Chapter 13

COATINGS ON SAND GRAINS FROM SOUTHWESTERN EGYPT

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ABSTRACT

Sand samples from the Gilf Kebir plateau region in southwestern Egypt were analyzed to study the coatings on quartz grains. Although some iron oxide (hematite) is present, kaolinite forms much of the coatings, making them chemically similar to classical "desert varnish". The coatings have pitted surfaces, with grooves and cracks that probably originate from eolian abrasion. Under high magnification (using a scanning electron microscope, SEM) the coatings show distinct platelet morphology, with books or layers of smaller platelets on top of larger ones. In addition to the Al- and Fe-rich material, some gypsum and halite were detected. The reflectance properties of sand deposits as depicted in Landsat images and space photographs are believed to be affected by the coatings on the quartz grains. Assuming that the red colored sands of southwestern Egypt are analogous to the reddish brown particles on the surface of Mars, their reflectance properties should be studied for correlation.

INTRODUCTION

Sands from the Western Desert of Egypt vary considerably in composition. Microscopic studies of samples from various parts of the desert have revealed that they are composed of at least 40% quartz, and varying amounts of calcareous grains (including chalk, limestone, dolomite, marl, and calcite), heavy minerals (including glauconite, phosphates, hornblende), shale, and gypsum (El-Baz and others, 1979b). Although these different minerals cause variations in the overall sand color, it is nonetheless believed that the color of the quartz grains themselves can be an indication of the time of exposure and distance from the sand source. This is based on the proposition that the red color of quartz sand is caused by the presence of hematite coatings on individual grains.

Reddened sands have been observed in deserts throughout the world. However, their mode of formation is a matter of controversy.

According to one hypothesis, the hematite is detrital having been formed in lateritic soils of hot, humid climates and later transported to desert basins (Van Houten, 1973). The second hypothesis contends that the hematite coating is post-depositional and results from weathering of iron-bearing minerals (Walker, 1967; 1979; Glennie, 1970).

Although the origin of the red color is controversial, the fact that the red color increases with the distance from the sand source has been established in many locations. Examples include the study of Skylab 4 photographs of the Namib Desert of Southwest Africa (McKee and others, 1977), the Apollo-Soyuz photographs of the Sturt (El-Baz, 1978a), and Simpson Deserts of Australia (Breed and Breed, 1979), and of the Western Desert of Egypt (El-Baz and El-Etr, 1979).

In addition, in the Algodones dunefield, the intensity of sand color increases from north to south; 25 to 60 percent of the grains are hematite-coated, with maximum values (60%) occurring in the south (Norris and Norris, 1961, p. 611). Because the sand transport direction in this field is to the southeast (Sharp, 1979, p. 908), the redder sands are farther from their source and have been exposed for a longer period of time.

Because of the importance of sand color variations, samples from the Western Desert of Egypt are being studied to investigate the nature of coatings on sand grains. Initially, samples from the southwestern part of the desert were selected because they fall near the end of the sand transport cycle in Egypt, which is generally from north to south (Gifford and others, 1979). This region showed increased reddening in Earth-orbital photographs and thus, the sand grains were presumed to show thicker coatings.

SAMPLE LOCATION

The sample discussed in this chapter was collected by T. A. Maxwell from the floor of Wadi El-Bakht (Fig. 13.1) during a journey

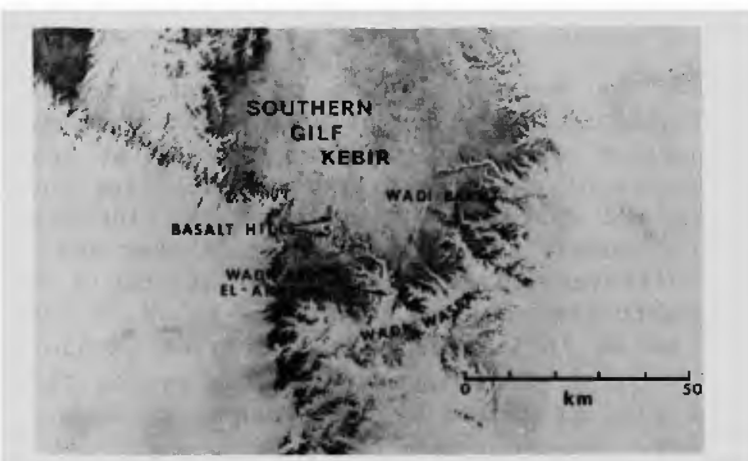

Figure 13.1 Part of the southern Gilf Kebir plateau as photographed by Landsat 1 (from Maxwell, 1980; Landsat Image E-1131-08141).

