Color of Desert Surfaces in the Arabian Peninsula

Farouk El-Baz[a†]

ABSTRACT

The Arabian Peninsula was photographed during the Apollo-Soyuz mission with a stereostrip of 21 photographs starting at the Red Sea coast at west-central Yemen and ending at Qatar. These photographs sample all the major geologic and structural provinces of the peninsula. The natural color of the photographs enables the recognition of these provinces and the detailed study of some of their features.

Among the features discussed in this report are the Red Sea islands and the coastline at west-central Yemen; the red-colored plains that separate the Red Sea from the crystalline massifs of the Arabian shield; the structures, lineaments, and drainage patterns displayed by these igneous and metamorphic massifs; the various desert surfaces of the sedimentary interior; and the Dukhan anticline and eolian streaks in the Qatar Peninsula.

Detailed analysis of the Apollo-Soyuz photographs resulted in establishing the following facts: (1) available charts and maps can be updated using the orbital photographs, particularly of coastal zones; (2) geologic maps can be improved by use of the natural color photographs, which clearly delineate major geologic features and their characteristics; (3) the photographs can be used in characterizing sand fields and classifying dune forms; and (4) enlargements of the photographs can be useful in detailed studies of small areas, such as the city of Ad Dawḥah (Doha), Qatar, and its environs.

INTRODUCTION

Deserts may be defined as those arid areas of the Earth that receive less than 25 cm of rain per year. Although deserts occupy more than 20 percent of the land area of the Earth, information on their morphology is scanty and in some cases inadequate. Among the reasons for this limited knowledge of the Earth's deserts are their immense size and their remoteness and inaccessibility. These reasons make conventional surveys and detailed studies of desert regions impractical and costly.

Experience gained from the Gemini, Apollo, and Skylab missions indicated that orbital surveys of desert regions were very effective. Much new knowledge was gained from studying desert photographs obtained by the astronauts from Earth orbit (ref. 1). One factor that increased the effectiveness of orbital photographs was their natural color; desert surfaces are colorful and the colors are meaningful (ref. 2). Therefore, color photographs helped greatly in understanding desert morphology, in classifying sand dunes, and in evaluating eolian landforms (ref. 1).

For these reasons, photography of desert regions was one of the major objectives of the Earth Observations and Photography Experiment on the Apollo-Soyuz Test Project (ASTP). Excellent photographs were taken of the Arabian Peninsula, Argentina, Australia, and the North

[a]National Air and Space Museum, Smithsonian Institution.

[†]Principal Investigator.

African Sahara (ref. 3). This paper will discuss the ASTP photographic strip of the Arabian Peninsula (fig. 1) with emphasis on color variations in the terrain.

GENERAL SETTING

The Arabian Peninsula occupies the southwestern corner of Asia. It is bounded on the west by the Gulf of Aqaba and the Red Sea, on the south by the Arabian Sea, and on the east by the Gulf of Oman and the Arabian (Persian) Gulf. Its northern borders are common with southern Iraq and Jordan.

Politically, the Arabian Peninsula includes Saudi Arabia, Yemen, Southern Yemen, Oman, the United Arab Emirates (U.A.E.), Qatar, Bahrain, Kuwait (fig. 1), and several neutral zones, which are owned by more than one state.

The Arabian Peninsula is a great plateau of ancient crystalline rock, which is overlain by limestone and sandstone (ref. 4, p. 130). The crystalline rocks crop out, in the south and east, in a belt that parallels the Red Sea coast. The greatest height is achieved in southwestern Arabia, where the mountains are approximately 3700 m high (ref. 5).

The high coastal mountains of the Arabian Peninsula catch the little moisture that is carried by the passing winds; thus, the interior region is one of the most arid areas of the Earth. The precipitation in the interior of Arabia is less than 10 cm per year (ref. 4, p. 130). The extreme aridity of its interior is exemplified by the lack of any perennial streams and, hence, the lack of natural vegetation.

The basin-shaped interior consists of alternating steppe and desert landscapes. The Nafūd Desert in the north is connected with Ar Rub' al Khālī in the south by Ad Dahnā' Desert, a narrow sand corridor. Ar Rub' al Khālī, which means "The Empty Quarter," is the largest sand field in the world.

References to the geology of the Arabian Peninsula before the start of oil research in Saudi Arabia in 1933 are scarce. Camel trips across the interior escarpment by H. S. J. B. Philby, during World War I and later years, provided the first concrete evidence that marine rocks were extensively exposed in central Arabia (ref. 6, p. 2). Geological exploration entered a particularly interesting phase when the U.S. Geological Survey and the Arabian American Oil Company (Aramco) began a series of geologic-geographic maps covering most of the peninsula. To perform this task, which was begun in 1954, Saudi Arabia became one of the few countries in the world that was completely covered by high-altitude aerial photographs (ref. 6, p. 4).

Geological mapping started with the preparation of 1:500 000-scale maps compiled on topographic base maps of the same scale. From these maps, a geologic map was prepared at 1:2 000 000 scale and published in 1963 (ref. 7). To this day, the map remains a major source of geologic information on the Arabian Peninsula.

One image taken by the Nimbus-3 high resolution infrared (HRIR) scanner (0.7 to 1.3 μm) at 1:2 000 000 scale gives an excellent view of the general geology of the peninsula. The image shows that the rocks which parallel either side of the Red Sea are nearly identical. This is true since the Arabian shield is regarded by most geologists as being a continuation of the African shield and is now separated from it by the Red Sea rift (e.g., ref. 8).

The crystalline rocks that form the massifs of the Arabian shield are mostly Precambrian in age. Since Precambrian time, these massifs have been amazingly stable and subject only to gentle epeirogenic movements (ref. 6, p. 5). On these rigid peneplaned landmasses was deposited a thick sequence of continental and shallow water shelf sediments that dip gently to the north and east. The sediments are clearly depicted on the Nimbus-3 image (fig. 2) as occupying the central and eastern parts of the peninsula. The white areas in figure 2 appear to reflect thick sand accumulations that overlie the sedimentary rocks.

The major structural provinces of the Arabian Peninsula are shown in figure 3. The Arabian shield just east of the Red Sea coast is composed mainly of igneous and metamorphic rocks that are locally overlain by Cenozoic volcanics and Quaternary alluvial and eolian sediments (ref. 9).

