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# REMOTE OBSERVATIONS OF ACTIVE AND STABLE SAND SHEET SURFACES IN SOUTHWEST EGYPT

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## *ABSTRACT*

*From the southwestern border of Egypt to the Nile Valley, the surficial deposits of the Western Desert record the effects of changing climate on landscape evolution. Since the first geologic mapping of this desert by the Geological Survey of Egypt in the 1960's, improvements in techniques and recognition of the archaeological importance of the region have led to a greater understanding of the role of landscape inheritance and climate change. Using registered and radiometrically corrected remote sensing information from the past 20 years and field mapping of discrete sedimentary deposits, we have seen only minor net erosion in an area south of Black Hill where active movement of sand is evident in remotely sensed images. The changes in this area seen in orbital images result primarily from the replenishment of sand supply rather than by large scale erosion of the sand sheet and underlying deposits. After masking out zones of active sand, variations in spectral reflectance present in the stable surface do not show any patterns indicative of subsurface drainage as are present in radar optical wavelength images 150 Km to the south. Instead, the depth to subsurface soil units in this area and hence, the lithology of the surficial lag, varies as a function of the vertical position on several scales of ripples and undulating relict topography.*

## INTRODUCTION

Between the Gilf Kebir and the southern margin of the limestone plateau in southern Egypt (Fig. 1), the surface of the Selima Sand Sheet consists of a flat, monotonous, vegetation-free expanse of sand and granules, broken only by nearly impercepitble gaint ripples and widely scattered low bedrock exposures. Although late Pleistocene and Holocene climatic fluctuations are well documented by archeological investigations (Wendorf and Schild 1980, Close 1987) and geologic chronologies (Haynes 1982,