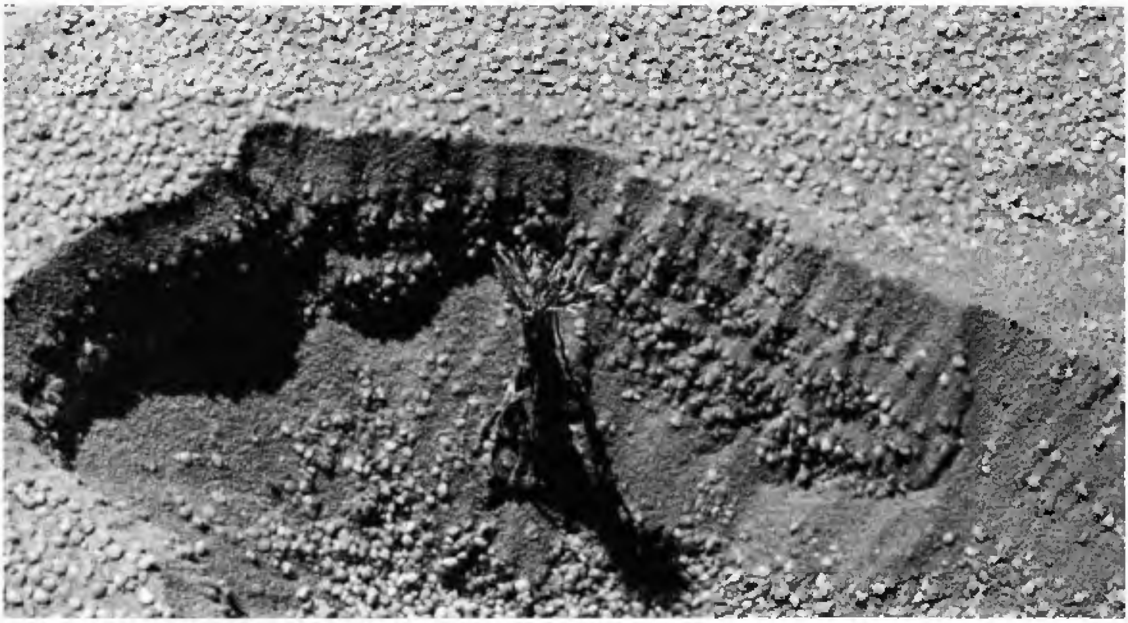

Figure 13.2 Layered coarse sand deposits in the floor of Wadi El-Diq on the eastern edge of the southern Gilf Kebir. Plant is about 12 cm high.

to the southeastern edge of the Gilf Kebir plateau (El-Baz and others, 1980). This plateau lies south of the gigantic dunefield of the Great Sand Sea. Grains from this sand mass travel southward with the prevailing winds, and field observations indicate that some sand climbs up and travels southward on top of the plateau. Thus, accumulations of sand south of the plateau come from either side or from its top. Some small component may result from the erosion of the hardened sandstones and quartzites that cap the plateau.

Numerous wadis incise the Gilf Kebir plateau, particularly along its southeastern margin. The floors of the wadis are flat with a sand cover, which is often coarse and laminated. Trenches in this sand reveal darker layers with a high percentage of heavy minerals intercalated with lighter, finer-grained layers (Fig. 13.2). This suggests that the sand was deposited by winds of varying velocities; the strongest winds deposit the coarser sands with the heavy minerals, and the weaker winds deposit finer, light-colored sands.

Wadi El-Bakht is located in the southeastern corner of the southern Gilf and trends toward the northwest. In the upper reaches of this wadi a thick deposit of mud indicates beds of ancient lakes. Here, "the old lake floor consisted of alternating thin sheets of mud and partly cemented sand with an upper capping of mud some 6 inches thick. Similar reddened and hard sand was found in the meander terraces in the wadi beds; probably iron oxides derived from the sandstones and basalts and washed into these sands during their transport are responsible for the alterations" (Peel, 1939b, p. 306). The Wadi El-Bakht sample was collected from a dune that crosses it (Fig. 13.3). The sand in the dune is well-sorted and contains small amounts

Figure 13.3 Dune partly blocking the upper reaches of Wadi El-Bakht in the southeastern edge of the southern Gilf Kebir (Photograph by N. S. Embabi).

of heavy minerals (Prestel and El-Baz, 1979; Prestel and others, 1980).

EXPERIMENTAL PROCEDURE

The quartz sand grains were initially examined with a binocular microscope to study the main textures and overgrowths. Single, small, heavily-coated grains were examined by X-ray powder diffractometry to characterize the mineralogy of the coatings. Due to the thin nature of the coatings, which occur in amounts below the detection limit (by volume) of the diffractometer, only quartz appeared in the diffraction pattern. Heavily-coated sand grains and those with coatings concentrated in pits or cracks were chosen for X-ray powder diffraction using the Gandolfi camera. The coating was gently scraped from many individual grains in order to collect sufficient material for analysis. The Gandolfi camera geometry allows precession of the sample in the X-ray beam so that crystals in all orientations can be brought into the diffraction condition, thereby enhancing diffraction lines produced by a small number of crystals. Fe K-alpha X-radiation was used to minimize fluorescence from iron in the sample. Concurrently, additional grains were fractured under liquid freon to expose the interior of the grains and a cross section of the coating. The grains were examined by scanning electron microscopy (SEM) at magnifications from 100X to 200,000X. Energy dispersive X-ray analysis (EDXA) was used to qualitatively determine the chemistry of the coating and attached crystals.

MICROSCOPIC CHARACTERISTICS

Examinations using a binocular microscope indicate that the reddish-brown color of the sand grains may be attributed to: 1) an extremely thin coating or stain of reddish-brown material entirely covering the grains except on freshly broken surfaces, 2) small clumps of reddish-brown granules in pits on grain surfaces, 3) a reddish-brown material concentrated within cracks in the grains, and 4) detrital dark brown grains occurring within the sand grains, which were probably present in pore spaces when the parent sandstone was lithified.

Grains having either a relatively thick coating or a high concentration of material in pits or cracks were selected for X-ray diffraction analysis. The material concentrated in cracks was removed for detailed examination. The SEM study of the morphology of the

Table 13.1 X-Ray diffraction data on scrapings of quartz grain coatings.

D Å	Kaolinite HKL	Hematite HKL	Quartz* HKL
7.277	001		
4.261			100
4.146	111		
3.721	021		
3.591	002		
3.349			101
2.696		104	
2.578	130,201		
2.455		110	110
2.282			102
2.235			111
2.123			200
1.980			201
1.817			112
1.693		116	
1.671			202
1.541			211
1.488		214	
1.452		300	113
1.382			212
1.374			203
1.289			104
1.256			302

*+ 10 additional quartz lines.

coatings in depressions corresponds to that on exposed grain surfaces, and associated EDXA chemical analyses supported the assumption that the material concentrated in the cracks was of the same composition as that on the grain surface.

