Eolian streaks in southwestern Egypt and similar features in the Cerberus region of Mars

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Abstract—The Western Desert of Egypt has long served as a basic source for data on desert dunes and the transport of sand in an eolian environment. Similarities between the Western Desert and Mars include evidence of wetter climatic conditions in the past, present-day extreme aridity, and dominance of eolian transport of material. Recently, satellite pictures of the Western Desert revealed streak patterns that seem to be analogous to those on Mars. Wind processes have produced numerous bright and dark-colored streaks in southwestern Egypt that are similar in both scale and morphology to those in the Cerberus region of Mars. Bright streaks in the Western Desert 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 dark rock that form immature desert pavements. The size range of the streaks in southwestern Egypt is consistent with that of streaks in the Cerberus region; in both regions, streaks range from a few kilometers to 40 km in length and from a few kilometers to 20 km in width. The 1:2 ratio of width to length is consistent for streaks on both planets. Detailed study of bright and dark streaks in southwestern Egypt will help us to better interpret the results of eolian transport and deposition on Mars.

INTRODUCTION

The Western Desert of Egypt is a north-dipping plain of sedimentary rocks composed mainly of sandstones in the south and limestones in the north (Said, 1962). It is separated from the topographically higher and more rugged Eastern Desert by the Nile Valley. The generally flat terrain is broken by occasional depressions (Fig. 1), which include oases. The rocky platform is crossed by numerous belts of sand dunes, predominantly of the longitudinal type (El-Baz, 1978a).

Much of the original work on eolian features and the classification of desert dunes was performed in the Western Desert. Early explorers such as Beadnell (1910), Ball (1927) and Bagnold (1933; 1939) mapped the basic distribution of these sand dunes and described their morphology. In addition, the classical treatise on the transport of sand by wind (Bagnold, 1941) was based on observations made in the Western Desert.

Since these pioneering studies, little attention has been given to desert research in general and the Western Desert in particular (El-Baz, 1978a). However, during the past decade scientific interest in deserts has increased because of three de-
Fig. 1. Mosaic of Landsat images of Egypt showing the numerous bright streaks in the Western Desert, particularly southeast of the Great Sand Sea, and the dark spindle-shaped area in the lee of Gebel Uweinat.

velopments: (1) the 1974–1978 drought that devastated the Sahel region of Africa, (2) the photographs obtained by manned and unmanned spacecraft from Earth orbit, which provide a new tool for desert investigations (El-Baz, 1978b), and (3) the evidence from the Mariner 9 and Viking missions, which revealed the presence of dunes and other eolian patterns on the surface of Mars (McCausley, 1973;
Cutts et al., 1976; El-Baz, 1976; Breed, 1977). In this paper, we compare the eolian streaks in the southwestern desert of Egypt to those in the Cerberus region of Mars.

REGIONAL SETTING

The surface of the Western Desert gradually drops 600 m in elevation from the Egyptian/Sudan border northward to the Mediterranean seacoast. It is believed that fluvial processes during the Pleistocene were responsible for the erosion of debris from the Western Desert, and that these erosional products were transported northward by fluvial action in a manner similar to that of the present-day Nile River system. This hypothesis is supported, in part, by the existence of faint drainage lines observed during numerous air flights over the Western Desert. Former fluvial activity west of the Nile River is also supported by archaeological evidence, which indicates that the southern part of the Western Desert experienced wetter climatic conditions in the past (Wendorf et al., 1976; Haynes, 1978).

Starting approximately 6000 years ago, rainfall diminished and an eolian regime dominated over the Western of Egypt (Haynes, 1978), and probably the rest of the Sahara. Since then, the erosion and transportation of debris has been done exclusively by wind, which blows generally from the north. The pattern of dunes supports a clockwise motion of sand-moving winds about a center near Kufra Oasis in southeast Libya (Bagnold, 1933).

Streaks in the Western Desert of Egypt are, without exception, the product of eolian action. These streaks are observed in color photographs obtained by the Gemini, Apollo, Skylab, and Apollo-Soyuz astronauts as well as the multi-spectral images of the Landsat satellites (Fig. 1). As on Mars, the streaks in the Western Desert of Egypt are either bright or dark with respect to the surrounding terrain.