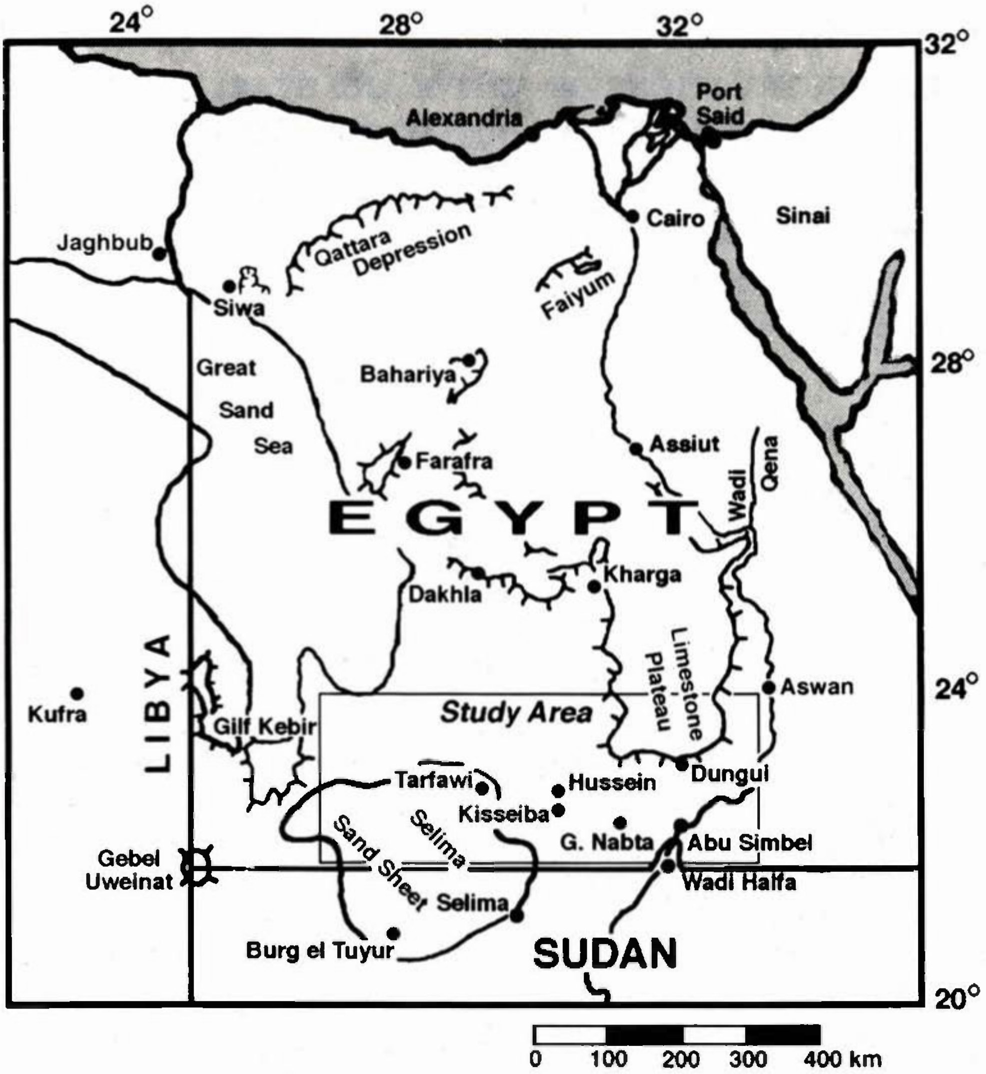

Figure 1 Lcoation map of southern Egypt showing areas referred to in this pa a per. The Selima Sand Sheet (at border of Egypt and Sudan) is avast aeolia nlag covered surface that overlies variations in subsurface topography created by earlier pluvial episodes.

1987, Ritchie and others 1985) , the earlier Tertiary modifications that led to the present landscape are less well understood (Issawi and McCauley1992). The use of remotely sensed images in this region has led to the identification of buried channels beneath the sand cover (McCauley and others 1982), mega-ripples (Breed and others 1987), and large-scale, low-amplitude ripples (chevrons) that vary on a yearly basis (Maxwell and Haynes, 1989). Beneath this surface cover lies a complex of sediments and uneven topography that is relict of former climates. Using techniques designed to map discrete surficial units from orbital data, it may be possible to map variations in both lithology and the relative depth of subsurface materials. However, such an application depends on the accuracy of delineating active sand. In this paper, we concentrate on those depositional units and adjacent erosional lag deposits that are visible in orbital images in an area 20 Km south of Black Hill, the delineation of active sand based on multi-temporal, comparisons of landsat images, and the potential for mapping surface and subsurface units based on spatial variations in spectral reflectivity.

## DISTRIBUTION OF AEOLIAN SEDIMENTS

Although evidence of sand movement is obvious at times of high winds, documentaton of the amounts of erosion and deposition in the sand sheet enviroment is much more difficult due to the absence of well defined stratigraphic marker horizons in surficial materials. The most apparent sedimentary accumulations seen in orbital images are dunes. Large fields of barchans, such as the Abu Hussein dune field between Bir Tarfawi and Black Hill (Fig. 2) are composed of complex transverse parabolic dunes at the northern (windward) side of the field, that grade into individual barchans typically 800 m wide at the south end. At the southern margin of the Selima Sand Sheet, monitoring of an isolated barchan indicates an extremely consistent migration rate of 7.5 m/yr (Hanyes,1989). Aeolian transport of material is less noticeable on the sand sheet because of the absence of large (dune-size) bedforms, but comparisons of orbital images from 1972-1992 indicate extensive changes in the surface cover in the form of alternating dark and light chevron-shaped ripples, termed chevrons (Maxwell and Haynes 1989).

Based on our field surveying, we have identified several scales of extremely long wavelength ripples, ranging from 130m to over 1200m, and occuring 10's of Kilometers downwind from topographic breaks such as bedrock scarps or barchan dune fields. No obvious cross stratification is present in the sediments; instead, planar horizontal stratification caused by interlayered fine sand and granules is typical. The youngest sediments consist of loose sand sheet deposits that reach their maximum thickness (10-20 cm) in the lee of the most prominent crests of the ripples. From correlation between the location of ripples in the field and their appearance on orbital images, we have interpreted the light chervons to be areas of active sand sheet deposits that cover the coarse, ferruginous granule component present in darker areas (Maxwell and Haynes 1989). Dark,, discrete chevrons are most likely the stoss sides of long wavelength ripples, and owe their lower reflectance to an admixture of coarse grains exposed on the surface of older sand sheet deposits and paleosols.

