Temporal Changes as Depicted on Orbital Photographs of Arid Regions in North Africa

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ABSTRACT

Processes typical of arid environments can be monitored from space by comparing orbital photographs taken over a period of years. Using the zoom transfer scope, it is possible to superimpose two photographs and detect changes occurring with time. Oblique photographs can be used, but best results are obtained with vertical or near-vertical photographs.

Changes observed by comparing the 1975 Apollo-Soyuz photographs with data from previous missions include (1) an increase in vegetation west of the Nile Delta of approximately 1108 km^2 in 10 years; (2) an average shift of 2.5 km over a 6-year period in the sand patterns of the Oweinat Mountain region at the borders between Egypt, Libya, and Sudan; and (3) a reduction in the water level of Lake Chad and dune encroachment upon the lake over a period of 9 years.

As a result of this investigation, it is concluded that studies of temporal changes in arid and other regions are facilitated when orbital photographs are vertical and are taken from similar altitudes.

INTRODUCTION

Photographs taken from space enable studies of temporal changes in dynamic processes by documenting these changes on a scale that is not possible in the field. Processes characteristic of arid environments are examined in this paper by comparing photographs taken during the Gemini, Apollo, Skylab, and Apollo-Soyuz missions.

The three processes considered in this paper include the following: (1) land reclamation, specifically on the western margin of the Nile River Delta in northern Egypt; (2) shifts in eolian sand patterns, as seen in the Oweinat Mountain region at the borders between Egypt, Libya, and Sudan; and (3) changes in lake boundaries, as in the example of Lake Chad in north-central Africa (fig. 1).

The comparison of photographs was facilitated by the use of the model ZT-4 zoom transfer scope (Bausch and Lomb). This instrument enables the projection of one photograph onto another, despite differences in obliquity and scale, by optically rotating, stretching, and enlarging the photographs. Only when they are vertical or near-vertical can entire photographs be overlaid. When using two photographs of varying scale and obliquity, it is necessary to continually adjust the photographs from area to area. By superimposing permanent features, it is possible to compare the area surrounding each feature by transposing details from one photograph onto another. The best technique when using oblique photographs is to fix three points, which form a triangle. This procedure will ensure that the transposition is correct in more than one direction. The zoom transfer scope can also be used to make accurate measurements by translating photographic data directly onto maps.

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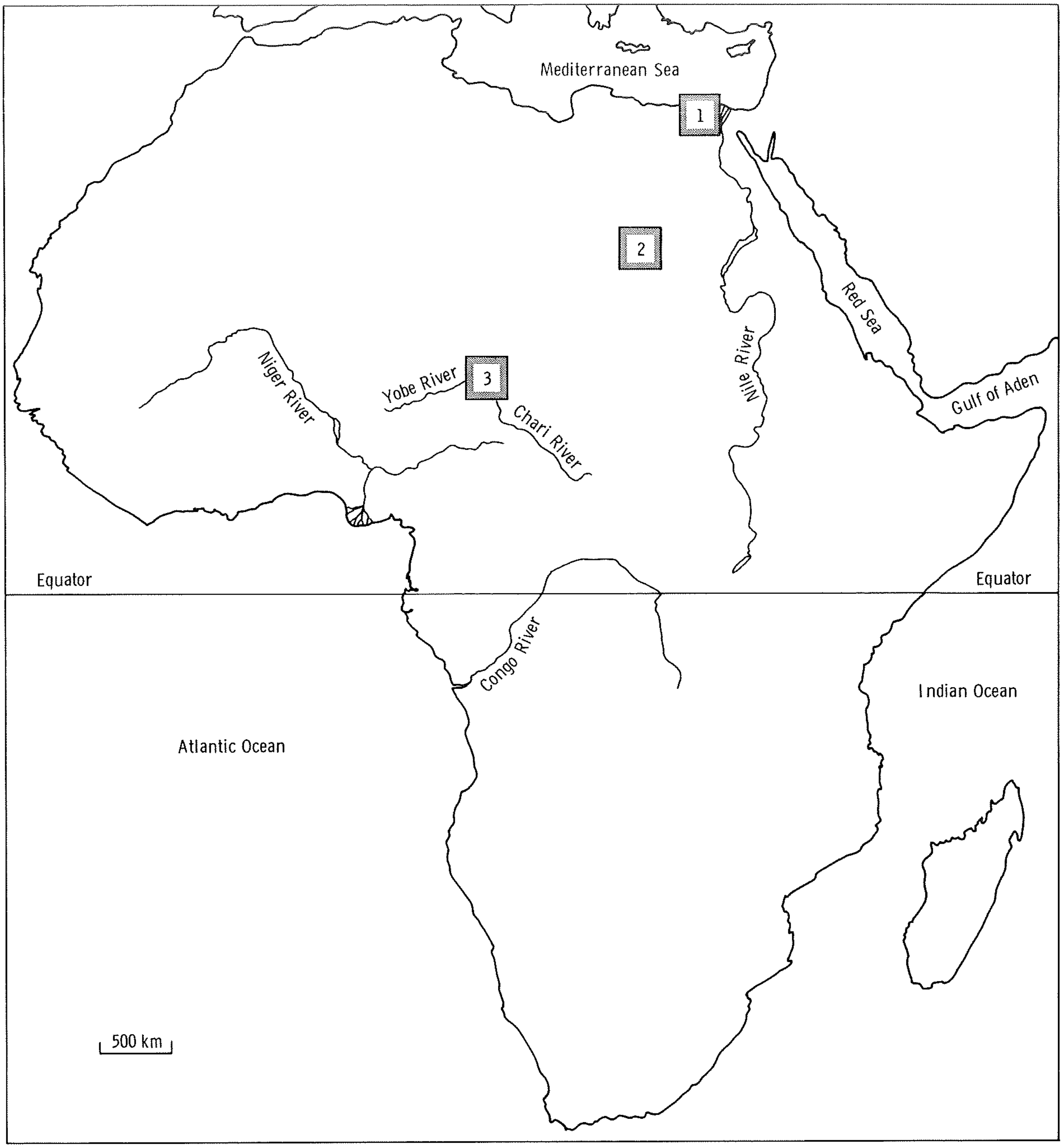

