SEMIANNUAL REPORT ON CONTRACT NAS5-28774

"Environmental Processes and Spectral Reflectance Characteristics Associated with Soil Erosion in Desert Fringe Regions."

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October 20, 1987

(NASA-CR-182332) ENVIRONMENTAL PROCESSES AND SPECTRAL REFLECTANCE CHARACTERISTICS ASSOCIATED WITH SOIL EROSION IN DESERT FRINGE REGIONS (National Air and Space Museum) 28 p Avail: NTIS HC A03/MF A01

N88-13811

Unclas
G3/43 0114229

ENVIRONMENTAL PROCESSES AND SPECTRAL REFLECTANCE CHARACTERISTICS ASSOCIATED WITH SOIL EROSION IN DESERT FRINGE REGIONS

1.1 Introduction

Both data acquisition and analysis have continued through the past year as data have been acquired. Dune migration measurements have begun in the active dune environment site (Bahariya, Egypt), and data analysis is in progress for both spectral baseline development sites (the Tombouctou and Okavango field areas). Taken in sequence, these three study areas form an environmental series encompassing active aeolian processes, active desertification, and (as yet) stabilized vegetation and soil development processes in desert fringe dunes. Thus far, our baselines extend over a few months and our conclusions are thus preliminary; however, trends in the data are beginning to emerge.

TM data provide the foundation for baseline development concurrent with field measurements in all three environments. In order to establish where these baseline trends fit in the context of longer-term study, we have added archival MSS data to the study, as noted in prior reports. Some of these MSS images were in hand, having been acquired for different programs of study; because of the importance of long-term vegetation changes to our understanding of the stabilized dune environment, an additional MSS scene was acquired of the Okavango study site. In addition, to further constrain TM spectral variations by detailed mapping in the spatial domain, SPOT data have been acquired for dune mapping in Bahariya as a project supported by the PEPS program (Programme d'Évaluation Préliminaire SPOT), the objectives of which dovetail with our TM work. SPOT data of Tombouctou will also be forthcoming as part of the joint NASA-CNES agreement this year. The combination of SPOT panchromatic band spatial detail, together with the spectral resolution and repetitive coverage afforded by our TM data, provide an exciting opportunity to merge the two datasets for maximum benefit in surface processes studies.

Preliminary analysis of the data in hand, together with completion of phase 1 field work for all three sites, have provided a sufficient base to begin to address the following objectives of the Environmental Processes study: 1) to establish morphologic criteria for stabilized duneforms; 2) to track color and brightness changes through time for homogeneous, field-characterized intensive study sites; 3) to develop criteria for discrimination between seasonal and aperiodic spectral changes; and 4) to begin to draw some conclusions about the processes inherent in dune stabilization and destabilization.

2.0 <u>Progress</u>

2.1 Bahariya Depression, Egypt

Last year we reported on analysis of migration and vegetation interactions on an irregular sand mass within the Bahariya Depression, and on the interactions between this sand body and the oasis into which the sand is encroaching. Our studies since then have concentrated more fully on the linear dunes of the Ghard el-Ghorabi on the eastern rim of the Depression (Figure 2.1.1).

The El Ghorabi dunes are characteristically complex linear duneforms with well-defined, lag-covered but largely sand-free interdune corridors. This active dune system forms the hyperarid end-member of the environmental study, and was chosen as a means of constraining the spectral and spatial character and rate of movement on linear dunes unencumbered by vegetation or moisture. Although Landsat data are available for the past fourteen years, the rates of movement for large linear dunes are much slower than can be detected during this time interval. Therefore, aerial photographs taken in the 1940's have been used over the past year, in combination with MSS data from 1972 and 1984, TM data from 1984, and 1986 SPOT data, to study dune movement and spectral variation in the El Ghorabi system.

Analysis of spectral variations along the flanks of the El Ghorabi dunes, using both multitemporal Landsat MSS and TM data and aerial photography, reveal little or no net southward extension or movement of the seifs over the 40-year interval examined. However, definite spectral and brightness variations along the flanks of the El Ghorabi system can be seen in seasonal TM, MSS and SPOT data, and suggest seasonal reversals of sand movement in response to changes in the dominant direction of sand-transporting winds (Figure 2.1.2).

Dominant north to northeast winds during September-November result in the formation of sand shadows on the downwind (southwest) side of the dunes. Reversal of the dominant sand-transporting wind occurs in late spring, with corresponding translation of sand shadows to the northeast flank of the dune system. TM data analysis and field measurements show the sand shadows to be quite thin and patchy as compared with estimates based only on MSS data; use of MSS data alone, while clearly indicating the presence of the sand shadows, results in an overestimation of the extent of sand cover.

Elongation or southward growth of the El Ghorabi dunes is not apparent over the interval studied, although field measurements and remote sensing data both indicate small-scale lateral migration of dune crests and interdune corridors through time. The primary process of sand transport for these dunes seems to be lateral rather than longitudinal, in response to seasonal shifts in dominant wind direction. This has significant implications as a mechanism for transporting sand into the interdune corridors and retaining it there during stabilization of dune systems, and will be a focus of further study.

FIGURE 2.1.1: On the following page is a sketch map showing the location of the Bahariya Depression in the Western Desert of Egypt; an enhanced Landsat TM view of a portion of the Ghard El-Ghorabi study area is shown on with Fig.2.1.2. Seasonal comparisons of the dunes reveal changes in the transport of sand into interdune corridors in response to seasonal changes in the dominant wind patterns, resulting in temporary storage of sand in interdune corridors or on the lee side of isolated dunes.