MINERALOGY AND MORPHOLOGY OF THE COATINGS

X-ray diffraction analysis of the scrapings indicates that the coating on the quartz grains is composed of kaolinite (a 7Å clay mineral, indexed after kaolinite) and hematite. Table 13.1 shows the diffraction lines observed for each mineral present. Diffraction lines from kaolinite suggest a well-crystallized material. In contrast, hematite displays diffuse lines, which suggests poor crystallinity and very fine grain size.

A quantitative estimate of the amount of each mineral present cannot be made from these data. However, the greater number of diffraction lines corresponding to kaolinite compared to hematite, combined with the better resolution of the kaolinite lines suggests that kaolinite is either more abundant or better crystallized.

All of the grains examined had an irregular, pitted surface with a ubiquitous coating of fine-grained material. Figures 13.4 through 13.7 illustrate the variety of coating textures and morphologies observed. Figures 13.4a and b show the well-defined contact between the coating and its underlying quartz surface. The coating conforms closely to grain morphology. Although its thickness is roughly 2-5 μm, it has been observed to vary from 0.5 μm to 4.5 μm over the surface of a single grain. The sand grains exhibit a characteristically pitted surface with a rough, irregular, and slightly porous coating (Fig. 13.4c). Ridges protruding on the grains appear to have been smoothed during eolian transport.

At higher magnifications (Fig. 13.4d), the coating reveals a complex morphology consisting of a variety of sub-micrometer size particles and granules. Many of the particles are obviously crystals and frequently are hexagonal platelets (Fig. 13.5a). These platelets occur as randomly-oriented single grains or as books of platelets, with the individual platelets ranging in size from a few hundred angstroms to about 2 micrometers. Individual platelets have a powdery surface, with small platelets occurring on the surfaces of larger plates (Fig. 13.5b). This may indicate that books of platelets are formed as the result of in-situ growth of small platelets on larger, pre-existing ones.

Figures 13.6a and b are views of the coating in a depression in the surface of a grain. A well-defined contact and a lack of preferred orientation of coating particles are clearly shown. Some lineation along the quartz grain contact is indicated. Figure 13.6c shows books of platelets in a somewhat protected region along the contact with the fractured quartz grain surface. We observed incipient growth of coating crystals on a quartz grain surface (Fig. 13.6d), providing additional evidence that in-situ nucleation and growth processes are responsible for coating development. Thus, a mechanical