A combination of field mapping of the geographic extent of such sediments and

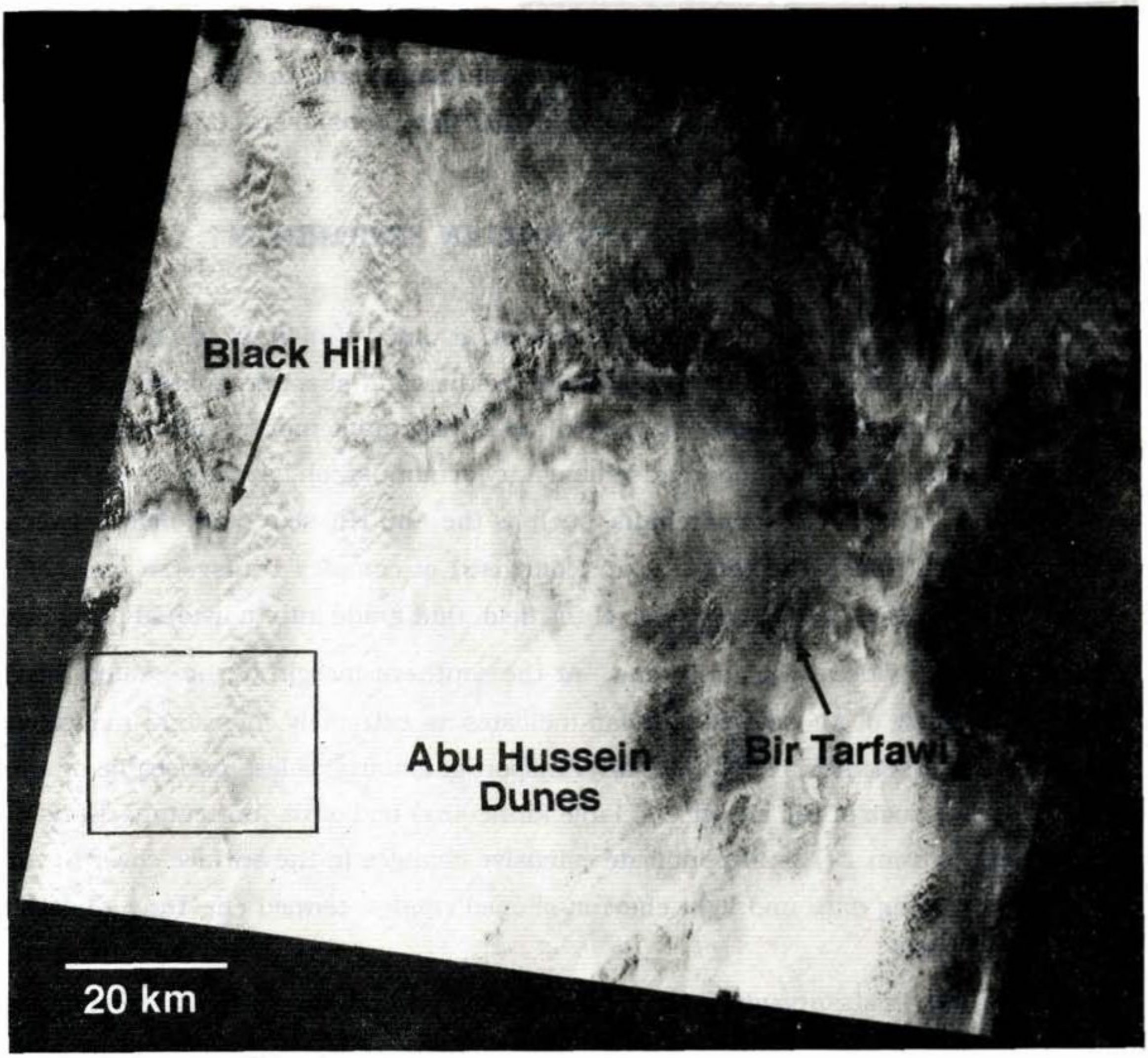

Figure 2 Landsat Thematic Mapper image (near-infrared, band 7) of the norther part of the Selima Sand Sheet. Nearly the entire western half of scene is covered by alternating light and dark streaks oriented transverse to the prevailing (northerly) wind. Box in lower left is area of detailed surveying carried out between 1987 and 1992.

dating by various means (Szabo and others 1993; Stokes, personal communication 1993) indicates that several periods of erosion and deposition are present in the sand sheet. Five stages of sand sheet deposits have been identified by Haynes and others (1993), consisting of active bimodal sand and granules with no pedogenic modification (Stage O), planar bedded bimodal deposits with enough cohesion to retain a vertical slope when trenched (Stage 1), similar planar bedded sediments with a prismatic structure (Stage 2), deposits that do not retain their stratification (Stage 3) and those with more advanced rubification and prismatic structure (Stage 4). Stage O, the active sand and granule cover, is responsible for large scale surficial changes seen in orbital images.

