Color Zoning in the Western Desert of Egypt

Farouk El-Baz and Hassan A. El-Ein

ABSTRACT

The Western Desert of Egypt was selected for detailed study as a type locality of the north African desert environment. In addition to astronaut observations, 55 color photographs of Egypt were obtained during the Apollo-Soyuz mission using 70- and 35-mm cameras. These photographs showed regional and local color zones that were mapped and checked in the field.

On the regional scale, a stereostrip of 15 photographs shows the following color zones from southwest to northeast: (1) a rosy-peach zone of sandstone plains (zone A), (2) a grayish-brown or taupe zone of sandstone tablelands (zone B), (3) a dusty-peach or dark-yellow zone of sand in the Great Sand Sea (zone C), and (4) a yellowish-mauve to dark-gold zone of gravel plains west of the Nile Delta (zone D).

In one photograph west of the Nile Delta, distinct color zones have been correlated in the field with (1) desert pavement with relatively inactive sand that is mixed with dark, desert-varnished gravel; (2) yellow, relatively active sand with or without sparse vegetation, and with increased reddening toward the north; and (3) dark, arable soil with a mottled appearance that is composed of quartz sand, clay, and calcium carbonate particles. The photograph also shows yellow, active longitudinal sand dunes within the first zone.

The Apollo-Soyuz color data were used in the selection of areas for field investigations and in the extrapolation of knowledge to unphotographed areas of the Western Desert. One of the results, the mapping of an arable zone west of the Nile Delta, attests to the potential value of color photographs in desert study.

INTRODUCTION

One of the objectives of the Earth Observations and Photography Experiment on the Apollo-Soyuz Test Project (ASTP) was to study the desert environment (ref. 1). During the project, observations were made and photographs were obtained of eight major desert regions (ref. 2). The Western Desert of Egypt was selected for detailed study as a type locality of the north African deserts. Reasons for this selection are, first, the fact that this desert is comparatively well studied and, second, the accessibility of parts of it for field investigations by local members of the experiment team.

The Western Desert occupies 681,000 km² (262,930 mi²; approximately the size of the State of Texas), or more than two-thirds the area of Egypt. It is basically a bedrock platform cluttered by sand fields that contain several varieties of sand dunes. The generally flat terrain is broken by several large enclosed or partly enclosed depressions and by the salient basement highs of the Oweinat region at the Egyptian-Libyan-Sudanese border (refs. 3 to 5).

Geological mapping of the study region has been accomplished by the Geological Survey of Egypt at scales of 1:1,000,000 in 1928 (ref. 6) and 1:2,000,000 in 1971 (ref. 7). For the more recent map, Gemini photographs provided data on the southwestern part of the Western Desert. Landsat images of the northern Western Desert have also

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*a National Air and Space Museum, Smithsonian Institution.

*b Ain Shams University, Cairo, Egypt.

†Principal Investigator.
been used in the construction of geological, structural, and drainage maps at 1:1,000,000 scale (ref. 8). A few larger scale maps and reports of parts of the Western Desert are available; for example, Khârga and Dakhla Oases (e.g., refs. 9 and 10), Bahârîya (ref. 11), Siwa (ref. 12), and the Oweinat region and the southern Western Desert (refs. 5, 13, and 14). The geologic setting of the area west of the Nile Delta has been described in some detail by Shata and El-Fayoumy (ref. 15). This area, whose color zones are discussed in this report, has received much attention in the past two decades because of its land reclamation potential.

The ASTP photographs of the Western Desert were obtained from an altitude of approximately 220 km (136 mi.) with a 35-mm Nikon camera and two 70-mm Hasselblad cameras. One of the Hasselblad cameras was bracket-mounted and was equipped with an intervalometer and a reseau plate to provide stereo, mapping-quality photographs. The second camera had a single-lens reflex mechanism for handheld photography. Photographs with the bracket-mounted camera were taken with a color-sensitive film (SO-242) that was specifically selected for desert photography (ref. 1). Figure 1 illustrates the ground coverage for these photographs.

Deserts portray a variety of colors described by astronauts in orbit. With the knowledge that the color films used by the ASTP astronauts could not faithfully reproduce these natural colors, a wheel of Munsell color chips was used to quantify the observed colors (refs. 1 and 2). Details of the astronaut observations of desert terrain have been previously discussed (ref. 2). Also, the color wheel and its use are discussed in a separate section in this volume.