FIGURE 1.—Location of the three areas discussed in this paper: (1) Nile Delta, (2) Oweinat Mountain region, and (3) Lake Chad.

NILE DELTA

The total geographic area of Egypt is 999 735 km². Of this, only 3.5 to 4 percent of the land, or approximately 35 000 to 40 000 km², is under cultivation; the remainder is barren desert. Not all the cultivated land is highly productive, however. In 1968, 20 percent of the cultivated land was degraded by the salinity and alkalinity of the soil and by poor drainage (ref. 1).

The Nile Delta contains 60 percent of the cultivated land of the Egyptian Nile, or approximately 22 000 km^2. The existence of topographically depressed areas within and around the delta, in conjunction with irrigation, silty soil, and relatively small fluctuations in annual temperatures, makes this area suitable for cultivation. In fact, two or even three crops per year can be raised (ref. 2). With a numerically large and rapidly increasing population, one of Egypt's major concerns is food production. Thus, the amount of arable land is of great importance to that country, as it is to other countries with large populations.

In 1964, estimates were made that the scheduled 1970 completion of the Aswân High Dam on the Nile, 860 km south of Cairo, would increase the amount of land suitable for cultivation by approximately 5260 km^2. The dam would also permit the conversion of approximately 2833 km^2 of land from basin to perennial irrigation (ref. 1). The increase in cultivated land was planned to occur mainly in the sandy area west of the delta where more irrigation is necessary than within the delta or along the flood plain of the Nile itself (ref. 2).

The results of this program can easily be seen by comparing two photographs that were taken during the same season: a Gemini V photograph taken in 1965 (S65-45736), whose footprint is shown in figure 2, and an Apollo-Soyuz Test Project (ASTP) photograph taken in 1975 (AST-16-1257). The western margin of the Nile Delta, targeted for cultivation in 1964, was compared in these two photographs.

To overlay the two photographs, features such as the Nile River and roads were used. The outline of the westernmost limit of the vegetation was traced from the ASTP photograph onto the Gemini photograph (fig. 3). A significant amount of desert plain has been reclaimed and cultivated to varying degrees during the 10 years separating the two photographs. There are three distinct areas of vegetation increase: (1) the southernmost area, which is a thin zone parallel to the previously cultivated land, with approximately 186 km^2 of increased vegetation; (2) the central area consisting of two broad zones, with approximately 732 km^2 of increased vegetation; and (3) the northernmost area characterized by linear belts of vegetation that parallel the coast of the Mediterranean Sea, with an increase in vegetation of approximately 190 km^2.

The total increase in vegetation west of the Nile Delta is 1108 km^2. This represents approximately 111 km^2 per year of land reclaimed from the desert. It does not take into account vegetation, such as that marked with an "X" on figure 3, which appears sparse in the 1965 photograph and has grown more dense in the 1975 photograph.

This example shows that orbital photographs can be used to monitor and document the amount of land being denuded, being cultivated for the first time, or being rendered more fertile; and they can also be used to monitor the processes of desertification as well as land reclamation.