From 1987 through 1992 we have made repeated surveys of surficial topography and shallow stratigraphy through an area of prominent chevrons (Fig. 3). Only minor varitations of 1-2 cm of active sand have been found year to year (surveying was done with a laser theodolite with an accuracy of about one millimeter, and stations were duplicated within a meter of their original locations, although we avoided spoil piles from the prior years'trenching). Detailed changes as seen from orbit are shown in Figure 4.

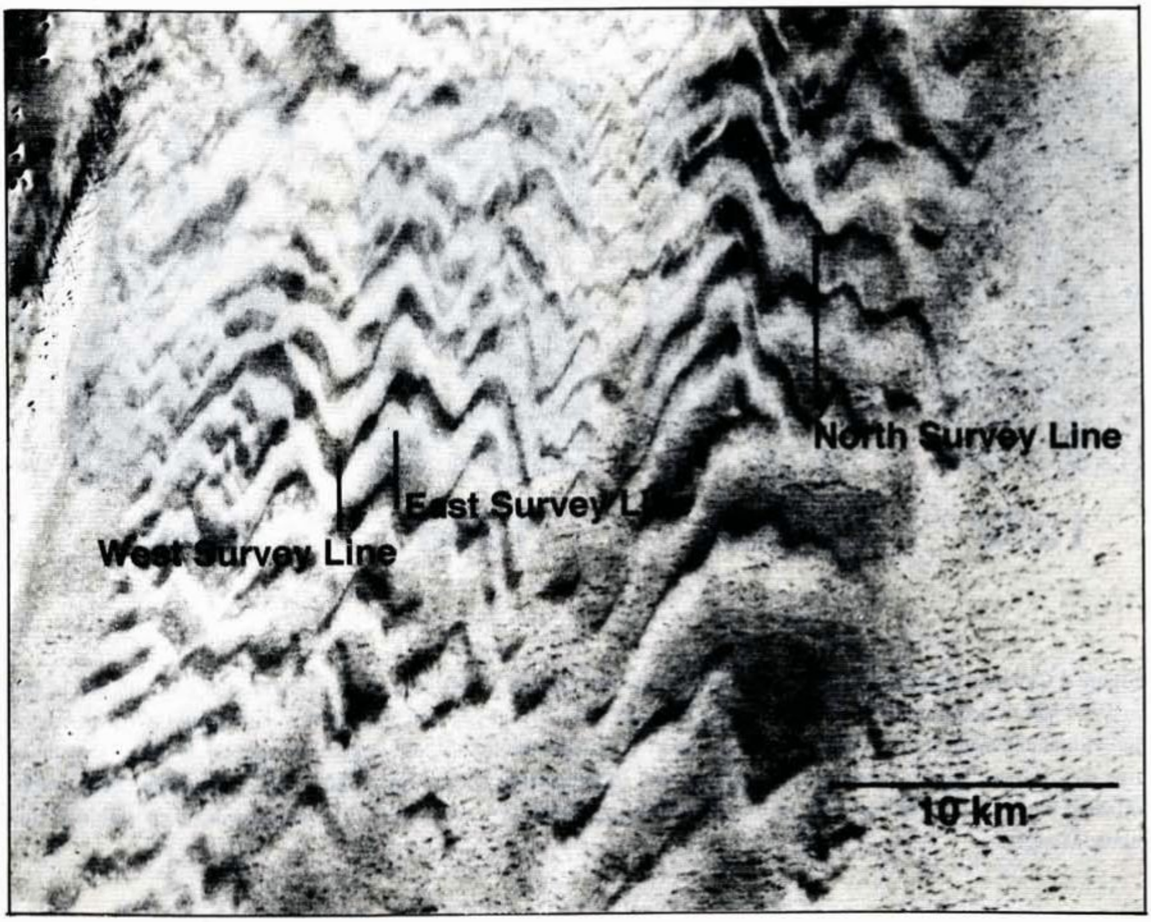

Figure 3 Loctions of repaet urvey lines to monitor near-surface changes in the sand sheet. Light chevrons in this area migrate at rates of 1 Km/ yr. although only minor thicknesses of active sand ( 1 cm) are changing from year to year.