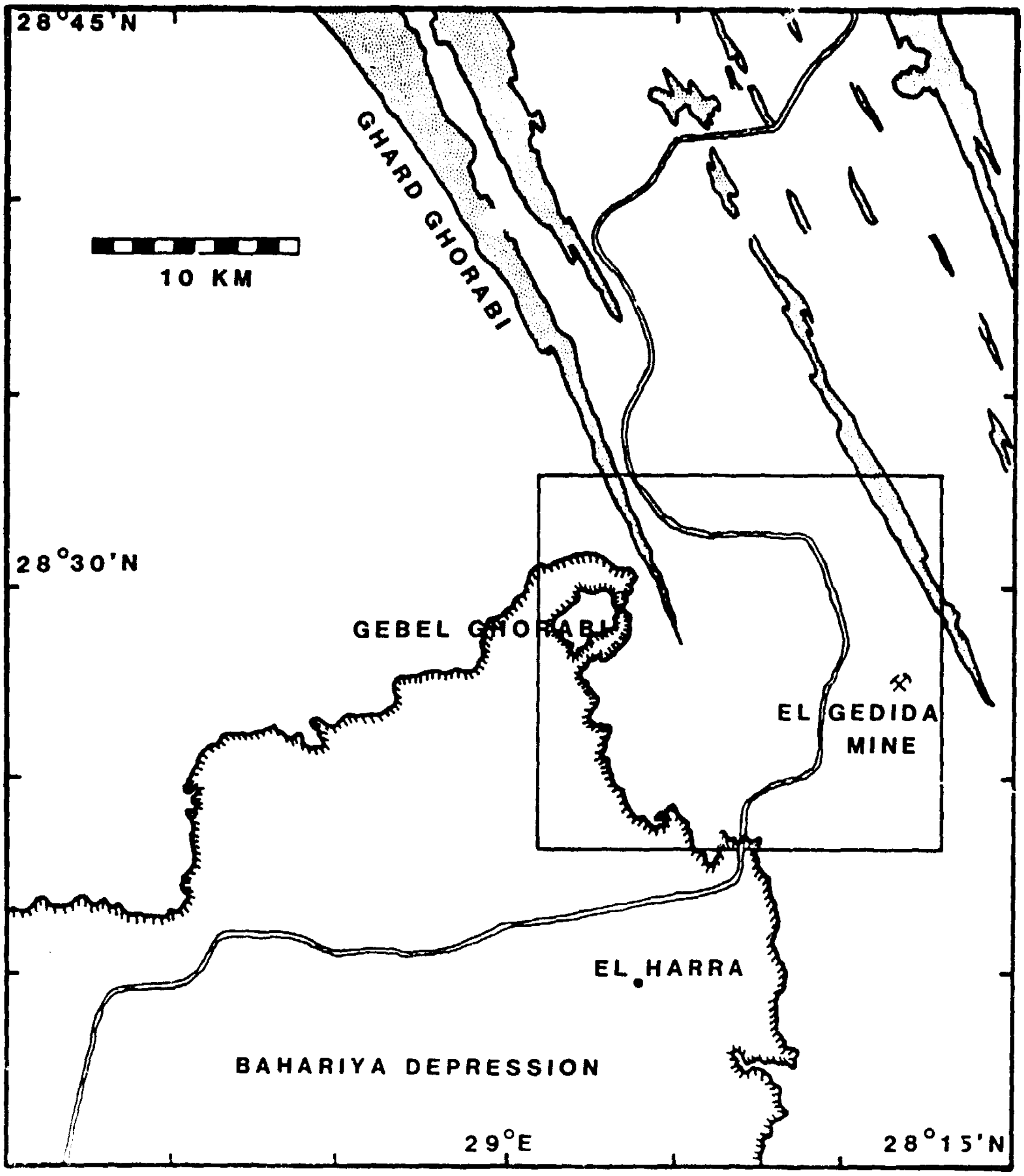

28°45'N
GHARD GHORABI
10 KM
28°30'N
GEBEL GHORABI
EL GEDIDA
MINE
EL HARRA
BAHARIYA DEPRESSION
29°E
28°15'N

Figure 2.1.1

Figure 2.1.2: Seasonal variation in brightness along the flanks of the El-Ghorabi dunes as seen from MSS data comparisons. Although the 80-meter resolution of the MSS sensors prevents quantitative analysis of the spatial character of the lee-side "sand shadows", the brightness trends shown are suggestive. More quantitative studies are in progress using TM data.