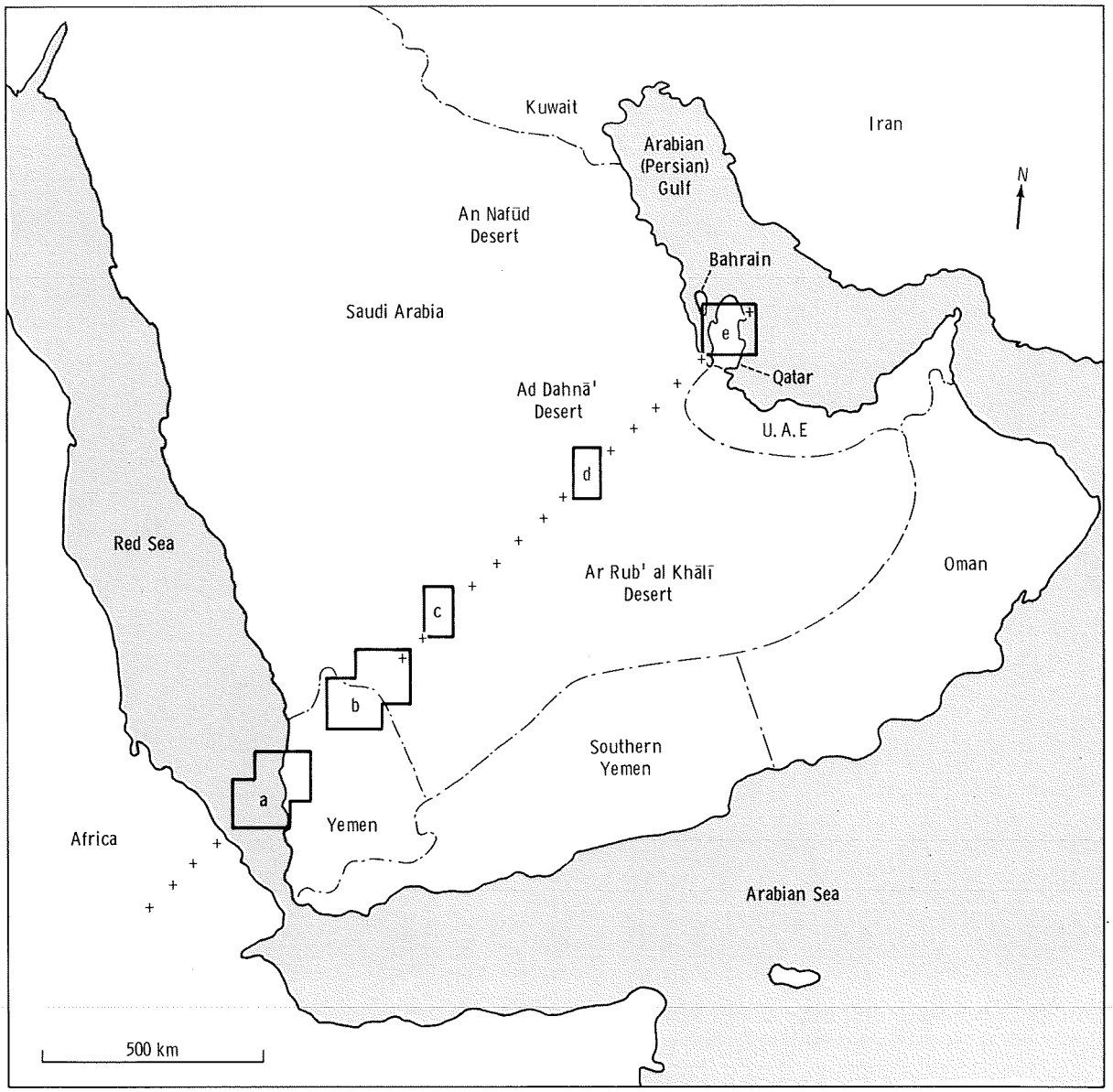

FIGURE 1.—Sketch map of the Arabian Peninsula showing the photographic strip obtained on the Apollo-Soyuz mission. Crosses show centers of the photographs, and the lettered areas show the locations of figures in this paper: "a," figure 4; "b," figure 6; "c," figure 7; "d," figure 8; and "e," figure 9.

It is interesting to note that the shape of the Arabian shield in this map (fig. 3) is almost identical to that on the Nimbus-3 image (fig. 2).

The interior homocline borders the Arabian shield and consists of eroded limestone, dolomite, shale, and sandstone. Dominating the exposed part of the homocline is a series of essentially parallel, west-facing, strike escarpments, each supported by a resistant limestone cap (ref. 6, p. 6). Sandstone and shale, which are less resistant to eolian weathering, floor intervening valleys and plains. Covering parts of the homocline are exten-

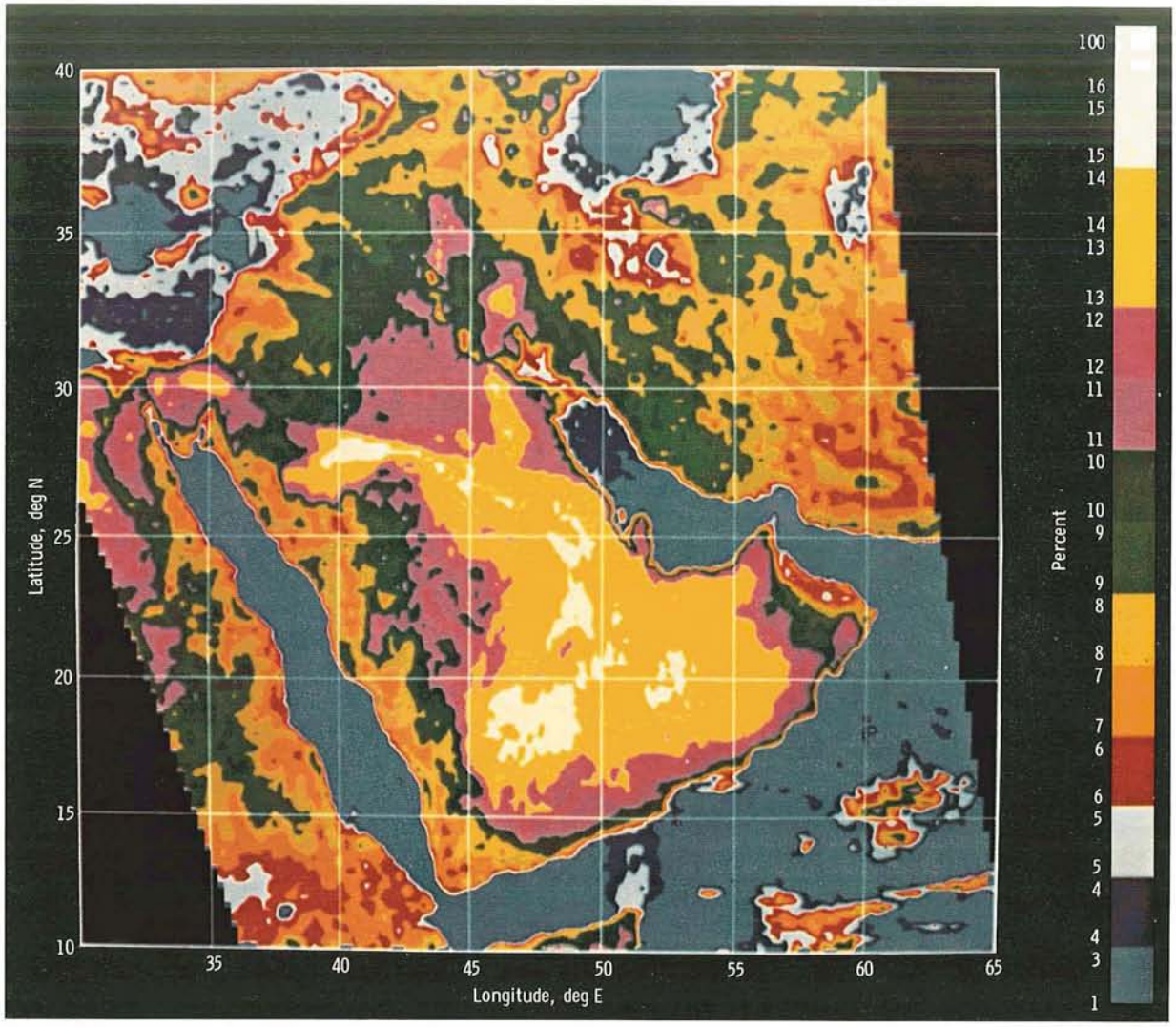

FIGURE 2.—Nimbus-3 HRIR image (0.7 to 1.3 μm) of the Arabian Peninsula obtained on June 6, 1969, 7:55 to 8:08 Greenwich mean time. The scale on the right edge shows the heat reflectance values of the various surface units (NASA 74-HC-156).

sive windblown eolian sands in An Nafūd and Ar Rub' al Khālī deserts, to the north and south, respectively. The Hadramaut plateau along the south is made up of limestone, shale, and marl strata with a dominant east-west drainage system, which is beautifully documented by Gemini IV photographs (ref. 10, pp. 19 to 21).