Only two of the images show changes that can be directly traced because of the rapidity of motion of chevrons. Between 1986 and 1988, a light chevron moved ~^2 Km downwind to occupy the central portion of the East Survey Line. In the same time period (1987 - 1989), only 1-2 cm of active sand was deposited. No net erosion has been noted along the survey lines to date. These observations of little erosion of older sand sheet, yet periodic influx of active material are consistent with the continuing presence of late Pleistoncene and Holocene deposits that would have been extensively eorded had they been involved in the yearly changes.

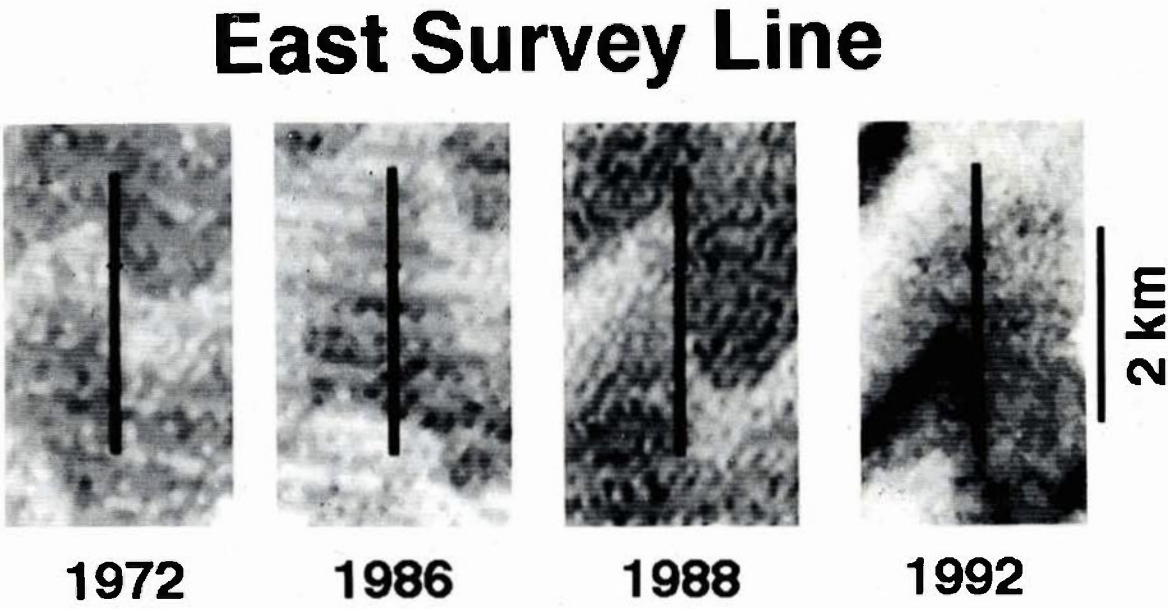

Figure 4 Changes in appearance of East Survey Line between 1972 and 1992. Bright chevron at northern end of line in 1986 had migrated to the center of the line by 1988. The 4-year gap between 1988 and 1992 not allow tracing of individual chevrons at this scale. Geometric error in coregistration of these images is about the width of the survey line as shown (240m), based on using dunes and rock outcrops for control points. All images are in the near-infrared bands; 1972-1988 images are Landsat Multispectral Scanner, and the 1992 image was taken with the Thematic Mapper.