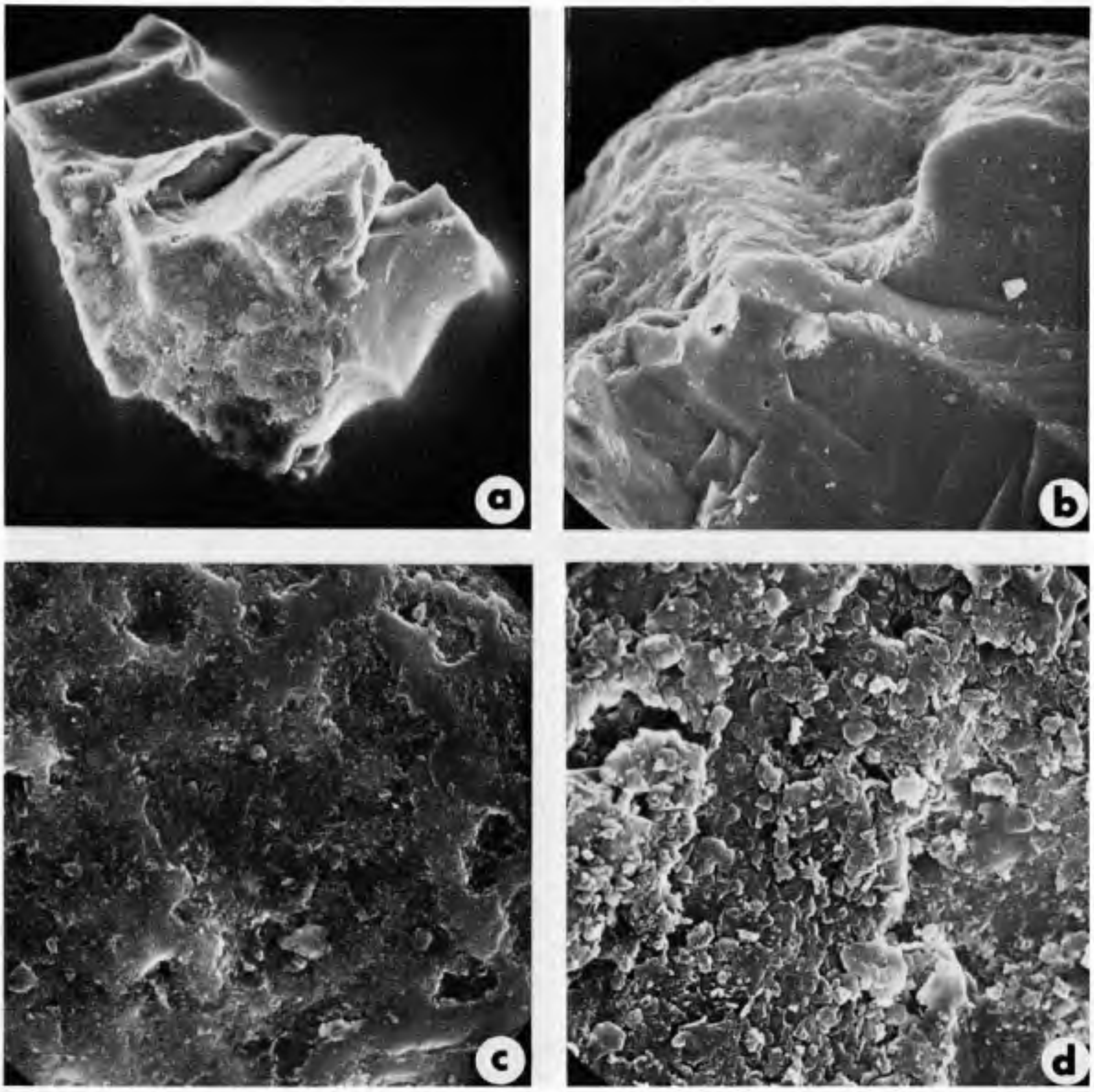

Figure 13.4 (a) A fractured sand grain showing a well-defined contact between the unweathered quartz and its surface coating (300X, width of field 300 μm); (b) An SEM view illustrating how the coating covers the entire grain surface and conforms to its morphology (300X, width of field 300 μm); (c) A sand grain exhibiting the characteristic pitted surface with ridges, probably smoothed during eolian transport (1000X, width of field 90 μm); (d) The same grain under higher magnification (8000X, width of field 11.25 μm) showing the porous nature of the coating and its complex morphology.

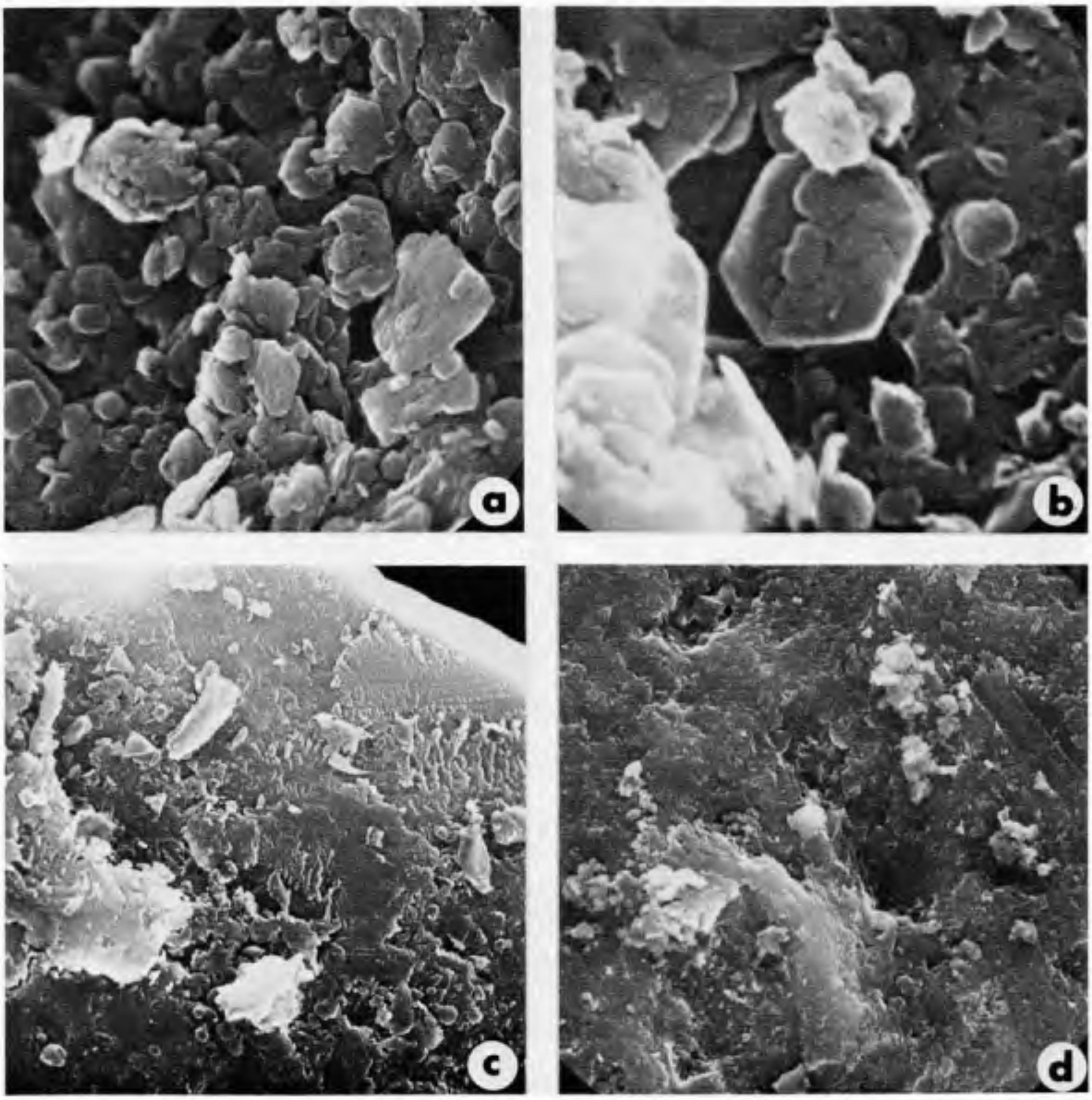

Figure 13.5 (a) Texture and morphology of hexagonal platelets of quartz grain coating (20000X, width of field 4.5 μm); (b) Books of platelets, small ones on top of a larger plate. The dusty appearance is probably due to fine grained hematite (80000X, width of field 1.12 μm); (c) An unusual, cracked coating with grainy rather than porous material. The grooves may be a result of extensive abrasion (6000X, width of field 15 μm); (d) A feathery silica deposit with white gypsum crystals especially in the lower left part of the view (6000X, width of field 15 μm).