East of the homocline is a broad expanse of relatively low relief terrain in which older rocks are buried by Tertiary and younger deposits. Paleozoic and Mesozoic strata do not reappear at the surface until the Oman Mountains in the easternmost part of the peninsula (ref. 6, p. 6).

As stated previously, the major geologic and structural maps of the Arabian Peninsula show much similarity to the Nimbus-3 image (fig. 2). Similar comparisons were made between geologic maps of the peninsula and Nimbus-5 and Nimbus-6 data on microwave brightness temperatures (ref. 11). It is believed that comparisons of all such data may yield significant results. Perhaps the comparisons could be done digitally as in the

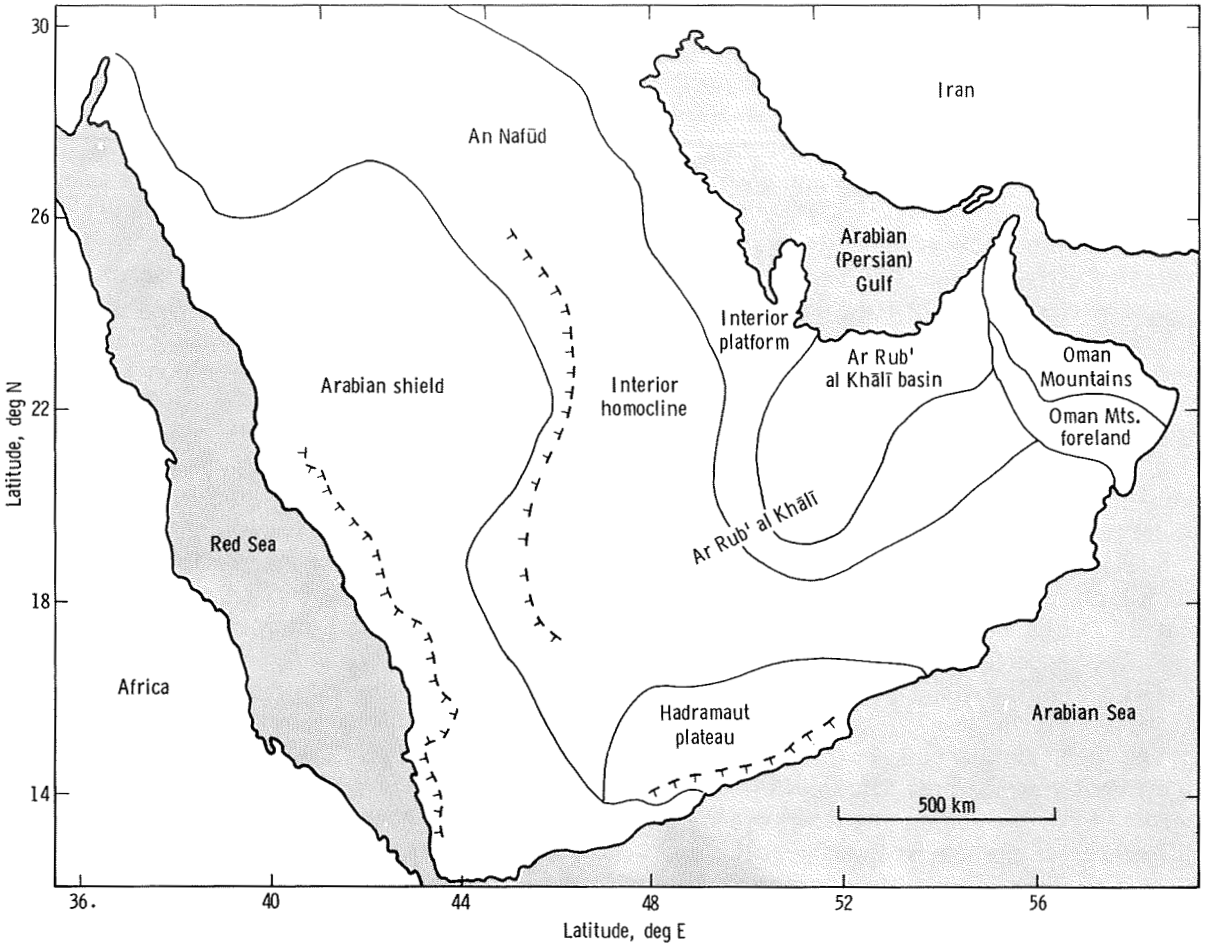

FIGURE 3.—Map showing structural provinces of Saudi Arabia and adjacent areas. Dashed lines indicate major escarpments. (Simplified from ref. 6, plate 2).

correlations of the Apollo lunar-orbital data with geologic maps at the U.S. Geological Survey, Flagstaff, Arizona (ref. 12).

COLOR ZONES IN ASTP PHOTOGRAPHS

Photographs of the Arabian Peninsula were obtained during the ASTP mission using the "black" Hasselblad camera on revolution 40 as part of photographic strip M5 (ref. 3). The photographic objectives of this strip were the Afar Triangle at the Horn of Africa, the structures bordering the Red Sea rift, the dune patterns in Ar Rub' al Khālī Desert, and the coastal processes at Doha, Qatar (ref. 13, p. 110).

The camera (with its 100-mm lens) was bracket-mounted in spacecraft window 5, and the intervalometer was set at 6.5-second intervals. This particular strip differed from other photographic strips on the Apollo-Soyuz mission; it was obtained with a difference of 90° in spacecraft yaw. This resulted in the reduction of overlap from 60 to 30 percent; the stereographic overlap covered the lower-left and upper-right corners of the photographs rather than being normal sidelap. (See stereopairs marked "a" and "b" in fig. 1.)

The ASTP crewmen obtained a total of 21 partial stereophotographs of the Arabian Peninsula

(fig. 1). The strip started at the southern end of the Red Sea off the coast of Yemen and continued in a northeasterly direction to the tip of the Qatar Peninsula (fig. 1). These excellent photographs cross all the major geologic and structural provinces of the Arabian Peninsula and clearly show the following:

1. The numerous islands, shoals, and coral reefs in the coastal waters of Yemen
2. The coastal strip of red-colored plains with numerous lighter colored alluvial fans
3. The rugged southern part of the Hijāz Mountains at the border between Yemen and Saudi Arabia
4. The eastern foothills of the Arabian shield with a major drainage pattern of east-trending wadis (valleys)
5. The numerous eolian landforms including sand dunes and color zones in Ar Rub' al Khālī and Ad Dahnā' deserts
6. The lineated limestone exposures in the eastern part of the Arabian Peninsula, particularly in Qatar

The ASTP photographs show color zones within many of these features. The color variations are believed to be caused by compositional differences of the exposed surfaces. Because of the apparent significance of geographical distributions, the color zones and variations thereof will be discussed separately for each of the following regions: (1) the Red Sea coast, (2) the mountainous west, (3) the sandy interior, and (4) the Qatar Peninsula.

Red Sea Coast

The first two photographs of the ASTP strip of the Arabian Peninsula clearly display the coastal features of west-central Yemen (fig. 4). The Red Sea coastline appears sharp and crisp in these photographs. Dark splotches near the coast are probably *sebkhas,* which are accumulations of silt, clay, and sand often with saline encrustations (ref. 5). The author has seen many larger *sebkhas* on the eastern edge of the Arabian Peninsula, which show the same photocharacteristics as these small features in the coastal areas of Yemen.

The natural color of the ASTP photographs helps delineate the flat coastal plains, which appear bright earthy-red in color (closest to 5A on the ASTP color wheel; Munsell 5R 6/6).[1] These plains appear much lighter in color than the foothills of the crystalline rocks of the Arabian shelf, which are more brown in color (fig. 4).

