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**WORKSHOP ON REMOTE SENSING TECHNIQUES**  
**WITH APPLICATIONS TO AGRICULTURE, WATER**  
**AND WEATHER RESOURCES**

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**LECTURE ABSTRACT**

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DECIPHERING WIND DIRECTIONS FROM DUNE ORIENTATIONS  
IN SPACE IMAGES OF DESERTS AND SEMIARID LANDS

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ABSTRACT

Major air movements at the earth's surface follow two models: (a) in flat deserts air movements follow high pressure cells (Sahara, Kalahari, Namib, Rub Al Khali and Australia); and (b) in arid areas with alternations of flats and mountains air masses are often deflected (Chinese deserts).

I. INTRODUCTION

Desertification, a tragic degradation of the environment of a semiarid area, is a phenomenon, the causes of which are periodic droughts, but may be produced by combined natural and man-made effects; The mechanisms of which are physical and chemico-physical; and the consequences of which are biophysical and biological, meaning affecting the plant cover and reducing bio-productivity.

Combatting desertification can only be done through better understanding of the physical mechanisms among which wind and water erosion are now recognized worldwide as the most significant causes of the process of land degradation.

Better understanding of wind erosion must begin with the recognition of the importance of the analysis of wind actions as they result in: (a) erosional effects; and (b) depositional effects: sand and other particle deposits such as loess, sand sheets and sand dunes.

II. DISTRIBUTION OF SAND DEPOSITS

In the Sahara, the largest desert in the world, mapping of sandy areas with Landsat and Meteosat images results in the surprisingly low distribution of

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20 to 22%. We also find that aeolian deposits are not restricted to arid landscapes. Again, with the help of satellite images, we observe that the thickest and more continuous sand deposits are found at the edge of the desert, in the semiarid areas of the Saharo-Sahelian zone and Sahelian zone, south of the Sahara.

Similarly in northern China, aeolian deposits of loess are in the sub-humid area downwind of the gobi plains of Mongolia (El-Baz, 1982a) in the direction of paleowind which is close to but not identical to the direction of the present day winds.

Furthermore, along the shorelines in all ecozones, there are sandy coastal dunes. The latter also occur leeward of the cold desert in areas of glacial outwash.

For any of these sand deposits to form, what is required are the necessary ingredients for sand production, a sand transport mechanism, and a reason for sand accumulation.

The problem of sand production is one of the most difficult to solve. It has never received an answer that could be globally applied. The two main hypothesis proposed for the regional scale are:

1. Production of sandy material in cold environment under the effect of cryoclasty during, in time, the cold periods of earth climate, and in space, around cold ecozones even during hotter periods.
2. Production of sandy material in the weathering covers of wet topical ecozones.

The other main hypotheses applicable to a local scale include: (a) sand production in coastal areas: wind reworked marine deposits; and (b) wind reworked sandy fluvial deposits.

Sandy aeolian deposits may be divided into three types: (a) sand sheet; (b) sheets carved at their surface by dunes (Figure 1); and (c) isolated dunes on any basic substrata: coarse sand, reg, rocky surface (figure 2).

The main cause of sand deposition is the decrease of wind speed because of roughness of the substratum as caused by (a) appearance of a vegetation cover which produces micro-roughness, or (b) megaroughness caused by high mountainous massives around which the speed varies as shown in Figure 3.

In order to understand the different types of sand accumulations and their meaning, one must consider the nature of the sediment balance. This was suggested by Mainguet (1983), for examining the dynamics of sandy areas such as dunes, dune fields, ergs, etc. A positive sediment budget occurs when particle deposition in a region is quantitatively higher than the export. A negative sediment budget develops when deflation and export are quantitatively higher in a region than the incoming particles. A balanced sediment budget occurs when the arrival and departure of particles are quantitatively equal.

In the case of accumulation of sand dunes, the shapes differ according to the aeolian regime, which can be classified into three families:

1. A monodirectional wind regime gives crescentic barchans, transverse chains (figure 4), and hilly sandy landscapes ("akles") when the sand has been spread under slightly humid climates. This last case is characteristic of the Sahelian ergs.
2. A bidirectional wind regime produces linear dunes, seifs and "bouquets of seifs".



