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The Meaning of Desert Color in Earth Orbital Photographs

Apollo-Soyuz photographs were used to map soil types, to establish the degree of dune reddening, and to explain patterns of shifting sands in Australia and Egypt.

ABSTRACT: *The color of desert surfaces as seen in Earth orbital photographs is indicative of soil composition. Apollo-Soyuz photographs of the Sturt and Simpson Deserts of Australia confirm that sand grains become redder as the distance from the source increases. Reddening is caused by a thin iron-oxide coating on individual sand grains and can be used, in some cases, to map relative-age zones.*

Photographs of the Western (Libyan) Desert of Egypt indicate three distinct and nearly parallel color zones that have been correlated in the field with: (1) arable soil composed of quartz, clay, and calcium carbonate particles; (2) relatively active sand with or without sparse vegetation; and (3) relatively inactive sand mixed with dark (desert-varnished) pebbles. The youngest sands are in the form of longitudinal dunes, which are migrating to the south-southeast along the prevailing wind direction. Some of the young dune fields are encroaching on the western boundary of the fertile Nile Valley.

INTRODUCTION

BASED ON EXPERIENCE gained from the Gemini, Apollo, and Skylab missions, an "Earth Observations and Photography Experiment" was planned for the Apollo-Soyuz Test Project (ASTP) of July 1975. The objective of the experiment was to make visual observations and acquire photographs related to geology, oceanography, hydrology, and meteorology (El-Baz and Mitchell, 1976). A detailed account of the experiment and particularly the visual observations, will soon be published (El-Baz, 1977). This paper will summarize new results from Apollo-Soyuz desert photographs.

Most ASTP photographs were taken with a bracket-mounted 70mm Hasselblad camera equipped with a *reseau* plate. Both 60mm and 100mm Zeiss lenses were used to acquire the photographs. The camera also was equipped with an intervalometer that allowed 60 percent overlap between successive frames for stereo viewing and the making of semi-controlled photomosaics. Another 70mm Hasselblad camera with a single-lens reflex mechanism and two lenses (50mm and 250mm) was handheld by the astronauts for photography of selected targets.

One objective of the Apollo-Soyuz photography was to obtain data on desert color. Optimum results were gained by: (1) using a color-sensitive film (Kodak SO-242, High Definition Aerial Film) that was especially manufactured with a yellow filter overcoating and sensitometric color-wedges; (2) processing the film products under well-controlled conditions in order to optimize the color balance of the photographic products; and (3) utilizing a "color wheel" with 54 standard Munsell color chips for inflight, visual comparison with the colors of observed deserts.

DESERT COLOR

Desert color depends primarily on the composition of exposed rock and rock rub-

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ble. Field investigations have established that the red color of desert sand is due to the presence of iron-oxide (hematite) coatings on individual grains. The occurrence of reddened sands has been observed in deserts throughout the world, but their mode of formation is a matter of controversy (Van Houten, 1973; Folk, 1976).

Several conflicting hypotheses have been used to explain the origin of red color due to 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. A second hypothesis contends that the hematite coatings form after eolian deposition and result from the weathering of iron-bearing minerals.

Walker (1967) provides some of the more convincing evidence for the post-depositional formation of red sands in a study of two stratigraphic sequences containing red beds (Holocene deposits in the Sonoran Desert of Mexico and late Paleozoic deposits in Colorado). Glennie (1970, p. 190) concurs in part with Walker (1967) but also believes that "much of the oxidation of iron in solution takes place at the interface between the groundwater saturated sediment below the water table and the air-filled pore space above."

In a definitive study of the Algodones dunes of Southern California, Norris and Norris (1961) present the important factors in the development and persistence of hematite coatings on individual grains. Although some workers have questioned whether the modern desert environment can produce dune reddening, "an extensive array of investigators offer evidence that red soils and sands do in fact form today in desert environments" and that "reddening of desert and subtropical dune sands clearly progresses with the flow of time" (Norris, 1969, pp. 8 and 9).

