REMOTE SENS. ENVIRON. 28:287–295 (1989)

Reflectance Characteristics and Surface Processes in Stabilized Dune Environments

P. A. Jacobberger

Center for Earth and Planetary Studies, National Air and Space Museum, Smithsonian Institution

Analysis of multitemporal TM data for three environmentally related field areas yields information on the response characteristics of stabilized dunes and desert-fringe environments. The three field sites studied include dune fields in Egypt, Mali, and Botswana, ranging in climate from hyperarid to semiarid, and may be classed as an environmental series relating surface processes under Saharan, Sahelian, and Savanna conditions. Sites were field mapped and monitored with TM data for lengths of time up to a year. The complexity of spectral response characteristics is greatest where vegetation is dense and diverse, but study of the three environments together places constraints on the importance of vegetation to spectral response as well as to mechanisms of sand transport. In both Mali and Botswana, the Sahelian and Savanna environments, contrast reversals occur on dune crests and reflectance patterns change through the dry season to resemble the response curves of the hyperarid study site in Egypt. In these analyses, overall surface brightness is controlled by sand composition, while spectral features are controlled by vegetation dynamics.

Address correspondence to Dr. P. A. Jacobberger, Ctr. for Earth and Planetary Studies, Natl. Air and Space Museum, Smithsonian Inst., Washington, DC 20560.

Received 25 August 1988; revised 16 February 1989.

0034-4257/89/$0.00

INTRODUCTION

Although its current climatic conditions range from semiarid steppe to subhumid, the southern fringe of the Sahara is rich in aeolian sand and in relict desert landforms. Large areas of the Sahel are covered by linear dunes, now stabilized by vegetation and soil development (Grove and Warren, 1968). The same is true of the Kalahari Desert, where vegetation cover approaches 100% and in which precipitation can be as high as 800 mm/yr (White, 1983).

The high wind transport potential of sand and sand-based soils, together with characteristically low and unpredictable precipitation, combine to make these areas inherently vulnerable to soil erosion, vegetation loss, and sand movement as a function of drought. Prolonged drought-related stress in desert margins and semiarid lands classically results in destruction of vegetation and soil cover, with ensuing destabilization and progressive remobilization of the underlying sands and soils (e.g., UNCOD, 1977). These are geomorphologic processes that change over short time scales, are spatially discontinuous, and which can exert a strong influence on both the brightness and color of the land surface. In turn, color and brightness patterns may serve as indicators of soil stability and vegetation health and abundance in semiarid environments. Analysis of multitemporal Thematic

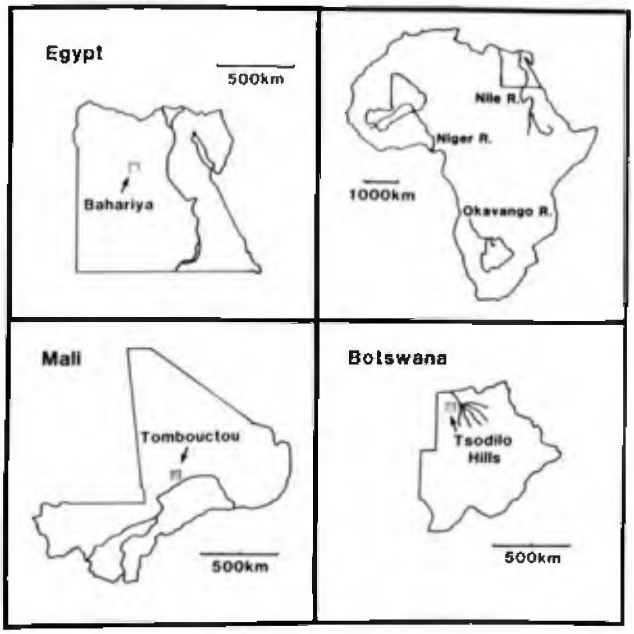


Figure 1. Location of the three field areas discussed in the text.

Mapper (TM) data provide a means of monitoring such changes.

In order to study these processes, a series of three geomorphologically similar field areas were chosen for TM-based analysis and field study (Plate LXI). All three field areas have linear dunes as the dominant landform, indicating past episodes of hyperaridity and dune-building; however, current climatic conditions range from hyperarid through semiarid. Field areas were monitored seasonally using TM data. The objectives of the study are: 1) to establish spectral reflectance "baseline" curves from TM data for the series of desert and desert-fringe environments; 2) to correlate surface processes with reflectance patterns; and 3) to compare across environments for geomorphologic relationships.

THREE FIELD SITES: GEOGRAPHIC SETTING AND RELATIONSHIPS

Figure 1 shows the location of the three field sites: the El Ghorabi dunes near Bahariya, Egypt (N28°30′, E29°30′); the Azaouad dunes near Tombouctou, Mali (N16°49′, W2°59′); and Kalahari dunes south of the Tsodilo Hills in northwestern Botswana (S18°47′, E21°48′). As outlined above, the dominant geomorphologic features in each of these three field sites are linear dunes, with

Table 1. Setting and Use of Dune Crests

Location	*Vegetation*	*Rainfall*	*Land Use*
Bahariya	none on dunes	< 10 mm	none
Tombouctou	grassy; few trees on dunes	< 200 mm	grazing/herding
Tsodilo	woody/grassy mix on dunes	< 800 mm	minimal

current climatic conditions ranging from hyperarid through semiarid savannah. While these sites are geographically widely separated, they form an environmental series in terms of rainfall, vegetation, and land use (Table 1). In each case, unconsolidated sediments underly the dunes and are exposed locally in interdune corridors.