Figure 1. The southern half of the Western Desert of Egypt as depicted in Landsat photograph. The great sand sea covers the left half.



Figure 2. Detail from the southern part of the Great Sand Sea showing remnant dunes from a sand sheet (after El-Baz, 1981).

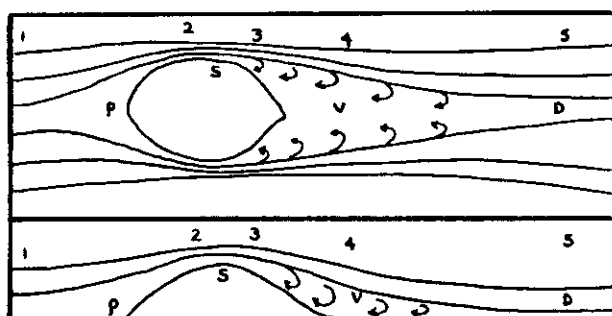


Figure 3. Model of air movement showing wind speeds and sand deposits around an obstacle.

- 1, Upwind area of an obstacle: the pressure is maximum and the speed is low: it becomes zero at the point P.
- 2, Lateral areas of the obstacle where the air laminae are compressed, the speed increases and the pressure becomes low, much lower than the environmental pressure. These areas are active corrosion areas where transport of sand occurs.
- 3, and 4, Areas of detachment of the air laminae. From the point S, point of separation, vortices (V) are formed. The deposits are limited to the outer boundaries of the area.
- 5, End of detachment area; here begins the maximum deposition D, the wind here recovers its initial direction.

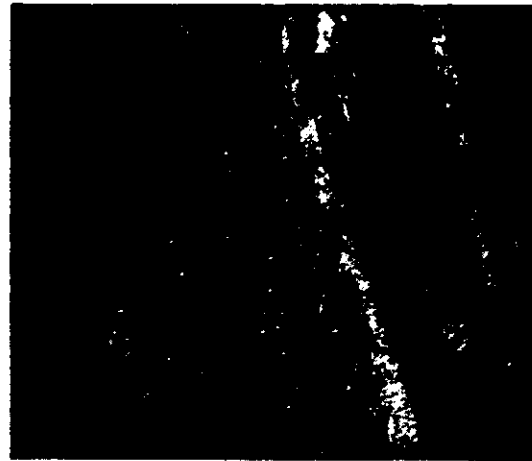


Figure 4. Landsat views of transverse dunes and chains of crescentic and barchan dunes:

Left: The Qatar Peninsula in the Arabian Gulf with the wind direction from northwest to southeast. Near the junction of Qatar and the Arabian Peninsula transverse dunes form at nearly right angles to the direction of transport. Top: Lines of barchan dunes in the Kharga Depression in the Western Desert of Egypt. This area is a detail of the center edge of Figure 1. The dunes coalesce and separate with the changing topographic setting and man-made structures such as villages and fields.

3. A multidirectional wind regime, as a rule, results in star dunes. This type of dune is the most prevalent in the two northern ergs of the Sahara, the Grand Erg Occidental and the Grand Erg Oriental (Mainguet et Jacqueminet, 1984 and Mainguet et al., 1984).

When dune shapes result predominantly from the erosion of pre-existing deposits, the sediment budget is negative with the formation of these different dune families: parabolic dunes, star dune chains, and sand ridges. The second and third ridges are separated by deflation stripes, or interdunal corridors. The latter are characteristic of the dynamics of deflation and transport which can be quantified by the extent of separation (E):

$$E = \frac{C_1}{C_d}$$

$C_1$ : Width of sand ridge  
 $C_d$ : width of interdunal corridor

In the central Sahara, the Erg Chech is the most pronounced example of a negative sand budget ridge with the ration E being 1/10. The same ratio calculated for the sand ridges which constitute the Great Sand Sea in Egypt

(Figures 1 and 2) is 1/3 to 1/4. The southern part of the Sahara is composed of sand ridges in which the E ratio equals 1/1 or even reverses itself to 2/1, as in the "Grand Erg" of Bilma or the south of the Ténéré.