## DELINEATION OF ACTIVE SAND

As shown in Figure 4, only the near - infrared bands of the satellite data record the spectral variation of lag and active sand. Using the 1986, 1988 and 1992 images, we have delineated zones of active change to use as a tool to separate active from stable surficial materials. In order to correct for differences in cameras and ground processing techniques, all images were corrected to exoatmospheric reflectance values (the reflectance at the top of the atmospheric column) usin methods outlined in Markham and Barker (1986; summarized in Maxwell and Haynes 1989). Comparison of the different spectral bands of these images indicates little contrast variation of the sand sheet in the green and red wavelengths, so we used the near-infrared bands (band 4 of MSS; 7 of TM) to delineate the active materials. To create a map of the active sand in the area shown in Figure 3, we subtracted the 1986 image from the 1988 image. In the resulting image, areas that had not changed between the two dates had reflectance (dn) values close to zero, and were essentially "zeroed out;' areas that had become brighter appear white in the resultant image, and those that became darker (negative values) were set to zero. White areas in Figure 5 thus represent active sand deposits, and dark areas are places where there was either no change, or net erosion of active material. A similar procedure was used to determine areas of active deposition between 1988 and 1992, and both difference images were despiked and filtered to remove high frequency noise. A threshold map of the net change between 1986 and 1992 was produced by simply adding the two images (Fig. 5).

For this paper, the thershold value to delineate the active sand was chosen manually by ensuring that the light chevrons that could be matched from scene to scene were included in the active designation. In reality, the variation of reflectance values in the difference images could be used to generate fractional coverage images (e.g. Blount and others 1990). However, to determine patterns of active sand deposition, as opposed to sub-pixel components, we used the method described above.

In order to separate patterns of active and stable surface materials, we then used the net change image as a "mask" on the original 1992 TM image. The top of Fig. 6 shows only those areas where active sand movement occurred between 1986 and 1992. If this technique was applied over a longer time interval, it is likely that the entire area would be classified as "active". However, we did not use the 1972 image because determining a thershold as specified above (by evaluating discrete movement of chevrons) was not possible over that long a time period. As shown in the top of Fig. 6, it is apparent that the chevrons retain their patterns, if not the integrity of individual forms, even over a 6-year period. In addition to these obvious patterns, the megaripples at the eastern edge of the area show evidence of resurfacing by active sand. No changes in this area had been noted either in orbital data (because of the smaller extent of the ripples and their less distinct appearance) or in the field. Changes in this area will be investigated in the field over the next 2 years, and if migration is really occurring there, then much greater inventory of sand transport than previously suspected is likely.

## INFERENCES FOR SUBSURFACE TOPOGRAPHY

The use of multi-temporal remote sensing data to identify the active surface sediments also allows us to map surficial materials that are a key to the Quaternary history. In the early 1980;s, space shuttle radar coverage (SIR-A and -B) 150 Km south of this area led to the discovery of subsurface channels because the radar was able to penetrate the sand cover (McCauley and others, 1982). Using multispectral images, mapping of surficial materials delineates areas of concentrated limestone fragments such as those surrounding Bir Tarafawi, zones of erosion of late (?) Quaternary sands, and the margins of subsurface channels. By masking areas of active sands, it may also be possible to use variations in the composition of the lag deposits to identify areas where the bedrock is close to the surface. Although no such variations were predicted by field work in this area, we have applied this technique to see whether there are any coherent spectral variations in the lag deposits.

The "stable component" indicated at the bottom of Figure 6 is a gray-scale representation of the color variations present in the lag surface, produced by masking the active sand and allowing only the stable component to appear on the image. As indicated by variations in shading, there appear to be no discrete boundaries in the lag sediments that would indicate the presence of any coherent subsurface influence on surficial deposits in this area. Our repeated field traverses of this region are consistent with this observation in that we have found only one isolated area where a 3-meter wide patch of bedrock protrudes to the surface. Shallow trenching along the survey lines and in other scattered locations indicates that the near-surface deposits are either active aeolian sediments, or older, wind-sorted deposits that have been reworked by pedogenic processes. Angular alluvial deposits such as those near the boundaries of the radar-detected channels have not been found in this area. Whether this is the result of a greater thickness of aeolian material, or simply a planar underlying surface is unknown, but may be tested when SIR-C returns radar coverage of the area. The results presented here, however, suggest no buried drainage as is present 150 Km to the south.