The age of dune formation is unknown for the dunes near Bahariya; however, they are fully mobile dunes and show no evidence of ever having been stabilized. Vegetation is dominantly palm and is wholly confined to oasis areas.

The dunes north of Tombouctou are estimated to be 20,000 years old, and have undergone several episodes of stabilization alternating with remobilization in response to broad climatic changes (McIntosh, 1983); near Tombouctou, complex transverse duneforms are superimposed on the linear trends. These dunes are presently semistable, with surface movement of sand accelerated in areas of heavy grazing and land use. Previously heavily wooded, the dominant flora is now scattered *Acacia sp.* interspersed with ephemeral grasses that flourish during rainy weather and which quickly wither and disappear in response to drier conditions.

The Tsodilo Hills dunes are also old; although the actual date of dune construction is unknown, the dunes presently are well stabilized by vegetation, with 100% cover not uncommon. Vegetation on these dunes is diverse, with a multiplicity of woody and gramineous species. Land use in this area is minimal at present, but is likely to increase.

The potential for active sand transport exists in all three environments, but surface stability and mode of transport varies. In the most stable environment, the Tsodilo site, aeolian transport was not observed directly, but evidence of fluvial transport exists in the development of gullies and ephemeral channels in interdune corridors. In the drought-damaged dunes north of Tombouctou, mobile sand attests to active aeolian transport, though the duneforms themselves are fixed in place

Table 2. Timing of TM Acquisitions

Location	*Scene ID*	*Date*
Bahariya	50105-08045	14 Jun 84
	51321-08040	13 Oct 87
Tombouctou	50743-09570	14 Mar 86
	50903-09522	21 Aug 86
	51015-09494	11 Dec 86
	51127-09533	02 Apr 87
Tsodilo	51028-07501	24 Dec 86
	51124-07533	30 Mar 87
	51188-07553	02 Jun 87
	51252-07565	05 Aug 87

and relict fluvial channels indicate past water transport. At Bahariya, aeolian processes dominate.

METHODS

Site Selection

Prior to acquisition of digital TM data, scenes were obtained in print form and weather data were consulted when available to screen against images taken under cloudy conditions or during dust storms. Digital TM data were acquired for each field area (Table 2). Data for Tombouctou span a full year (quarterly acquisitions). Due to cloud cover, data for the Tsodilo site cover a more confined interval, with the first acquisition in the early part of the rainy season and the remaining three scenes spaced through the dry season. Reflectance changes in these two areas contain contributions from both vegetation and soils. Since the El Ghorabi dunes of Bahariya are active and vegetation-free, data for this site were acquired only twice, to determine to what extent the direction of sand transport varied in response to seasonal changes in wind direction (Maxwell and Jacobberger, 1988).

Data subsets were extracted to target areas of interest for each field site. Available maps for these field areas are broad-scale and contain minimal topographic information; for this reason, a Magnavox Satellite Navigation Instrument (SatNav) was used in the field to control the location of features and sample sites more precisely than would have been possible using map and compass control. SatNav locations were used not only to locate sample sites, but to establish control points for geometric correction. Multitemporal images were coregistered using a combination of SatNav fixes and control points located both in image data and in the field. Estimates of accumulated error in SatNav fixes, and least-squares estimates of error in the digital coregistration process, indicate that positional error ranged from 90 to 120 m (3–4 TM pixels) for Bahariya to less than 30 m (1 pixel) for Tombouctou.

Ideally, data should have been corrected for atmospheric effects prior to conducting multitemporal analysis of reflectances; however, the character, optical depth, and scattering geometry of mineral aerosols in these desert fringe regions are poorly understood. Field observations during the dry seasons in both Tombouctou and the Tsodilo site suggested that optical thickness can be highly variable and that the commonly made assumption of lateral homogeneity may not be justified in these regions. Therefore, instead of applying standard correction procedures or algorithms designed for use in well-understood, low optical depth and laterally homogeneous conditions, atmospheric contributions were retained as a valid component of the data. Analyses in this study therefore deal with earth–atmosphere system reflectances, and a corollary objective of the study became the determination of whether the atmospheric contribution to scenes in desert fringe regions is in fact seasonally consistent. The results of this study of atmospheric parameters have been completed for publication elsewhere.

Geomorphologic Criteria

Using field data in combination with TM images, geomorphologic overlay maps were developed for each target area. Homogeneous landform, soil, and vegetation units were defined in the field and transferred to image data. As might be expected, the complexity and number of discrete units varied according to climatic variability; 10 vegetation/soil units were defined for the Tsodilo site, where vegetation is most dense and diverse and where soils are best developed and preserved. Six units were developed for the more arid Sahelian site at Tombouctou, and two sufficed to characterize the modern dune environment at Bahariya. These units are presented in Table 3.