An analysis of the state of Saharan Ergs is given in figure 5. It reveals that on the northern margin, the Sahara has a partially positive sand budget (Grand Erg Occidental and Grand Erg Oriental). In the hyper-arid center of the Sahara, the ergs have, for the most part, a negative sediment budget. In its Sholian margins the sediment budget is again positive. The analysis of the surface of the northern Sahara reveals a belt of northern and western margins, which are still in a positive phase and, on the other hand, the southern margins are in a negative phase.

The northern ergs are rich in sand because of the abundance of alluvial sediments deposited by wadis in the area during the Quaternary, for in these northern margins the climate has never really been arid (Dresch, 1982).

In the central Sahara, which is poor in sand, there are negative budget sand seas with narrow sand ridges separated by large corridors. The ergs are Iguidi, Chech, Ténéré of the north, Rebiana, Calansho, and the Great Sand Sea.

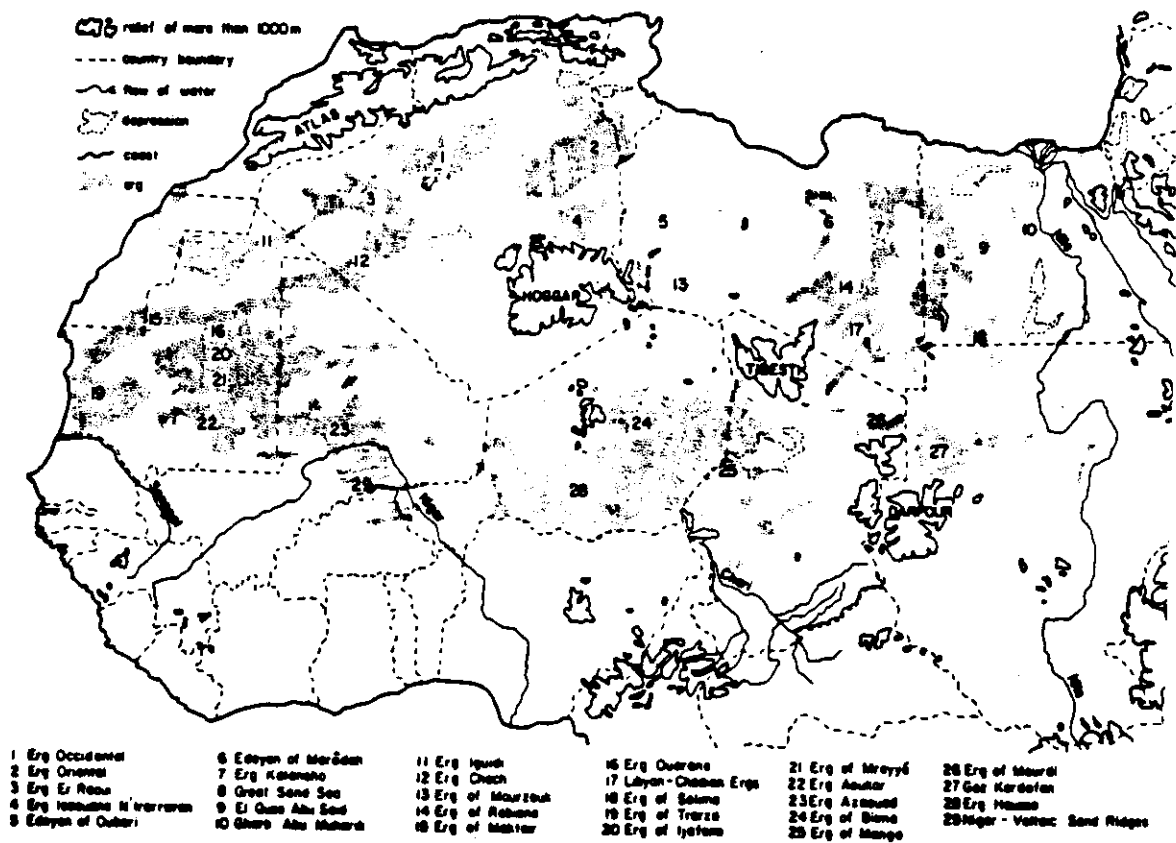


Figure 5. Sand deposits in the Sahara

The Saharan-Sahelian belt, which is rich in structures of akles of a transverse type, is in essentially a positive sediment budget phase with corridors of deflation. These deflation corridors have an increasing role in each drought crisis. The ergs with transverse edifices (Kanem, Manga, Haoussa, Malian, and Mauritanian ergs) are separated in the Sahelian belt by areas of longitudinal, aperiodical sand ridges (nigero-voltaic ridges) or weak, dense barchanic area (Azaouad region), which undergo transport of sand.