BRIGHT STREAKS

Bright streaks in the Western Desert are composed mainly of sand dunes and dune belts, sand sheets, and lag deposits of light-colored bedrock.

Dune Belts

The Western Desert of Egypt contains an anomalously high amount of sand. Although only one-seventh of the surface of the Sahara is covered by sand (El-Baz, 1978b), of the 681,000 km$^2$ of the Western Desert, nearly one-fourth (159,000 km$^2$) is covered by sand deposits (Gifford et al., 1979). Most of these surficial deposits are concentrated in the Great Sand Sea and smaller fields of longitudinal dunes.

The Great Sand Sea, which is shared by Libya and Egypt, represents the largest accumulation of dune sand in North Africa and occupies the west central
Fig. 2. (a). Enhanced Landsat images showing the numerous bright and dark streaks in the Uweinat area of southwest Egypt. (b). Sketch map of the area shown in Fig. 2a showing the effect of topography and surface roughness on streak orientation.
part of the Western Desert. It begins just south of the Siwa depression and continues uninterrupted to the Gilf Kebir plateau 600 km to the south (Fig. 1). The main sand mass is in the form of enormous whaleback dunes with sharp-crested longitudinal or seif dunes (Bagnold, 1933; El-Baz, 1976). The gently sloping whaleback dunes are relatively static, whereas the longitudinal dunes shift in response to the prevailing wind from the north. Dune belts that form bright streaks in the Uweinat region (Fig. 2a) are southern extensions of the longitudinal dunes of the Great Sand Sea. These dunes have drifted southward over the Gilf Kebir plateau, and form both individual seifs and coalescing dune belts south of the plateau. Field observations have indicated that there is an increase of red color of sand grains as one travels southward (El-Baz, 1978c), similar to the dune reddening with distance downwind observed by Norris (1969) in the Algodones Dunes of southern California.

Longitudinal dunes and dune belts in the Uweinat region curve gently from north to south-southwest, and reach lengths as great as 150 km (Fig. 2a). Individual light-colored longitudinal dunes are commonly less than 1 km wide, although coalescing belts of dunes occur up to 5 km wide. As observed on Landsat images, these dunes are lighter in tone than the surrounding sand sheet, although they are much redder than the sand sheet when viewed on Apollo Earth-orbital photographs.

Sand sheets

The Western Desert contains two major tracts covered by sand sheets. The smaller of the two is just west of the Nile Delta in the northeastern part of the desert (El-Baz, 1978c). The second is a vast area in the center of the southern part of the desert. This area was mapped by Bagnold (1933) who named it the Great Selima Sand Sheet after the Selima Oasis in Sudan. Recent field investigation indicates that parts of the area are covered by granule and pebble lag deposits rather than by sand.

Apart from these two large areas, bright streaks are formed in southwestern Egypt on either side of the lee of knobs. These knob-related streaks show great variability in width, ranging from 100–200 m streaks surrounding small knobs to 30 km streaks surrounding Uweinat and smaller mountains to the west (Table 1).

<table>
<thead>
<tr>
<th>Location</th>
<th>Width of topographic barrier</th>
<th>Streak width</th>
<th>Streak length*</th>
<th>Area</th>
</tr>
</thead>
<tbody>
<tr>
<td>Uweinat</td>
<td>45 km</td>
<td>72 km</td>
<td>166(130) km</td>
<td>7680 km²</td>
</tr>
<tr>
<td>Archenu</td>
<td>18</td>
<td>34</td>
<td>57(26)</td>
<td>1230 km²</td>
</tr>
<tr>
<td>Hager El Garda</td>
<td>3</td>
<td>5</td>
<td>18(16)</td>
<td>50 km²</td>
</tr>
<tr>
<td>Yerguehdha Hill</td>
<td>1.5</td>
<td>2.5</td>
<td>3.5(2.0)</td>
<td>25 km²</td>
</tr>
</tbody>
</table>

* Value in parentheses is length from downwind edge of mountain.
In the Uweinat area, topographic highs cause the orientation of light-colored streaks to deviate from the regional wind pattern (Fig. 2b). In the rough terrain to the east of Uweinat, light streaks form between the knobby exposures of local sandstone bedrock (Fig. 3A). Individual dunes can be distinguished from the wide, light patches of sand by their higher reflectance on orbital images.