The units thus defined were used as training fields for subsequent TM analyses. From the standpoint of potential sand transport, sand storage, and soil erosion, the two most important units in each

Table 3. Geomorphologic Units

Location	*Unit Name*
Bahariya	dune crest
	dune flank
	interdune corridor
Tombouctou	stable dune crest
	interdune corridor
	active dunes
	floodplain deposits
	abandoned channels
	urban areas
Tsodilo	unvegetated urban
	open canopy sand
	open canopy w/grass
	dense tree/scrub crest
	grassy crest
	tree-covered crest
	interdune corridor
	grass-covered corridor
	grass/tree-covered corridor
	dense tree/scrub corridor

field area are 1) dune crests and 2) interdune corridors. The remainder of this paper is confined to discussion of these units.

Sand Composition

Field observations and measurements of these dune sands suggest that overall brightness is related to sand composition and degree of pedogenesis. In order to test this hypothesis, split samples from each environment were analyzed for grain size distribution, petrographic composition (established by point counting), total percent organic content, and presence or absence of carbonates. The results of these analyses are presented in Table 4. Based on the dominance of mineral constituents rather than organics, and lack of development of soil horizons noted in field observations, both the Tombouctou and Tsodilo sands should be considered to be Entisols (USDA, 1975). The sand that forms the Bahariya dunes is essentially unpedogenized aeolian sediment.

Reflectance Calculations

Mean digital numbers (DNs) and standard deviations were extracted from the image data for each morphologic unit, for each scene. These data were converted to reflectance values using

$$\rho_p = \frac{\pi \cdot L_\lambda \cdot d^2}{\mathrm{ESUN}_\lambda \cdot \cos\theta}, \tag{1}$$

where

ρ_p = dimensionless exoatmospheric reflectance,
L_λ = spectral radiance at sensor aperture, ($\mathrm{mW\,cm^{-2}\,sr^{-1}\,\mu m^{-1}}$),
d = earth–sun distance in AU,
ESUN_λ = mean solar exoatmospheric irradiance ($\mathrm{mW\,cm^{-2}\,\mu m^{-1}}$),
θ_s = solar zenith angle in degrees.

(Markham and Barker, 1986).

From calculated reflectances and histograms of DN values for each scene, it was determined that overall brightness dominates the differences among the three field areas, and that saturation of TM5 data was prevalent in both dune crest and interdune corridor units for two of the three environments (Bahariya and Tombouctou). In order to examine TM5 saturation more fully, laboratory measurements of the brightnesses of these sands

Table 4. Sedimentologic Data for Representative Sand Samples from Each Field Area[a]

	Mean Grain Size (mm)	*% Organics*	*% Quartz*	*% Carbonate*	*% Heavy Min.*	*% Opaque*
Bahariya						
Crest	2.00 (0.25)	0.2	60	14	20	6
Corr.	0.50 (0.71)	0.2	66	16	14	4
Tombouctou						
Crest	2.75 (0.15)	0.5	81	0	15	4
Corr.	2.75 (0.15)	0.9	80	0	16	4
Tsodilo						
Crest	2.00 (0.25)	0.6	86	0	11	3
Corr.	2.00 (0.25)	0.8	84	0	12	4

[a]Percent organic content was obtained through hydrogen peroxide dissolution; mineral percentages were obtained by point counts on four splits per sample (300 grains per split). Bahariya samples contain significant carbonate derived from underlying limestones at sampling locality.

were obtained for the wavelength range 0.38–1.2 μm using the Cornell University goniometer. Reflectance curves (relative to barium sulfate) for dune crest sands are presented in Figure 2. These show the distinct brightness differences among the three sand samples and environments. Sand from the active dunes at Bahariya is brightest overall, with a peak reflectance of nearly 70% relative to $BaSO_4$ at $\lambda = 1.2$ μm. In order to quantify TM saturation, calculations were made to determine the sun elevations at which data would saturate for TM Bands 3, 4, and 5 in the study areas (assuming Lambertian scattering) and using Eq. (1). These values are presented in Table 5.

Reflectances calculated as above are presented in Figures 3 and 4. TM5 values are not plotted for scenes in which these data were saturated, so as to avoid unintentional suggestion of spectral features in the 1.55–1.75 μm range. While omitted from these analyses, saturated DNs do provide definite