The examination of these continental wind systems proves that deciphering wind directions on satellite images (Meteostat, NOAA), the indicators used are high reflectance features, which are sand ridges and/or currents along which saltation leaves its scars on the surface. On Landsat the investigation can go deeper because all sorts of linear elements can be observed.

### III. DECIPHERING WIND DIRECTIONS BASED ON DUNE ORIENTATIONS

All wind deposits imply aeolian transport at different distances - short distances from the seashore to the coastal areas or long, but discontinuous in time and space, transport within a given wind system. An analysis of the aeolian circulation according to gomorphological indicators on satellite images shows traces left by sand deflation, saltation and dunes.

#### A. SYNOPTIC WIND SYSTEMS AND WIND DIRECTION

1. **Saharan Wind System:** (Figure 6) Analysis of NOAA satellite and Meteosat from 30 May 1978 to 25 January 1979 reveals a unique wind system which in geological time scale sweeps the sand from the northern Sahara to the central Sahara then to the Sahel and finally to the Atlantic Ocean. The wind system shows interconnection between the Mediterranean areas of northern Sahara at 30° North and the Sahel through the hyper-arid heart of the desert and until the Atlantic Ocean at 10° N.

Figure 6a. Analysis of NOAA satellite imagery showing in schematic form the different wind currents in the Sahara along which sand deflation, sand transport, and sand deposition occur.

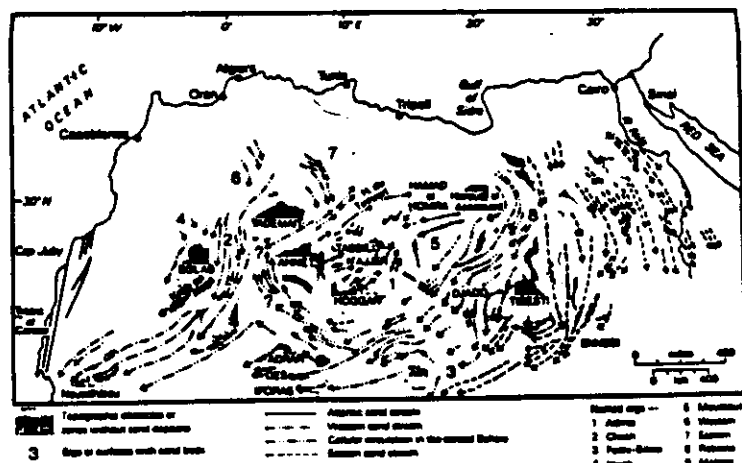
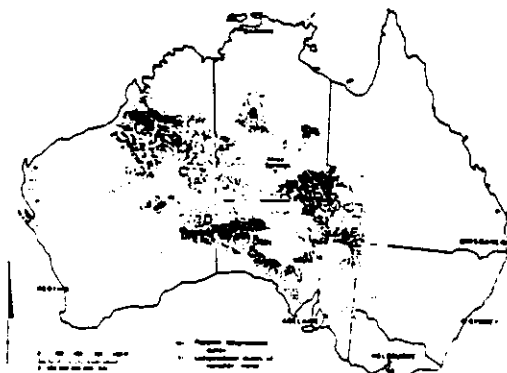




Figure 6b. Saharan wind system as derived from Meteosat images. Solid lines represent depositional features (most often longitudinal sand ridges). Dashed lines represent deflation and transport features.