El Ghorabi

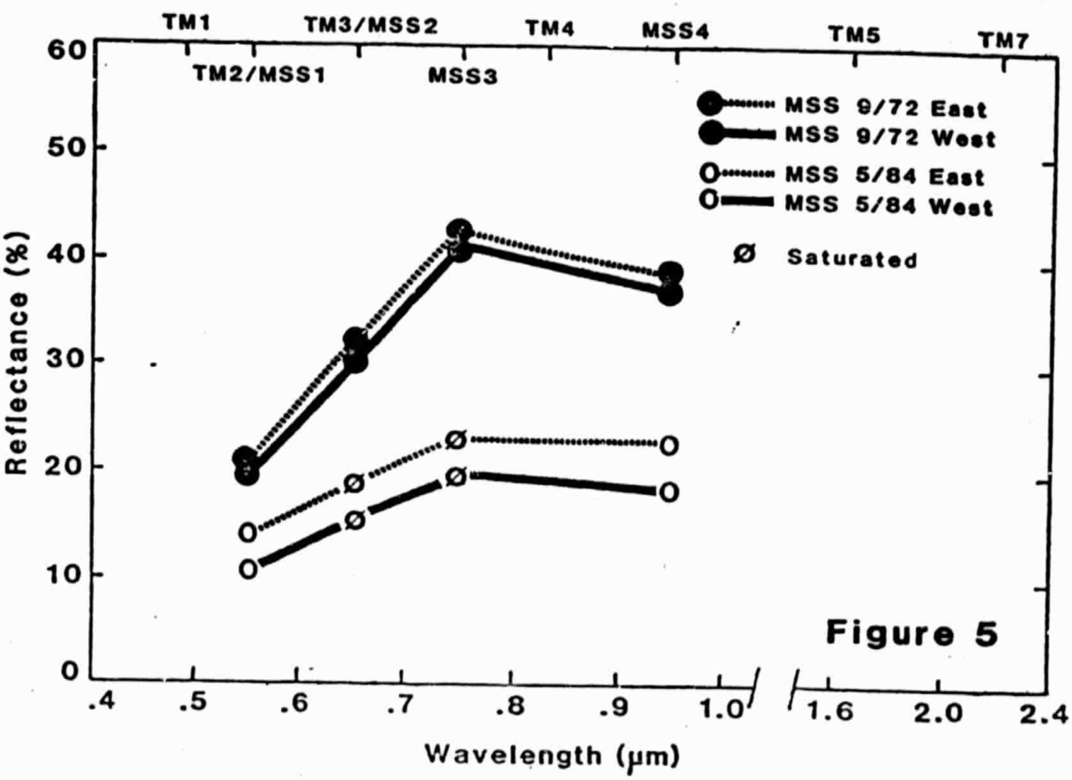


Figure 2.1.2

2.2 Tombouctou/Azaouad Dunes, Mali

The desertified dunes under study north of Tombouctou are old (possibly as much as 20,000 ybp) and were formerly well-stabilized by gramineous and woody vegetation, as the Botswana study site is today (Figure 2.2.1). However, the dual onset of vegetation loss and changes in dominant species in response to Sahelian drought predates the availability of satellite observations by nearly a decade, and thus our earliest Landsat data are of a stressed environment already beginning to desertify. Research in this site over the past year has been concentrated on the recent morphologic evolution of the region as expressed in relict landforms, as a means of setting limits on the availability of moisture to these dunes prior to the onset of drought. In addition, analysis of seasonal reflectance characteristics of the dunes based on three TM acquisitions and additional MSS data has begun. Further TM acquisitions have been scheduled and will extend seasonal coverage to form an eighteen-month baseline.

Prior drainage of the Niger River northward past Tombouctou and into the region now occupied by dunes is evidenced by the morphologic traces of an extensive channel system. Attempts to map this system using MSS data were of mixed success, due to the overprinting of the dunes and the 80-meter resolution of the MSS sensors. Over the past year, TM data have been used to map that portion of the paleochannel system that falls within our data (TM path/row 196/48, quad 3), using a high-pass asymmetric filtering technique developed for this purpose. The filter is designed on a Laplacian pulse, and the resulting images suppress the 1500-meter wavelength spatial distribution of the dunes, permitting mapping of the paleochannel network (Figure 2.2.2).

Temporal variations in the reflectance characteristics of both dunes and associated paleochannels suggest that these channels still may conduct near-surface water from the Niger Bend to the dunes during the rainy season. Comparison of TM reflectances for dune crests in the study area show close correlation of brightnesses between 3/86 and 8/86, and a marked decrease in TM5 reflectance in December 1986 relative to both March and August (Figure 2.2.3). The delay and near-failure of the 1986 wet season (April to October) is responsible for the similarity between the 3/86 and 8/86 curves; gramineous vegetation failed to emerge. It is unclear at this point what caused the decreased TM5 reflectance observed in the 12/86 scene; however, calculation of Normalized Vegetation Difference

Indices for all three scenes shows a slight but measureable increase in NVDI between 3/86 and 8/86, and a 3x drop in NVDI for 12/86 (Figure 2.2.3, inset).

Repeatability of these measurements in TM data through the wet and dry seasons of 1987 will be a key factor in determining the baseline trends and processes involved. One consequence of these preliminary observations is that coring of interdune sediments and trenching of dunes in the field area will be necessary in order to understand the influence of the paleochannel system on near surface hydrology. Funding has been secured for sediment coring north of Tombouctou in early 1988, and the data that result from the coring program will help to constrain the impact of fluvial morphology and sedimentologic characteristics on the spectral results obtained.

Figure 2.2.1: Sketch map of Mali showing the location of the Azaouad Depression study site north of Tombouctou. A full-resolution detail image of the TM data covering the study site is provided with Fig. 2.2.2.