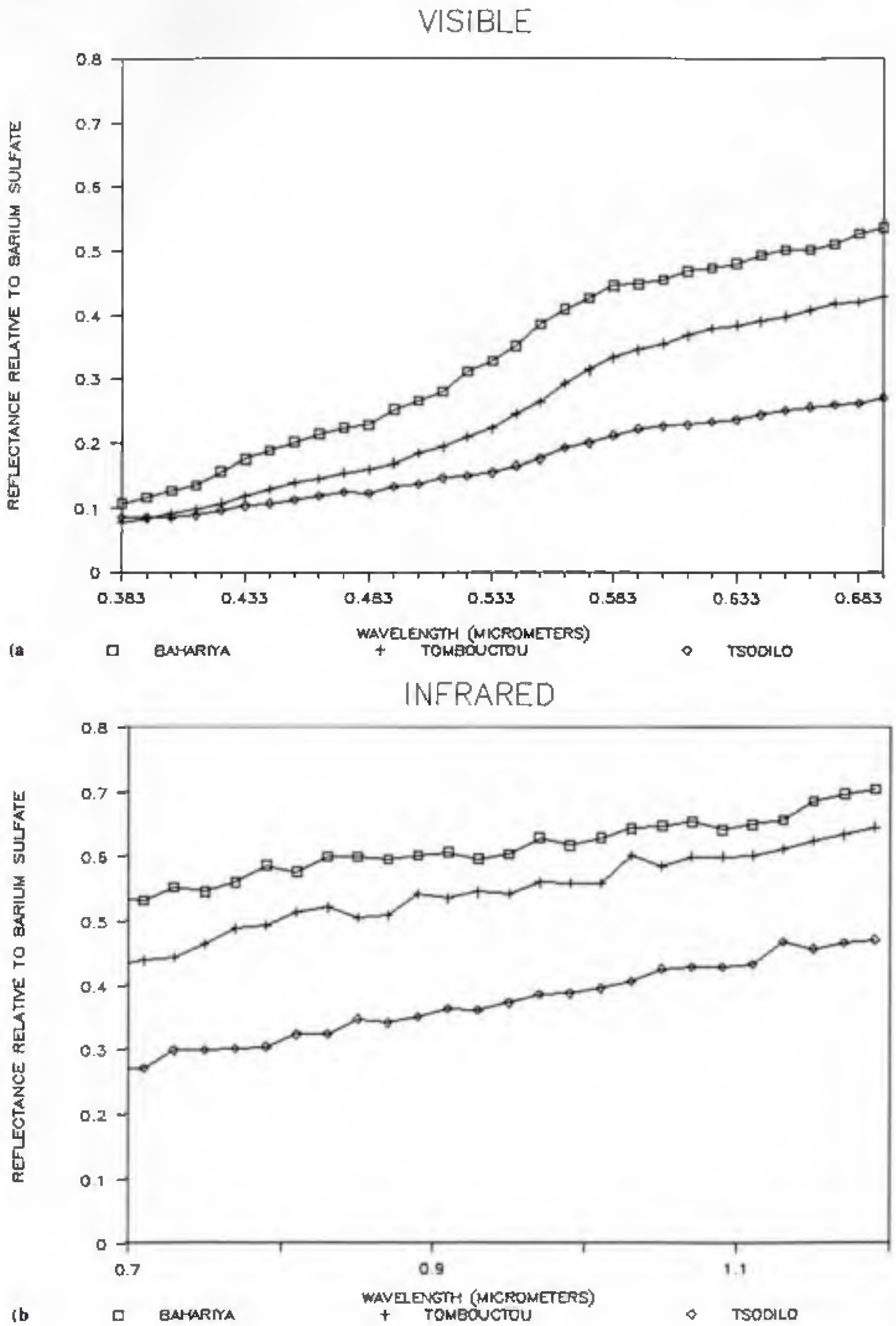


Figure 2. Laboratory spectra from 0.383 to 1.2 μm for dune crest sands from the Bahariya, Tombouctou, and the Tsodilo field sites. Spectra were taken with emission angle = 0° and incidence angle = −5°.