A Great Sandy Desert C Gibson Desert E Simpson Desert  
B Tanami Desert D Great Victoria Desert F Sturt's Stony Desert

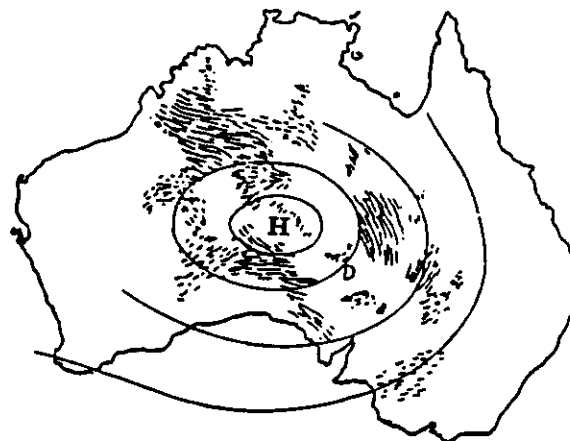
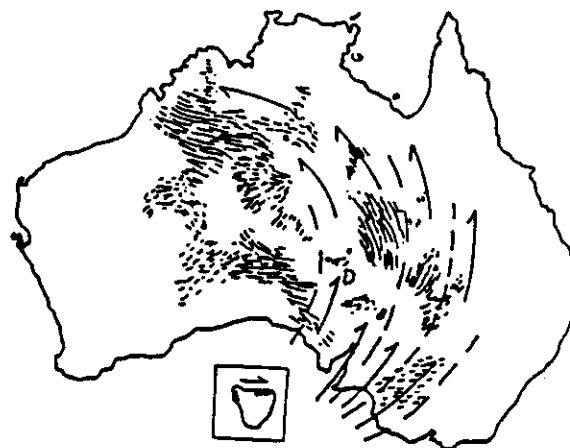


Figure 7. Australian dunes and wind systems: Top, the continental system of longitudinal sand ridges (after Twidale, 1981); Upper right, the Australian continental arc of sand ridges with reconstruction by Tseo(1986) of an approximation of the mean trace of ancient summer anti-cyclones; Right, Prevailing winds of the modern summer anti-cyclones (Sprigg, 1980). Comparison of the three figures reveals the sliding of the heart of the anticyclone slightly towards the south.

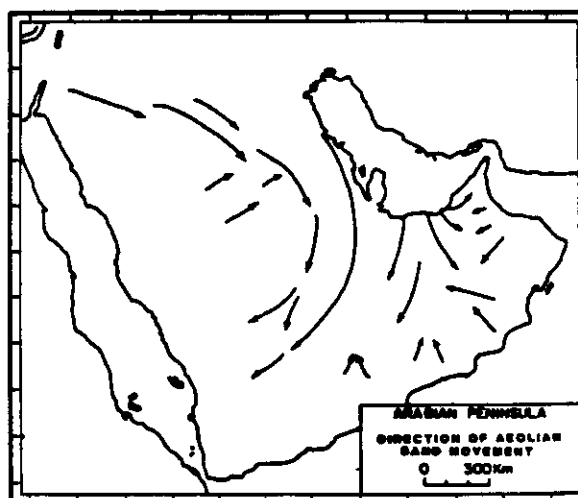


2. Kalahari-Namib Wind System: Lancaster (1981) studying the fixed dunes of Kalhali between 16° and 28°S, also found a synoptic scale wind system. The dune deposit is concentric around a circle of 2,000 kilometers in diameter, which follows more or less the movement of the south African anticlockwise air movement. The only difference between the palaeoclimate fixed dune system and the present day winds is a sliding of some degrees of the south African anticyclone to the south and a less efficient present day wind system.
3. Australian Wind System: (Figure 7) Australia as shown by Twidale (1981) has a continental system of longitudinal and linear dune fields. Tseo (1986) proposed an approximation of the mean trace of ancient summer anticyclone according to relic dune system and compared it with the "Scheme of Modern Summer Anticyclone" of Sprigg (1968).
4. Arabian Peninsula Wind System: (Figure 8) The Arabian Peninsula wind system showing a general counterclockwise movement of air and sand as demonstrated by Holm (1968).
5. Chinese Deserts' Wind System: For the Chinese deserts our ideas are not so clear even if the sand systems are following the same rules. The big difference introduced by the huge obstacles can explain that instead of a concentric wind system around the Mongolian-Siberian High Pressure cell there is a diverting system as shown by Zhao in 1981 (Figure 9). The precise analysis from Landsat of the wind system in the Taklimakan desert shows also a diverging system from the Lop Nor boundary with a concentric system in the western half of the desert (Figure 9).