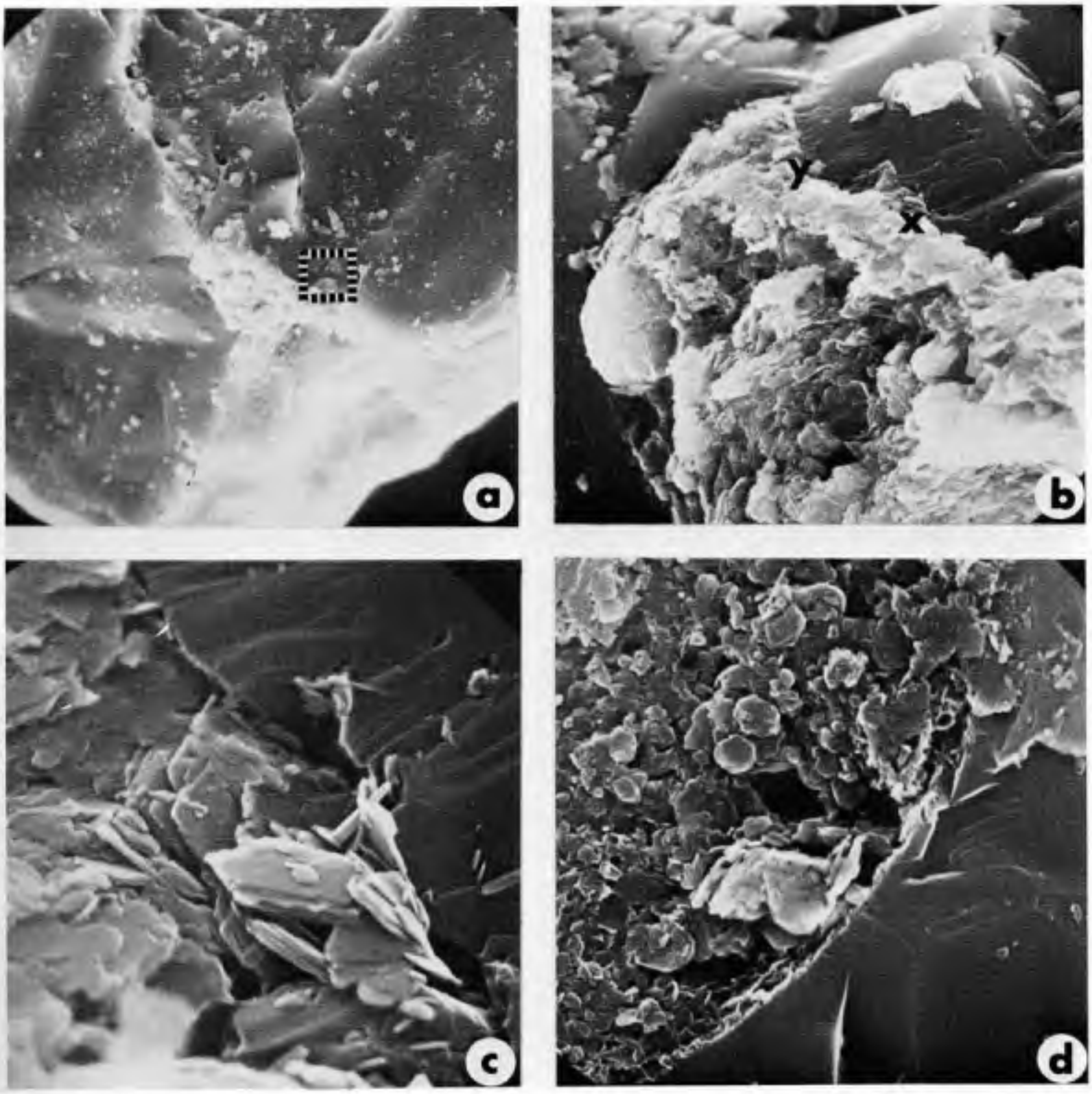

Figure 13.6 (a) A typical coating in a depression in a quartz grain (500X, width of field 180μ m; marked area is shown in Fig. 13.7b); (b) Enlargement of the same coating showing the lack of preferred orientation of particles, although some layering of the coating is visible along the contact with the grain surface (2000X, width of field 45 μ m); (c) Additional enlargement of area X in Figure 13.6b, showing books of platelets on a somewhat protected area of the grain surface (20000X, width of field 4.5 μ m); (d) Another enlargement, of area Y in Figure 13.6b, showing initial growth of coating crystals on the grain surface (10000X, width of field 9 μ m).

