Paper G 6

AN INVESTIGATION OF MAJOR SAND SEAS IN DESERT AREAS THROUGHOUT THE WORLD

Edwin D. McKee, *U.S. Geological Survey, Denver, Colo.,* and Carol S. Breed, *U.S. Geological Survey, Flagstaff, Ariz.*

ABSTRACT

This study of sand seas on a global scale consists of identifying and measuring characteristic sand forms, examining structures, determining the processes involved, and ascertaining the world distribution of various types of sand bodies. ERTS imagery has the advantages of permitting (1) direct comparison of areas because the same scale prevails on all images, (2) ready observation of relationships to surrounding features, and (3) recognition of major trends or lineations where minor details are obscured.

Fifteen major areas or sites in the Eastern Hemisphere and three sites in the Western Hemisphere have been examined to date. For each area, mosaics of false-color prints showing sand patterns have been prepared and these mosaics form a base map for all subsequent types of study.

Many attempts have been made in the past to classify sand bodies and assign names, but the studies have been mostly local in scope, and classification has been based in part on supposed genesis. In this study an attempt is made to develop a strictly objective classification of worldwide application. The principal types recognized are (1) parallel straight or linear, (2) parallel wavy or crescentic, (3) star or radial, (4) parabolic or U-shaped, and (5) sheet or stringer types. Numerous variations of each group are also recognized.

Principal controlling factors in forming the various types of sand bodies are believed to be wind direction and strength, topography, vegetation, moisture, available sediment, and distance from source. Efforts to recognize and delineate these factors for specific areas are being made and methods of illustrating the relationships on transparent overlays are being developed. Ground truth investigations to determine internal structures of sand masses also are under way.

Ultimate objectives of this study are threefold. First, a better understanding of stratification in ancient rocks of dune origin; such structures are important in the migration of water and oil. Second, a further insight into the controls of sand migration that in some areas adversely affects various enterprises of man may be obtained. Finally, an appreciation of certain similar patterns on Mars, apparently wind-formed, may result.

INTRODUCTION

This investigation is a study of desert sand seas on a global scale and illustrates the use and value of ERTS imagery for this purpose. The study consists of the identification, description, and measuring of characteristic forms and structures within the principal sand bodies. It facilitates the determination of world distribution of the various dune types and the classification of these. In addition, the basic forms of sand deposits, analyzed together with data derived from ground truth studies, make possible an interpretation of the processes responsible for each dune type.

The advantages of employing ERTS images in this study are readily apparent. Because the same scale is represented in all images, direct comparisons of widely separated areas are possible. Further, the relations of sand areas to surrounding features are easy to recognize and major lineations or other patterns in the sand fields are clearly defined. Finally, mosaics that are developed from combinations of images make excellent map bases on which to superimpose many kinds of data.

For purposes of this study, 15 desert or semidesert areas, all of them in the Eastern Hemisphere, were initially selected (fig. 1). Subsequently some of these test site areas were combined and others were reduced in size in order to eliminate non-sandy areas and to consolidate mosaics for greater efficiency in handling data. A few relatively small areas located in the Western Hemisphere (fig. 2) were later added to the coverage primarily because they were easy of access. These areas were chosen because they can readily be checked by air photography and, in most of them, ground truth is available for interpreting genetic features.

The methods used in this investigation have gradually evolved with experience in employing various types of ERTS imagery as they have become available. Initially only small black-and-white negatives were received and these were scarcely adequate for careful analysis. With the arrival of relatively large prints, and the enhancement of these by photo processing methods, both through printing techniques and differences in paper, considerable improvement was made. A comparison of available prints from the green, red, and near-infrared bands was another major advance, for it facilitated the recognition of water, vegetation and other associated features bordering sand bodies. Finally, when false-color images became available, the discernment of sand through its yellow color places the interpretation of sand bodies through ERTS images on a high level of accuracy.

CLASSIFICATION

A partial review of the literature on eolian sand dunes has disclosed that more than 20 attempts have been made to name and classify dune types, at least locally. Many proposed names are based on inferred genesis; some are defined differently by different workers, others are overlapping in scope. As a result, the present status of the classification of sand bodies is chaotic.

