MONITORING SAHARAN DUST SOURCE AREAS WITH MULTISPECTRAL IMAGERY*

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ABSTRACT

Desert dust has a strong impact on our planet's local and global climate. The Saharan desert is the world's largest supplier of dust, but little is known about the location and composition of the surfaces material actually releasing the dust. An area of the Saharan desert in Algeria was investigated through an off-road ground campaign. Surface samples were characterized with respect to location, texture, color and roughness. Samples were collected and analyzed for grain size distribution, mineralogical composition, and spectral reflectance measurements in the laboratory. Using the results of previous experiment in Southern Tunisia, a Landsat TM image was classified using a TM1/TM7 band ratioing technique. A useful map of soil surface characteristics was obtained. TM data does not easily provide a complete and frequent coverage of the Sahara and an example of Nimbus-CZCS imagery is used to discuss future broader-scale remote sensing studies of desert surface material.

1. INTRODUCTION

1.1 IMPORTANCE OF DESERT DUST

Dust storms are common phenomena over many parts of the world and their environmental impact has been increasingly recognized. Dust particles transported in the Earth's atmosphere have strong effects on ocean sedimentation, soil formation, ground water quality, crop growth and, more broadly, on local and global climate. Most of this dust is produced in arid areas ; the Saharan desert is the world's largest supplier, it releases an estimated 25 to 50 million metric tons of dust over the Atlantic per year (Goudie, 1978 ; Coudé-Gaussen, 1982).

Sedimentological and geomorphological studies on desert dusts have been primarily focused on mineralogy, particular size and grain shape of deposited dust samples collected in 'sink' areas (Pye, 1987).

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Aerological experiments have investigated the wind conditions capable of entraining and transporting dust. Recent studies have attempted to assess the impact of dust on global climatic changes by implementing different scenarios in global atmospheric circulation models. These simulations have proven the potentially strong effect of variations in desert dust production and trajectories, as well as the lack of data about the characteristics of dust sources.

Indeed, even if the main source areas are identified, like the Saharan desert, little is known about the location and extent of the surfaces actually producing dust within these wide regions. In the Sahara, the variability of the geologic and geomorphic background is likely to produce variability in the composition and the amount of dust produced. This major dust source cannot be considered homogeneous and its surface characteristics need to be better defined.

1.2 PARAMETERS INFLUENCING DUST PRODUCTION

Numerous experiments have been conducted to establish the parameters involved in particles entrainment from the surfaces (Bagnold, 1973). External factors such as air velocity, density and turbidity are essential, but several properties of the surfaces themselves have been found to be of great impact. Among them, mineralogical composition, particle size, particle cohesion and roughness of the soil surface are the most important (Gillette, 1979). A better assessment of dust sources will need to specify these parameters over large areas known as potentially releasing particles in the atmosphere.

When considering the Sahara, existing documents that could be used for assessing potential dust production are very scarce. Geologic maps basically deal with stratigraphy rather than with composition of surficial deposits, while geomorphic and soil studies are restricted to very limited areas (Dutil, 1971 ; Skowronek, 1987). These documents do not provide sufficient information to infer the location and types of surfaces of the Sahara, and aerial photography is not available for that purpose either.

1.3 OBJECTIVES

Since the area to cover is very large and difficult to access, it is impossible to accomplish such mapping by systematic ground investigation. The use of satellite imagery appears as the only technology that might address this problem.

In this study we tested the applicability of previous results obtained over arid Southern Tunisia, on the east fringe of the Saharan desert. During that soil survey project, Landsat Thematic Mapper data were found to be a very efficient tool for mapping soil surface condition (Escadafal et Pouget, 1987 ; Escadafal, 1989) .

Here, a desertic area was investigated, located within the Sahara in central Algeria, close to one of the two major Saharan sand seas, the Erg Occidental (Fig. 1). The geomorphic features of this area have been studied in detail on the ground by Callot (1987). They consist mainly of large calcareous plateaus (called 'hamadas'), sand deposits of various thickness (from sand sheets to large dunes) and endoreic depressions (gypsiferous and argillic). The characteristics of the surface of these quaternary deposits observed on ground were related to their spectral feature measured in the laboratory. Multispectral satellite imagery was then processed in an attempt to discriminate surface types from space.