Subtle tonal differences within the extensive sand sheets may represent differences in the size, spacing and composition of lag deposits. Typically, these deposits are stratified into 1–2 cm layers of medium to fine sand separated by lag granules (Fig. 4). The lag granules are relatively uniform in size (−1.0 to −2.0 \( \phi; \) 2–4 mm) and are composed of frosted quartz grains in areas where they are not affected by local bedrock. In all cases, lag deposits are less red than the adjacent sand, although they may be lighter or darker than the sand depending on the abundance of local bedrock.

Based on the sorting within the sand-size fraction alone, it is possible to distinguish sand-sheet sand (excluding lag granules) from that of longitudinal dunes and barchans. Both dune types exhibit much better sorting than sand sheet samples (Fig. 5), which are skewed to both fine and coarse grain sizes. This is consistent with the less frequent, high velocity winds needed to move the protective lag surface (Peel et al., 1974) as opposed to the more frequent moderate wind speeds needed to build dunes.

Light-colored streaks in the Cerberus region of Mars occur in the lee of craters and knobs (Fig. 3B). As in southwestern Egypt, the martian streaks in the lee of knobs are aligned oblique to the prevailing wind. Both knob and crater-associated streaks form similar patterns, and the type of topographic barrier is difficult to determine for the smallest streaks visible (approximately 3 km). When these light-colored streaks are closely spaced, the result is an apparent dark streak that emanates from between the topographic obstacle. Although this is the opposite situation from that of the Egyptian streaks, we believe that the similar patterns of streaks on both planets are controlled by movement and deposition of light-colored material.

**DARK STREAKS**

Numerous circular granitic mountains and trachyte hills are present in the southwestern part of Egypt's Western Desert. The largest of the mountains is called Gebel Uweinat (1900 m high), Arabic for small springs, after the many groundwater wells on its southern and western sides. Dark-colored streaks in the Uweinat region occur in the lee of nearly all topographic highs (Fig. 6A), and are

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Fig. 3. (A) Alternating bright and dark streaks in the lee of craters and knobs east of Uweinat in southwest Egypt. Knob pattern transverse to wind direction is controlled by bedrock exposures. Width of Landsat image is 60 km. (B) Bright and dark streaks at the northeast end of the dark patch in the Cerberus region of Mars (12°N, 205°W). Width of Mariner 9 image is 450 km.
Fig. 4. Typical exposure of lag pebbles in the Selima Sand Sheet. Coarse grains are underlain by lighter colored sand. Pencil is 14 cm long.

similar in pattern to crater streaks on Mars (Fig. 6b). Under the prevailing northerly wind, this mountain creates a flow pattern similar to that inferred for martian craters from terrestrial field observations and laboratory experiments (Greeley

Fig. 5. Relation between mean grain size (Mz) and sorting ($\sigma_1$) for sand size fraction of longitudinal dunes, barchans and sand sheet samples from southwest Egypt. Because of high velocity, infrequent winds, the sorting of sand-sheet deposits is much poorer than that of both dune types. Graphic mean and inclusive graphic standard deviation ($\sigma_1$) are defined in Folk (1974).
et al., 1974; Iversen and Greeley, 1978). Field investigations of the northern part of the Uweinat dark streak indicate that it is formed by lag deposits of irregular chips of local rock consisting mostly of sandstone and quartzite. These chips or flakes blanket the ground and are underlain by smaller, usually lighter-colored sand grains.

Dark streaks occur both as individual streamlined forms, and as composite patches that extend downwind from groups of closely-spaced hills. Individual streaks range from several hundred meters to more than 100 km in length (Table 1), and occur where a single hill or mountain protrudes through the surrounding sand sheet. 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 in this region 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.

The importance of local bedrock outcrops as a source of the material for dark streaks in southwestern Egypt is also demonstrated in the lee of Qaret El Maiyet hill (Fig. 7). 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. 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.