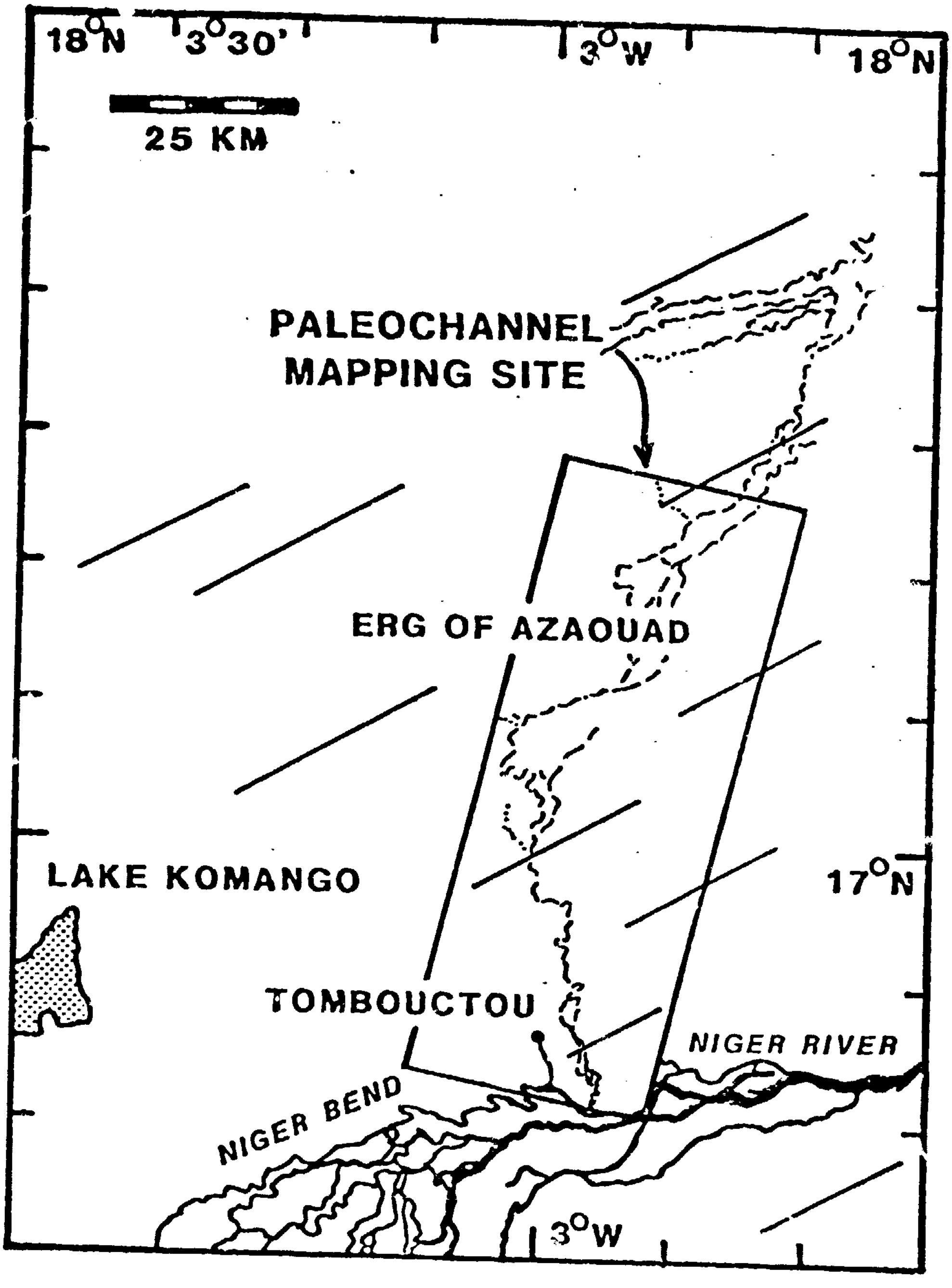
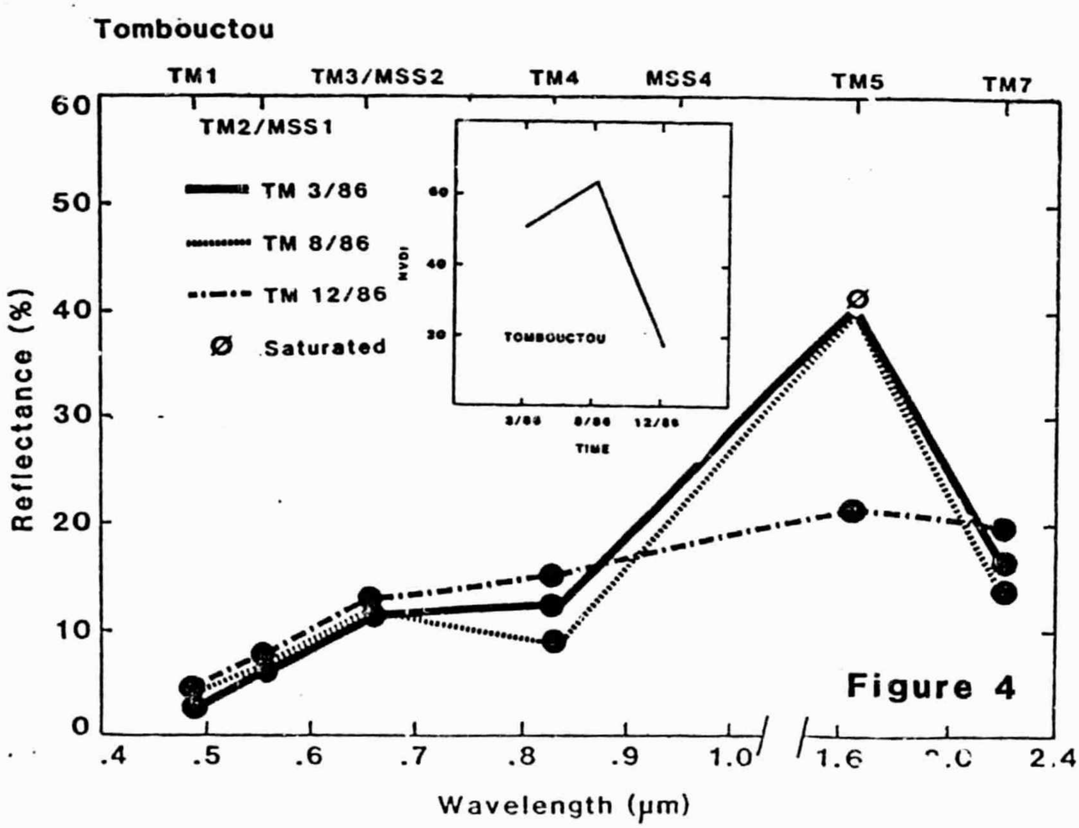

18°N
3°30'
3°W
18°N
25 KM
PALEOCHANNEL
MAPPING SITE
ERG OF AZAOUAD
LAKE KOMANGO
17°N
TOMBOUCTOU
NIGER RIVER
NIGER BEND
3°W

FIGURE 2.2.1

Figure 2.2.2: Full-resolution 512x512 pixel TM image of a portion of the Azaouad Depression, showing a detail of the relationship between the dunes and the abandoned channels. This paleochannel system likely represents a former course of the Niger River and may have continued effect on the near surface hydrology and dominant surface processes in the Depression. (These conclusions are discussed more fully in Attachment A.)