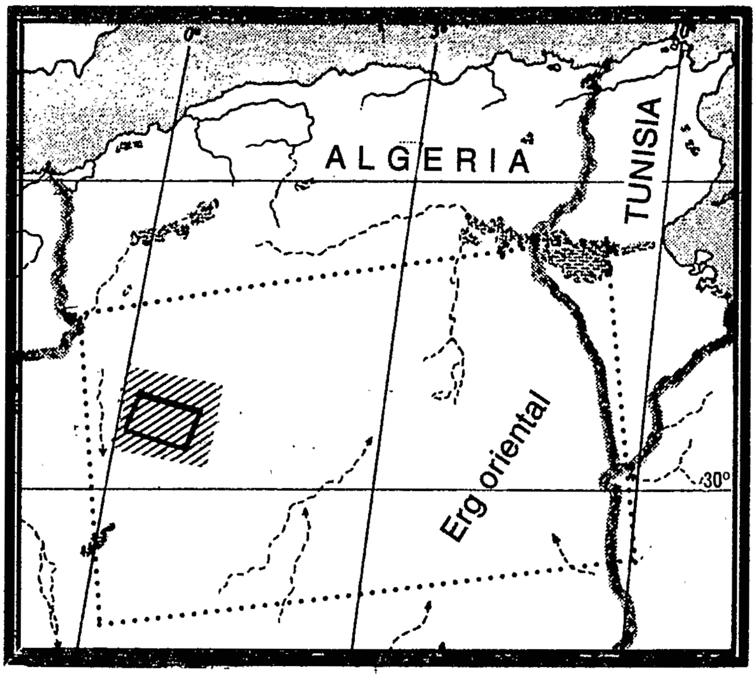


Figure 1. Location of the study area (hatched) and imagery:

a) solid line, Landsat Thematic Mapper image (Fig.4)
b) dotted line, Nimbus-CZCS image (Fig.5)

2. GROUND SURFACE SAMPLING

According to the previous study undertaken in a similar geological context, but under a less desertic climate (Escadafal et Pouget, 1987), the surface parameters influencing the way the solar radiation is reflected towards the satellite are: the surface roughness, the amount of green vegetation, the surface mineralogical composition, the surface color. The surface roughness includes the size and density of coarse elements as well as the abundance of dry vegetation.

Here the vegetation cover varied from zero to only a few percent and was not considered as a major surface variable. A ten-day intensive off-road ground campaign in this hostile unihabited environment allowed the authors to sample the surface of the main types of geomorphic units. The strategy for sampling tried to combine to goals: 1) cover the widest area possible and, 2) collect data effective both from the dust production and the remote sensing points of view.

Sampling was stratified by main geomorphic units, in each of the units an average of 5 sites were studied. In each site the following parameters were recorded: precise position (using maps and navigation techniques), size and type of coarse elements, Munsell color, texture, dominant minerals and cohesion of fine earth. Because of limited time per site, the surface characterization technique used here was a simplified version of the one developed by Escadafal (1981).

After statistical comparison with the series of 63 samples collected in Tunisia (Escadafal, 1989a) a total of 22 samples representative of the Algerian site variability were finally selected for further investigation, including analysis in the laboratory. Figure 2 displays photographs of 5 main types of soil surface encountered.

3. SPECTRAL ANALYSIS

The spectral properties of the main minerals are easily accessible through laboratory reflectance curves of pure powders published in the literature (Hunt and Salibury, 1970). While some of the collected samples could be considered as dominated by one mineral (calcite, for example), most of them were mixtures and needed spectral characterization.

As radiometric or spectroradiometric field instruments covering the visible to mid-infrared spectrum were not available for this experiment, spectral measurements were performed on small samples in the laboratory using a spectrophotomer equipped with an integrating sphere. An example of the reflectance curves obtained is given on Fig. 3.