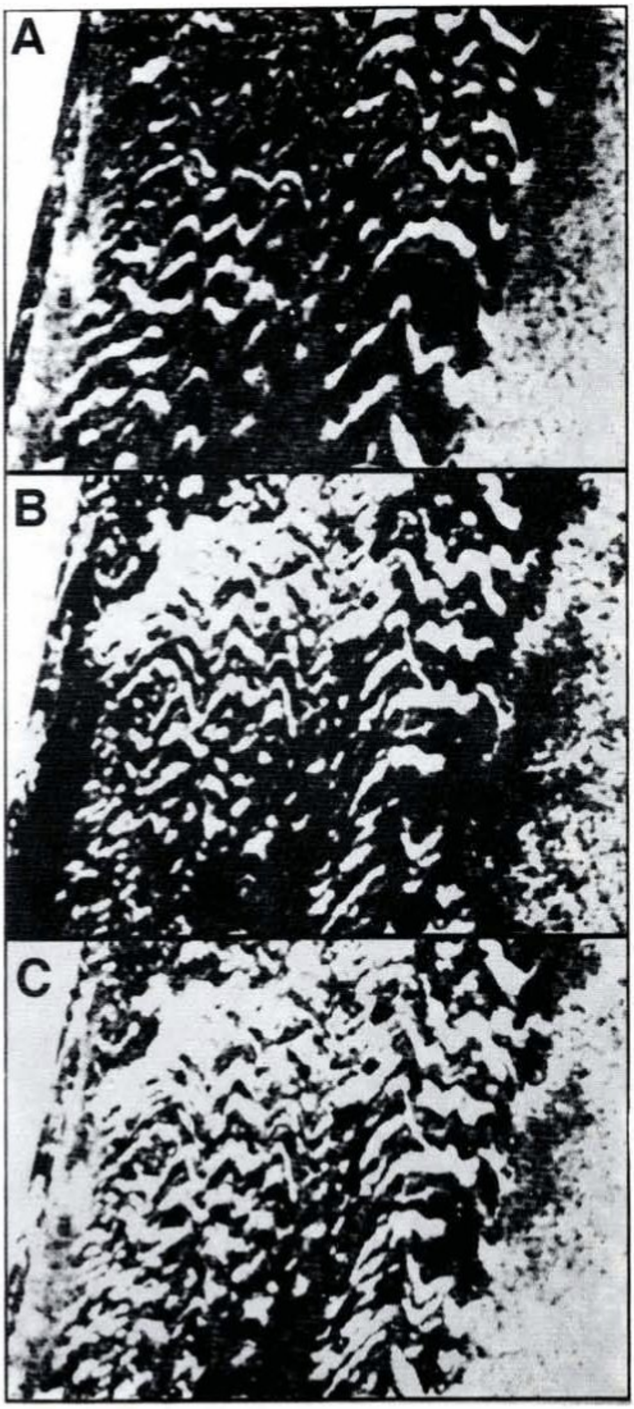

Figure 5 Black and white masks composited from 1986, 1988 and 1992 scenes to delineate zones of active sand transport. A) Difference between 1986 and 1988 scenes; compiled by subtracting the 1986 data from the 1988 data such that any surface that was dark in 1986 and became brighter in 1988 is shown as white. Areas that retained similar reflectance values are shown as black. Resultant difference image was despiked and filtered to smooth high frequency variations. B) Difference between 1988, and 1992 images, processed in the same manner. C) Summation of images (A) and (B) to show net areas of deposition (white) and stability (black) between 1986 and 1992.