Figure 2.2.2

Figure 2.2.3: Preliminary spectral curves for dune crests within the Azaouad study site. The 3/86 curve represents data from the end of the dry season; 8/86 is the end of the wet season; and 12/86 is the height of the dry season. High correlation between the 3/86 and 8/86 curves indicates lack of vegetation growth because of failure of the 1986 rains, while the sharp decrease in TM5 reflectance in 12/86 may indicate further actual loss of standing vegetation. This interpretation is based on comparisons of the Normalized Vegetation Difference Indices calculated for each scene, shown in the diagram inset.



Tombouctou
TM1
TM3/MSS2
TM4
MSS4
TM5
TM7
TM2/MSS1
TM 3/86
TM 8/86
TM 12/86
Ø Saturated
Reflectance (%)
60
50
40
30
20
10
0
.4
.5
.6
.7
.8
.9
1.0
1.6
2.4
Wavelength (μm)
Figure 4
TOMBOUCTOU
NVDI
TIME
3/86
8/86
12/86

Figure 2.2.3

2.3 Tsodilo Hills, Western Botswana

The linear Kalahari dunes in western Botswana are of undetermined age, but their massive size, dense vegetation, degraded morphology and incongruence with current climatic conditions all argue for the antiquity of the dunes. Based on field observations, the degree of dune stabilization here by soil development and vegetation growth is unmatched in any other dune environment in Africa, and thus provides an ideal test site for monitoring surface processes in truly stable dune conditions. The past five years have been drought years in Botswana; however, anthropogenic impact on these Kalahari dunes has been minimal due at least in part to their inaccessibility. Current trends towards increased use of the Kalahari for grazing may soon impact the field area, and therefore the baseline development now underway is critical.

Field work in northwestern Botswana was conducted in July-August 1987. An area of intensive study was selected in the Tsodilo Hills region, 45 km west of the Okavango River floodplain (Figure 2.3.1). The linear dunes in this section of the Kalahari desert are 2.1 km in wavelength and attain an average height of 25 m. Slope measurements of 1.5 to 3.0° were measured on the flanks of dunes.

Prior to field work, the reflectance characteristics of these dunes were used as the test case for development of a technique to extract relative topography from TM data. Preliminary results of this technique agree well with the dune measurements taken in the field; however, the technique has as yet only been tested in one study site and must still be considered experimental. (A more detailed description of the technique and its basis is contained in Attachment A).

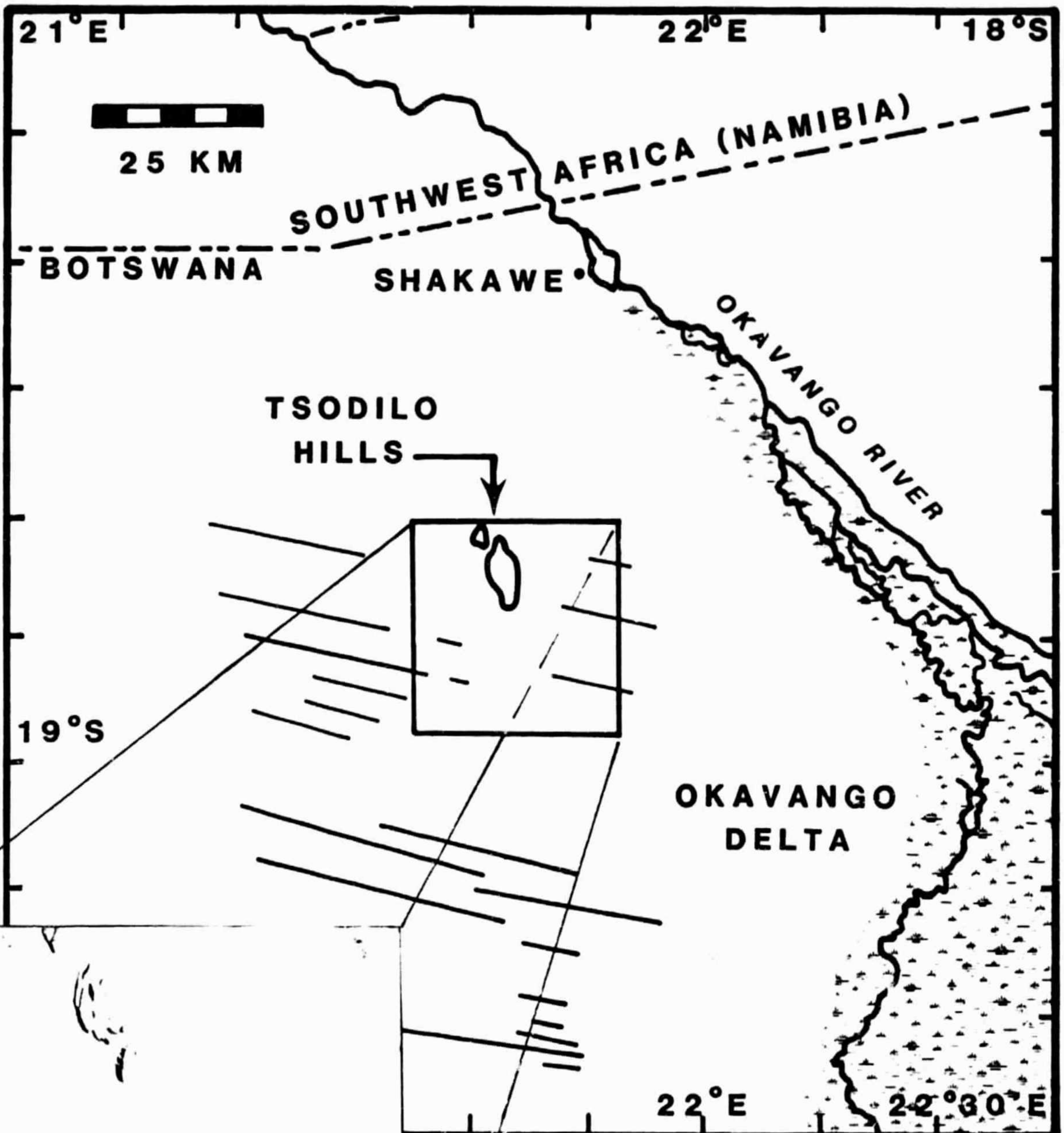
Dune crests are broad and have 60% to 90% vegetation cover, consisting of grass, trees and scrub. The trees and scrub vegetation are dominated by mophane, acacia, kiaat, and wild syringa. Interdune corridors are typically narrow, flat, and are grass-covered with only a few percent trees and scrub. Dense tree and scrub groves similar to populations on dune crests occur locally within some corridors.