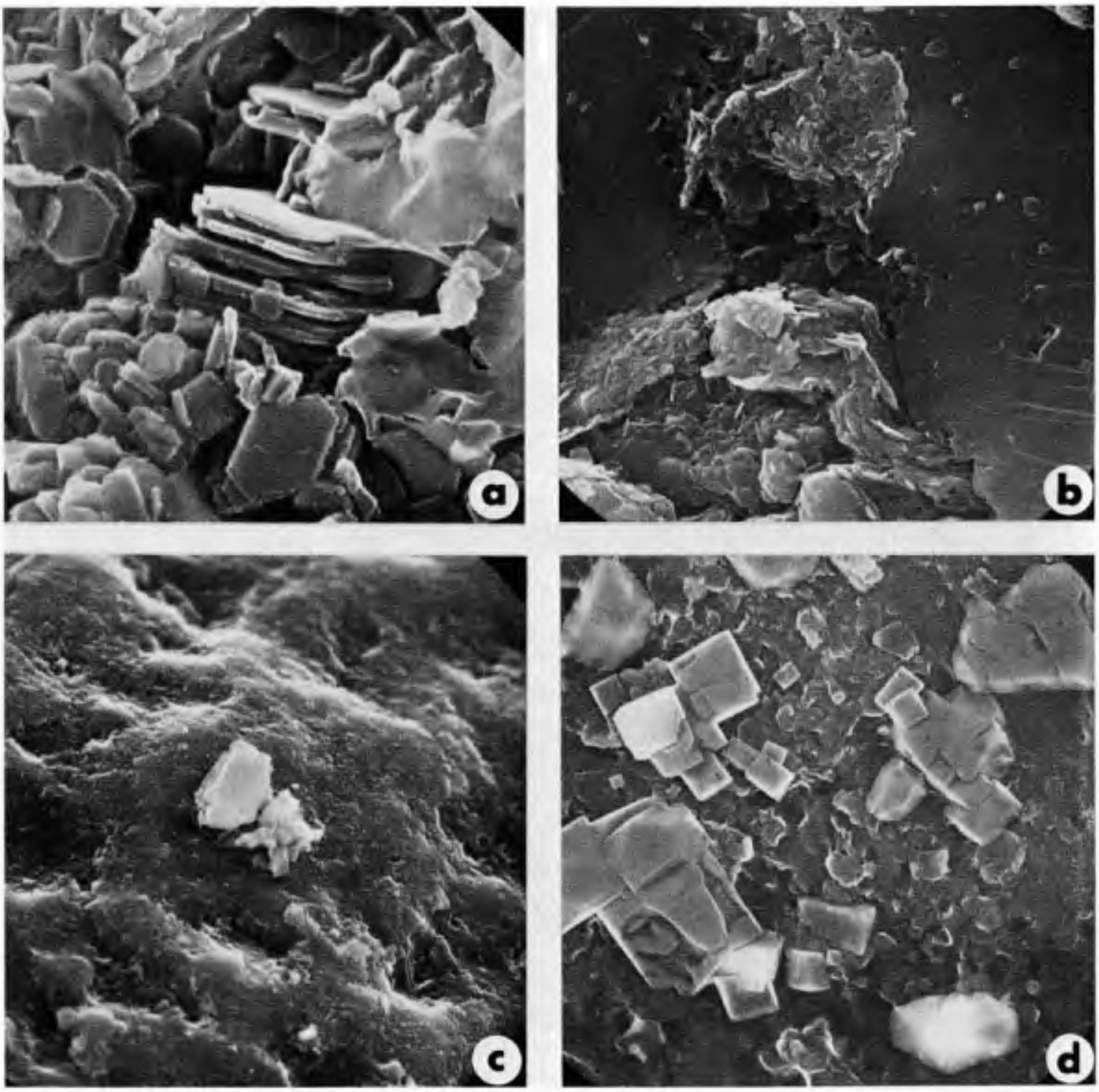

Figure 13.7 (a) Randomly oriented books of hexagonal platelets that appear powdery and delicate (30000X, width of field 3 μm); (b) Examples of twisted platelets and of oriented platelets in a pit shown in Figure 13.6a (8000X, width of field 11.25 μm); (c) Crystals of calcium sulfate (gypsum) attached to a coating on quartz grains (1500X, width of field 60 μm); (d) Growth steps and penetrating crystals of sodium chloride (halite attached to the coating (15000X, width of field 6 μm).

plastering of clay particles on a quartz substrate cannot be a predominant process in coating formation. Figure 13.7a shows the randomly-oriented books of hexagonal platelets frequently observed.

Although the coating probably develops gradually during eolian transport, it shows little evidence of successive layers of deposition over most of the surface area of the grain. The lack of successive layering most likely precludes episodic growth periods with intervening erosion and is consistent with gradual, continuous growth. No systematic changes in morphology (crystal size or orientation), mineralogy or chemistry were observed in the coatings. However, in a few pitted regions, some preferred orientation of platelets in response to grain morphology was seen (Fig. 13.7b). Twisted platelets and oriented (flat-lying) platelets occur within pits and in areas surrounding pits.

Additional features of interest were secondary crystals and abrasion features on the coatings. Secondary crystals of gypsum (Fig. 13.7c and 13.8) and halite (Fig. 13.7d and 13.9) were observed attached to the coatings and were identified by EDXA. A silica deposit with superposed gypsum crystals (Fig. 13.5d) was also recognized. The crystals are believed to have grown in situ, since they exhibit growth steps on crystal faces and penetrating crystal forms. These deposits indicate that processes involving a fluid phase were encountered after the underlying coating was formed. Recognized abrasion features include extensive grooving, cracking, degrading of the coating to a grainy texture, and polishing of protruding ridges on the grains (some of these features are visible in Figure 13.5c).

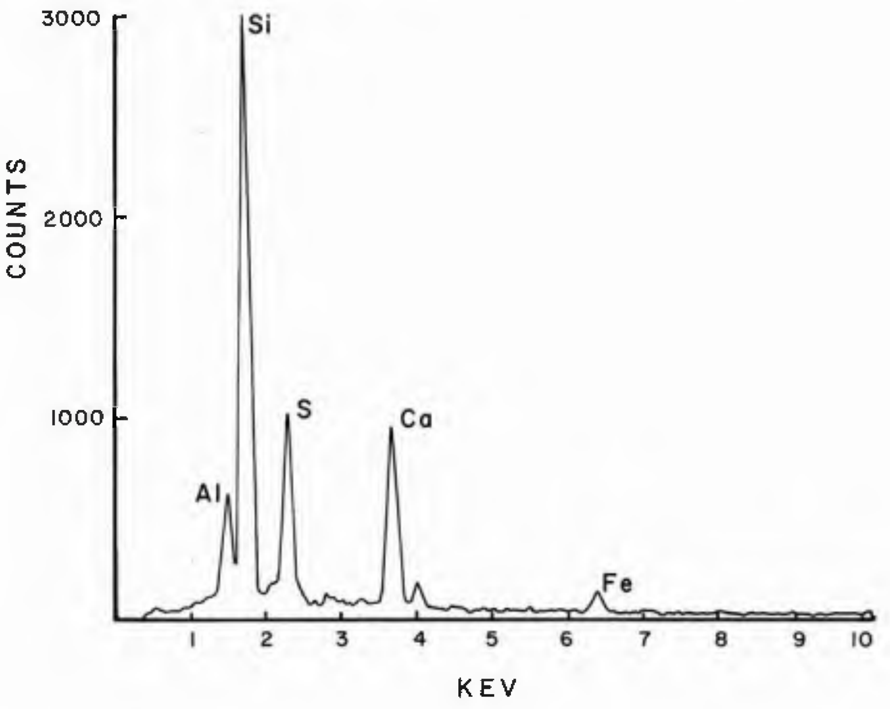

Figure 13.8 X-ray spectrum of calcium sulfate (gypsum) crystal attached to the coating.