In the case of the Algodones dunes, Norris and Norris (1961, p. 611) found that the intensity of sand color increases from north to south; 25 to 60 percent of the grains are hematite-coated, with maximum values to the south. Since the more southerly dunes are older, the degree of reddening may be used to determine the relative age of the sands.

This, however, can be done only on a case-by-case basis. Dune reddening may depend on many factors. As summarized by Folk (1976, p. 605), there are three prerequisites for the process: (1) a source of abundant iron; (2) deposition above or not very far below the water table, for readier access to oxygen; and (3) a high rate of oxidation. In addition to these, three factors are important: heat, moisture, and time.

Orbital photographs provide an excellent tool for the study of desert color by: (1) documenting regional variations in the color of desert sands; (2) aiding in the location of areas for ground investigations; (3) providing evidence of transport directions and potential source areas; and (4) aiding in the determination of the relationship between dune morphology and desert color.

An example of the utility of orbital photographs in confirming and extending field observations is that of the Namib Desert of Southwest Africa. Logan (1960, p. 136) studied the linear dunes there, which have migrated from sources along stream courses. He found that the sands farthest inland are much redder in color and of greater age. Skylab 4 photographs of the same region portray color zones in the dune sand. In these photographs younger sands near the coast appear brighter than the redder zones farther inland (McKee and Breed, 1974).

Although Landsat data are well suited to classify major features of dune areas (McKee and Breed, 1976), they show few density and brightness variations in sand seas. True color photographs are more suitable for the study of desert color because: (1) the photointerpreter does not have to mentally translate one color into another, as 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 a photographic print from a color negative.

Apollo-Soyuz Results

Photographs obtained by the Apollo-Soyuz astronauts show two distinct patterns of desert color variations: (1) a gradual change towards a redder end member, as in the case of Australian deserts; and (2) abrupt changes to lighter and darker components, as in the case of the Western Desert of Egypt.

RED DESERTS OF AUSTRALIA

Apollo-Soyuz data on the Australian deserts illustrate the utility of orbital photographs in determining sand color variation and dune reddening with time. The astronauts obtained a bracket-mounted, stereo strip of the Sturt Desert and numerous handheld-camera photographs of the Simpson Desert, both in southern Australia (Figure 1).

Photographs of the Lake Blanche area, on the northern foothills of the Flinders Ranges, show the lake basin as the probable source of closely spaced linear dunes (Plate 1, top). This dry lake is 45 km long and covers an area of about 840 km². Sand grains from the lake extend northward into the western edge of the Sturt Desert. The color photographs indicate three distinct zones, each about 40 km wide: a light-colored zone close to the sand source; a dark red zone farthest from the lake; and an intermediate zone in between. This sequence confirms dune sand reddening with time, or at least as the distance from the source increases.

Darkening of dune sand with time in this region also is known from field investigations. Norris (1969, p. 9) states that: "H. Wopfner (1965, written communication), in connection with his studies of the Lake Eyre Basin, Australia, also has observed a consistent darkening of sand grains with increasing distance from sources and with increased time of exposure."

The Apollo-Soyuz astronauts photographed the area of the Simpson Desert just north of Lake Eyre (Figure 1). The photographs show dune reddening with the increase of distance from the sand source. In this case, the source of the sand appears to be the dry Lake Eyre and numerous small lakes north of it. The dunes are closely-spaced linear ridges; the sand is brighter near the lakes and darker (redder) to the north. This direction is also that of the prevailing wind. According to Madigan (1936, p. 209), the mean wind direction in this part of Australia is due north; it changes slightly to north-northwest in January. Thus, the Apollo-Soyuz photographs of the Simpson Desert constitute another example of dune reddening with time and along the prevailing wind direction.

WESTERN DESERT OF EGYPT

The Apollo-Soyuz mission obtained a photographic strip of eastern North Africa from Lake Chad to Alexandria, Egypt. This strip shows numerous broad color zones. For example, photographs taken of the Great Sand Sea show its bright yellow color, in contrast with the older and redder plains associated with the Nubian Sandstone (Figure 2).