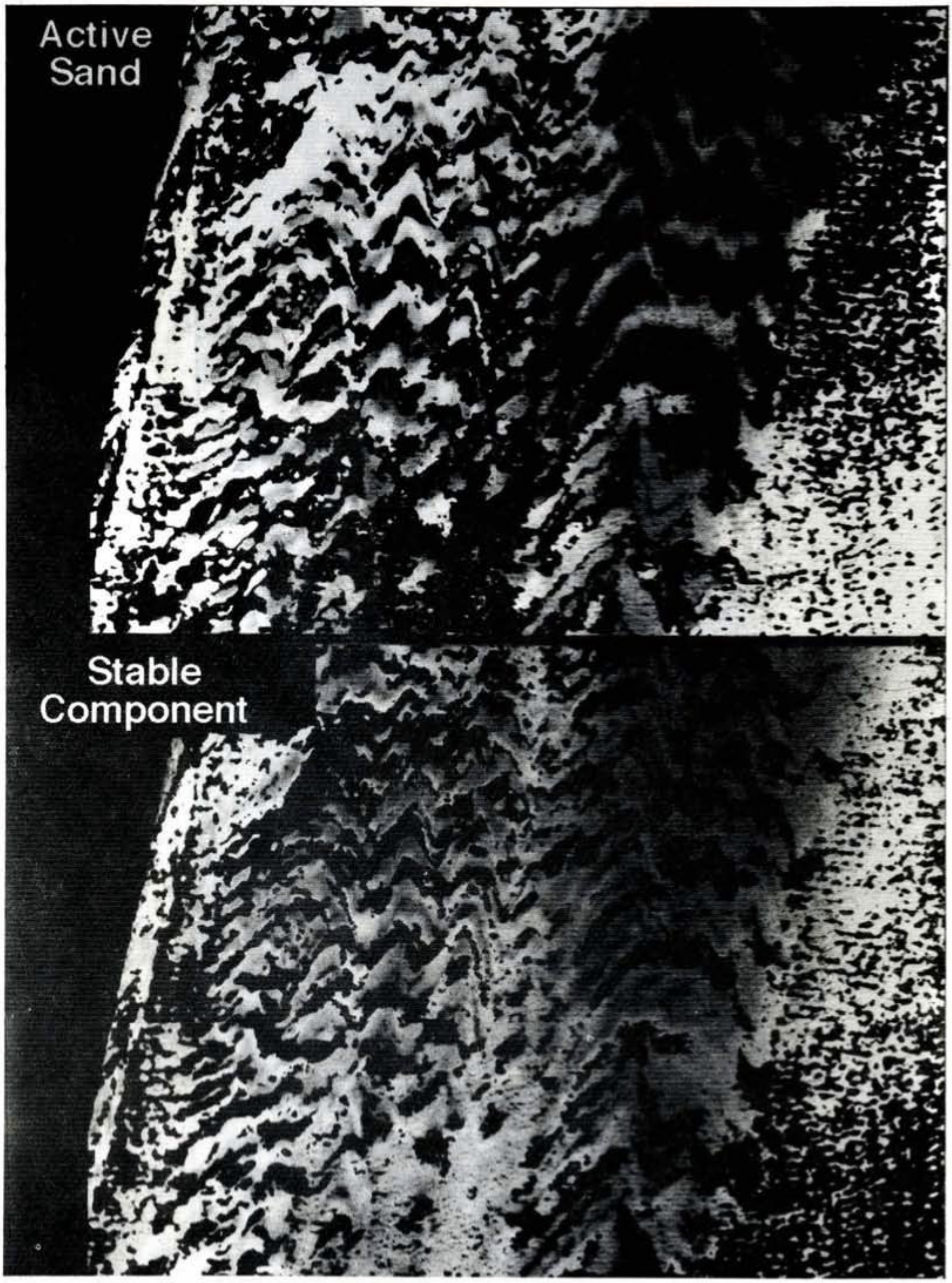

Figure 6 Delineation of active sand and stable lag surfaces on 1992 TM band 7, created by overlaying mask (Fig. 5) on the 1992 data. Spectral variations are more noticeable in false-color composite versions. In addition to obvious chevrons, mega-ripples at the right side of this image display active change, an effect not noticed in the field.

## CONCLUSIONS

Within this area of the Selima Sand Sheet, the use of multitemporal remotely sensed scenes allows delineation of zones of active sand deposition and areas where the surface has either remained stable, or been eroded to uncover a dark lag deposit. Because of the rapid motion of chevron-shaped ripples, a two-year time interval has provided the best delineation of discrete patterns of movement, although the net change between 1986 and 1992 also indicates that the chevrons retain their discrete patterns, even though it is difficult to trace individual forms over the six-year period. This observation is consistent with the distinctive pattern of the chevrons being controlled by subtle topographic relief caused by the low amplitude ripples identified in the field.

For delineation of zones of surface stability the identification of discrete active zones of sand movement provides a benchmark for mapping variations in the lag component. Within the area south of Black Hill, neither field nor remote sensing data indicate any coherent patterns in the stable surface component that would suggest topographic variations in the subsurface. We believe that the minor color variations that are present are related to different stages of sand sheet deposits being exposed. The exact relation between lithology, degree of pedogenic modification and particle size with spectral reflectivity will be investigated further over the next field seasons.

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