The coastal plains are dissected by east-west drainage patterns of wadis, valleys, or dry watercourses. The most distinctive of these is Wādī La'ah, which displays a dark course of the dry streambed. The dark color of the wadi and its delta-shaped alluvial fan is probably due to scant vegetation; it is somewhat darker than the color of *sebkhas* nearer the Red Sea coast. Other wadis, particularly north of La'ah, are marked by lighter colored, probably more sandy, alluvial fans.

West of the Yemen coastline, the ASTP photographs show numerous variations in the color of water. Somewhat murky, purplish-bluish-gray water colors dominate the coastal zone (color 48A on the ASTP color wheel; Munsell color 5PB 5/6). The water that surrounds some of the numerous islands, which probably reflects bottom topography, is more bluish-green (color 32A on the ASTP color wheel; Munsell color 2.5PB 5/6). The open seawater is deep purple-blue (color 45B on the ASTP color wheel; Munsell 2.5PB 5/6). A wake of one island on the left edge of figure 4 (Jabal at Tayr) trends in a southeasterly direction and appears darker than the surrounding seawater.

The ASTP photographs clearly display both the coastline and the boundaries of the islands. The photographs were compared with the Defense Mapping Agency charts of the region (Operational Navigation Charts ONC J6 and ONC K5). The comparison showed that these charts, at 1:1 000 000 scale, did not accurately depict the natural boundaries (fig. 5). The ASTP photographs can be used to update the maps by (1) correcting the coastline, particularly north of Al Luḥayyah; (2) changing the boundaries of many of the large islands, such as Takghash; (3) deleting some of the islands that do not appear in the photographs; (4) changing the positions of some of the islands; and (5) adding the islands that appear on the photographs but not on the charts.

[1]These and similar color notations are explained in the section of this volume entitled "Comparison of Astronaut Visual Color Observations with ASTP Photographs."

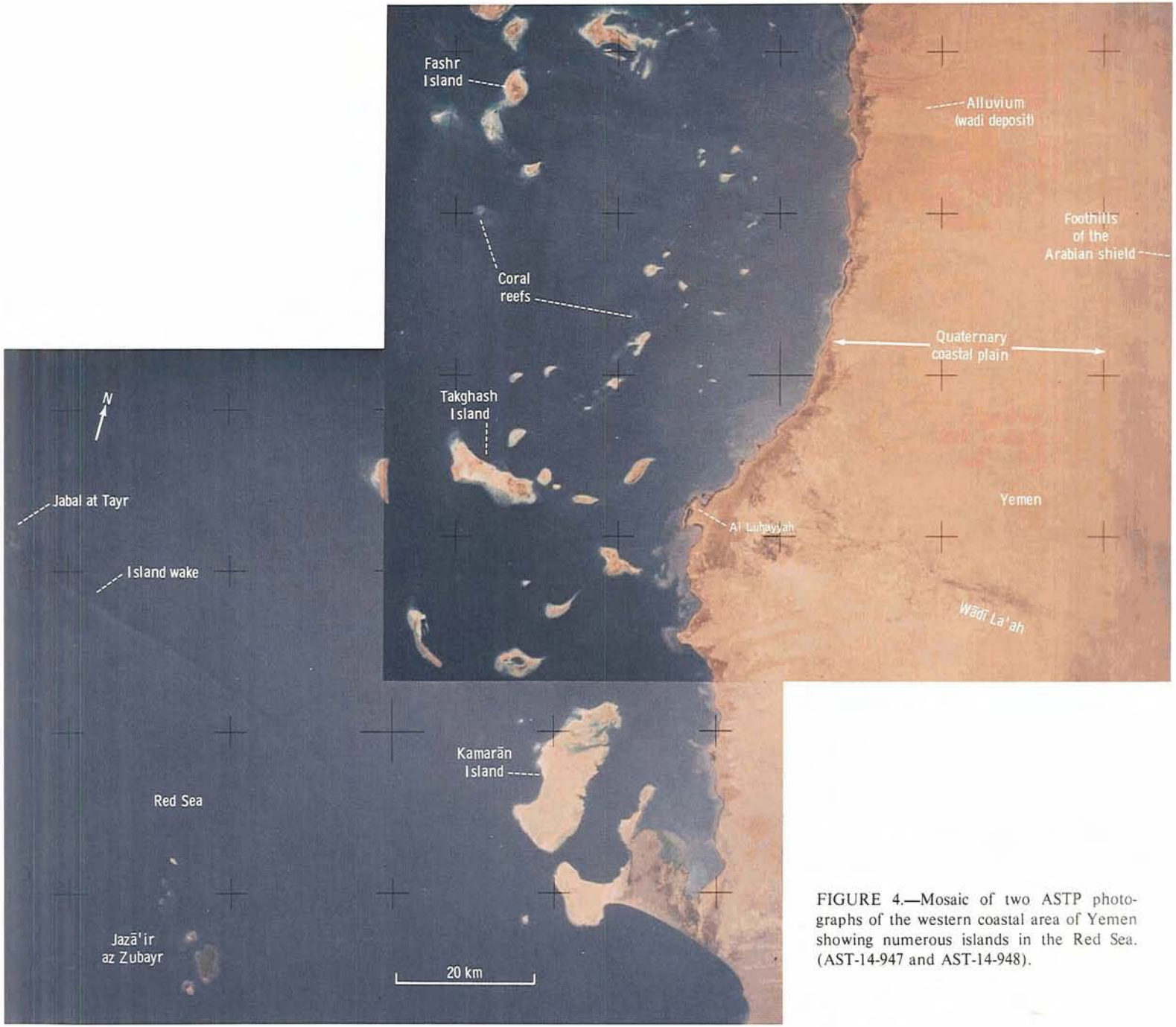

FIGURE 4.—Mosaic of two ASTP photographs of the western coastal area of Yemen showing numerous islands in the Red Sea. (AST-14-947 and AST-14-948).