Farther to the northeast, these photographs distinguish numerous color zones, in addition to individual dunes. In that part of the desert just west of the Nile Delta and

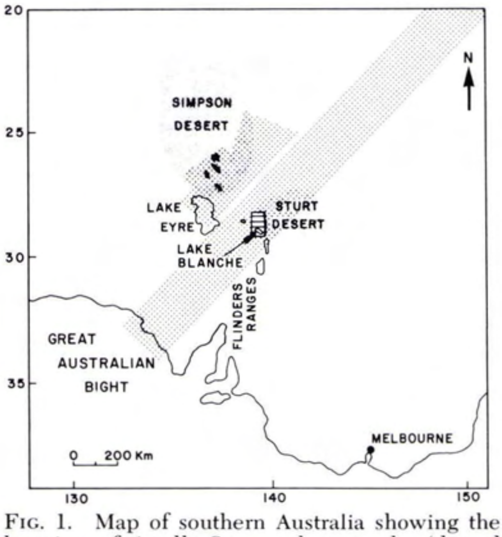

FIG. 1. Map of southern Australia showing the location of Apollo-Soyuz photographs (dotted areas). Those of the Sturt Desert were taken by a bracket-mounted camera in a northeast-trending stereo strip; photographs of the Simpson Desert were obtained by the astronauts using a handheld camera. Lined area shows the location of photograph in Plate 1, top.

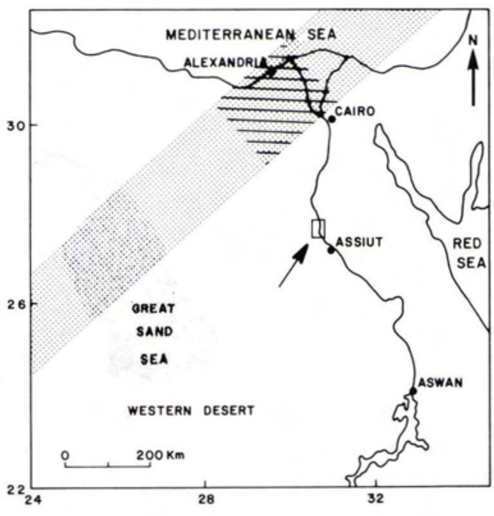

FIG. 2. Sketch map of Egypt showing the coverage (dotted strip) of the bracket-mounted camera on the Apollo-Soyuz mission. Lined square shows the location of photograph in Plate 1, bottom. Arrow points to the location of both the Landsat image enlargement and the aerial photograph in Plate 2.

southwest of Alexandria, one photograph shows three distinct color zones (Plate 1, bottom). These zones do not correspond to mapped boundaries of geological formations as compiled by Said (1962).

A field trip was undertaken to determine the cause of these color variations. Field observations resulted in the confirmation of the color zones, which are nearly parallel and run approximately in an east-west direction (Plate 1, bottom).

The zone closest to the Mediterranean coast is triangular in shape and varies between 6 and 45 km in width; its most obvious photo-characteristic is a mottled appearance. The surface rock in this zone is covered by a soil composed of sand grains mixed with clay and calcium carbonate particles. This soil is reasonably arable as evidenced by the apparent success of land reclamation projects extending the vegetated Nile Delta (Plate 1, bottom). Field investigations affirm that this arable zone extends all along the coast of the Mediterranean to the west, with varying width.

The second zone displays the brightest yellow color and averages 22 km in width. It is basically a sand sheet with some desert brush. The density of natural vegetation is much less than in the first zone. It would be very difficult to increase the area of vegetated land within this zone. In it, there are several indications that the sand is active; it migrates from place to place as the prevailing winds shift directions. These indications include sand ripples and sand mounds beneath desert vegetation.