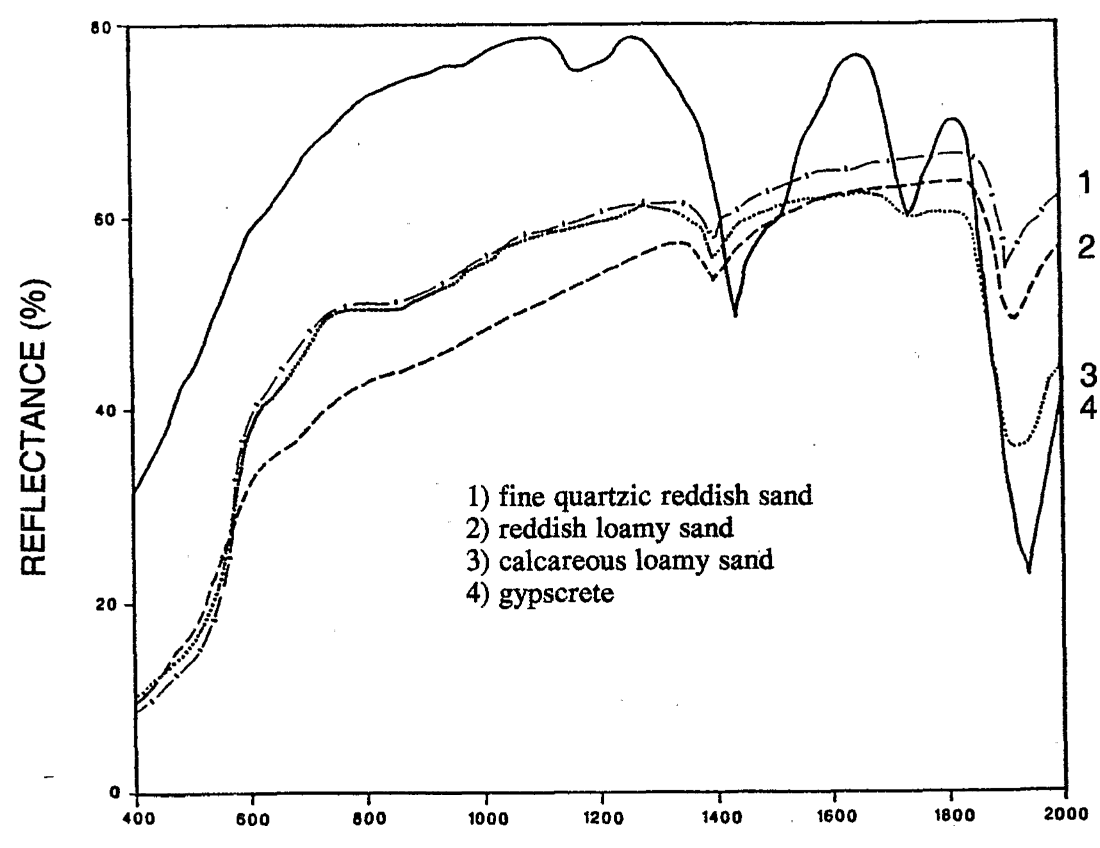
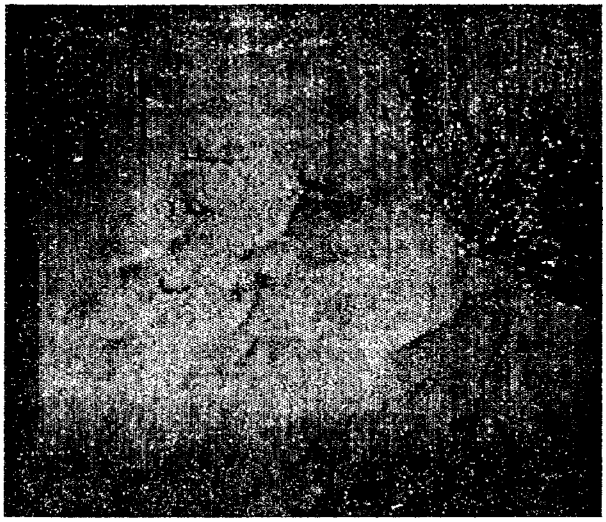
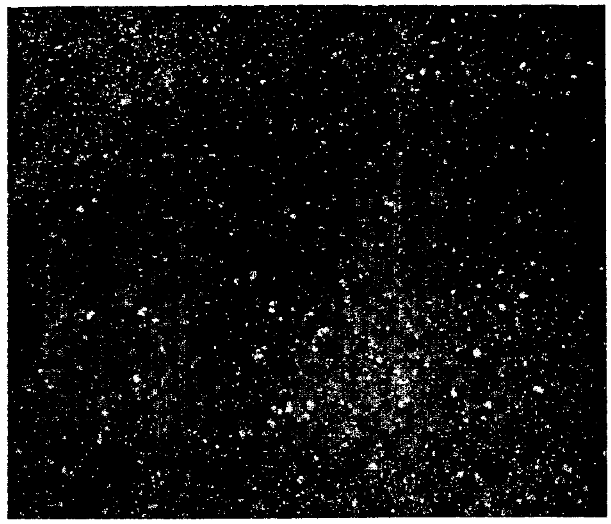


