DISCRIMINATION OF SAND TRANSPORT RATES AND ENVIRONMENTAL CONSEQUENCES IN CENTRAL EGYPT FROM SPOT DATA

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ABSTRACT

Three SPOT images from the largest longitudinal dune complex of the Western Desert of Egypt have been used to discriminate zones of sand infringement on agricultural and other inhabited regions, and to document dune migration rates over a 14-year period. In the Bahariya region, increased use of active sand surfaces for agriculture is observed, as well as the development of vegetation wind breaks to stabilize sand within a village. The northern part of the Ghard Abu-Muharik dune complex consists of individual longitudinal dunes that shift in response to seasonal wind directions, as shown by comparison of 1986 SPOT data with Landsat images from 1972 and 1984, and air photographs from 1944. At the resolution of the orbital data, no lengthening of the individual dunes is observed. In the central part of the Abu-Muharik, spectral reflectance differs between the active, lighter-toned western dunes, and the more stable, redder seifs of the eastern part of the complex. Such differences are consistent with observations of active dune movement in the west, and relatively stable dunes in the east. The southern terminus of the dune complex consists of individual barchan dunes that migrate southward through the Kharga depression. Here, dune movement of 60-220 m was measured by coregistration of SPOT and 1972 Landsat MSS data. Continuing analysis of spectral reflectance from multiyear data will aid in distinguishing rates of transport, as well as those areas prone to sand encroachment.

INTRODUCTION

Ground based studies of desertification and surface destabilization in arid regions have in the past been based primarily on a few select inhabited regions where observers have been able to document surface changes in the field. Such studies commonly result in estimates of erosion and deposition rates in areas where human influences on sand movement are greatest. In order to study sand transport and surface characteristics in environments unaffected by human intervention, as well as inhabited areas within the same transport zone, we have investigated three regions in central Egypt utilizing data from the SPOT satellite, and retrospective data from Landsat and other sources. Within the Western Desert of Egypt, the lack of significant cloud cover, dearth of vegetation, and relatively simple geologic setting provide an ideal location for the study of arid landforms and processes from an orbital perspective. We have utilized SPOT data by comparing it with lower resolution Landsat data taken 14 years earlier in order to determine changes both in the shape and morphology of dunes, as well as the patterns of land use within the oases.

This study concentrates on the longest complex longitudinal dune in the Western Desert, which affects two oases, Bahariya and Kharga. From its origin just north of the scarp which bounds the northern edge of the Bahariya Oasis,

the Ghard Abu-Muharik crosses several facies of the Eocene limestone, and continues 400 km to the south to the northern scarp of the Kharga Oasis. In the Kharga region, the dune breaks up into individual barchans and loses its continuity as a single entity, although the pattern of sand transport is still evident from streaks of active sand and individual barchan dunes. The dune is ideally suited to the study of spatial and spectral variations, because it is superimposed on one dominant lithology (limestone) throughout its length, which appears distinctly different in spectral reflectance from the quartz sand of the dune.

Three areas along the Ghard Abu-Muharik were studied: the northern region near the village of El-Harra in the Bahariya depression, a central region where longitudinal, transverse, and individual barchans are present, and the southern tip of the dune complex where the dune has broken up into individual barchans in the Kharga Oasis (Figure 1). Results reported here concentrate primarily on spatial variations of active dune sand observed by comparison with retrospective data from 1972 and 1973 (Table 1). Analysis of spectral reflectance variations is in progress and will be submitted for publication at a later date.