Table 5. TM Saturation Limits for Dune Crests

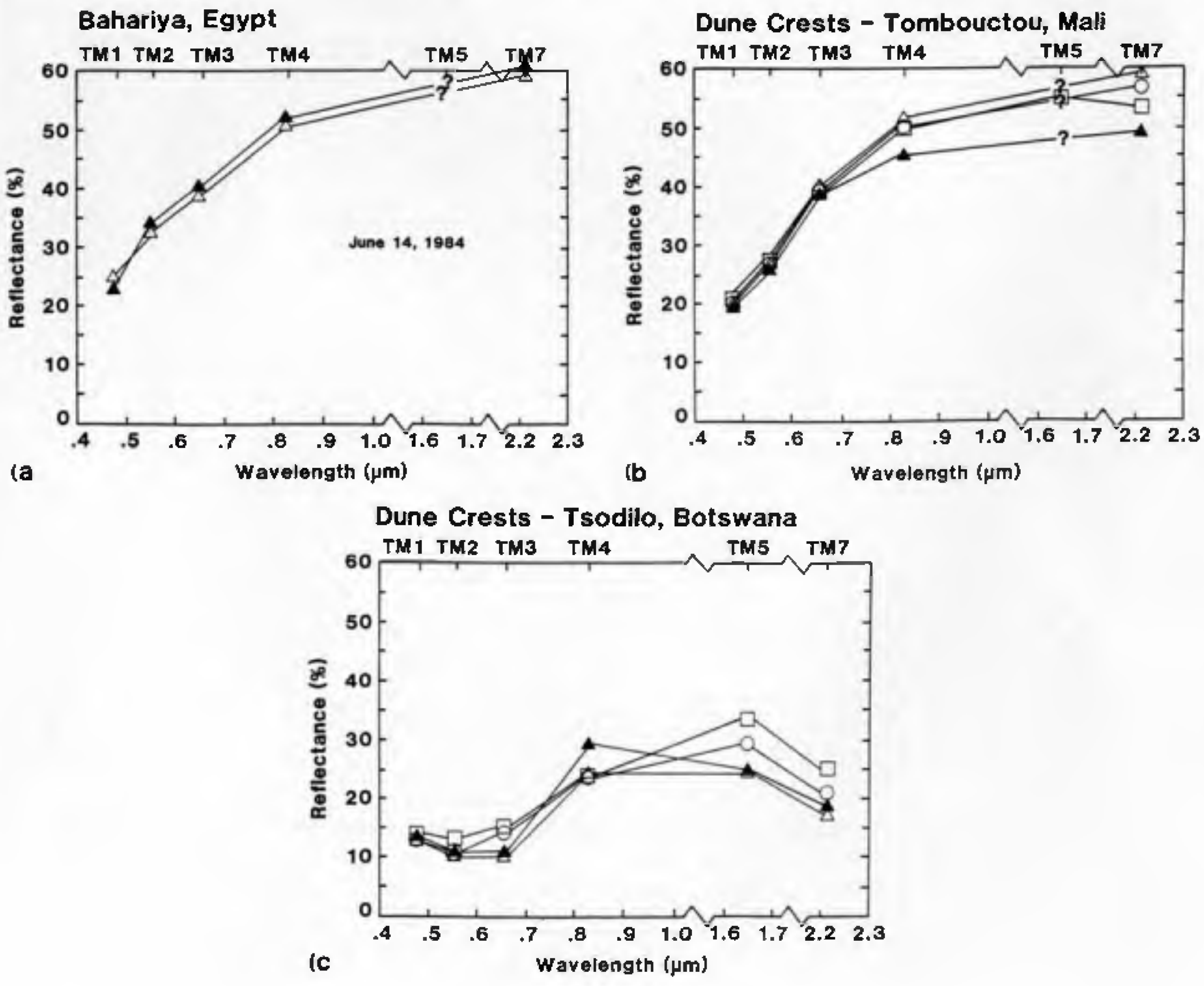
Location	*Path / Row*	*Sun Elevation Angle at Sensor Saturation*	*Months Sun Angle Exceeded*
Bahariya	178/40	TM3: 55°	April–August
		TM5: 34°	March–November
Tombouctou	196/48	TM3: no saturation	
		TM5: 37°	January–December
Tsodilo	175/73	TM3: no saturation	
		TM5: 56°	November

minima in these spectral ranges that might be useful in other contexts.

DUNE CRESTS: COMPARISONS OF REFLECTANCES

Because of the high potential for transport of sand on dune crests, study has thus far concentrated on these morphologic units. Figure 3 shows reflectance curves for dune crests in each field area. As expected, overall brightnesses are highest for mobile, unvegetated dune sand in Bahariya. Reflectance measurements based on TM data provide a smooth curve ranging from 25% reflectance in TM1 to 60% reflectance in TM7; sensor saturation on the dune crest prevented accurate readings for TM5 (graphically indicated by question marks), so this value was interpolated based on TM4 and

Figure 3. TM-based reflectance curves for dune crests in A) Bahariya, B) Tombouctou, and C) the Tsodilo field sites. a) (▲) Crest; (△) corridor. b) (△) 14 March 1986; (▲) 21 August 1986, (□) 11 December 1986; (○) 2 April 1986; (?) saturated. c) (▲) 24 December 1986; (△) 30 March 1987; (○) 2 June 1987; (□) 5 August 1987.