Figure 3. Laboratory spectral reflectance curves of 4 characteristic surface samples

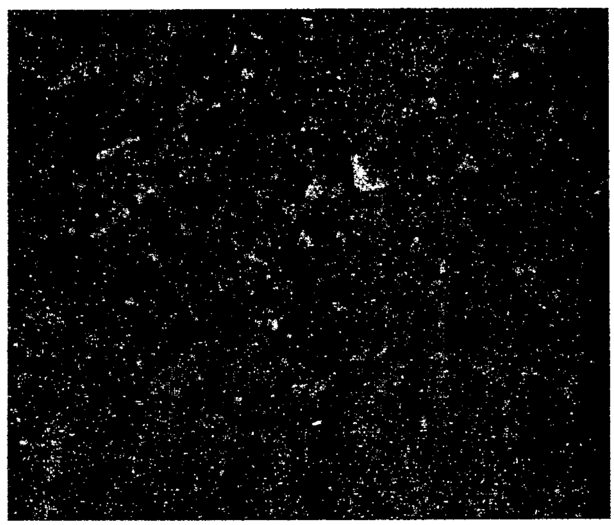
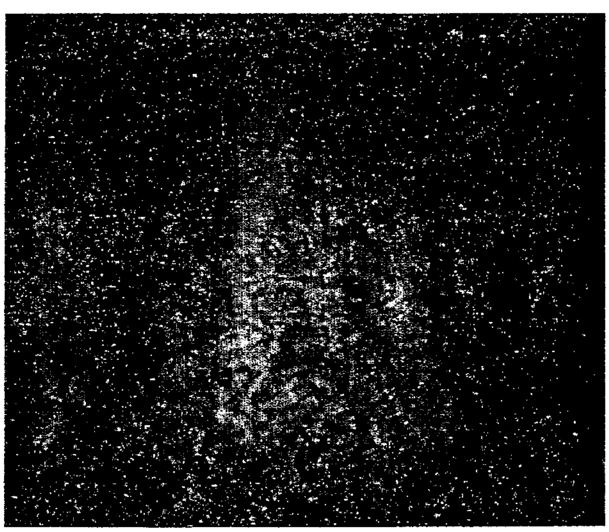



Figure 2.

Photographs of five main soil surface aspects of the studied area.
Approx. 50X50 cm

(see section 5.1 for comments)

The spectral features of the studied samples can be summarized as follows:

- in the visible and near-infrared part of the spectrum, the reflectance is generally gradually increasing with wavelength and varies mainly in amplitude, with small alterations of the curve shape. These are related to iron oxides absorption bands in the shorter wavelengths, so that the sample #1 and #2 appear redder than the others (Barron and Torrent, 1986).

- in the medium infrared part of the spectrum, the absorption features are much more pronounced, particularly in the longer wavelengths where samples with similar visible features are easily discriminated. Note that the gypsiferous samples presents the stronger absorption in that spectral domain.

These results are consistent with previous studies on soil spectral properties (Baumgardner et al. 1985). Spectral properties of real complex surfaces were infered from these individual component spectra by assuming linear mixing of spectra of the differents components (calcareous stones and sand, for instance).

4. IMAGE SELECTION AND PROCESSING

From the spectral curves dicussed above, multispectral imagery covering both visible and mid-infrared spectral domains should offer the maximum discrimination among soil surfaces. Landsat Thematic Mapper data are the only one matching these requirements.