#### B. DUNES AND WIND DIRECTIONS

Aeolian sand transport (deflation and saltation) has erosional effects the actions of which are longitudinally in the landscape. All the dunes carved in a framework of negative sediment balance also have a longitudinal disposition. Sand ridges and star dune chains follow the main wind direction.

Figure 8. Wind and sand movements in the Arabian Peninsula including the Kub Al Khali desert (after Holm, 1968). The whole wind system is shaped around the high pressure cell located on the Arabian Peninsula. Note that the Mediterranean wind as it reaches the Levant, it rotates in a clockwise motion until it reaches the Rub Al Khali in the southern part of the Arabian Peninsula.



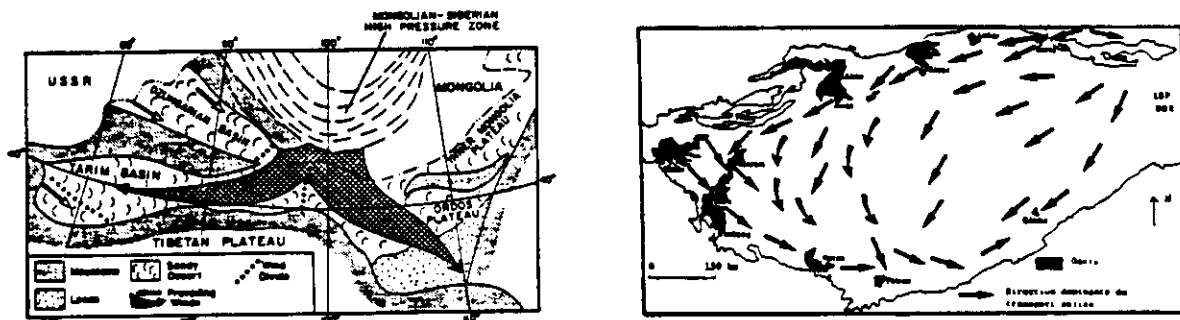


Figure 9. Left, dominant wind system in winter in northwestern China (after Zhao, 1981). This wind system is influenced by the Siberian high pressure zone and by the topographic high of the mountainous systems of the Tibetan Plateau; Right, counterclockwise wind system in the Taklamakan Desert of northwestern China. The wind system is also strongly influenced by the surrounding mountains.

Crescent dunes and barchanic edifices which correspond to a deposit in a positive sediment balance display an axis of symmetry which is parallel to the main wind direction. However, when barchanic edifices form chains, these chains are called transverse chains, because their orientation is perpendicular or almost perpendicular to the main direction of the monodirectional wind system in which they are formed.

Barchanic arms are oblique to the main wind direction. This obliquity on each side of an axis of symmetry is also existent in linear dunes (seifs), for which it is the rule. The obliquity of the linear dune to the two wind directions was not highlighted enough in the literature. The cause of this comes from the confusion between linear dunes, which are depositional features and longitudinal dunes, which represent residues of erosion in a sand sheet and located between two deflation corridors (El-Baz 1982b).

The area north of Burkina Faso is typical because of the very asymmetrical sand ridge-like edifices. Comparison with the main wind direction which is NNE-SSW (Harmattan Wind) shows the obliquity of these ENE-WSW edifices. In fact they are not sand ridges but compound linear dunes receiving sand obliquely. However, because they are in the Sahelian zone they are fixed by a palaeo-soil and are vegetated. As a result, they have lost their sharp crests and spread out with an evolution between linear dunes and sand ridges.

In Australia, the sand ridges are cropped in a sub-parallel way by narrow linear dunes which are the result of reactivation of the fixed sand ridges which are very much larger. This has caused confusion between longitudinal and linear dunes.