**DISCUSSION**

Interpretations of both Mariner 9 (McCauley, 1973; Cutts and Smith, 1973) and Viking 1 and 2 images indicate the presence of a dominant eolian regime on Mars (Ward, 1978). Local and planet-wide sandstorms (duststorms?) have produced streaks, dunes and even small drifts seen from the Viking 1 Lander. Orientations of streaks associated with craters have been used to map global wind circulation patterns on Mars (Sagan et al., 1973), and have been successfully modeled in wind-tunnel experiments (Greeley et al., 1974). The high quality Viking Orbiter images allow detailed studies of the martian eolian regime on both a local (Greeley et al., 1977) and regional (Veverka et al., 1977) basis. With the exception of modeling studies, the relation of topography to streak pattern and distribution has not yet been studied in detail.

Calculations of the density of the martian atmosphere based on Mariner 9 data suggest that much higher wind velocities and a smaller mean sediment size would be the most important constraints on the eolian regime of Mars (Arvidson, 1972).
Fig. 7. Ground view of a dark streak in the lee of Qaret El Maiyet granitic hill in southwestern Egypt. The dark surface is composed of angular fragments derived from the hill itself.

It was also suggested that while light streaks are most probably areas of deposition of fine-grained material, the dark streaks may be areas of non-deposition, erosion, or bedrock surfaces (Sagan et al., 1973). These hypotheses have been tested in wind tunnel experiments (Greeley et al., 1974). Although the particle entrainment size and wind speeds may be quite different; the southwestern part of the Western Desert provides sufficient variability of sand supply and wind orientation, and the natural topographic barriers of circular shape that nearly approach the martian cratered environment.

The uplifted rims of impact craters on Mars play a major role in shaping the streak directions, and the turbulence created in the lee of craters is most likely responsible for both light and dark streaks. A horseshoe-shaped vortex of high surface stress in the lee of craters has been presented as one model responsible for the characteristic patterns of erosion and deposition (Greeley et al., 1974).

Fig. 6. (A). Dark streak in the lee of Hager El Garda, a 3 km wide hill in southeastern Libya. (B). Dark streak in the lee of a 25 km crater in the Cerberus region of Mars. Note the more symmetrical pattern of the dark streak as compared to knob streaks.
This model may be tested in southwest Egypt, where volcanic crater clusters occur along the discontinuous scarps.

The size range of the Egyptian streaks is consistent with the size of streaks measured in the Cerberus region of Mars, although the Uweinat streak is a factor of 10 larger than the martian counterparts (Fig. 8). Preliminary study of small knob streaks in this region of Mars indicates that their patterns are similar to the more numerous crater streaks. In addition, analysis of changes in the Cerberus region indicates that the outer boundary of dark material has moved up to 130 km in the 5 years between observations by Mariner 9 and Viking spacecraft. As in the case of the Egyptian dark streaks, such changes are most likely controlled by an influx of light-colored deposits covering the upwind edges of the dark material.

**CONCLUSIONS**

This study of bright and dark streaks in the southwestern desert of Egypt indicates that: (1) the bright streaks are depositional; sand dunes, sand sheets and light-colored lag deposits form most of these streaks; (2) the dark streaks are erosional products of high mountains and hills; they represent virtually sand-free areas; and (3) the morphology of both light and dark streaks is controlled by the flow

![Fig. 8. Comparison of length of width of individual dark streaks near Uweinat in Egypt and in the Cerberus region of Mars. Egyptian streaks exhibit the same range in size as both crater and knob streaks on Mars.](image-url)
of the wind around topographic highs. This appears to be the case in both the southwestern desert of Egypt and the Cerberus region of Mars.

We conclude that detailed study of the bright and dark streaks in the southwestern desert of Egypt will result in our understanding of: (1) the relationship of brightness levels in LANDSAT images of the Western Desert and in other arid environments; (2) the causes of differences in color of desert surfaces including the relationship of oxidation to sand reddening and desert varnish development; (3) the relationship between wind regimes and local topography; and (4) the origin and temporal variations of streak patterns on the surface of Mars.

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REFERENCES