The third and most extensive zone covers the southwestern half of the area of the photograph of over 8,000 km^2. It displays the darkest color of all three zones. This is reasonable since field observations indicate that the zone is basically a desert pavement composed of sand mixed with dark pebbles. Most of these are desert-varnished, i.e., limestone and chert pebbles coated with a thin, glossy film of iron and manganese oxides.

A fourth, bright yellow, color in this zone is represented by longitudinal sand dunes of the type noted by Bagnold (1933), Sanford (1935), Said (1962), and Smith (1963), among others. The dunes which lie in the third and darkest zone are parallel to the prevailing wind direction. The trend of most dunes is south 25° east. These dunes, 3 to 35 km in length, are disturbed by subsidiary winds creating an apron of sand that starts from their southern tips. The aprons trend south 70° east to due east, which are the directions of seasonal winds. Although these aprons extend up to 40 km long and 5 km wide, they cover the terrain with a sheet of sand that is only inches thick. Migration of sand in this way does not represent a threat to habitable land as much as the dunes themselves do.

During a flight over these longitudinal dunes, it was recognized that some are encroaching on fertile land of the Nile Valley to the south (Plate 2, left). In this case, an advancing longitudinal dune field changes into a complex of barchanoid shapes. As segments of the dune field come in contact with wet soil, they often leave behind islands of vegetated land. This process is active in several places along the western border of the Nile Valley south of Cairo (Plate 2, right). If this process of dune encroachment on fertile land is allowed to continue, it can present some danger to the economy of Egypt. This is brought into focus if we consider that only 4 percent of the land area of Egypt is presently being farmed. If anything, Egypt needs to increase that area rather than lose to the desert any small part of it. More detailed study of color aerial or space photographs can help in determining areas in danger of dune encroachment, as well as regions that may be suitable for reclamation from the desert.

Conclusions

(1) Apollo-Soyuz photographs of the southern Australian deserts confirm dune reddening as the distance from the source increases, and provide further evidence of the process of reddening with time. The photographs can be utilized in mapping relative-age zones in these deserts.

(2) Three zones in the Western (Libyan) Desert of Egypt were recognized on the basis of their color signatures. Field work proved that the zones correspond to three soil compositions: sand mixed with desert-varnished pebbles, loose sand with sparse vegetation, and relatively arable soil composed of sand, clay, and calcium carbonate particles.

(3) ASTP photographs made possible the recognition of patterns of shifting sands in the Egyptian deserts. Londitudinal sand dunes parallel the prevailing north wind, and thin sand sheets are spread by seasonal winds from the west.

(4) Color photographs taken from Earth orbit provide an excellent tool with which to study the vast and mostly inaccessible deserts. Attempts should be made to obtain stereo, color, high-resolution photographs on future space

missions to help in the study of deserts, particularly in view of world-wide concern for the desert environment and the process of desertification. The Space Shuttle program will make this possible by the use of the "Large Format Camera".

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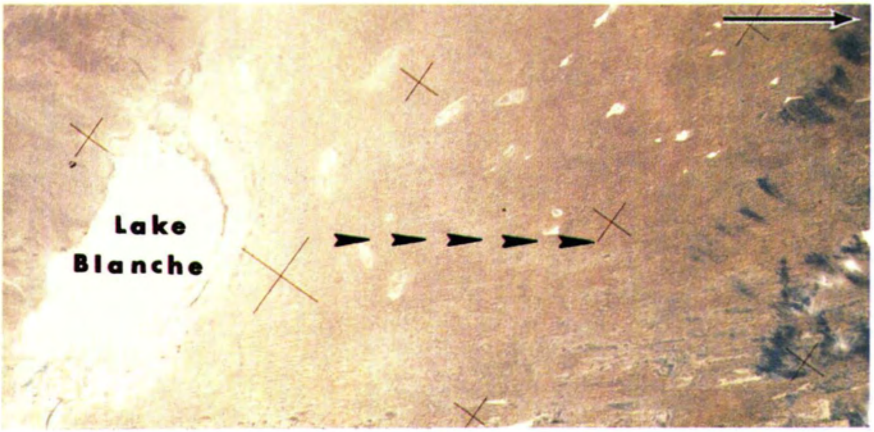