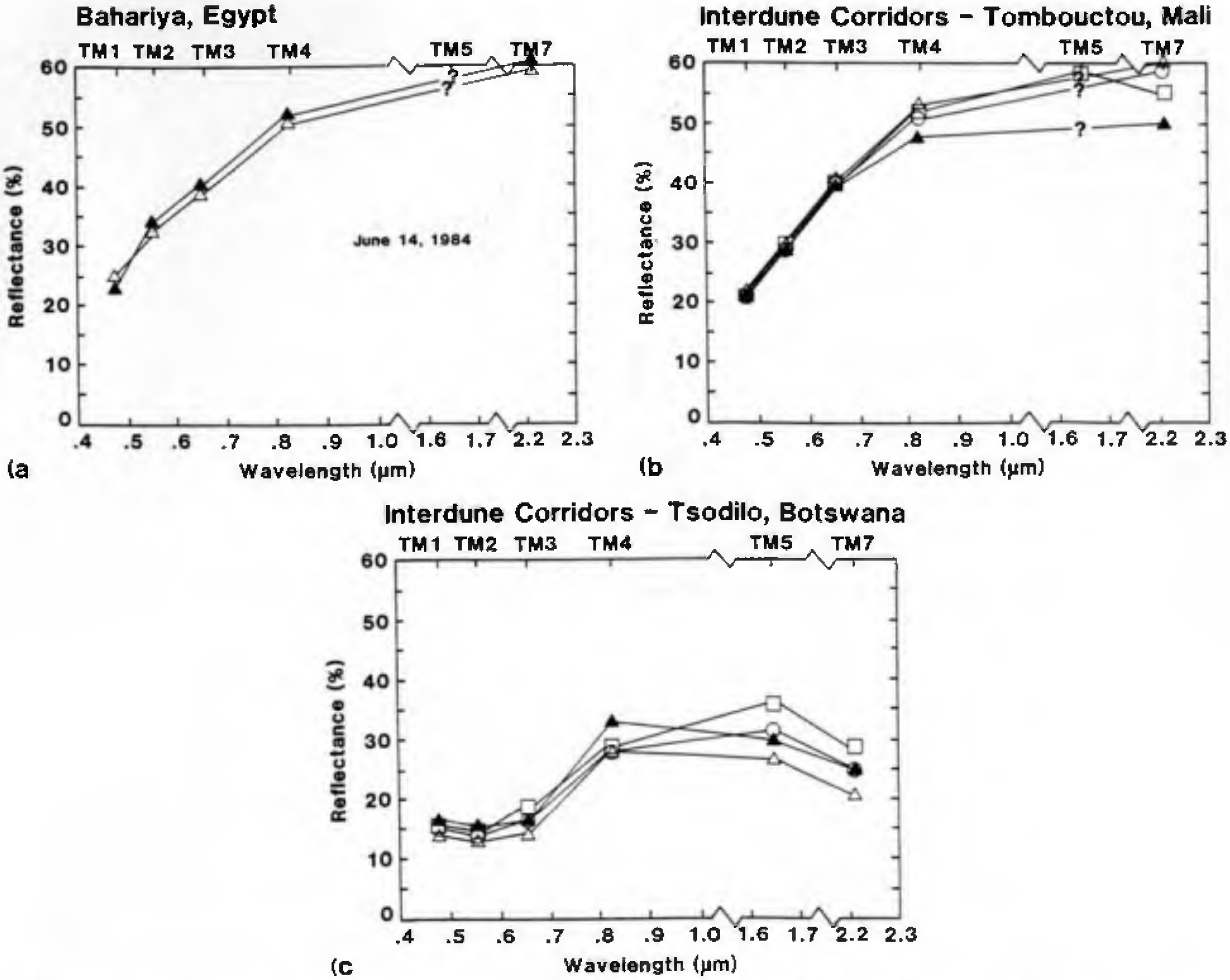


Figure 4. TM-based reflectance curves for interdune corridors in a) Bahariya, b) Tombouctou, and c) the Tsodilo field sites. a) (▲) Crest; (△) corridor. b) (△) 14 March 1986; (▲) 21 August 1986, (□) 11 December 1986; (○) 2 April 1986; (?) saturated. c) (▲) 24 December 1986; (△) 30 March 1987; (○) 2 June 1987; (□) 5 August 1987.

TM7 values. The shape of the curve thus defined matches well with curves presented for clean dune sand by Condit (1970), and with the laboratory spectrum presented in Fig. 2. The absolute position of the curve relative to brightness is slightly lower than that obtained in the laboratory; since the TM-based reflectances are corrected for sun elevation angle, this suggests that the spectral behavior of the sand may not be Lambertian, but rather is phase-angle-dependent.

The family of curves presented for Tombouctou spans 1 full year, from dry season (3/86) through the rainy season (8/86) and on to the next dry season (12/86–4/87). While the visible reflectance values match fairly well with visible reflectances for the Bahariya clean sand, seasonal differences appear in the reflected IR bands. Specifically, TM4 reflectances are depressed during the rainy season months, resulting in near-zero slopes between TM4 and TM7. This feature disappears as the dry season proceeds, leading to the "Bahariya-like" 12/86 curve.

Interpretation of these differences still must be considered preliminary since only a single set of seasons has been spanned, and because of the TM5 interpolations. However, these spectral patterns support the emergence of vegetation and increased soil moisture, with resulting shifts in TM3 and TM4, and, possibly, in the TM5 response related to water contained in leaf cellular structure. Woody vegetation comprises less than 5% of the vegetation cover in these dunes. Because of the low concentration of woody vegetation and the extremely high brightness of the surrounding bare sand, it is unlikely that the woody vegetation exerts much spectral influence on the dunes. The classic, rapid emergence and senescence of the dominant grasses (for example, *Cenchrus biflorus*) control the response variations observed in the TM data. The resemblance between the dry season Tombouctou curves and the curve for Bahariya is consistent with the near-total absence of vegetation in the dry season for this desertified environment. Close correspondence between the Tombouctou 1986 and 1987 dry season curves also suggests that the atmospheric component of the spectra may in fact be seasonally consistent and therefore predictable.

In contrast, for the Tsodilo site the overall reflectances are approximately 15% lower in the visible wavelengths and nearly 20% lower in the reflected IR. These data do not span an entire sequence of rainy and dry season responses; the rainy season in the western Kalahari begins in November and runs through April, while the dry season spans May–October. Thus, the 12/86 curve represents the mid-rainy season, the 3/87 curve is representative of late rainy season color and brightness, and the 6/87 and 8/87 scenes show the senescence of vegetation over the beginning and middle of the dry season. These data together with the laboratory spectra and with field information confirm that the overall lower reflectances are controlled by sand composition, but that seasonal variations are a response to the high density and diversity of vegetation. Grass and tree cover is nearly 100% on most dune crests, although the proportion of each varies from place to place. Transects were taken in the field, keyed to image data; these have been used to constrain the relationship between color and proportion of woody vegetation (Hooper, 1988). Species diversity is also much higher, and therefore the range of color/brightnesses possible is multicomponent. Treating the vegetation in a simplified way, however, as a two-component system (woody and gramineous) together with the signature of bare sand yields a simplified ternary system that can be better compared with Tombouctou.