Devegetated areas occur in the vicinity of villages and settlements in a pattern typical of more desertified regions such as Tombouctou. In these areas, grazing, foraging and trampling by livestock, and woodgathering by village inhabitants, has destroyed grass cover and has significantly reduced the percentage of woody vegetation. In these areas, the highly reflective Kalahari sands are distinctly visible.

Based on preliminary synthesis of field and TM results, the major variations in color and brightness across the dune system are strongly related to vegetation type and density, modulated by seasonal and drought-related factors (Figures 2.3.2, 2.3.3, 2.3.4). The months of May through October are typically the dry season in northwestern Botswana, but drought, common to semi-arid environments, occurred in this region in the early 1970's and again through the early 1980's. MSS and TM data thus far permit clear discrimination among dune crests, interdune corridors, and high-reflectance dune margins. Values derived from MSS data acquired in September 1972, after two successive dry years, show high brightness values for dune crests and margins relative to TM data from September 1984, also after several successive years of drought. However, the difference between 1972 and 1984 data is small for interdune corridors, possibly because of the way the distinct vegetation populations of the two landforms react to drought stress.

Comparisons of September 1984 and May 1985 TM data show strong brightness gains at 0.83 micrometers for interdune corridors, suggesting seasonal vegetation growth. Individual dune crests which had similar spectral properties in September 1984 display greater variation in May 1985; dune margins exhibit the same trends. These differences likely relate to seasonal growth of understory and variations in canopy density. While these preliminary results are complex and as yet are poorly constrained, the reduction of further field data and the repetition of TM measurements with 1987 acquisitions will help to clarify these trends.

Figure 2.3.1: Sketch map showing the location of the Tsodilo field area in the Kalahari dunes of western Botswana, together with a TM image of the field area. Note the regular appearance of the dunes and the clear spectral populations of dune crests, interdune corridors, and bright dune margins.



21°E
22°E
18°S
25 KM
SOUTHWEST AFRICA (NAMIBIA)
BOTSWANA
SHAKAWE
OKAVANGO RIVER
TSODILO
HILLS
19°S
OKAVANGO
DELTA
22°E
22°30'E

Figure 2.3.1

Figures 2.3.2, 2.3.3, 2.3.4: Spectral curves for dune crests, interdune corridors and bright dune margins in three TM scenes acquired several months apart.