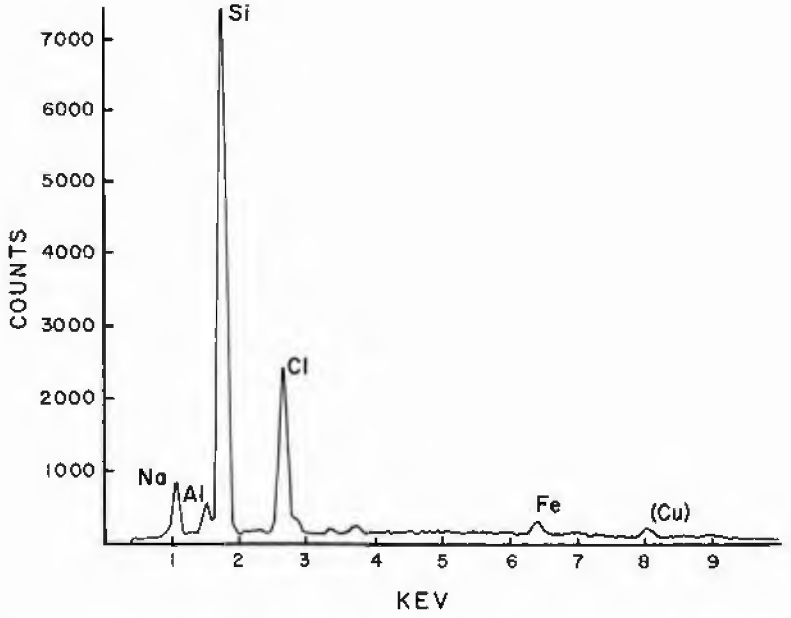

Figure 13.9 X-ray spectrum of sodium chloride (halite) crystals attached to the coating, using a Cu sample holder.

The hexagonal platelet nature of the coating agrees well with the presence of kaolinite and hematite, since both minerals are known to have a hexagonal, platy habit. Chemical analyses by EDXA indicate that the coating is much richer in Al than Fe (Fig. 13.10). This suggests that the coating is composed predominantly of a clay material with very finely disseminated hematite. The two minerals are probably growing either simultaneously or successively, since all attempts to separate them with SEM-EDXA have failed.

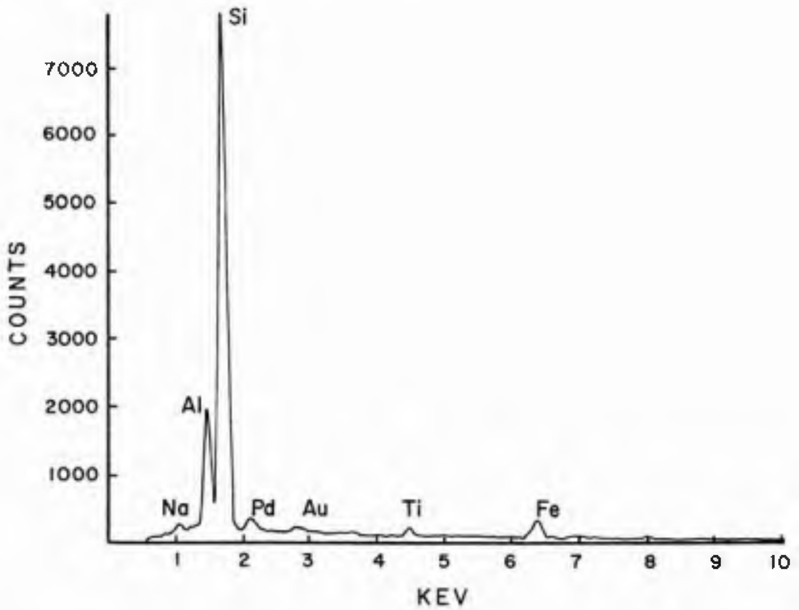

Figure 13.10 X-ray spectrum of overall coating on quartz sand grains.

DISCUSSION

From observations of fine drainage lines leading northward towards the Mediterranean and eastwards towards the Nile Valley, it is postulated that the sands of the Western Desert originated from the "Nubian" and from other sandstones exposed in the southern part of the desert. The sand was most likely transported to the northern part via the Nile and subsidiary drainage wadis, particularly during wetter climatic conditions in the past. After the climate became drier and an eolian regime dominated, the sands were driven southward by the action of wind. Most of the physical characteristics and chemical coatings were probably acquired in this eolian regime in an extremely arid environment.

The presence of large amounts of sand-sized grains not originally from the Nubian Sandstones is related to the nature of local rocks, particularly in the Western Desert depressions that enclose oases. Preliminary study of the sands from the northern and central parts of the desert supports this hypothesis. Sand samples from the various oases show varying compositions of sand-sized grains, with certain unique components such as phosphate, glauconite, shale, and carbonate (El-Baz and others, 1979b).