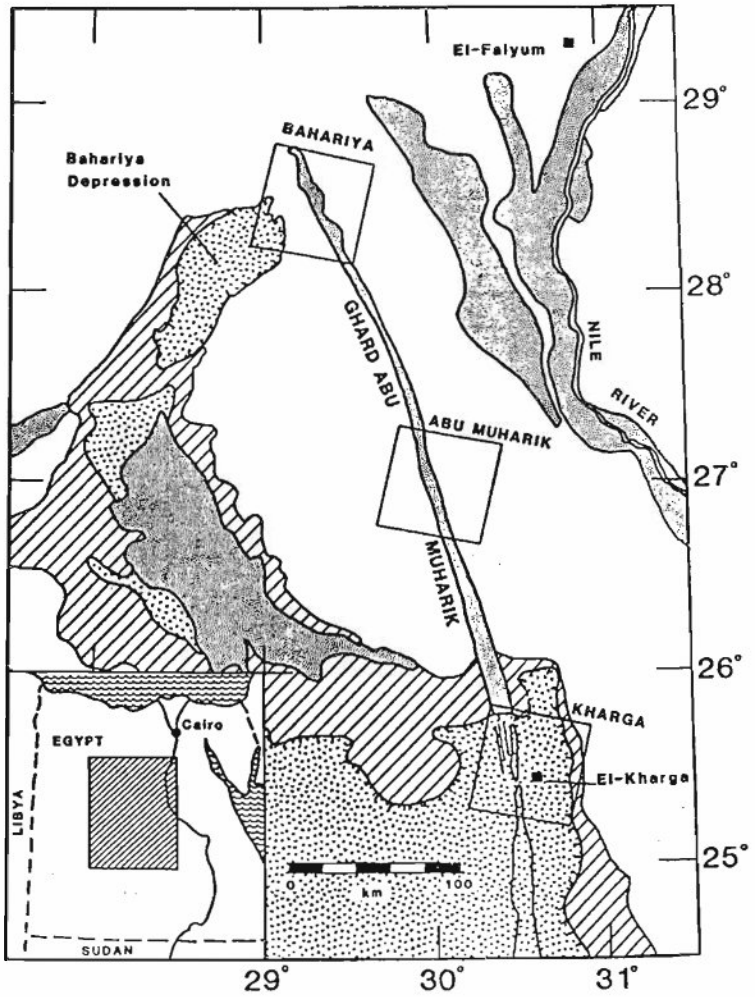

Figure 1. Index map of central Egypt showing location of the Abu-Muharik dune, the three study sites chosen for SPOT scenes, and regional geologic units. Patterned areas are Cretaceous clastic deposits, Quaternary sand, and floodplain deposits of the Nile River. White areas consist of Paleocene gravels and Eocene limestone.

Table 1. Scene dates used for multi-temporal coverage of the Abu-Muharik dune system.

	RETROSPECTIVE SCENES	SPOT SCENES
Bahariya Depression	9/19/72	8/9/86
Abu-Muharik Dunes	1/4/73	9/4/86
Kharga Oasis	11/10/72	8/25/86

Geometric correction and registration with retrospective scenes was performed with a combination of field control points (for the Bahariya scene), and control points derived from the SPOT data. Field control in Bahariya was obtained using satellite navigation locations obtained during a 1985 field trip. The Abu-Muharik and Kharga scenes were registered by using control points from the SPOT data, and correcting the older Landsat scenes into the SPOT coordinate system. The Landsat MSS data originally obtained at 80 m spatial resolution were resampled to 20 m resolution to match the SPOT data using bilinear interpolation. The accuracy of the geometric correction varies from 20 m to 200 m between different scenes, and in addition to the inherent error of locating definable control points on the lower resolution scenes, the correction is subject to error because of the difficulty of picking points for which no changes can be expected over the 14 year period.