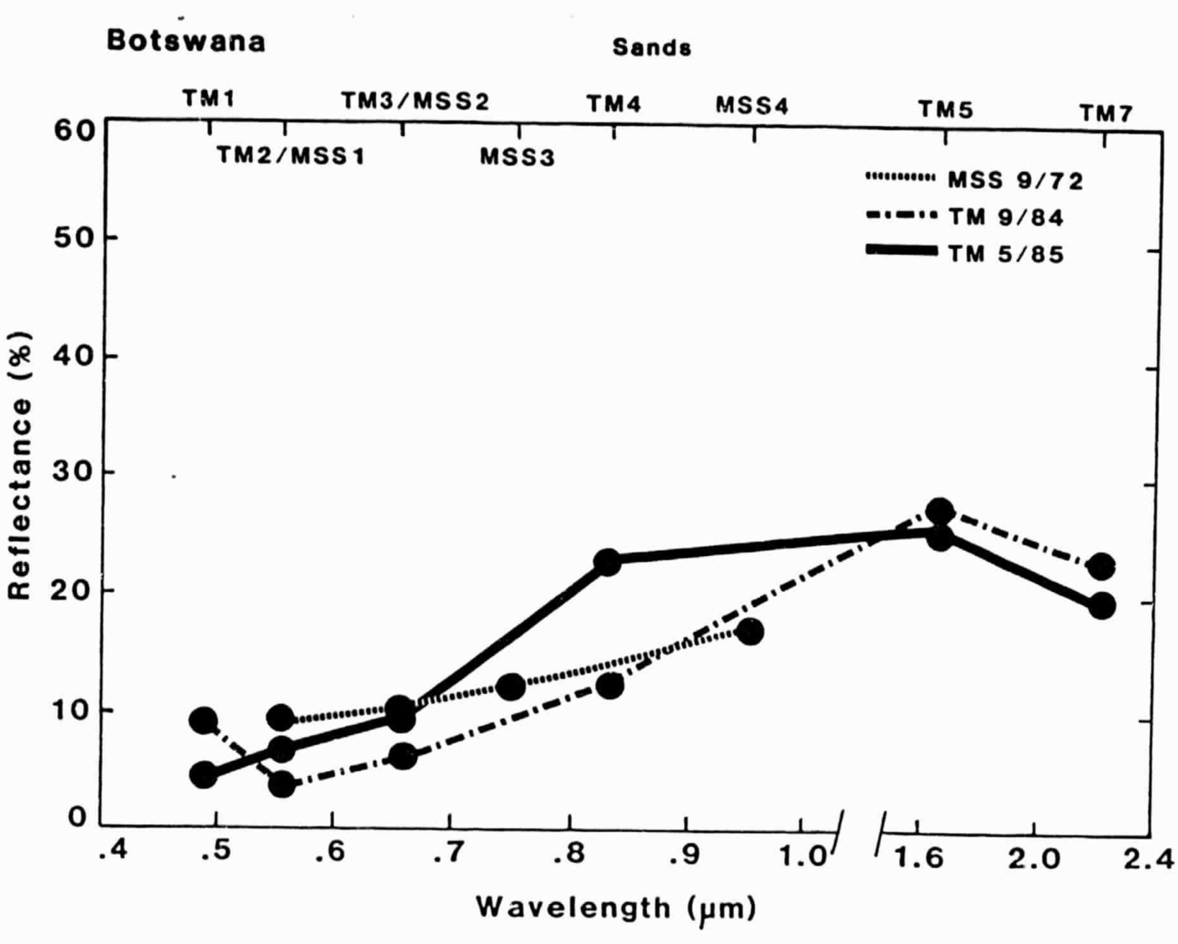
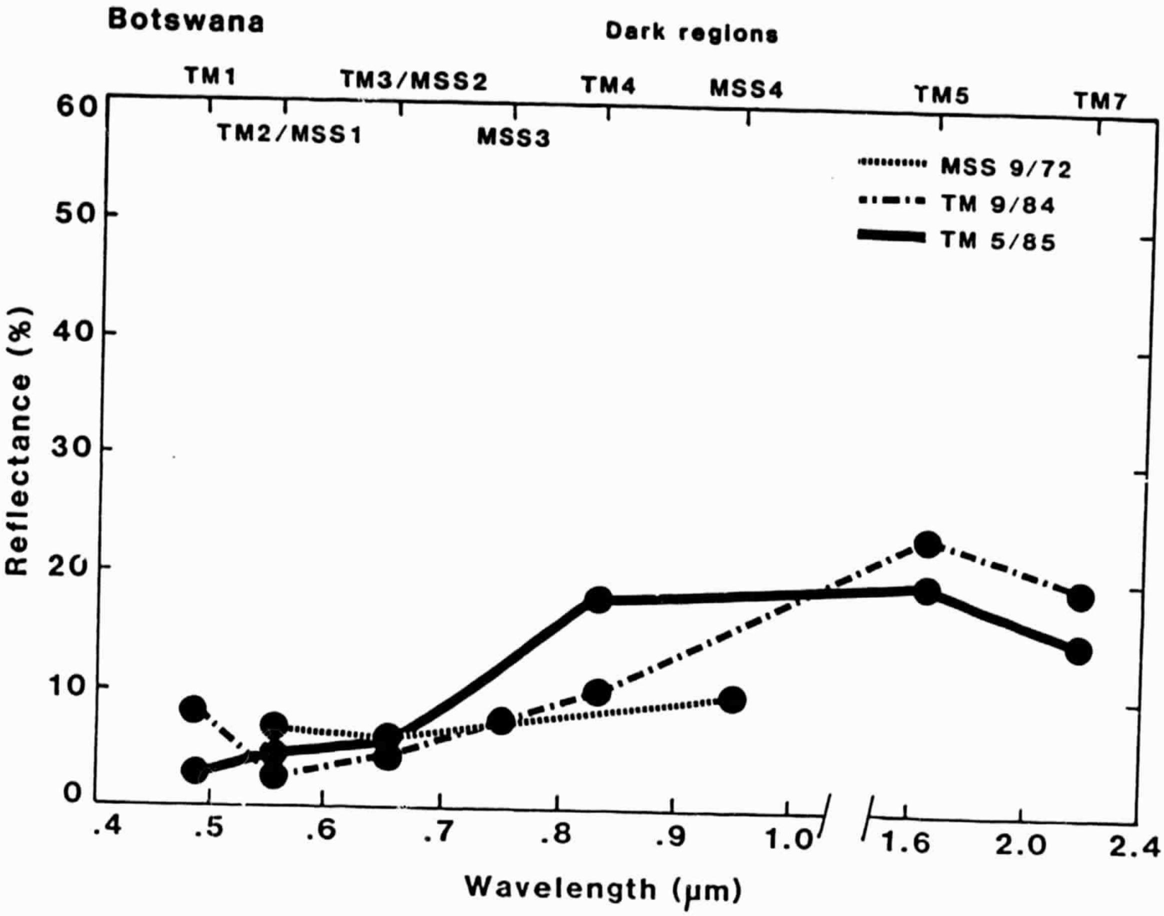

Botswana
Sands
TM1
TM2/MSS1
TM3/MSS2
MSS3
TM4
MSS4
TM5
TM7
MSS 9/72
TM 9/84
TM 5/85
Reflectance (%)
60
50
40
30
20
10
0
.4
.5
.6
.7
.8
.9
1.0
1.6
2.0
2.4
Wavelength (μm)

Figure 2.3.2



Botswana
Dark regions
TM1
TM3/MSS2
TM4
MSS4
TM5
TM7
TM2/MSS1
MSS3
MSS 9/72
TM 9/84
TM 5/85
Reflectance (%)
60
50
40
30
20
10
0
.4
.5
.6
.7
.8
.9
1.0
1.6
2.0
2.4
Wavelength (μm)