OWEINAT MOUNTAIN REGION

The Oweinat Mountain region is located at the boundaries of Egypt, Libya, and Sudan (fig. 4). This region is dominated by Precambrian or slightly younger mountains formed by ring-dike-type intrusions composed mainly of granites, syenites, and monzonites (refs. 3 and 4). Gebel Oweinat, 1934 m high, and Gebel Arkenu, 1435 m high, form the highest topographical barriers to the wind in this region, followed by Gebel Babein, 1104 m high, and Gebel el Bahri (fig. 4).

Between these mountains are streaks of wind-deposited active sand that is lighter in color than the rest of the region. Darker areas are presumed to be windswept zones and/or higher ground. South of Gebel Oweinat and Gebel Arkenu, where the deposition of the sand is not constrained by the mountains, the sand streaks become subdivided into individual seif dunes separated by areas of desert pavement.

This region was analyzed in an effort to determine the temporal changes that may have occurred between the time that an Apollo 9 photograph was taken in 1969 and the time ASTP photographs were taken in 1975. Special attention was given to sand streaks between the mountains to determine whether they had shifted laterally and whether the seif dunes south of the mountains had migrated in the direction of the prevail-

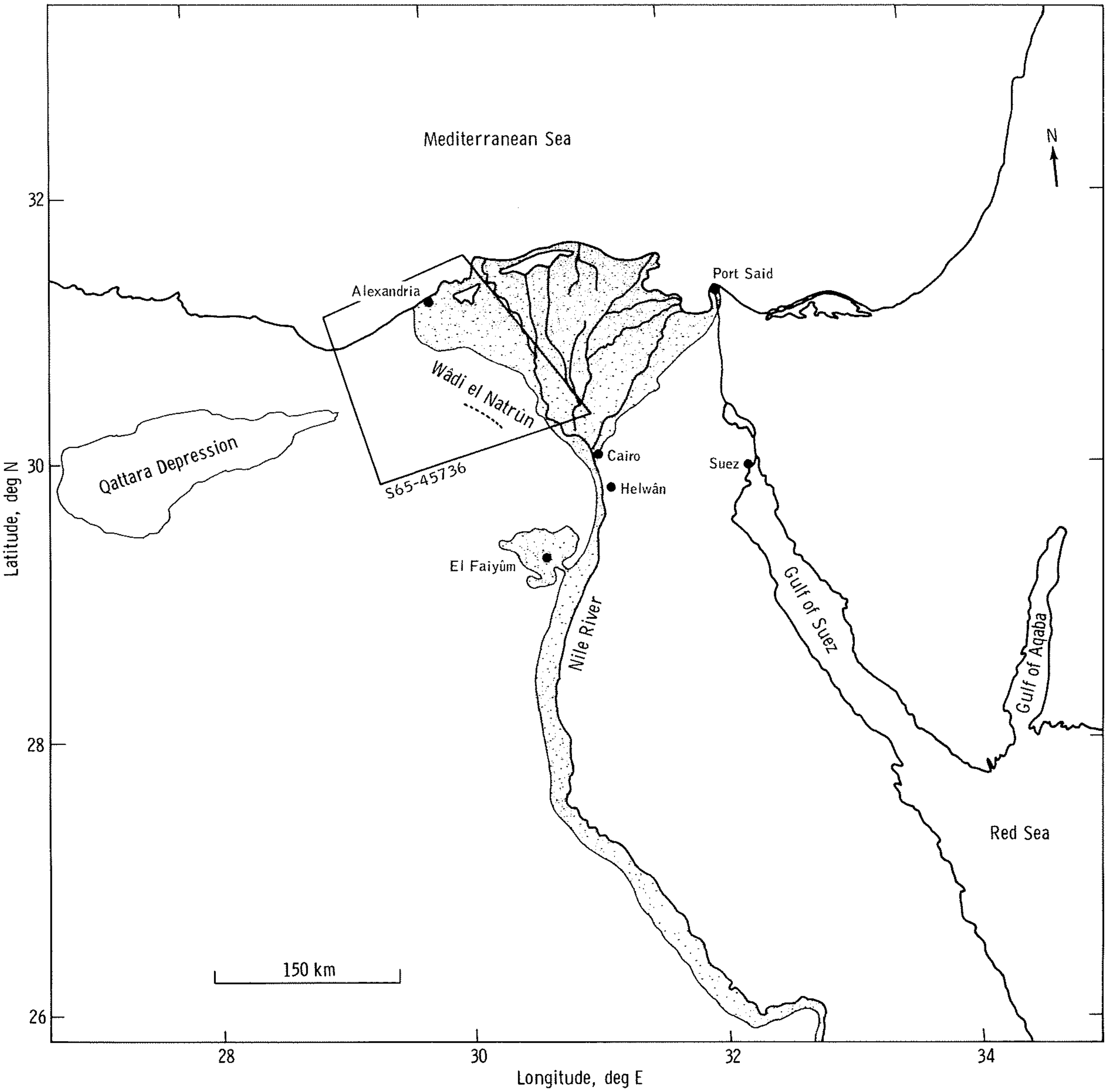

FIGURE 2.—Ground coverage of Gemini V photograph S65-45736 (fig. 3), west of the Nile Delta.

ing wind. In each instance, distances were measured.