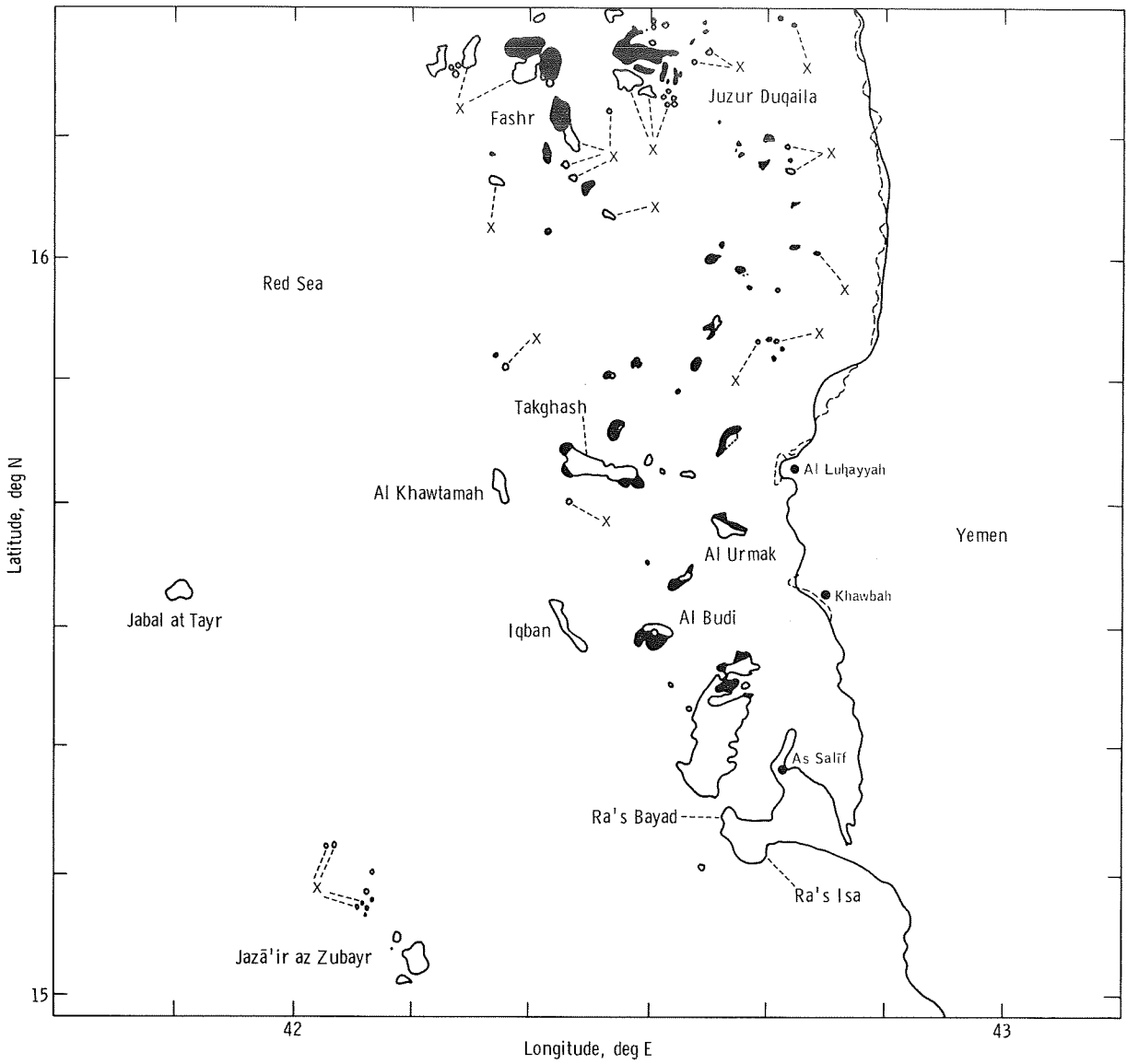

FIGURE 5.—Map of the coastal area of west-central Yemen based on Operational Navigation Charts ONC J6 and ONC K5. Dashed line at Khawbah and north of Al Luḥayyah marks the coastline as depicted on Apollo-Soyuz photographs. Black areas indicate corrections to island coastlines or locations of islands as seen on the ASTP photographs; islands marked by an "X" do not appear on these photographs.

Mountainous West

The ASTP stereophotographs clearly display the rugged nature of the high massifs of the Arabian shield. The color of these mountains is brownish-red (color 11A on the ASTP color wheel; Munsell color 10R 6/4). The structural grain in the photographed part is dominantly north-south. As shown in the central part of figure 6, numerous belts of north-south-trending lineaments abound. Intersecting this major trend are lineaments trending in a northeast-southwest direction and a few east-west-oriented lineaments. The latter are particularly emphasized by the wadis, which spread eastward from the mountains toward the low-lying desert surface.

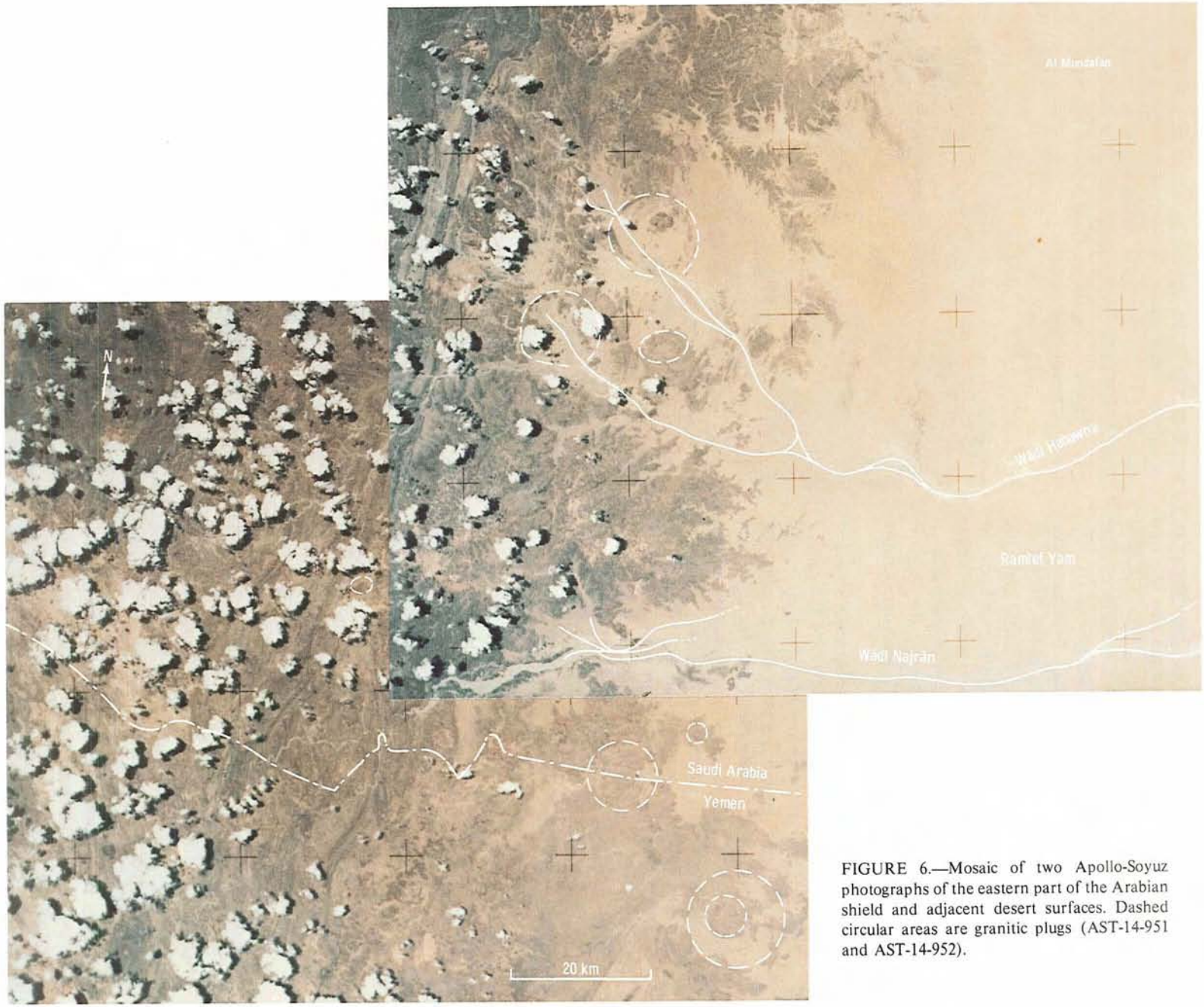

FIGURE 6.—Mosaic of two Apollo-Soyuz photographs of the eastern part of the Arabian shield and adjacent desert surfaces. Dashed circular areas are granitic plugs (AST-14-951 and AST-14-952).

Circular features abound in the central part of the photographs illustrated in figure 6. The one that is divided by the border between Saudi Arabia and Yemen as well as all those north of that border are mapped as peralkaline granite (ref. 7). The U.S. Geological Survey map, however, does not show the structure south of the border in figure 6. The shape, color, and texture of this structure suggest that it is identical to the ones in Saudi Arabia. It is believed that it also is a circular plug of probable peralkaline granite composition This interpretation is supported by the map of Grolier and Overstreet (ref. 14), who mapped the rocks in this area as granites.