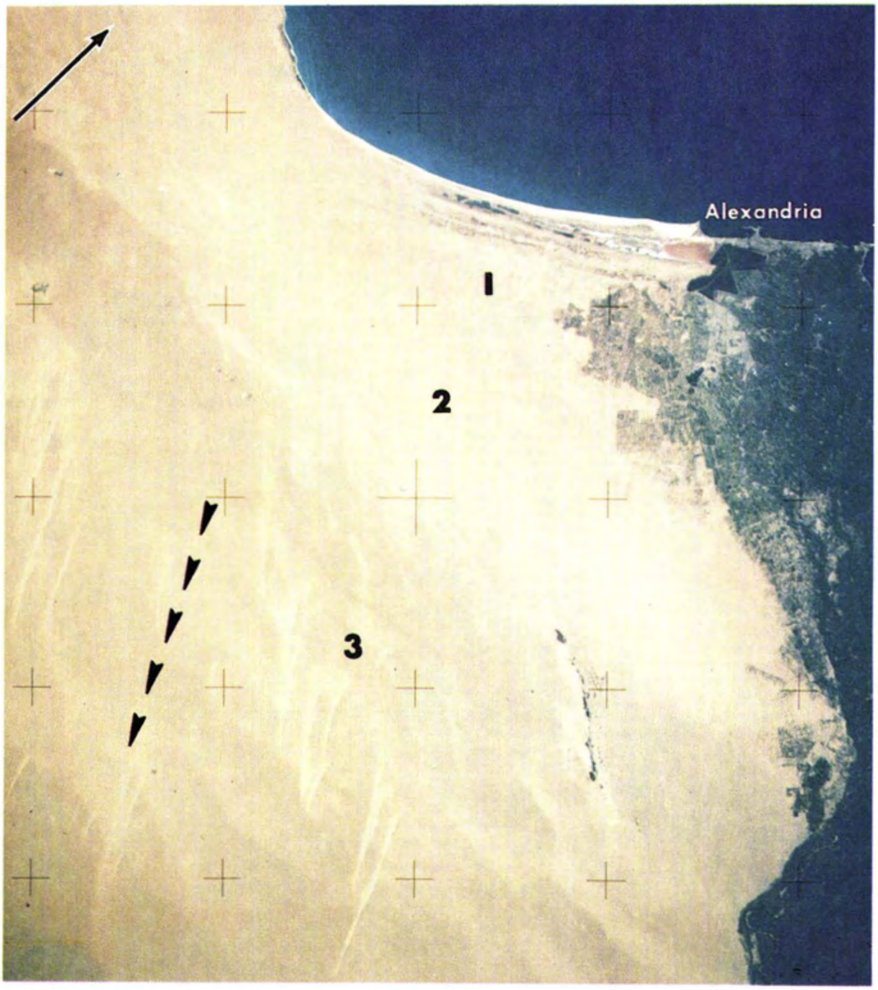

PLATE 1. *Top*, Linear dunes emanating from the dry Lake Blanche (45 km in length) in southeastern Australia (ASTP photograph 1133). The fine, subparallel dunes north of the lake are brighter (more tan) near the sand source, and darker (redder) farther away from the lake; *Bottom*, Three color zones in the Western Desert of Egypt as seen in Apollo-Soyuz photograph 1256. The bright yellow sand dunes in zone number 3 are of the longitudinal type. Arrow heads parallel the prevailing wind direction, and arrows point to the north.

PLATE 2. *Left,* Photograph taken by the author, from 850m altitude with a 35mm camera, of sand dunes encroaching on fertile land northwest of Assiut and about 250 km south of Cairo; *Right,* Enlargement of Landsat false color composite that includes the same area. Note islands of vegetated land (red specks) that are left behind advancing dunes along the west (left) side of the Nile Valley. Arrow heads parallel the prevailing wind direction.