The analysis consisted of transposing ASTP photographs AST-2-126, AST-2-127, AST-2-129, and AST-2-130 onto different sections of Apollo 9 photograph AS9-23-3533 and tracing the outlines of the 1975 sand streaks onto the 1969 photograph (fig. 4). The mountains were used as reference features in superimposing the photographs.

The orientation of the sand streaks is controlled by the prevailing north-northeasterly winds and by the deflecting influences of the mountains. North of Gebel Arkenu and Gebel Oweinat, the sand streaks are oriented north-

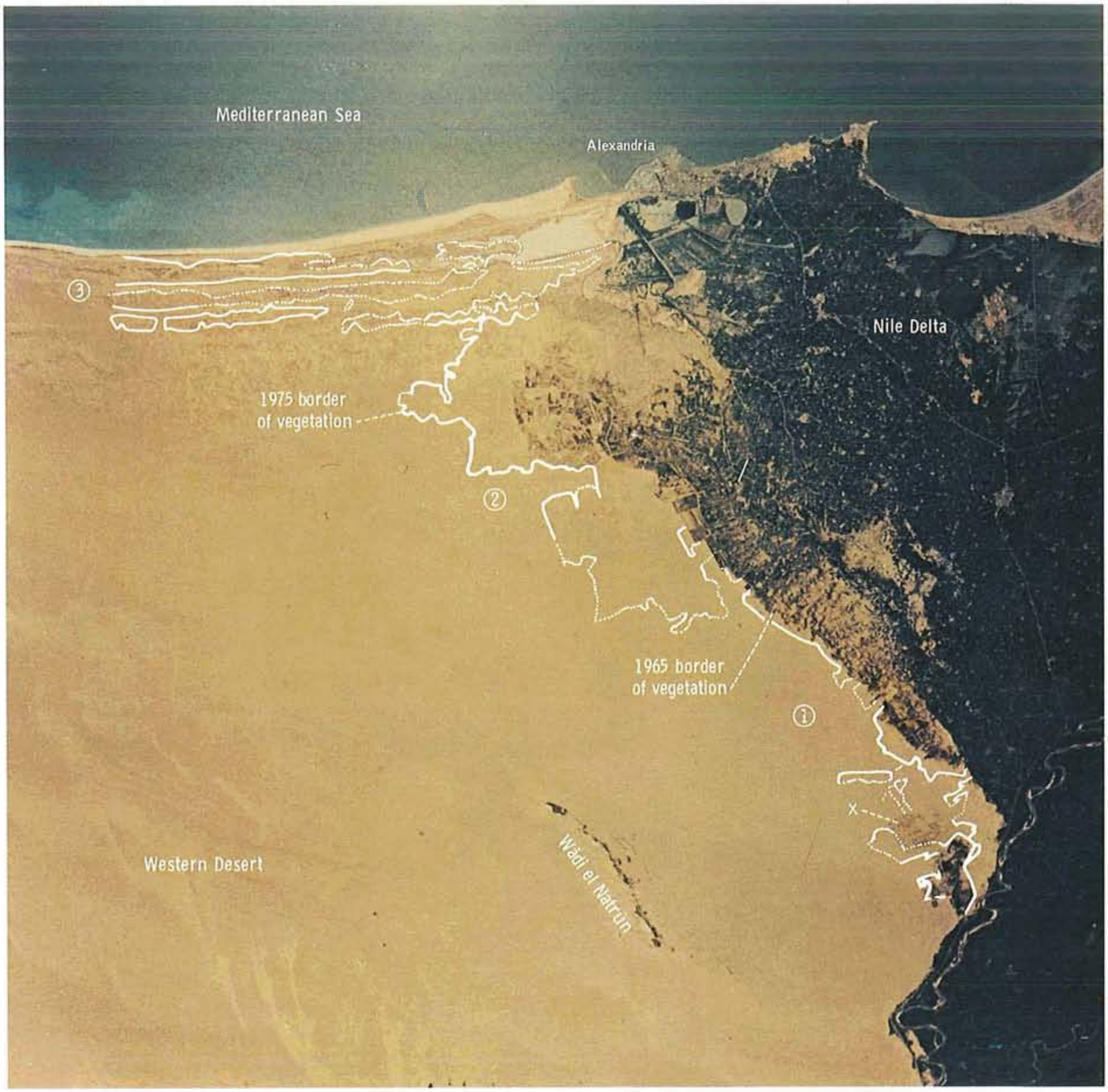

FIGURE 3.—Increase in vegetation at the western edge of the Nile Delta in 10 years. Drawn on Gemini photograph S65-45736 from ASTP photograph AST-16-1257. Dotted lines indicate sparse vegetation; solid lines represent dense vegetation. At area "X," vegetation appears denser in the 1975 photograph.