Among the Landsat TM images available over the studied area, the one recorded november 26, 1986 has been selected as it shows 0% cloud cover and excellent contrast. The atmospheric disturbance is then considered low and constant. Thus, the spectral discrimination of the surfaces within this specific image is possible using raw digital counts. The selected quarter scene has been registered with the topographic map at a 1/200 000 scale to allow precise positioning of the ground sampled sites.

The overall spectral characteristics of this Landsat image are depicted by the matrix of the correlations between the visible to mid-infrared bands (Table 1).

Table 1. Matrix of the correlation between the bands of the selected TM image

bands	TM1	TM2	TM3	TM4	TM5	TM7
TM1	1.00					
TM2	0.96	1.00				
TM3	0.90	0.97	1.00			
TM4	0.91	0.97	0.99	1.00		
TM5	0.90	0.96	0.98	0.98	1.00	
TM7	0.83	0.93	0.97	0.97	0.98	1.00

When considering the two spectral domains discussed above, the 3 bands providing the less redundant data (maximum information) are band 1, 3 and 7.

A simple ratioing technique was used to eliminate most of the brightness effect, which is not only related to surface composition (presence of carbonates or sulfates) but also to the surface rouhgness and humidity, as well as to the topography. TM1/TM3 band ratio expresses the surface color saturation (or 'redness') as shown in recent studies (Escadafal et al., 1989; Escadafal, 1989b).

Here we focused on the contribution of the longer wavelength spectral band and used the TM1/TM7 band ratio to discriminate the mineralogical types of surfaces. Training areas were used to define the center of classes based on this ratio. Using the PLANETES software developped under Unix on Sun3 workstation (Rakoto et al., 1988), each pixel was assigned the nearest class (euclidian distance to the center).

5. RESULTS & DISCUSSION

5.1 SOIL SURFACE TYPES

Most of the soil surfaces encountered could be described by reference to five main types. The argillic depression was the only geomorphic feature that could not be accessed and sampled. These 5 surfaces types are the following (see also Fig.2):

a) aeolian deposits of fine sorted reddish quartzic sand, with small variations of the grain size and color , forming small individual dunes as well as large dune fields,

b) sandy loamy reddish calcareous deposits with altered quartzic gravels, in longitudinal depressions,

c) calcareous rocks (and outcropping calcrete) on the eroded hamadas surfaces, forming a pavement of flat shaped boulders and stones,

d) reddish quartzic sand sheet on calcareous rocks, (less eroded hamadas),

e) outcropping gypsiferous deposits (gypscrete) in endoreic depressions (paleolakes).

They are primarly characterized by their mineralogy, but to each mineralogy corresponds a specific dominant size of elements, which is also important when considering dust production. As these main mineralogical types are spectrally different (see Fig.3), these five surface type are likely to be discriminated by Landsat TM imagery.

5.2 LANDSAT TM IMAGE CLASSIFICATION (FIG.4)

The result of the TM image classification appears on Fig. 4. Ranked by increasing TM1/TM7 band ratio, the classes are displayed with the following colors (surface types refers to previous section):

- in red, quartzic fine sand, (surface type a),
- in yellow, fine sand on calcareous plateau, (surface type d),
- in beige, gravelly carbonated sandy loam , (surface type b),
- in blue, stony eroded calcareous plateau, (surface type c),
- in purple, gypsiferous deposits (surface type e),

Shadowed areas appear in dark colors, whereas sun facing areas appear in light colors, this allows to underline the major topographic features. The overall classification accuracy seemed very good when compared to what is known from the area, but it was not possible to do further ground checking in this very remote and almost inacessible part of the Sahara.

When considering these surface types in the dust production perspective, fine sands are the surface material most easily entrained by wind. Since it is made of quartz grains coarser than dust particles, it is not a dust source by itself. But during strong winds, fine sands are likely to produce smaller quartz particles by aeolian comminution, and above all, they will erode other materials. The sandy loam surfaces are moderately protected from abrasion by gravels and will release carbonated dust, while the paleolakes surfaces are likely to release large amounts of gypsum dust by abrasion. On the other hand, the stony calcareous hamadas can be considered as inert surfaces.