BAHARIYA DEPRESSION

The northernmost scene covers the eastern part of the Bahariya Depression, a NE-SW elongate depression floored by Cretaceous sandstone and shale. This region provides an ideal location for observing temporal variations in a hyperarid environment, because of the availability of remote observations dating from 1944, the relative ease of accessibility for field work, and the presence of agricultural settlements, which allow observations on the human aspects of coexistence with the active desert. The village of El-Harra lies in one of the sand transport corridors, situated because of the near-surface groundwater table. Field trips between 1978 and 1985 indicate that despite the continual encroachment of sand from the north, the village is growing by emplacement of wind breaks (dried natural vegetation) and cultivation of crops on the dune sand. Additional changes detected between 1972 and 1986 images are the result of increased agricultural land use and its effects on the pattern of evaporite deposits at the southern margin of the cultivated zone. A vegetation barrier that blocks the north-to-south transport of sand was completed between 1972 and 1986, helping to protect the dune sand within the central oasis from further movement. As depicted in the SPOT image, the dune sand within the central oasis has an apparent lower albedo than the active sand infringing on the northern windbreak. In addition, individual fields that could not be detected with Landsat can now be discriminated, as well as the extent of cultivation within each field. The areas of evaporite deposits south of the oasis have an apparently higher overall albedo in the 1986 SPOT scene than in the 1972 Landsat scene, despite a similar time of year for acquisition of both scenes (August and September, respectively). One possibility for this change is that the higher albedo is due to increased evaporation resulting from increased groundwater usage, although the conversion to absolute reflectance (less atmospheric variations) is still under investigation.

Northeast of the depression, the El-Ghorabi dunes provide an opportunity to examine an area of active sand transport not influenced by human activity. In this area, comparison of a SPOT image with a Landsat Thematic Mapper image taken two years earlier suggests that eastward transport of the longitudinal dune has dominated. However, we have supplemented this study with air photos taken in 1944, as well as additional Landsat images taken in 1972 and 1984, which indicate that seasonal effects dominate the growth and movement of the dunes (Maxwell, 1987). The dominant N-NE wind during the winter months (October-March) reverses during the summer, and creates a zone of sand cover extending several kilometers on the downwind side of the dune. A broader zone of sand cover is evident on the SPOT image at the eastern edge of the depression as a distinct zone of brightening in the interdune areas. Elongation of the longitudinal dunes is not apparent, even over the 42-year record of remote sensing data for the region.

Farther to the east in the same scene, the Ghard Abu-Muharik sand dune, one of the longest linear dunes in the world, originates at the latitude of the Bahariya Depression. At its northernmost tip, the dune covers Pliocene gravel deposits, but starting 10 km farther to the south, it crosses Eocene limestone for most of its 400 km length. As noted in the field, eroded fragments of the nummulitic Eocene limestone are present on the flanks of the dune, but are rarely found on the central, more active portions of the dune. The Abu-Muharik is distinctly brighter than counterpart longitudinal dunes that are present in mixed Pliocene and Eocene deposits farther to the east. We interpret this brightening to be due to cover of the local limestone being incorporated into the dune sand, and are presently determining the extent of the limestone cover utilizing SPOT data.

ABU-MUHARIK

South of Bahariya, the Abu-Muharik breaks into individual barchans on the western flank, but retains belts of linear seif dunes on the eastern side. Interdune sand on the eastern side of the complex is distinctly redder in color than the active sand of the sharp-crested seifs or the individual dunes on the western side. Such a coloration suggests a more stable environment than the western part of the dune complex. Comparison of the January 1973 Landsat scene with the September 1986 SPOT scene reveals surprisingly little variation in the location of individual seifs or the distribution of active sand on the eastern side of the dune complex. Individual seifs coregister to within 1-2 pixels, and expanses of dark interdune lag surfaces have the same boundaries in 1986 as they had in 1972.

In contrast to the eastern side of the Abu-Muharik, the western side of the complex is composed of individual barchans and barchanoid dunes that overlie dark, relatively sand-free surfaces of lag deposits. The sand here is whiter in color that that of the eastern dune complex, and the movement of dunes is evident in images composed using multiyear data.