The detailed analyses of sand samples from the Gilf Kebir area in the southwestern part of the desert produced one major unexpected result. Although hematite is present in coatings of the quartz grains, there is a considerable amount of kaolinite. The presence of clays in the quartz sand coatings makes these coatings more like "desert varnish". (Recent studies of desert-varnished rocks indicate that clays constitute a significant component of the varnish; (Potter and Rossman, 1977, 1979.) The coatings in quartz grains in southwestern Egypt show complex morphology and mineralogy. Although kaolinite and hematite comprise the major part of the coatings, gypsum and halite do occur in minor amounts.

We are presently analyzing samples from other parts of the Western Desert. The purpose of these investigations is to study the quartz sand grain coating to determine its mineral components, and whether local components affect the composition of the coating. Additionally, samples from different localities will be studied to determine whether the observed geographic variations in desert color are due to varying thickness and mineralogy of the coatings on individual sand grains. These studies should allow us to further ascertain how the coatings develop and if they vary in different environmental conditions.

Also, the effects of these coatings on the reflectance properties of the sand accumulations will be studied. The chemistry and thickness of the coatings were assumed to affect the reflectance of the desert surfaces as measured by remote sensing (e.g., by the Landsat multispectral sensors). Attempts will be made to relate a measure of reflectance in the Landsat data to the nature of coatings on sand grains. In addition, there are possible correlations between the reddish brown sands of the extremely dry Western Desert and the yellowish brown grains on the surface of Mars. Results of the Viking mission to Mars indicate that the color of the surface is consistent with an abundance of Fe+3-rich weathering products, notably nontronite (Huck and others, 1977, p. 4401). Thus, the study of the kaolinite/ hematite coated grains of the Western Desert of Egypt may provide an analog to the oxidized regolith on Mars.

REFERENCES

Breed, C. S. and Breed, W. J., 1979, Dunes and other wind forms of central Australia (and comparisons with linear dunes on the Moenkopi plateau, Arizona): in El-Baz, F. and Warner, D. M., eds., Apollo-Soyuz Test Project Summary Science Report, Volume II: Earth Observations and Photography: NASA SP-412, Wash. D. C., p. 319-358.

El-Baz, F., 1978a, The meaning of desert color in Earth orbital photographs: Photogramm. Eng. and Remote Sens., v. 44, p. 69-75.

El-Baz, F., Boulos, L., Breed, C., Dardir, A., Dowidar, H., El-Etr, H., Embabi, M., Grolier, M., Haynes, V., Ibrahim, M., Issawi, B., Maxwell, T., McCauley, J., McHugh, W., Moustafa, M., and Yousif, M., 1980, Journey to the Gilf Kebir and Uweinat, Southwest Egypt, 1978: Geogr. Jour., v. 146, p. 51-93.

El-Baz, F. and El-Etr, H. A., 1979, Color zoning in the Western Desert of Egypt: in El-Baz, F. and Warner, D. M., eds., Apollo-Soyuz Test Project Summary Science Report, Volume II: Earth Observations and Photography: NASA SP-412, Wash. D. C., p. 203-217.

El-Baz, F., Sleazak, M. H., and Maxwell, T. A., 1979b, Preliminary analysis of color variations of sand deposits in the Western Desert of Egypt: in El-Baz, F. and Warner, D. M., eds., Apollo-Soyuz Test Project Summary Science Report, Volume II: Earth Observations and Photography: NASA SP-412, Wash. D. C., p. 237-262.

Glennie, K. W., 1970, Desert Sedimentary Environments: Amsterdam, Elsevier, 222 p.

Gifford, A. W., Warner, D, M., and El-Baz, F., 1979, Orbital observations of sand distribution in the Western Desert of Egypt: in El-Baz, F. and Warner, D. M., eds., Apollo-Soyuz Test Project Summary Science Report, Volume II: Earth Observations and Photography: NASA SP-412, Wash. D. C., p. 219-236.

Huck, F. O., Jobson, D. J., Park, Wall, S. K., Arvidson, R. E., Patterson, W. R., and Benton, F. D., 1977, Sectrophotometric and color estimates of the Viking lander sites: Jour. Geophys. Res., v. 82, p. 4401-4411.

McKee, E. D., Breed, C. S., and Fryberger, S. G., 1977, Desert sand seas: in Skylab Explores the Earth: NASA SP-380, Wash. D. C., p. 5-47.

Peel, R. F., 1939b, The Gilf Kebir: Part 4 in Bagnold, R. A. and stern others, An Expedition to the Gilf Kebir and Uweinat, 1938: Geogr. Jour., v. 93, p. 295-307.

Potter, R. M. and Rossman, J. R., 1977, Desert varnish: The importance of clay minerals: Science, v. 196, p. 1446-1448.

Prestel, D. J. and El-Baz, F., 1979, Microscopic characteristics of quartz sand from the arid environment of the Gilf Kebir, southwest Egypt (abstract): in Reports of Planetary Geology Program, 1978-1979, NASA Tech. Memorandum 80339, Wash. D. C., p. 293-295.

Prestel, D. J., Wainwright, J. E., and El-Baz, F., 1980, Studies of coatings on sand grains from the Gilf Kebir, southwest Egypt (abstract): Reports of Planetary Geology Program, 1979-1980, NASA Tech. Memorandum 81776, Wash. D. C., p. 43-45.

Sharp, R. P., 1979, Interdune flats of the Algodones chain, Imperial Valley, California: Geol. Soc. Amer. Bull., Part I, v. 90, p. 908-916.

Van Houten, F. B., 1973, Origin of red beds: A review: Ann. Rev. Earth and Planet. Sci., v. 1, p. 39-61.

Walker, T. R., 1967, Formation of red beds in modern and ancient deserts: Geol. Soc. Amer. Bull., v. 78, p. 353-368.

———, 1979, Red color in dune sand: in McKee, E. D., ed., A study of global sand seas, U. S. Geol. Survey Prof. Paper 1052, p. 61-81.