northeast to south-southwest, rotating to an east-northeast to west-southwest trend exhibited by the seif dunes south of the mountains. This is due, in part, to the general clockwise rotation of the prevailing wind direction and to the channeling of the wind between the mountains as illustrated in figure 4. Sand is deposited on the lowest ground between the mountains and on their windward slopes. Active sand is not found on the lee sides of the mountains; the leeward slopes are probably free of sand because of the lack of deposition.

In places such as the region directly west of Gebel Arkenu, the sand streaks consist of short, discontinuous longitudinal dunes, presumably

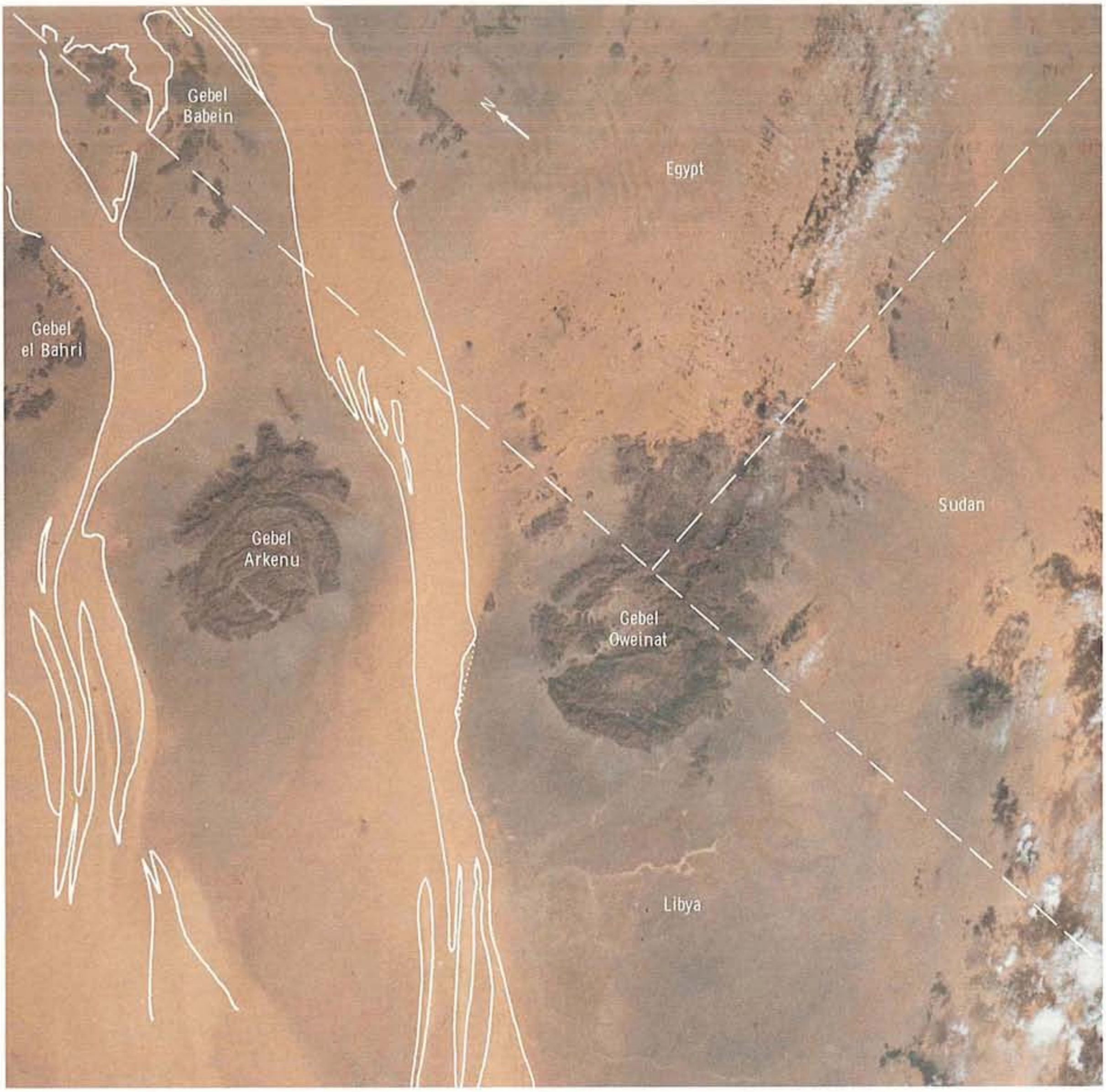

FIGURE 4.—Sand-streak boundaries transposed from 1975 ASTP photographs onto 1966 Apollo 9 photograph AS9-23-3533.