5.3 THE NEED FOR GLOBAL SCALE DATA - EXAMPLE OF NIMBUS CZCS (FIG.5)

Although the results obtained with Landsat TM data are very satisfactory, it is unlikely that this technique will answer the need for a global scale surface characterization of the whole Saharan desert. Less expensive satellite data with broader coverage are needed for such a task. The Nimbus-AVHRR data belong to this category, but only two bands (red and near infrared) are available in the spectral domain considered here. Furthermore, they are very redundant over these unvegetated landscapes (see Tab. 1 where TM data show a similar feature).

The NOAA Nimbus Coastal Zone Color Scanner (CZCS) is the only medium resolution sensor with large multispectral capability (6 visible-NIR bands). Although it had an oceanographic mission (ended in 1986), few data were recorded and used over terrestrial targets (Roller and Colwell, 1986). Most of the CZCS images over the Sahara are saturated because the instrument was calibrated for ocean reflectances, but we discovered an image recorded march 11, 1982 (orbit 17057 at 10:59 GMT) with usable data in channel 1 and 5 (blue and red bands).

The corresponding 'true' color composite on Fig. 5 shows that by using only visible bands it is possible to distinguish a wide array of surface material by their color: in white, gypsiferous and others dry playas, in blue, carbonated rocks, in reddish colors, the two major Saharan sand seas: the Erg Oriental on the right, and the smaller Erg Occidental on the upper left of the image. The color variations within these huge dune fields are related to different types of sands.

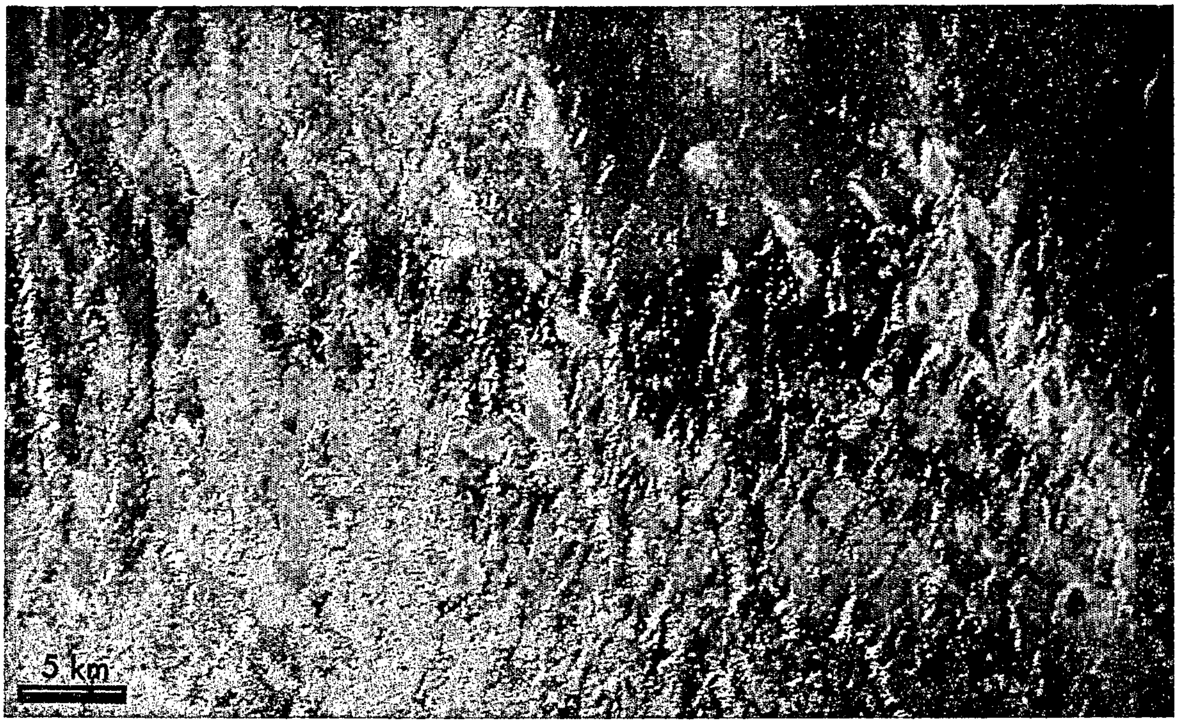


Figure 4. Classification of part of the Landsat TM image (see comments on opposite page)