The open desert east of the Arabian shield is shown in much lighter colors than the mountains. Although individual dunes are not distinct, the texture of the terrain suggests the existence of dunes, particularly in Ramlet Yam. The latter area lies between two major wadis, Habawna on the north and Najrān to the south (fig. 6). The wadi alluvium is grayish-white when compared to the yellowish-red color of the desert surface. The latter is much brighter in color (color 23A on the ASTP color wheel; Munsell color 2.5Y 8/6) than the surface of the coastal plains on the western side of the Arabian shield massifs.

Sandy Interior

As stated earlier, much of the interior of the Arabian Peninsula is occupied by sedimentary deserts. Approximately one-half of the sedimentary area is blanketed by eolian sand. Ar Rub' al Khālī is the largest sand field and occupies nearly 600 000 km^2. This desert was first explored by the English explorer Philby in 1932 (ref. 15). It covers much of the southern interior of the peninsula from the highlands of the Najd in the north to the Hadramaut plateau in the south. It slopes from an altitude of 1000 m in the west to near sea level in the east. Sand dunes of Ar Rub' al Khālī rise as high as 200 m in the southwest (ref. 4).

The ASTP photographs of Ar Rub' al Khālī Desert show some of these dunes. In one photograph, the dunes measure at least 100 km long. These dunes show a very regular wavelength, and they appear much redder than the limestone rock beneath (fig. 7). In the northwestern part of the desert, the dune sand is pinkish-red in color (color number 25A on the ASTP color wheel; Munsell color 2.5YR 8/4). As shown in the upper-left corner of figure 7, the dunes taper toward the west-facing interior escarpments.

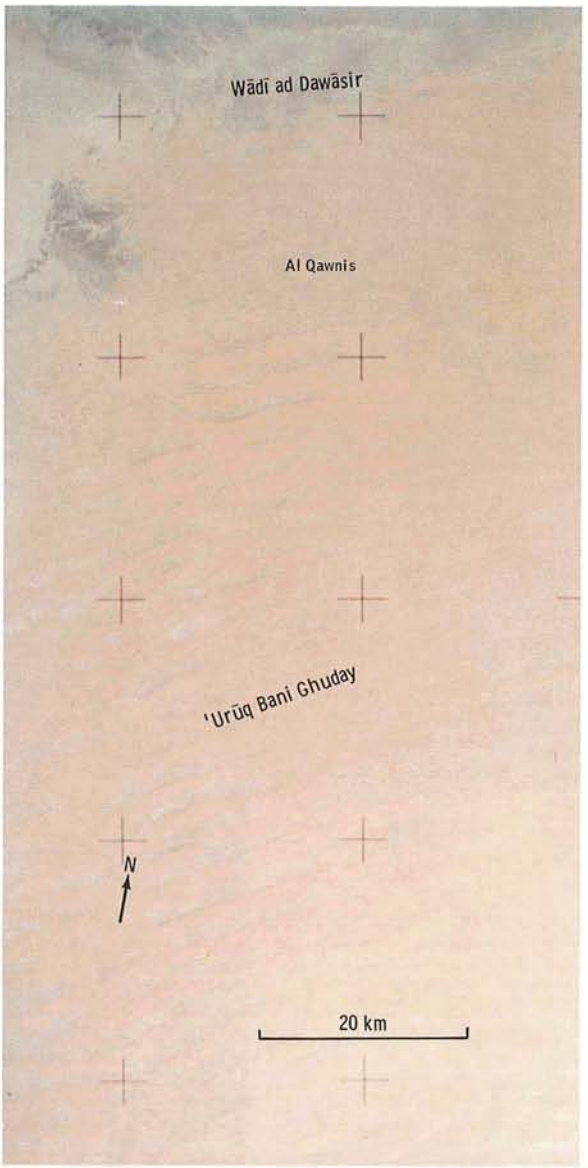

FIGURE 7.—Part of ASTP photograph showing the red-colored, nearly east-west-oriented dunes ('Urūq Bani Ghuday) at the northwestern edge of Ar Rub' al Khālī Desert, Saudi Arabia (AST-14-955).

North of Ar Rub' al Khālī, the ASTP photographic strip covers the sand dunes named 'Urūq ar Rumaylah. These appear to be continuations of Ar Rub' al Khālī dunes. However, instead of the near east-west orientations of 'Urūq Bani Ghuday of Ar Rub' al Khālī (fig. 7), the dunes of 'Urūq ar Rumaylah veer toward the northeast.

The deserts of Ar Rub' al Khālī in the south and An Nafūd in the north are connected by Ad Dahnā' Desert, which is a narrow corridor of sand, approximately 1300 km long. The Apollo-Soyuz photographs clearly depict this sand corridor because of its bright-red color (fig. 8). In the orbital photographs, the sedimentary rocks on either side of the sand corridor are light greenish-gray whereas the sand appears pinkish-red (color 26B on the ASTP color wheel; Munsell color 7.5R 8/4).

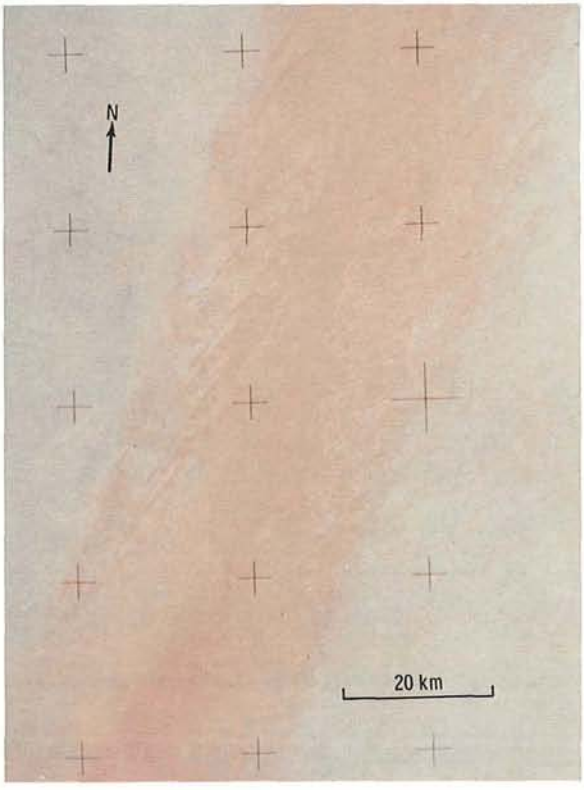

FIGURE 8.—Part of the red-colored Ad Dahnā' sand corridor (pinkish-red color), which connects the deserts of An Nafūd to the north and Ar Rub' al Khālī to the south. The Huraysan area to the west (left) of the sand corridor consists of limestone, dolomitic limestone, and dolomite. The formation east (right) of the sand is composed of sandstone, marl, and limestone. Note the fine drainage lines west of the sand corridor (part of Apollo-Soyuz photograph AST-14-961).

The ASTP photograph shown in figure 8 suggests a difference between the rocks exposed on either side of the sand deposit. The surface to the west (left side, Huraysan area) is darker in color and is dissected by fine drainage lines oriented in a nearly east-west direction. The rocks to the east (right side, Şummān area) are lighter in color with fewer drainage lines and with fine northeast to southwest lineaments.

This difference is reflected in the geologic map (ref. 7). According to this map, the rocks west of Ad Dahnā' belong to the Paleocene-age Umm ar Radhuma Formation. It is composed of limestone, dolomitic limestone, and dolomite (ref. 7). The rocks east of the sand belt are Miocene- to Pliocene-age sandstone, marl, and limestone strata.

Some color variations also occur within the sand zone itself (fig. 8). These may reflect thickness of sand cover and variations in dune morphology. For example, the eastern part of the sand field appears to contain numerous small complex dunes, with the interdune areas forming a dotted pattern. The central part of the red zone is smoother in texture and appears to have a relatively constant sand thickness. The western part of the sand field is characterized by relatively large dunes trending in a northeast-southwest direction. These variations in dune morphology and morphometry may be caused by topographic characteristics of the underlying terrain and their effects on the wind regime.

