifies the conditions resulting in light- and dark-colored streaks in the Western Desert of Egypt (Fig. 17.7). North of the dark trachyte mass, the terrain is an eolian peneplain covered by coarse sand with numerous 15 cm and smaller pieces of rock. The wind seems to be less effective just north of the topographic high than on either side of it. Near the sides of the hill the terrain is covered by a coarse lag composed of 20 cm size chunks of sandstone and trachyte. Stringers of sand up to 10 m long occupy low areas between patches of the rocky desert floor. On the lee side of the hill, however, only a dark, trachyte lag exists with no light-colored sand. The lag consists of fragments a few cms in diameter, and appears to have formed soley from erosional products from Ras El-Abd.

COMPARISONS WITH THE MARTIAN SURFACE

The extreme aridity of southwestern Egypt causes it to appear more like the deserts of Mars than any other desert on the Earth. This is suggested not only from an orbital perspective, but also from the nature of the surface materials. Rocks of various sizes cover many parts of this desert with a matrix of very fine grained sands,

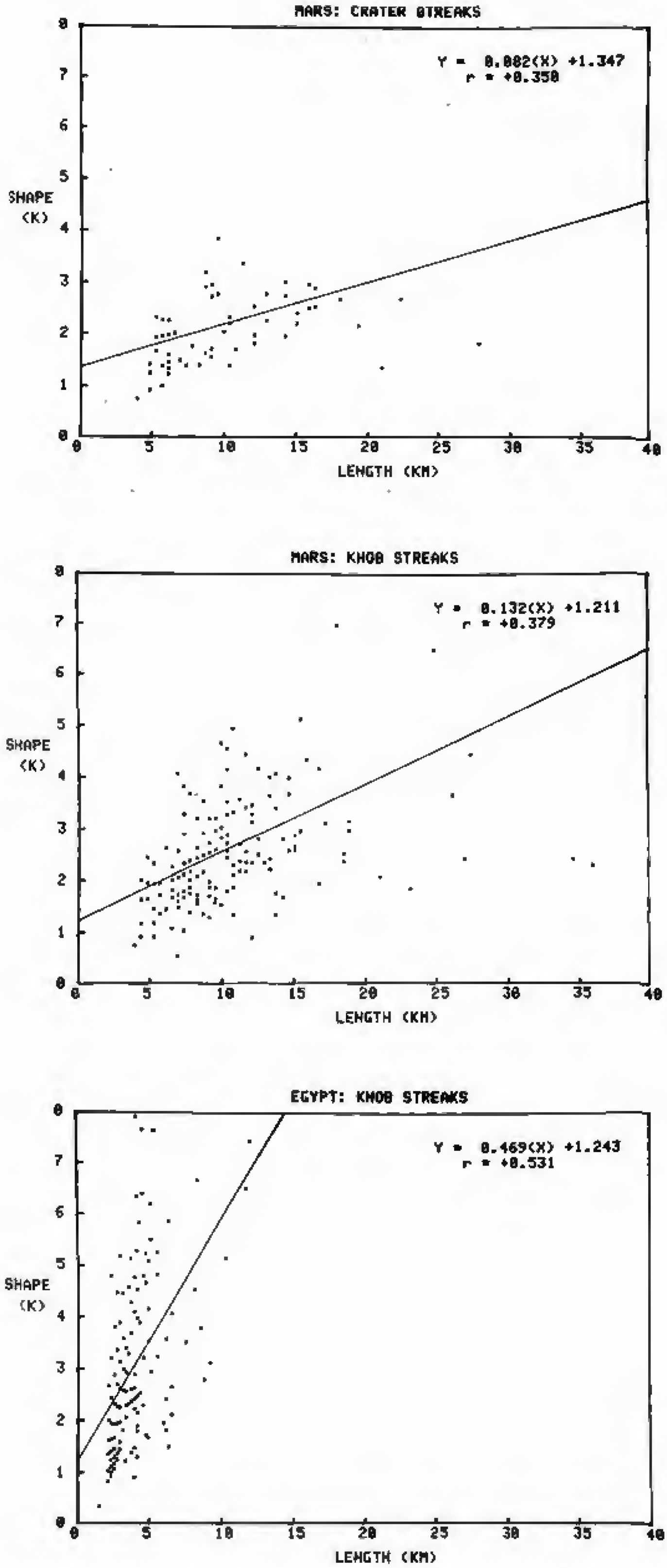

Figure 17.6 Shape factor (K) versus length of wind streaks; knob streaks in Egypt exhibit a greater degree of streamlining than do martian streaks.