Figure 2.3.3

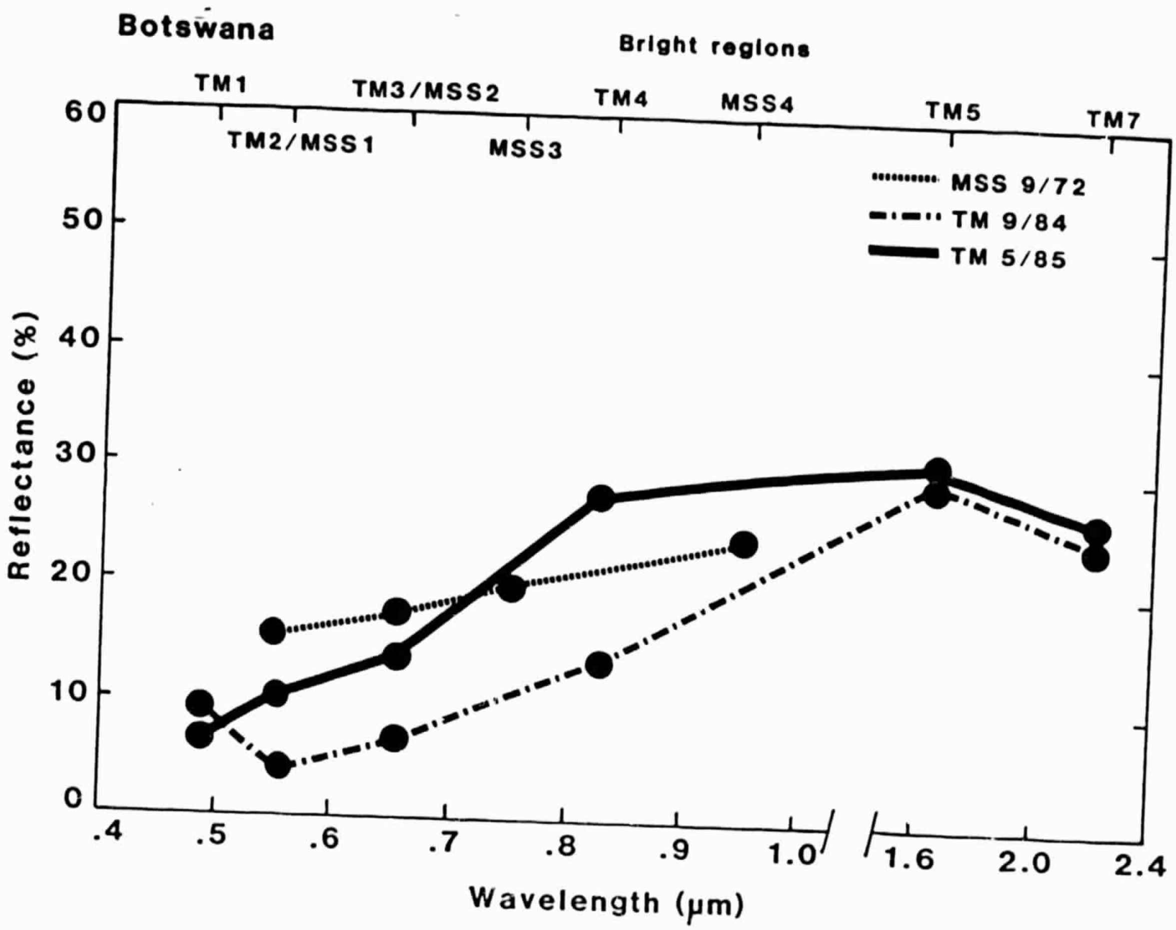

Botswana
Bright regions
TM1
TM2/MSS1
TM3/MSS2
MSS3
TM4
MSS4
TM5
TM7
MSS 9/72
TM 9/84
TM 5/85
Reflectance (%)
60
50
40
30
20
10
0
.4
.5
.6
.7
.8
.9
1.0
1.6
2.0
2.4
Wavelength (μm)

Figure 2.3.4

3.1 Next Phase of Study

The TM data to be acquired over the next few months will allow completion of the baselines for Tombouctou and the Tsodilo Hills, and will further constrain the preliminary conclusions presented above. Basaline data will be correlated with weather data for the same time periods, to further discriminate between seasonal and aperiodic change. The duneform topography technique developed for the Tsodilo Hills will be applied and tested in both Tombouctou and Bahariya, and sediment coring in the paleochannels north of Tombouctou will help to identify the mechanisms causing spectral variation in this region.

In addition, unique opportunity to study the spectral changes and processes of desertification from inception on has been presented by the drilling of a new borehole in the Tsodilo Hills area, within our study site; the hole was drilled in August 1987, during our field work there. Continued TM and field monitoring of the status of soils and vegetation as the area around the borehole is developed and used will allow documentation (and quantification) of the anthropogenic component of desertification in an area previously untroubled by these factors.

4.1 Attachments

The following is a listing of abstracts and papers produced since our last report, for future publication. Texts follow.

Jacobberger, P.A. (1987) "Enhancement of Relict Channel Patterns in Mali through Directional Filtering of TM Data," (working title), submitted to Remote Sensing of Environment.

Jacobberger, P.A. (1987) "Drought-related Changes to Geomorphologic Processes in Central Mali," Geological Society of America Bulletin, in press.

Hooper, D.M. and Jacobberger, P.A. (1987) "Spectral Reflectance Properties of Stabilized Dunes West of the Okavango Delta, Botswana," (Abstract), Geological Society of America Abstracts with Programs, in press.

Jacobberger, P.A. (1987) "Interaction of fluvial and aeolian processes in desertification," (Invited Paper and Presentation), in Proceedings, Twentieth International Symposium on Remote Sensing of Environment: Remote Sensing for Africa, Nairobi, December 4-10, 1986, in press.

Jacobberger, P.A. (1987) "Mapping the Abandoned Fluvial System of the Azaouad Depression using MSS and TM Data," in Proceedings, Twentieth International Symposium on Remote Sensing of Environment: Remote Sensing for Africa, Nairobi, December 4-10, 1986, in press.

Jacobberger, P.A. (1987) "Remote Sensing and Field Study of Drought-related Changes in the Inland Niger Delta of Mali," in Proceedings, Twentieth International Symposium on Remote Sensing of Environment: Remote Sensing for Africa, Nairobi, December 4-10, 1986, in press.

Maxwell, T.A. and P.A. Jacobberger (1987) Remote Sensing Observations of Sand Movement in the Bahariya Depression, Western Desert of Egypt," in Proceedings, Twentieth International Symposium on Remote Sensing of Environment: Remote Sensing for Africa, Nairobi, December 4-10, 1986, in press.

Jacobberger, P.A. (1987) "Geomorphology of the Upper Inland Niger Delta", Journal of Arid Environments, v. 13, p. 95-112. (This last paper, while not produced under NAS5-28774, represents research that provided background and impetus for the current study).