Qatar Peninsula

The Qatar Peninsula lies on the eastern shores of the Arabian Peninsula and occupies 11 400 km^2. It is largely a barren and rocky desert, with very little vegetation (fig. 9). The terrain is flat, and from field observations by the author, it consists mainly of fine-grained limestone that is crystalline or dolomitic and vuggy in many places. This limestone, which forms the major part of the peninsula, is lower Eocene in age and belongs to the Dammam and Rus Formations (ref. 7). It is

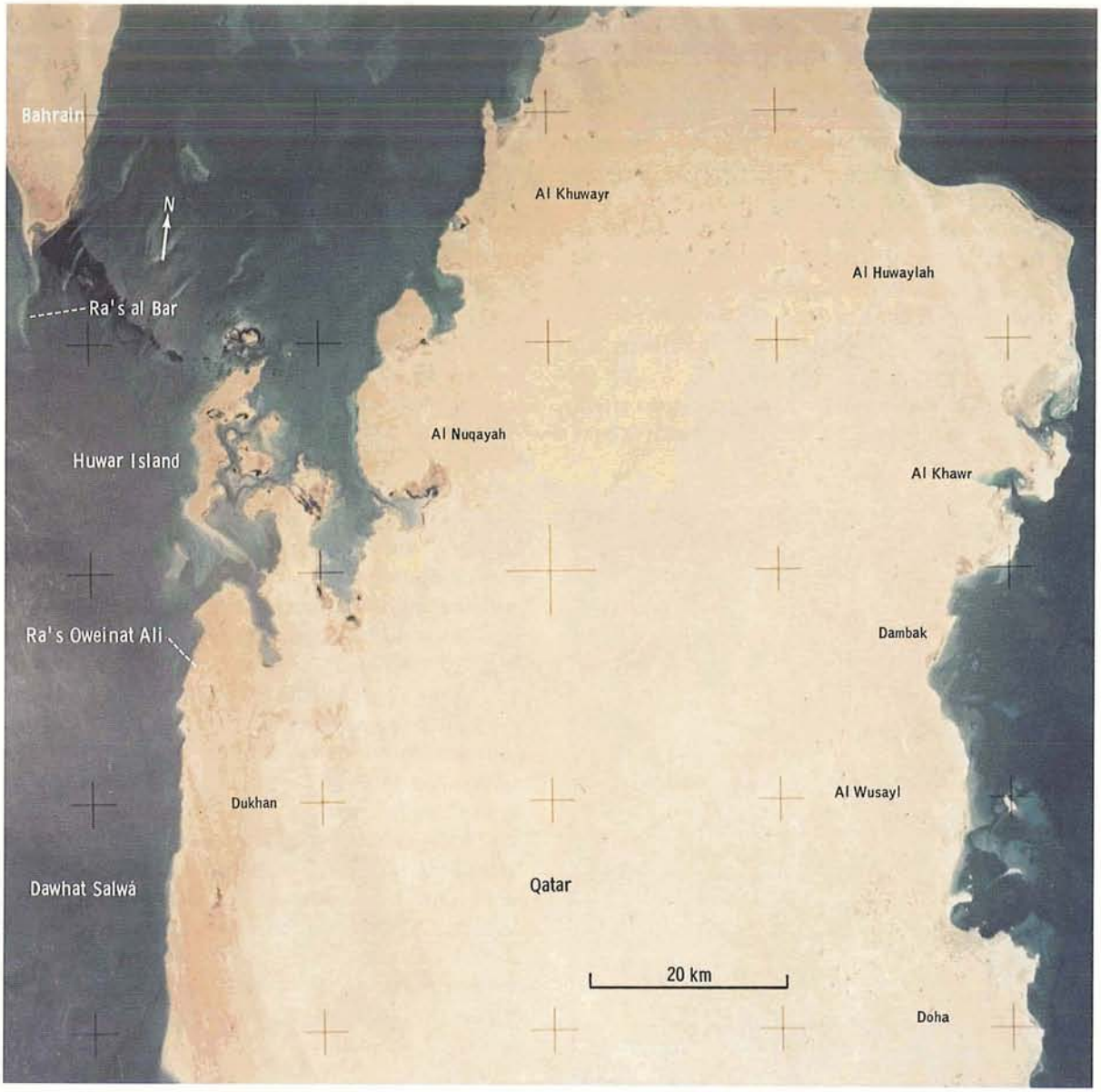

FIGURE 9.—The Qatar Peninsula as depicted in one Apollo-Soyuz photograph (AST-14-967). Note the shades of greenish-blue water that surround the coastline and reflect bottom topography.

overlain in the south and southwest by Eocene to Miocene marls and limestones and in the center by a cobble conglomerate of igneous, metamorphic, and sedimentary constituents. Sand deposits are limited to the south and southeast, where numerous barchan and complex dunes occur.

The ASTP photographs cover the northern two-thirds of the Qatar Peninsula. They clearly show the flat nature of most of the terrain; the only structurally high area on the western margin appears darker than the rest of the peninsula (fig. 9). This long, north-south-oriented rise is known as the Dukhan anticline. It parallels the