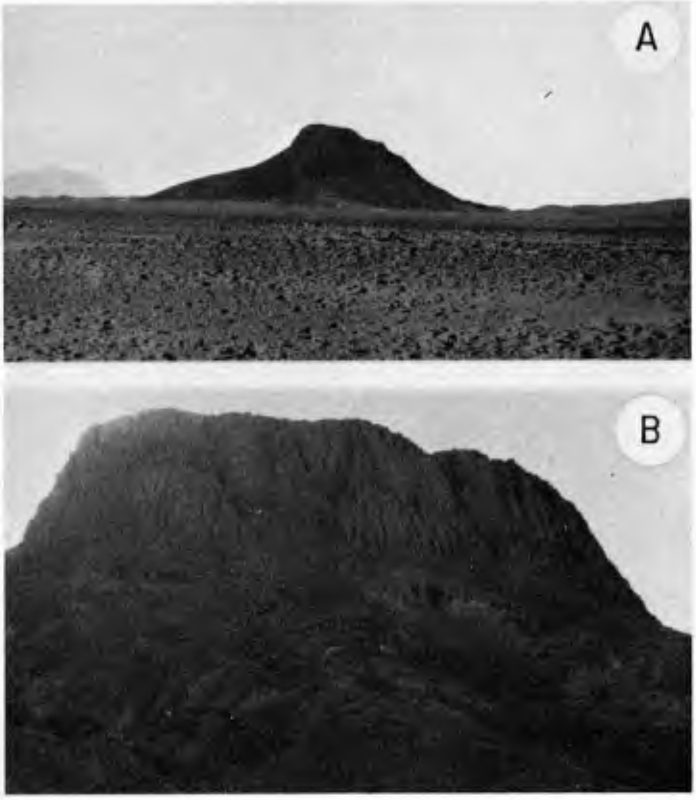

Figure 17.7 A) View of Ras El-Abd, a trachyte mountain east of Uweinat. Rocks in the foreground consist of both trachytes and fragments of the underlying sandstone. Gebel Uweinat is visible to the southwest (left side of picture). B) Close-up of Ras El-Abd, showing exterior talus deposits surrounding the mountain.

not unlike the setting on the surface of Mars as viewed by the Viking landers (Viking Lander Imaging Team, 1978).

Of special significance are the pitted rocks strewn on the surface of the southwestern desert (Fig. 17.8). These pits, usually smaller than 2 cm, occur in rocks of numerous types including sandstones, ferruginous quartzites, and basalts in the Uweinat region, and limestones north of Kharga. The basalts were always pitted on the surface, while dense and finely crystalline on the inside. One large basalt hill in the Gilf Kebir exhibited columnar jointing. All pieces strewn around it were dense inside with no evidence of vesicles, but contained windformed pits, a few mm across on the outer surface. Many of these pits had sand grains trapped within. It is believed that such entrapped grains act as grinders and enlarge the pits with each wind gust.

The similarity between such pitted surfaces and the pitted rocks on Mars was first noted by El-Baz and others (1979a) with additional work reported by McCauley and others (1979a), including results of wind tunnel simulations. These comparisons suggest that the pits on the