**ORIGIN OF DESERT COLOR**

Desert color is an indication of the composition of the outer surfaces of exposed rock and rock rubble. In addition to bright-yellow colors, the most widespread color in desert environments is red. Field investigations have shown that red color in desert sands is caused by the presence of hematite (iron oxide) coatings on individual grains. Reddened sands have been observed in deserts throughout the world, but their mode of formation is a matter of controversy (refs. 16 and 17).

There are two major hypotheses concerning the origin of the red color caused by hematite in desert sands. According to one hypothesis, the hematite is detrital, having been formed in lateritic soils of hot, humid climates and later transported to desert basins. Advocates of the second hypothesis contend that the hematite coating is postdepositional and results from the weathering of iron-bearing minerals.

Many reviews of this problem have been published (e.g., refs. 18 to 21). Although the origin of the red color is controversial, the fact that the red color increases with the flow of time has been established in many localities. For example, in the Algodones dunes, the intensity of sand color increases from north to south; 25 to 60 percent of the grains are hematite-coated, with maximum values occurring in the south (ref. 20, p. 611). Because the more southerly dunes are older, the degree of reddening may be used to determine the relative age of the sands.
Earth-orbital photographs have been used in the past to confirm field observations of desert color; for example, in the Namib Desert of South-West Africa. Here, the linear dunes have migrated from west to east along the coast of Namibia. As described by Logan (ref. 22), the sands farthest inland are much redder in color and are of greater age. Skylab 4 photographs of the same region show color zones in the dune sand. In these photographs, younger sands near the coast appear brighter than the redder zones farther inland (ref. 23). In addition, ASTP photographs of southern Australia were used to illustrate dune reddening as a function of increasing distance from the source. Photographs of the Lake Blanche area in the Sturt Desert and of the Lake Eyre region in the southern Simpson Desert show an increase in red color as the distance from the sand source increases (ref. 21).

COLOR ZONES IN ASTP PHOTOGRAPhS

Regional Color Zones

A strip of 15 ASTP stereophotographs of the Western Desert of Egypt (fig. 1) shows several color zones. Most of these zones have been correlated with known geological formations. Because successive photographs overlap by 60 percent, they can be used to study superposition relationships between these formations.

Figure 2 illustrates the four major color zones in the Western Desert as they are portrayed in ASTP photographs. Starting from the south end, these color zones are discussed in the following paragraphs.

Rosy-Peach Zone

The rosy-peach zone (zone A, Munsell 10R 7/1) occupies the southwestern part of the Western Desert in which a sandstone succession ranging in age from Paleozoic to Upper Cretaceous is exposed. The upper part of the sequence is commonly referred to as the Nubian (or Nubia) Sandstone. However, Issawi (ref. 14) prefers to designate this formation as the “Gilf Sandstone.”

The exposed sandstones in this region generally show variations in color, texture, and hardness. In the field (ref. 3), the color of the sandstone ranges from white to yellow to brownish red. Grain size commonly ranges from medium to coarse, and some horizons are conglomeratic. The rosy-peach color in the photographs represents sandstones that are poorly cemented. Such sandstones weather easily and their relief becomes fairly subdued; thus, they form low-lying isolated hillocks separated by broad sandy plains. These disintegrating sandstones are believed to be the main source of sands that feed the huge sand dunes of the Great Sand Sea to the north of this region.

Grayish-Brown or Taupe Zone

Prominences that lie northwest of the Gilf Kebir Plateau display brownish or taupe colors (zone B, Munsell 10R 4/1). They characterize Paleozoic sandstone rocks similar to those exposed to the southwest, but they are much more indurated because of cementation by silica and/or iron oxides; high concentrations of iron oxide are common. In this zone, the sandstones are more weather-resistant and form distinct, elevated tablelands and cuestas. Desert-varnished chert gravel is also present in the general vicinity, and it contributes to the dark tone of the zone.

Dusty-Peach or Dark-Yellow Zone

The dusty-peach or dark-yellow color zone (zone C, Munsell 7.5YR 7/4) coincides with part of the Great Sand Sea. This mass of sand comprises an area of 111,370 km² (43,000 mi²), or 340 times the area of the Algodones dunes of southeastern California. The ASTP photographs clearly show the difference in color between the linear or seif dunes of the Great Sand Sea and the redder and older sandstone rocks (fig. 3). Although there is a slight brightening of the sand color northward, this sand mass is essentially the same dusty-peach or dark-yellow color throughout the area.
FIGURE 2.—Mosaic of 15 ASTP stereo photographs, taken using the bracket-mounted camera, of the Western Desert of Egypt. The lettered color zones are described in the text (AST-16-1245 through AST-16-1259).
Yellowish-Mauve to Dark-Gold Zone

The yellowish-mauve to dark-gold color zone (zone D, Munsell 10R 6/4 to 10YR 7/4) encompasses a very broad area from the Bahariya Depression to the area west of the Nile Delta. The exposed rocks are basically limestones with some purplish units that account for the mauve tint, particularly near the Bahariya Depression (ref. 11). Toward the northeast, the dark-gold color predominates.