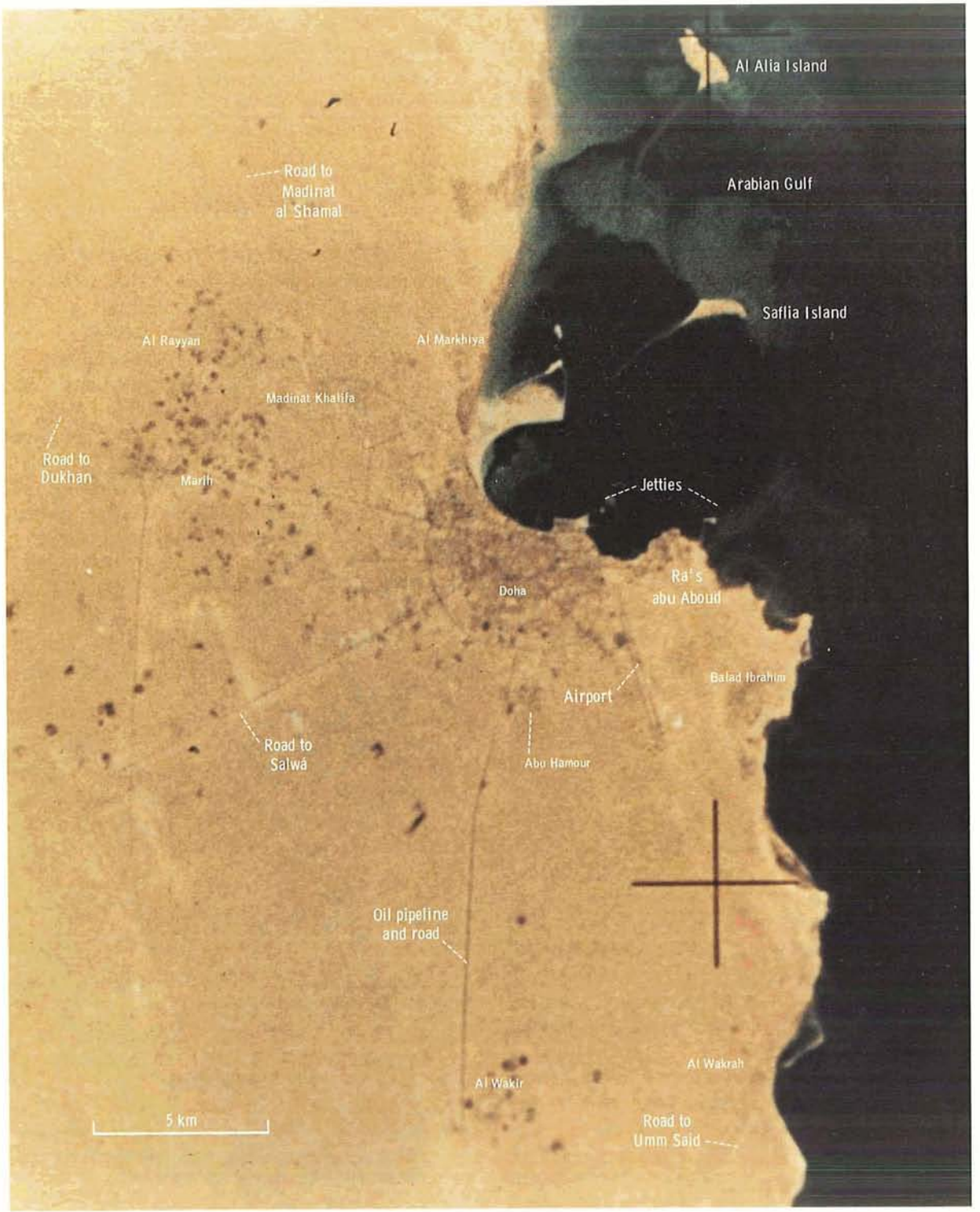

FIGURE 10.—Enlargement of the ASTP photograph in figure 9 showing details of the city of Doha and surrounding area, southeastern Qatar.

coastline of Dawhat Salwá and rises from it as a chain of hills approximately 100 m high. The anticline is approximately 55 km long and varies from 5 to 8 km wide. The anticline has previously been noticed on Landsat images by Grolier (ref. 16). It is interesting to note that this anticline houses the source of the major oilfield of Qatar.

The ASTP photographs clearly show numerous bright striations in the northern part of the Qatar Peninsula. These parallel streaks are reminiscent of the striations on San Miguel Island off the coast of California (ref. 13, p. 34). The brightest streak in figure 9 occurs between the cities of Al Huwaylah and Al Khawr. Other smaller streaks emanate from the northern and west-central coastlines of the peninsula.

The rocks in this streaked region, locally known as *barr Gatar*, consist of Tertiary carbonate rocks, which are undergoing strong wind erosion (ref. 16). These bright streaks consist of sand blown from the beaches along the northern shores and of particles eroded off the surface of the limestone plateau. The streaks trend north-northwest and taper toward the south-southeast. This direction indicates the trend of particle transport by the dominant northwesterly wind, the *shamal*. Based on field observations by the author, these streaks are the most likely source of the barchan and complex dunes that occur in the southeastern corner of the Qatar Peninsula, south of the capital city of Doha (fig. 9).

The natural color of the ASTP photograph helps to clearly delineate the coastline of the peninsula. It also helps to distinguish various color changes in the surrounding waters, which probably reflect bottom topography. Between Ra's al Bar at the southern tip of the island of Bahrain and Huwar Island west of the Qatar Peninsula, a dark band of water occurs. Its texture and dark color are reminiscent of island wakes (e.g., see fig. 4); however, its nature is not fully understood.

Some of the major features of the city of Doha were depicted in the ASTP photograph. An enlargement (10× the original negative) was made of the area to check the resolution as well as the color sensitivity of the photograph. The result is shown in figure 10. The enlargement clearly shows three circular beltways that ring the city. The Doha International Airport and all the major desert roads to the north, west, and south are clearly distinguished. At this scale (fig. 10), the photograph is useful to city planners. This attests to the color sensitivity as well as the resolution of the original ASTP photographs.

CONCLUSIONS

The ASTP stereostrip of photographs across the Arabian Peninsula shows all its major geologic and structural provinces. The natural color of these photographs enables the recognition of boundaries between the many surface units. It also enables detailed study of lineaments and drainage patterns in the massifs of the Arabian shield on the west, as well as dune patterns in the sandy interior plains.

The ASTP photographs are also useful in updating maps and charts, particularly of the coastal areas. They show that existing charts do not correctly portray the Red Sea islands off the coast of Yemen and their boundaries. Analysis of these photographs also resulted in the recognition of a circular granitic body in northern Yemen that had apparently been overlooked by geological mappers.

Based on the utility of these photographs, it is recommended that future Earth-orbital missions include the acquisition of stereographic, high-resolution photographs in natural color. These photographs will greatly aid in the study of vast desert regions such as the Arabian Peninsula.

ACKNOWLEDGMENT

This research was performed under NASA contract NAS9-13831.

REFERENCES

1. McKee, Edwin D.; Breed, Carol S.; and Fryberger, Steven G.: Desert Sand Seas. Sec. 2 of Skylab Explores the Earth, NASA SP-380, 1977, pp. 5-47.

2. El-Baz, Farouk: The Meaning of Desert Color in Earth Orbital Photographs. Photogramm. Eng. & Remote Sens., vol. 44, no. 1, 1978, pp. 69-75.

3. El-Baz, Farouk; and Mitchell, D. A.: Earth Observations and Photography Experiment MA-136. Sec. 10 of Apollo-Soyuz Test Project Preliminary Science Report, NASA TM X-58173, 1976.

4. Harris, William H.; and Levey, Judith S., eds.: The New Columbia Encyclopedia, Columbia University Press, 1975.

5. Map of the Arabian Peninsula, Scale 1:2 000 000. U.S. Geol. Survey Misc. Geol. Inv. Map I-270 B-2, 1965.

6. Powers, R. W.; Ramirez, L. F.; Redmond, C. D.; and Elberg, E. L., Jr.: Geology of the Arabian Peninsula—Sedimentary Geology of Saudi Arabia. U.S. Geol. Survey Prof. Paper 560-D, 1966.

7. Geological Map of the Arabian Peninsula, Scale 1:2 000 000, U.S. Geol. Survey Misc. Geol. Inv. Map I-270 A, 1963.

8. Muehlberger, W. R.; Gucwa, P. R.; Ritchie, A. W.; and Swanson, E. R.: Global Tectonics: Some Geologic Analyses of Observations and Photographs From Skylab. Sec. 3 of Skylab Explores the Earth. NASA SP-380, 1977, pp. 49-88.

9. Blodget, H. W.; Brown, G. F.; and Moik, J. G.: Geological Mapping in Northwestern Saudi Arabia Using Landsat Multispectral Techniques. NASA TM X-70961, 1975.

10. Earth Photographs from Gemini III, IV, and V. NASA SP-129, 1967.

11. Allison, Lewis J.: Geological Applications of Nimbus Radiation Data in the Middle East. NASA TM X-71207, 1976.

12. Eliason, Eric M.; and Soderblom, Laurence A.: An Array Processing System for Lunar Geochemical and Geophysical Data. Proceedings of the Eighth Lunar Science Conference, Geochim. et Cosmochim. Acta, Suppl. 8, Vol. 1, Pergamon Press, 1977, pp. 1163-1170.

13. El-Baz, Farouk: Astronaut Observations From the Apollo-Soyuz Mission. Vol. 1 of Smithsonian Studies in Air and Space, Smithsonian Institution Press (Washington, D. C.), 1977.

14. Grolier, M. J.; and Overstreet, W. C.: Preliminary Geologic Map of Region East of Sa'dah, Yemen Arab Republic (Landsat-1 Image No. 1117-06553), Scale 1:500 000. U.S. Geol. Survey, Open File Report 76-740, 1976.

15. Philby, H. St. John B.: The Empty Quarter. Henry Holt and Company (New York), 1933.

16. Grolier, M. J.: Interpretation of Landsat Images, Qatar. U.S. Geol. Survey, Open File Report 77-295, 1977.