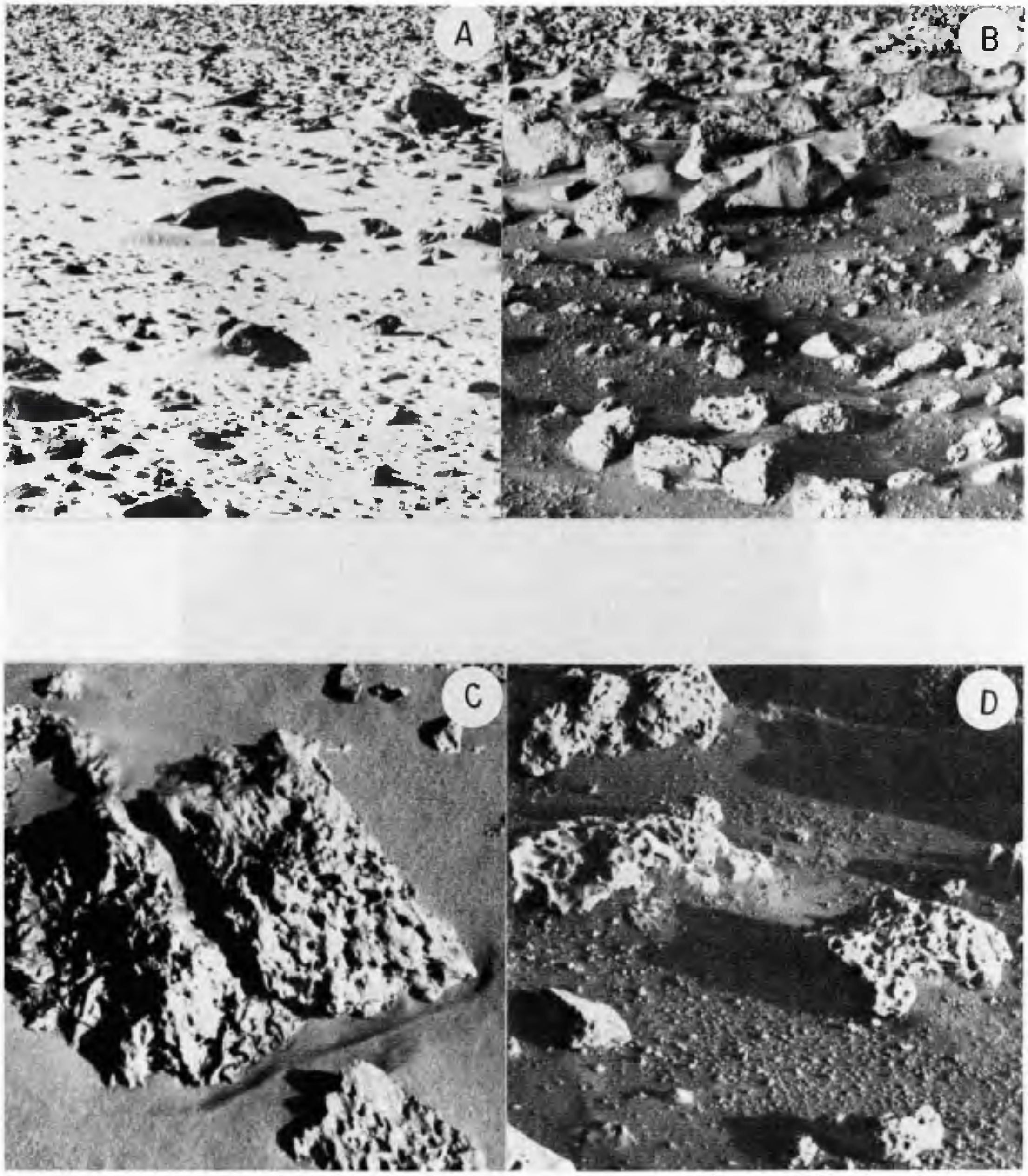

Figure 17.8 A) Windswept surface of faceted rocks and sand drifts near Black Hill. B) The Viking Lander 1 site in Chryse Planitia, Mars. C) Pitted and fluted quartzarenite from the Gilf Kebir. D) Pitted rocks at the Viking Lander 1 site.

martian rocks may have originated, or at least been enlarged by wind action.

In addition, some rocks show a transition between pits and flutes. Rows of elongate pits on the windward facing slopes of the Uweinat Mountain appear to grade into flutes. Some of the rocks in the Viking lander 2 site also show what appears to be flutes (McCauley and others, 1979a). These flutes, like those in the Western Desert of Egypt, may also be windsculpted and are being studied as possible indicators of prolonged wind directions at this site.

SUMMARY

Analogs of martian eolian features in the Western Desert of Egypt range in scale from the large streaks visible in orbital images and photographs, to the millimeter-size pits evident in rocks of various lithologies. Although both martian and Egyptian wind streaks occur at the same scale, the smaller, more distinct wind streaks in the Western Desert are generally narrower and more streamlined than their martian counterparts. Field observations indicate that dark streaks are composed of material derived from the hill or mountain on the upwind end of the streak, and that changes in the shape of the streak may result from the redistribution of the surrounding sand. In addition, pitted and fluted rocks, common in many areas of the Western Desert, provide evidence that rocks at the Viking landing sites may be extensively modified by wind erosion.

ACKNOWLEDGMENTS

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