In 3/87, at the end of the rainy season, the response curve shows a predictable rise in TM4 (indicative of higher biomass relative to the other curves) and a depressed TM5 value (likely due to water in plant leaves). In contrast to the Tombouctou rainy season curves, TM7 is also depressed, with a value of 20% and a steeply negative slope relative to TM5, due to the higher proportion of woody vegetation present on the dune crests. The shift from negative to positive TM4–TM5 slope between the rainy and dry seasons, and the progressive increase of TM3 response (i.e., a decrease in chlorophyll absorption) between the rainy and dry seasons can be explained by progressive vegetation senescence through the dry season. These curves represent predictable differences in seasonal response in a heavily vegetated dune environment, as distinct from the low-vegetation dunes of Tombouctou in which variations in infrared slope or TM3 response are completely lacking.

Interdune Corridor Comparisons

Comparison of spectra for dune crests with adjacent interdune corridors (Fig. 4) shows that differences are minor and are related to broad-band albedo rather than to specific spectral features. In Tombouctou, crests are a few percent darker than adjacent corridors, but seasonal spectral trends are identical. Field evidence suggests that this difference is due to the storage of bright, mobile sand in corridors, together with shadowing effects on crests due to the complex morphology and sinuousity of the crest lines.

In contrast, corridors are a few percent darker than adjacent, similarly vegetated crests in the wet season and early dry season Tsodilo data, but a contrast reversal occurs late in the dry season as the corridors become brighter and more "Tombouctou-like." The composition of sand in the Tsodilo corridors is different than the composition of sand from dune crests, and can be related to differential soil development and higher organic content in corridor materials (see Fig. 2 and Table 4).

Corridors are also darker than crests in the Bahariya field site; here, there is minimal sand storage in the interdune corridors, vegetation is absent, and surficial color is instead controlled by the spacing and composition of lag deposits atop fine-grained sediments (Bougan and Maxwell, 1986). Visual comparisons of TM, MSS, and SPOT image data for this region showed that a temporal brightness gradient exists across the corridors and dune flanks. This brightness change in the corridors is an expression of sand transport and ephemeral storage of sand in corridors, in response to seasonal changes in wind regime (Maxwell and Jacobberger, 1988).

CONCLUSIONS AND IMPLICATIONS

This work is part of an ongoing effort to characterize the reflectance properties of desert fringe environments and to relate spectral variations to surface processes. The results of these analyses may be summarized as follows:

1. Field and laboratory reflectance measurements and TM spectra suggest that there is a systematic variation in sand color of linear dunes in various states of stabilization and vegetation cover. Independent of the spectral contributions of vegetation cover and soil moisture, sand is brightest on unvegetated, mobile dunes, and is darkest in the most stable environment examined. Compositional differences account for brightness variations, as deduced from field observations, visual inspection of sand samples and laboratory measurements.
2. In stable dune environments that have undergone drought or desertification-related losses in vegetation diversity or stability, seasonal color changes are statistically insignificant in the visible wavelengths, but are resolvable in the reflected infrared. Without TM5 measurements, it is difficult to resolve whether the IR response is dominated by atmospheric contributions or surface vegetation.
3. Where dunes are well-vegetated, seasonal spectral responses gain complexity. As is true for other well-vegetated environments, changes in slope as well as brightness of spectra yield information on vegetation growth states, stress, and senescence. Dry season contrast reversals between dune crests and interdune corridors result in a reflectance pattern closer to that of the less-stable Tombouctou environment; the appearance, timing, and duration of this spectral feature may be useful as an indicator of environmental stress.
4. Although untested for full TM scenes or quadrangles, the close correspondence of dry season curves for Tombouctou suggests that for field sites of 200 sq km or less, atmospheric contributions to scene brightness are seasonally consistent and laterally homogeneous.

While these observations have not yet been tested in dune environments other than those discussed here, these results suggest some ways in which the condition of stable dune environments can be assessed, and place some constraints on the use of remotely sensed data in such applications. Continued baseline refinement for these field areas and application of the results established here to other locations will provide a means of estimating surface stability based on dune reflectance properties.

This research was supported through NASA Contract NAS5-28774, "Environmental Processes and Spectral Reflectance Characteristics of Soil Erosion in Desert Fringe Regions." Thanks are warmly extended to P. Helfenstein and J. Veverka of Cornell University for providing advice and access to the Cornell Goniometer, to D. J. Stanley and Harrison Sheng, National Museum of Natural History, for their assistance in obtaining sedimentological data, and to Donald M. Hooper for his help with drafting and data reduction. Thanks also go to two unnamed reviewers for their very helpful comments on the manuscript.