The simultaneous presence of sand ridges and linear dunes on their back with a very large fan of angular differences is observed in all deserts. The maximum angular difference of around  $30^\circ$  is measured in the Grand Erg of Bilma in Niger.

It is important to state that recognizing wind direction from dune orientations is essential where there is no meteorological station, which is the case of most desert regions. This recognition is vital in the cases where dunes on the march effect the livelihood of people that live in desert oases. This is the case of the Western Desert of Egypt, where research by the second author resulted in mapping of dangerous sand dunes in the Kharga Oasis (Strain and El-Baz, 1982). The resulting map (Figure 10) is presently used by the local people to plan desert reclamation projects.

#### IV. CONCLUSION

At a synoptic scale, the air movement near the surface is highly influenced by the high pressure cells, such as in the Sahara, Kalahari, Arabian Peninsula, and Australia. A second type of model occurs in arid areas where mountains and flat areas coexist, which is the case of the Chinese deserts.

On a smaller scale it is possible to conclude that barchanic dunes, transverse chains, and longitudinal dunes can be considered as indicators of wind direction. However, linear dunes and isolated or scattered star dunes can reveal in all cases the wind regime, but not in any case the wind directions.

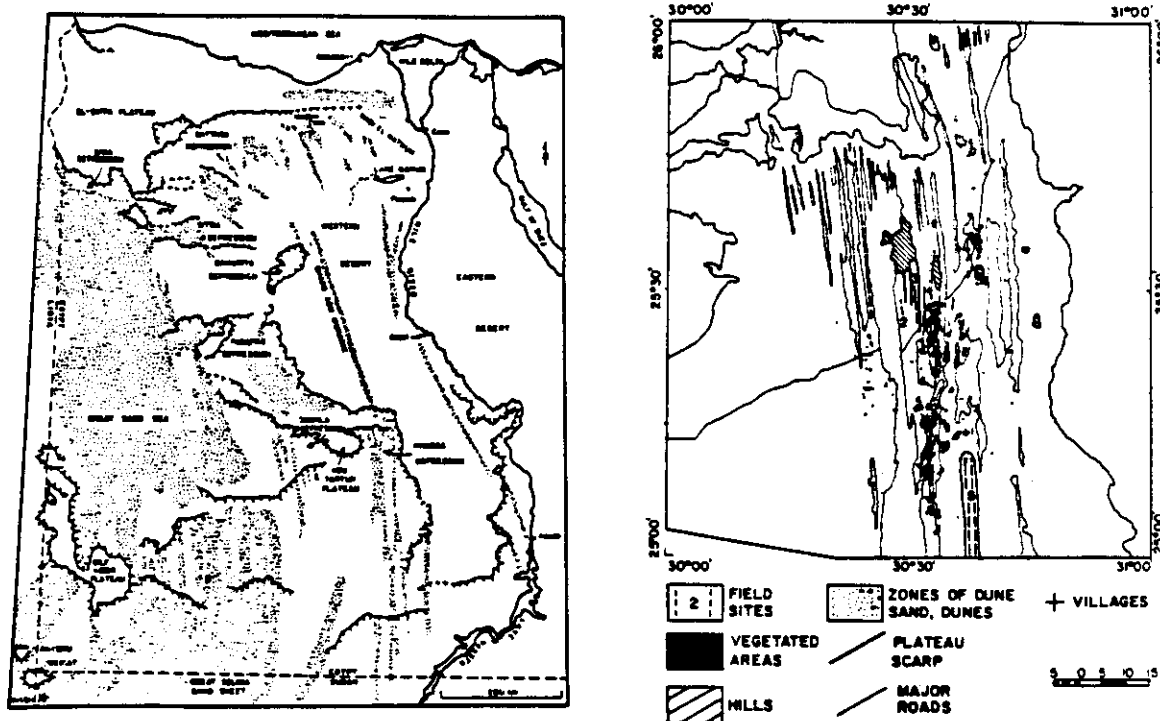


Figure 10. Left, map of the sand deposits in the Western Desert of Egypt; Right, map of the distribution of sand dunes in the Kharga region based on the interpretation of Landsat data. Vegetated areas depend on groundwater wells (after Strain and El-Baz, 1982).

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