Within this zone, the ASTP photographs depict numerous bright yellow-gold streaks. These streaks represent parallel belts of longitudinal sand dunes of a relatively young age. The young age of these dunes is supported by field observations of their migration patterns. Farther to the north, a color band that is nearest to the coast of the Mediterranean Sea is divided into a pink-yellow zone and a wedge-shaped area of mottled appearance. These local color zones are discussed in detail in the following section.

Color Zones West of the Nile Delta

The area of the Western Desert adjacent to the Nile Delta was selected for detailed study because a single ASTP photograph of this area depicts three distinct zones (figs. 4(a) and 4(b)). In addition, this region has received considerable attention recently because of its potential for development of arable land; wide tracts of it are now under reclamation using available surface water and ground water (ref. 15).

This region displays numerous examples of landforms typical of desert conditions. According to Shata and El-Fayoumy (ref. 15, p. 1), these conditions are characterized by the severe degradation of the surface (of both soil and plants), by the accumulation of dune sand deposits, by the presence of relict drainage features, and by the eventual domination of saline deposits and crust formation. The same authors also mention that these old drainage channelways are indicative of wetter climatic conditions in the past. The evidence for more humid conditions also includes extensive gravel plains with fossil wood and bone remains.

In considering these factors, and on the basis of its geological characteristics, this area was divided by Shata and El-Fayoumy (ref. 15) into five physiographic provinces. Boundaries of these provinces, however, do not correspond to the color zones in the ASTP photograph. Furthermore, the boundaries of these zones do not exactly match the boundaries of geological formations.
FIGURE 4.—Space photograph and sketch map of the Western Desert. (a) Three color zones in the area of the Western Desert of Egypt just west of the Nile Delta: (1) dark earthy-gold desert pavement with lighter colored patches and bright yellow-gold longitudinal dunes; (2) a pinkish-yellow zone representative of a sand sheet, with a red tint that increases toward the north; and (3) a dusty pinkish-gray, mottled area closer to the Mediterranean coast, with large ridges that parallel the seacoast (AST-16-1256).
(b) Sketch map of the area of the ASTP photograph in figure 4(a). Thick solid line indicates route of field investigation from Cairo to Alexandria and then west along the Mediterranean coast. Letters along the Cairo-Alexandria desert road show the location of surface photographs taken by the first author and illustrated as follows: "a" figure 5, "b" figure 6, "c" figure 7, "d" figure 8, and "e" figure 9.
(ref. 3), even those that are based on the interpretation of Landsat images (ref. 8). Accordingly, the boundaries of these provinces evidently need to be revised using the ASTP photographs.

To ascertain the cause of color change in these zones, the authors studied the terrain by traveling from Cairo in a northerly direction to Alexandria via a desert road that traversed all the color zones (fig. 4(b)). This paved road from Cairo to Alexandria is 211 km long. Frequent stops were made (every 5 to 10 km) to study the terrain adjacent to the road. The fieldwork confirmed the existence of three major zones that are essentially parallel and trend approximately in an east-west direction (fig. 4(a)). In each of the three zones, two distinct colors on the photograph were correlated with compositions of exposed sand and soil as discussed in the following paragraphs.

Southernmost Zone

The first zone encountered in the field was that located in the southwestern half of ASTP photograph AST-16-1256 (fig. 4(a), zone 1), which represents an area of more than 8000 km² (3100 mi²). This zone extends along the road from Cairo to a point approximately 108 km south of Alexandria.

The color of this zone in the ASTP photograph is dark "earthy" gold (Munsell 10YR 7/4), with brighter yellow-gold patches. Field observations indicate that the zone is basically a desert pavement composed of sand mixed with dark pebbles (fig. 5). Most of these are desert-varnished; i.e., coated with a thin, glossy film of iron and possibly manganese oxides. The topography of this zone is not flat but rather rolling or undulating. The

![FIGURE 5.—The wavy surface of the desert pavement west of the Nile Delta. Dark, desert-varnished pebbles are predominant on higher ground, whereas finer, light-colored sands fill most of the low areas. Dark, heavy mineral grains tend to be concentrated on the surface and contribute to the heterogeneity of the surface coloration of both highs and lows.](image-url)
amount of gravel increases on higher areas, and the low areas are covered mostly with sand (fig. 5). These microrelief characteristics may have been produced by wind deflation. Variations in the distribution of dark pebbles are probably responsible for the patchy texture of this zone in the ASTP photograph.