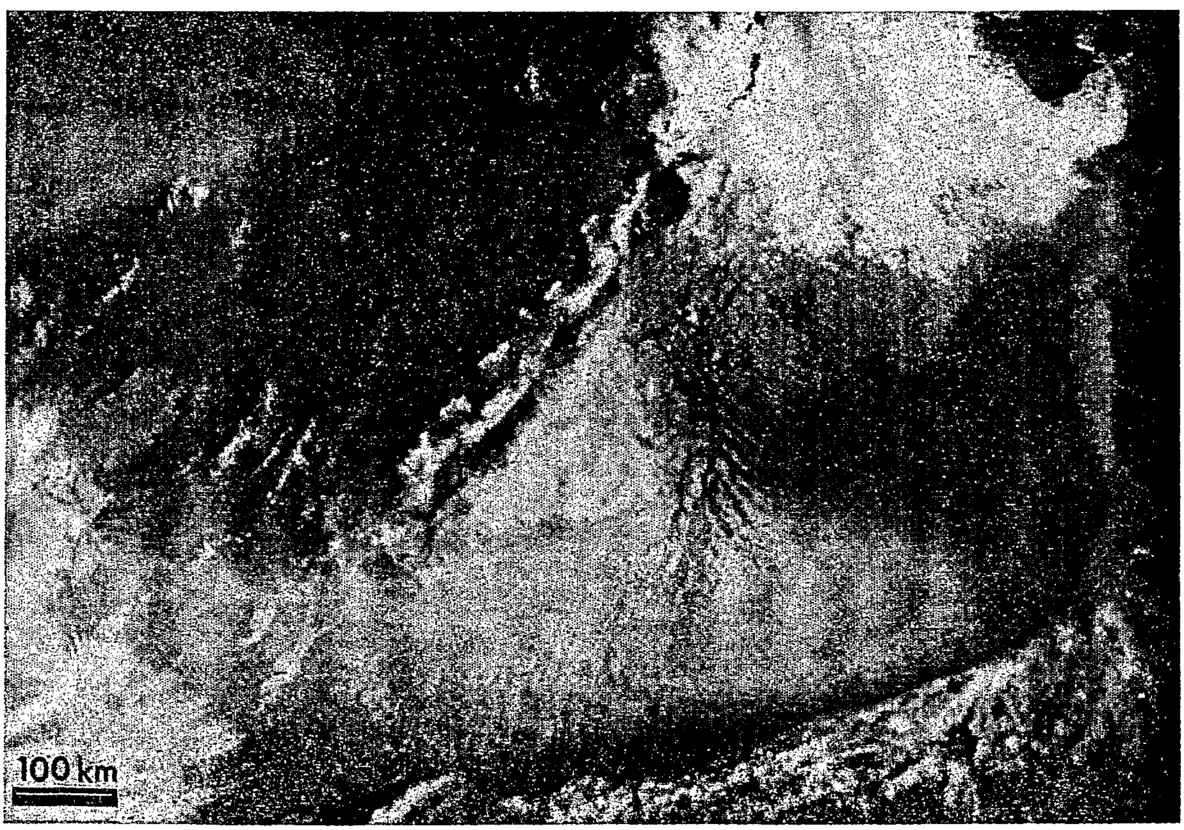


Figure 5. Nimbus-CZCS image (see fig.1 for location and comments on opposite page)

SUMMARY AND CONCLUSION

A better understanding and modeling of the major desert dust sources is needed to assess their impact on the terrestrial environment. Using ground data collected in a part of the Saharan desert offering a large variety of geomorphic features, Landsat Thematic Mapper data were successfully used to discriminate the main soil surface types and their potential for dust production. As the Thematic Mapper is not suited for continental study, an exploratory use of Nimbus-CZCS data showed the potential of medium resolution multispectral imagery for global scale assessment of surface materials. CZCS data allow remote sensing of surface color, which is a promising technique because an undergoing laboratory study indicates that the grain size of Saharan sands seems to be related to their color.

New sensors under development such as CNES-Spot 4 'Végétation' and NASA-MODIS will provide medium resolution imagery with visible to medium-infrared bands. Coupling with others instruments like radar (to measure roughness) and thermal infrared (for humidity) will then allow a real monitoring of desert dust sources.

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