derived from fragmented seif dunes. This pattern of disrupted seif dunes also occurs to the southwest of Gebel Oweinat and appears to be characteristic of areas in which seif dunes meet a major obstacle (ref. 5).

From 1969 to 1975, it appears that consolidation of these longitudinal dunes occurred, as shown by the line drawn at "A" on figure 5, in which changes documented by the photographs are summarized. This line was easily seen on the ASTP photographs but could not be drawn on the Apollo 9 photograph. Dune consolidation is presumed to have occurred, thereby delineating the boundary between desert pavement and sand more clearly on the ASTP photographs than on the Apollo 9 photograph.

For the most part, the sand streaks of the Oweinat Mountain region have not been displaced. However, there are sites at which differences can be seen. These are marked as "B," "C," "D," "E," and "F" on figure 5. At site B, the southern end of the seif dune has migrated 3 km to the northwest. The southern end of the dune at site C has also migrated to the northwest, but by 4 km, and at site D, the northern end of the dune has shifted to the northwest by 2 km. Site E presents a different situation in which the southwestern boundary of a sand streak has shifted 1 km to the north-northwest. At site F, the northern end of the seif dune has migrated 2.5 km to the southwest. Because the prevailing wind direction is to the southwest, the northwestern dune shifts can possibly be attributed to wind deflection by the mountains.

The average shifting distance of dunes in the Oweinat Mountain region is 2.5 km in 6 years, which is more than 400 m per year. This rate is higher than that estimated for longitudinal dunes in the northern part of the Western Desert of Egypt. In the latter area, comparison of ASTP and aerial photographs taken 22 years apart showed a southerly shift of 5.7 km, which is 260 m per year (ref. 6). However, it must be stated that the photographs covering the Oweinat Mountain region were particularly difficult to work with. When alining different features on the zoom transfer scope, equivalent results were not always obtained. The temporal change measurements discussed earlier represent the best results possible, but these should be viewed in light of the difficulty in transposing the photographs.

As illustrated by the example of the Oweinat Mountain region, orbital photographs can be used to observe temporal changes in patterns of sand distribution. Distances covered by these changes can be measured with reasonable accuracy, provided that the resolution of the photographs allows such measurements to be made.

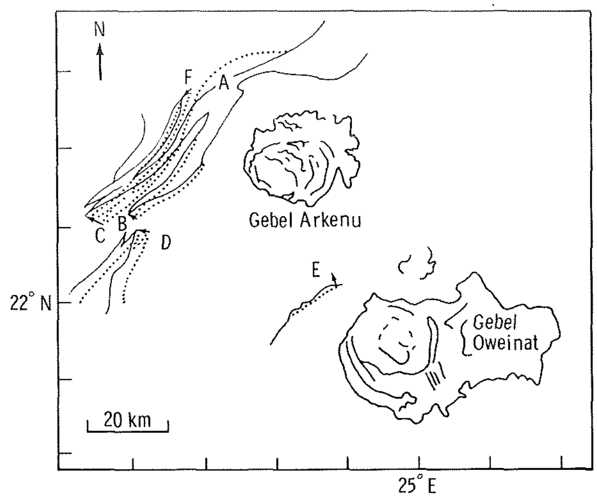

FIGURE 5.—Summary of sand boundary shifts over a 6-year period in the Oweinat Mountain region. Solid line outlines 1975 sand boundaries, dotted line indicates 1969 boundaries. Arrows at sites B, C, D, E, and F show the direction of sand movement.

LAKE CHAD

Lake Chad is situated at the junction of the borders of Niger, Nigeria, Cameroon, and Chad in north-central Africa (fig. 6). It is elongated in a northwest-southeast direction and consists of two basins partly separated by a barrier of sand dunes.

Lake Chad is extremely shallow, with the deepest water, 4.5 m, occurring in the northern basin (ref. 7). Sand dunes are irregularly distributed throughout approximately 85 percent of this basin. The dunes are elongate in shape and trend in a northerly and north-northwesterly direction. They have been measured to be less than 3 km in length (ref. 7). Sand dunes also form the eastern boundary of the southern basin.