The second, bright-yellow color in this zone is represented by longitudinal sand dunes (fig. 4(a)). These dunes are parallel to the prevailing wind direction and trend essentially S25°E. These dunes, 3 to 35 km in length, are disturbed by subsidiary winds creating aprons of sand that extend from the southern tips of the dunes in a S70°E to due east direction. Although these aprons have a great areal extent of as much as 40 by 5 km, they appear to have a thickness of only a few inches or less. This sheet of sand is substantial enough to change the color in the ASTP photograph from darker gold to brighter yellow.

Intermediate Zone

The intermediate zone in the ASTP photographs of the desert adjacent to the Nile Delta displays the brightest colors (fig. 4(a), zone 2). It is characterized by a pinkish-yellow color (Munsell 7.5YR 7/4) with a reddish tint that gradually intensifies toward the north.

This zone extends along the Cairo-Alexandria road from the 108-km marker to the 69-km marker. At the 108-km marker, two distinct differences were noticed between this zone and the southernmost zone. First, the sand appears to be active in this zone and forms ripples and sand shadows behind desert brush (fig. 6), whereas it is relatively inactive in the southernmost zone. Second, the surface is sparsely covered by vegetation in this intermediate zone, whereas it is densely covered by desert-varnished pebbles in the southernmost zone.

Driving northward, the authors observed that at the 104-km marker, the desert brush became smaller and darker. Eight kilometers farther, a marked increase in vegetation was noted, and 86 km from Alexandria, the sand showed a distinct increase in the red tint. Three kilometers farther, the authors visited a sand quarry (fig. 7), where the reddish sands are relatively pure and form a layer that is more than 3 m (10 ft) thick.

Northernmost Zone

The zone of color closest to the Mediterranean (fig. 4(a), zone 3) is subdivided into a belt parallel to the seacoast that displays bright white segments, and a larger area that is triangular in shape and shows a dusty pinkish-gray color (Munsell 7.5YR 7/2). The most obvious photo characteristic of this triangular area is its mottled texture.
Field investigations indicated that the surface rock in the northernmost zone is covered by a soil composed of sand grains mixed with clay and calcium carbonate particles. This zone extends from the 69-km marker from Alexandria, where the soil is reasonably arable as evidenced by the apparent growth of natural vegetation. In places, the authors noticed mud cracks on level plains indicating the existence of conditions that allow the accumulation of rainwater on the surface before evaporation (fig. 8). The high percentage of clays was demonstrated in trenches dug in this soil. Figure 8 illustrates a small trench that was dug in this soil approximately 60 km from Alexandria. In this area, the authors encountered large limestone blocks partly buried in the soil; some of the limestones were concretionary in nature. It was also noticed that the flora is more varied and includes flowering plants. Small hillocks of marly composition also were observed. The surface of some of these is lighter in color than the interior. This phenomenon is probably due to a thin crust of salts, which developed after repeated evaporation of collected rainwater.

The fact that the land in this zone is arable is evident by the westward growth of land reclamation projects. Similar projects have been started at the boundary between the Nile Delta and the desert in the intermediate color zone (fig. 4(a)). However, very limited westward growth of vegetation is apparent in the more sandy zone.

The northernmost belt of land in the Western Desert just west of Alexandria displays distinct characteristics. Its most prominent feature is the existence of closely spaced ridges that parallel the Mediterranean coast. Dark patches along these ridges are caused by vegetation (fig. 4(a)). In the field, white-colored ridges were noticed, which are
composed of clastic oolitic carbonates (calcarenite). These ridges were observed approximately 32 km from Alexandria (fig. 9).

The preceding discussion shows how the combination of photogeologic interpretation and field investigation has resulted in a full understanding of desert color in one ASTP photograph. It must be stated that the true color of this photograph made possible the recognition of color zones. Also, although fieldwork was conducted along a single line (the Cairo-Alexandria desert road), the findings can be extrapolated to the whole area of the photograph and to larger areas, as indicated in the following discussion.

**EXTRAPOLATION OF COLOR DATA**

It was shown in the previous discussion that the ASTP photographs were extremely useful in delineating color zones in a strip of the Western Desert of Egypt. These color zones can also be distinguished in additional photographs taken with the handheld camera that was used by the astronauts to document their own observations of color variations.