Ongoing work is planned to document the changes in spectral reflectance both between the western and eastern sides of the dune complex, and between the same surfaces seen at the two acquisition dates. These preliminary results suggest that the eastern, redder portions of the dune are more stable, consistent with the lack of movement noted for the seifs. The active sand of the western side of the dune complex most likely owes its lighter color to continued abrasion of iron-rich coatings, although it is also possible that limestone fragments may constitute a larger portion of these active dunes. Field investigations are planned for the spring of 1988 to test these hypotheses.

KHARGA OASIS

The third SPOT image covers the Kharga Depression at the southern end of the Abu-Muharik. Sand from the dune enters the depression from the northern scarp, and forms both N-S sand streaks on the floor of the depression as well as individual barchan dunes, which parallel the prevailing winds from the north (Beadnell, 1909, 1910, Strain and El-Baz, 1982). The Kharga Oasis region is one in which dune movement seriously affects the future agricultural use and settlement patterns, and increased resolution from SPOT panchromatic and multispectral data allows more precise estimates of dune movement than have been previously possible using orbital data.

Previous studies of dune movement in Kharga based on field and airphoto analysis have suggested movement ranging from 10 m to 100 m per year depending on dune size (Beadnell, 1910, Embabi, 1982, and Ashri, 1973). For this study, a Landsat scene acquired in 1972 was digitally registered to a SPOT multi-spectral scene of the same area from 1986. To confirm the accuracy of the registration, permanent features on both images were compared and a north-south error no greater than 2 pixels (40 m) was found. Some larger east-west errors were noted in localized areas.

The movement of 34 individual barchans located in dune belts west of the Oasis of Kharga was measured on the composite image. Dunes selected were those for which the 1972 and 1986 outlines could be delineated relatively clearly and distinguished from surrounding, often overlapping, dunes. The dunes ranged in size from roughly 80-380 m along the longitudinal axis (i.e., length in plan view from northernmost edge to slip face) and from 100-400 m wide (maximum width perpendicular to wind direction). The dune motion over the nearly 14 year time span ranged from 60-220 m to the south. Annual movement was from approximately 4 to 16 m with an average rate of about 10 m south per year.

A strong correlation between dune size in various dimensions and rate of movement throughout the study area was not found. Although previous workers have noted such a correlation, their measurements were generally made in localized areas of the depression where sand flow may have been relatively constant. By providing a broader view of the area, the satellite images allow study of regions over which conditions of sand flow and other environmental factors will vary.

Comparison of the two images provided rates of dune movement that are within the range of previous studies, but that are not limited to small field sites. The use of satellite images spanning the 15-year time period now available allowed these relatively slow but continual changes to be monitored. The process was subject, however, to certain limitations, such as localized errors in image registration, elimination of the smallest dunes which could not be resolved by the satellite sensors, and the inability to sharply delineate all dune boundaries on the lower resolution 1972 image. The finer resolution of the 1986 image enhanced the ability to make detailed measurements and will improve the effectiveness of such studies when available over comparable time periods.

CONCLUSIONS

1) Cultivation of active sand transport zones in the Bahariya depression has increased over the 14 years observed by remote sensing data. As depicted by SPOT data, windbreaks composed of vegetated fields are helping to inhibit active sand transport into the fragile oasis environment.

2) The increased size of an evaporate pond between 1972 and 1986 is consistent with utiliziation of the oasis, and has an apparent higher reflectance due to increased salinization of the soil, although absolute reflectance values have not yet been derived.

3) At the upwind end of the Abu-Muharik dune complex, seasonal effects dominate the appearance and disappearance of a thin sand cover that occurs lateral to the dunes, and no net elongation of individual dunes is apparent.

4) Spectral reflectance in the central part of the Abu-Muharik is consistent with spatial changes of the dunes. The western part of the system is composed of individual dunes that have changed position in 14 years, whereas the eastern part is composed of redder-appearing sand and individual seif dunes that have not moved.

5) Measurements of barchan dunes in the Kharga depression indicate an average rate of 10 m/yr southward migration, and in contrast to previous studies no correlation with other dune dimensions is apparent using orbital data.

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