Two rivers flow into Lake Chad. The Chari River supplies approximately 95 percent of the total fluvial discharge into the lake of 800 km^3 per year. The remaining 5 percent is supplied by the Yobe River (ref. 8). Rainfall adds approximately 80 km^3 to the lake annually (ref. 7).

Because no river outlet exists for the lake, water loss is due primarily to evaporation and secondarily to infiltration. The amount of water entering and leaving the system is not in equilibrium, resulting in fluctuations of water depth and lake boundaries. For example, from 1963 to 1971 the average level of the lake dropped by 2 m. Over a 3-year period of observation, the average volume decreased by 13 percent (ref. 8). Other factors contributing to the decrease in size of Lake Chad include the influx of sediment from the Yobe and Chari Rivers and of sand from the Sahara Desert (ref. 9).

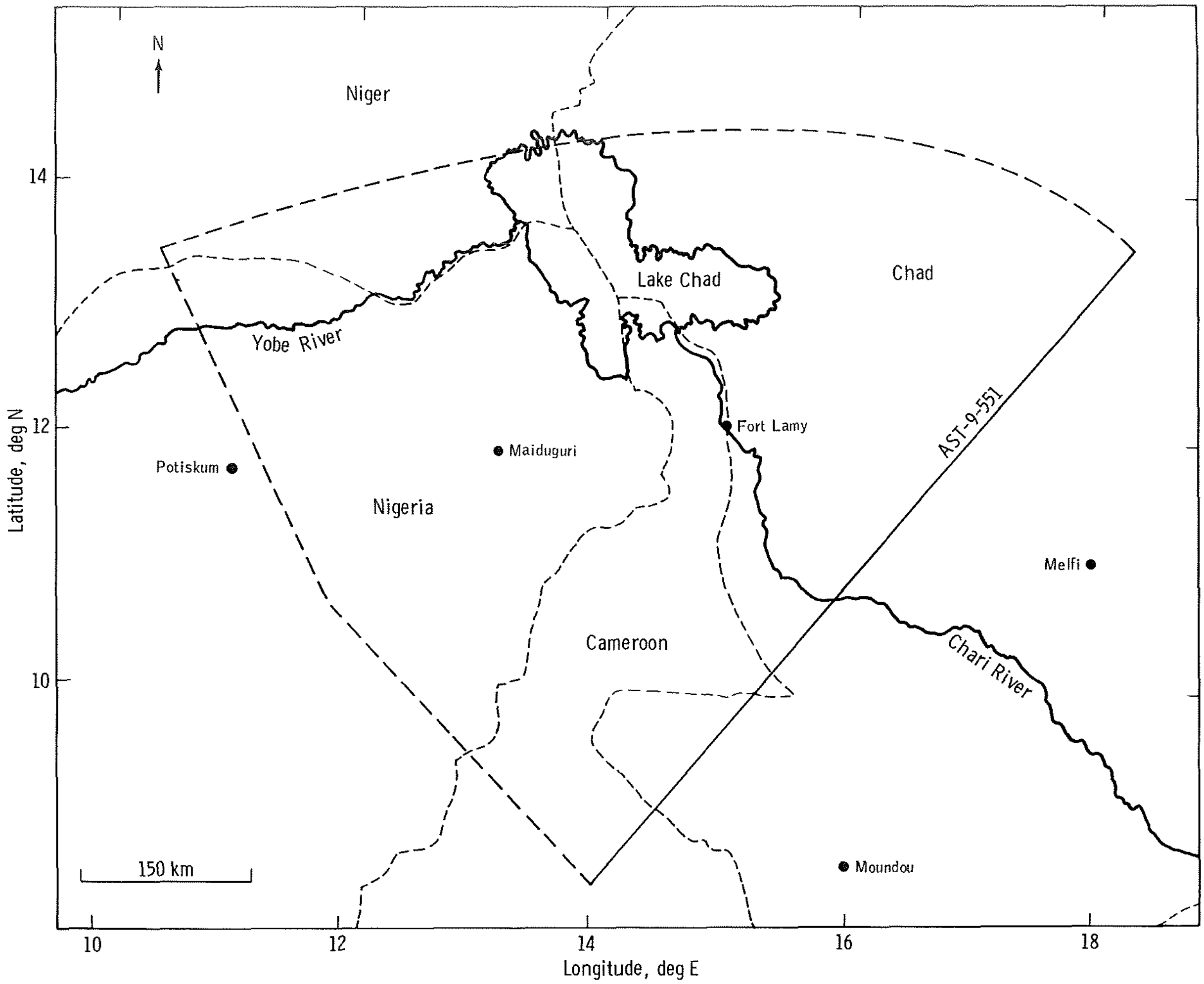

FIGURE 6.—Sketch showing the location of Lake Chad and the areal coverage of ASTP photograph AST-9-551.