However, the limited coverage of the ASTP photographs did not allow the extrapolation of color data to the whole Western Desert of Egypt. To do so, it was necessary to use Landsat data that constitute the only complete coverage. In recent years, studies of desert landscapes have been facilitated by the interpretation of Landsat data. For example, McKee and Breed (refs. 25 and 26) have used Landsat imagery to formulate a classification scheme for sand seas.

To allow the use of Landsat images in the extrapolation of ASTP data to larger areas, a false-color mosaic was prepared from these images. The mosaic comprised 70 images that cover the area of Egypt. It was attempted to produce false-color composites that simulate the true color of the ASTP photographs (fig. 10).

As an offshoot of the ASTP study, this mosaic is being used in a joint research project between the Smithsonian Institution and Ain Shams University, Cairo, with the authors of this paper as Co-Principal Investigators. An important aspect of this study is the correlation of the color zones depicted on the ASTP photographs and on the Landsat image mosaic.

Preliminary investigations indicate that the mottled, dusty pinkish-gray zone (fig. 4(a)) continues along at least a part of the Mediterranean coast. In its westward continuation, it varies between 5 and 45 km in width. This is significant because the zone is made up of arable land. Additional support for its nature is shown in the Land-
FIGURE 9.—A longitudinal ridge of calcareous sand that parallels the Mediterranean coastline. The ridge is one of a group of east-northeast/west-southwest ridges that produce the linear pattern in the ASTP photograph shown in figure 4(a). Interridge areas contain darker, more fertile soil. Palm trees are approximately 30 m high.

The ASTP orbital photographs and astronaut observations, including the description of desert surface color, have provided valuable information on color variations in the Western Desert of Egypt. This information has been successfully used to pinpoint areas for field study in which color can be correlated with the composition of exposed desert soil. The ASTP photographs confirm that older sands are redder. This is true on both regional and local scales. These photographs allow the recognition of areas of Egypt that can be reclaimed from the desert. The photographs also permitted the extrapolation of data to larger areas of the Western Desert of Egypt by the use of the Landsat false-color mosaic.

This study also indicates the limitations of both the ASTP photographs and the Landsat data. In Landsat images, color zones are not clearly obvious, even on false-color composites. However, it was possible to "calibrate" the Landsat image color with the ASTP true-color photographs. It was found that color photographs are more suitable for the study of desert color because (1) the photointerpreter does not have to translate mentally one color into another, as is necessary when working with Landsat false-color composites; (2) natural color photographs can be used as such, unlike Landsat data that require the support of a computer facility; and (3) use of true-color photographs saves both time and money; the cost of digitally enhancing Landsat data is prohibitive when compared to the cost of making a photographic print from a color negative.

Similarly, the ASTP photographs were found to have several adverse characteristics, which should
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FIGURE 10.—Mosaic of false-color composites made from Landsat data. The color of unvegetated land areas on the composites approximates as closely as possible the color on ASTP photographs. Red color represents vegetation, and water appears black. Note the presence of red (vegetated) areas near the Mediterranean Sea at higher latitudes east and west of the Nile Delta. (Mosaic prepared by the General Electric Company for the Smithsonian Institution.)

be remedied in future photographs. Among these are (1) the centers of most photographs of the stereostrip are overexposed; therefore, more effective antivignetting filters should be used; (2) although stereovision was achieved using ordinary mirror stereoscopes, depth perception was rather limited because of the inherent low relief of the region; therefore, the stereo angle of photographic acquisition must be modified to enhance the vertical exaggeration; and (3) the effective resolution of the photographs should be increased.

Based on the authors’ findings, it is strongly recommended that color photographs be obtained from Earth orbit in support of desert studies. However, attempts should be made to obtain high base/height ratio, natural color, and high-resolu-
 tion photographs on future space missions. The need for such photographs becomes increasingly important when the worldwide concern for the desert environment and the process of desertification is considered. The large format camera, which is planned for use on the Space Shuttle, is believed to satisfy the necessary requirements.

ACKNOWLEDGMENTS

Apollo-Soyuz astronaut Vance D. Brand participated in assigning the descriptive terms for the color zones discussed in this paper. The fieldwork was organized with the help of a grant from Ain Shams University, Cairo, under a joint research project with the Smithsonian Foreign Currency Program. The authors wish to thank the Geological Survey of Egypt for providing support for the fieldwork. The paper was prepared under NASA contract NAS9-13831.

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