REFERENCES

Bougan, S. J., and Maxwell, T. A. (1986), Spectral and spatial variation in desert lag deposits and inferences for mixing models of terrestrial and planetary remote sensing data, *GSA Abstracts with Programs* 1986, p. 548.

Condit, H. R. (1970), The spectral reflectance of American soils, *Photogramm. Eng. Remote Sens.* 36:955–967.

Grove, A. T., and Warren, A. (1968), Quaternary landforms and climate on the south side of the Sahara, *Geogr. J.* 134:194–208.

Hooper, D. M. (1988), Geomorphologic processes and spectral reflectance properties of dunes at the Tsodilo Hills, Northwest Botswana, M.S. thesis, George Washington University, Washington, DC, 134 pp.

Markham, B. L., and Barker, J. L. (1986), Landsat MSS and TM post-calibration dynamic ranges, exoatmospheric reflectances and at-satellite temperatures: Lanham, Maryland, *EOSAT Landsat Data User Notes*, No. 1, pp. 1–8.

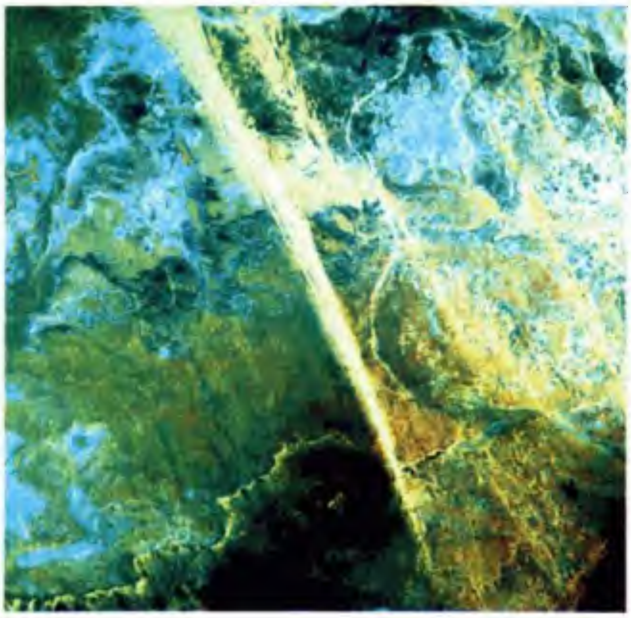
Maxwell, T. A., and Jacobberger, P. A. (1988), Remote sensing observations of sand movement in the Bahariya Depression, western Egypt, in *Proceedings of the Twentieth International Symposium on Remote Sensing of Environment: Remote Sensing for Africa, Nairobi, Kenya*, 4–10 December 1986, ERIM, Ann Arbor, pp. 721–729.

McIntosh, R. J. (1983), Floodplain geomorphology and human occupation of the upper inland delta of the Niger, *Geogr. J.* 149:182–201.

UNCOD (United Nations Conference on Desertification) (1977), *Desertification: Its Causes and Consequences*, Pergamon, Oxford, 448 pp.

USDA (United States Department of Agriculture) (1975), *Soil Taxonomy, USDA Soil Conservation Service*, Washington, DC, 754 pp.

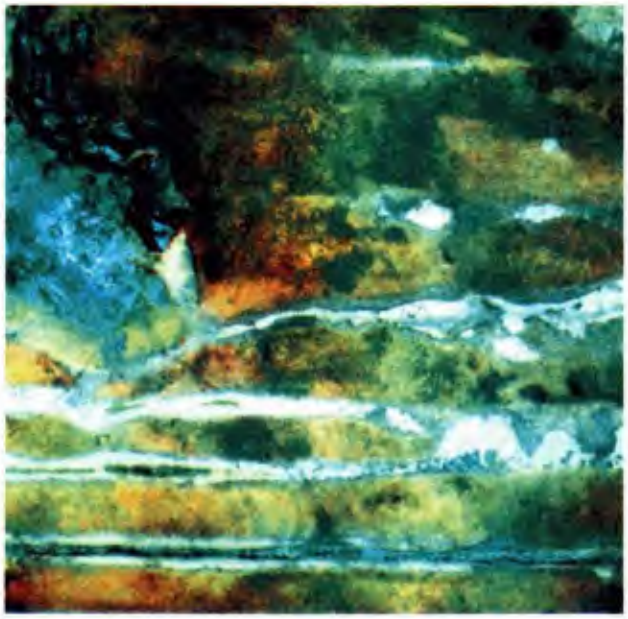
White, F. (1983), *The Vegetation of Africa: Descriptive Memoir To Accompany the Unesco/AETFAT/UNSO Vegetation Map of Africa*, Unesco, Paris, 356 pp.



(A)

(B)

Plate LXI. Color composites of TM bands 2, 3 and 4 showing the three field sites discussed in text. A) Mobile dunes at the rim of the Bahariya Depression, Western Desert, Egypt. B) Stable duneforms with surficial remobilization and low vegetation density north of Tomboucto C) Stable, well-vegetated liner dunes near the Tsodilo Hills in the Kalahari sandveldt of northwestern Botswana.



(C)