An enlargement of ASTP photograph AST-9-551, taken in July 1975 (fig. 7(a)), and Gemini IX-A photograph S66-38444, taken in June 1966 (fig. 7(b)), were compared. Emphasis was placed on visible changes in Lake Chad as a result of the increasing aridity of the environment. Two main problems were considered: (1) Are there changes in the areal extent of dune fields in and around Lake Chad and have specific dunes migrated into it? (2) Is a change in water level visible and, if so, could this be due to dune encroachment upon the lake?

Because of the extreme obliquity of the ASTP photograph, the subsequent distorted geometry of Lake Chad, and the lack of relatively permanent features, the ASTP photograph could not be directly superimposed onto the Gemini IX-A photograph. Therefore, the comparison was made by constant referral from one photograph to the other, aided by Skylab 4 photographs SL4-194-7253 and SL4-138-3785 and Gemini VII photographs S65-63970 and S65-63969. Areas of noticeable change between 1966 and 1975 are marked on both figures 7(a) and 7(b) for easy comparison.

At site 1 (fig. 7(b)), two dune fields on the southeastern boundary of the lake are seen to be submerged. By 1975, these dune fields are the same color as the surrounding desert (fig. 7(a)) and have therefore emerged above the level of the

FIGURE 7.—Lake Chad. (a) Enlargement of the 1975 ASTP photograph AST-9-551 showing the northern and southern basins of Lake Chad. (b) The northern part of Lake Chad as depicted in Gemini IX-A photograph S66-38444, taken in 1966.

water. This clearly indicates a reduction in the water level of the lake since 1966. Another example of this phenomenon is seen at site 2 (figs. 7(a) and 7(b)), the east-central side of the lake, where the boundary between dunes and water is not as clearly defined in the ASTP photograph as it is in the Gemini photograph. Immediately west of this boundary, previously submerged dunes have appeared above the surface of the water in the 1975 photograph.

At site 3 (fig. 7(b)), the dunes within the northern basin in the Gemini photograph are largely submerged and appear to cover only approximately 60 percent of the basin as opposed to emerged dune coverage of approximately 85 percent in the ASTP photograph (fig. 7(a)). Several Gemini photographs were examined and none revealed the presence of submerged dunes as far to the west and southwest in the northern basin as seen in the ASTP photograph, although their presence could be hidden by the deeper water depicted in the Gemini photograph. The greater occurrence of dunes in the ASTP photographs could be attributed to the emergence of previously submerged dunes or to dune migration.

From June through September, the prevailing wind direction in the Lake Chad region is to the southwest, whereas from October through January, it is to the north and northeast (ref. 7). From the photographs, the dominant wind direction appears to be to the southwest. Dune migration would be facilitated by the gradual reduction in water level over time.

A second example of the effects of dune migration on Lake Chad can be seen at the northern and northwestern boundary of the lake, site 4 (fig. 7(b)). This boundary is very sharply defined in the Gemini photograph. Because it is not clearly visible in the ASTP photograph, Skylab photograph SL4-138-3785, taken in the winter of 1973, was used for clarification and comparison. In this photograph, the boundary appears encroached upon by sand dunes, thereby giving it a crenulated appearance. The sand dunes have caused the water at this site to recede 48.3 km in the past 30 years (ref. 10).

Parallel to the northwestern shoreline of the lake, at site 5 (fig. 7(a)), a blue line is clearly visible in the ASTP photograph. This line is not seen on the Gemini photograph. Therefore, it appears plausible that this line represents a former shoreline of the lake, existing at the time that the Gemini photograph was taken. By 1975, the areal extent of Lake Chad had diminished, leaving this line as evidence of its once greater extent.

From orbital photographs, a reduction in the water level of Lake Chad is clearly visible. Evidence consists of the emergence of previously submerged dunes and the presence of a former shoreline. Field studies of Lake Chad have shown that the lowering of the level of the lake is due to the decrease in both fluvial discharge and rainfall, which reflects the increasing aridity of the environment (ref. 7). Analysis of orbital photographs also suggests dune migration into the lake, especially in the northern basin. Because of the altitude at which these photographs were taken, particularly the ASTP photograph (fig. 7(a)), the resolution was not conducive to a detailed study of the migration of individual dunes.

CONCLUSION

As the three examples cited in this paper indicate, photographs taken from Earth orbit are valuable in monitoring changes within a given area over a period of years. For maximum benefit, vertical photographs taken from similar altitudes should be used. However, oblique photographs from varying altitudes can be useful if comparisons between photographs are done carefully.

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