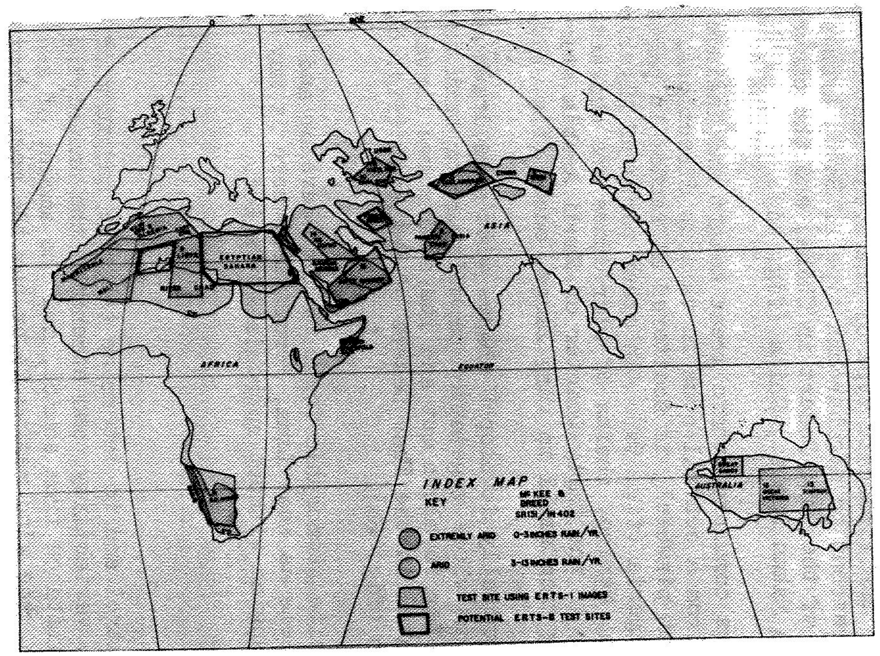


Figure 1.--Map of principal desert and semidesert regions and selected test sites (areas), Eastern Hemisphere.

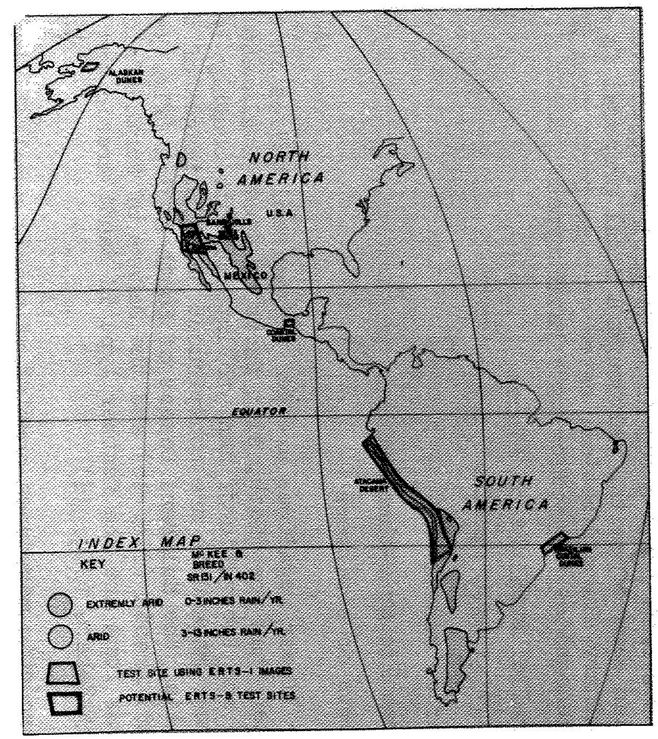


Figure 2.--Map of principal desert and semidesert regions and selected test sites (areas), Western Hemisphere.

A principal aim of this ERTS image study is to develop an objective classification of major eolian sand deposits. Although a final proposal is as yet far from ready, a preliminary classification, based on dune forms from ERTS imagery thus far examined, recognizes the following 5 basic types:

1. Parallel straight or linear
2. Parallel wavy or crescentic
3. Star or radial
4. Parabolic or U-shaped
5. Sheets or stringers

Parallel straight or linear megadunes are defined as sand bodies in which the length is much greater than the width, slip faces or steep avalanche surfaces occur on both sides, and the ratio of dune to interdune is roughly 1/1. Examples of such linear megadunes are conspicuous on ERTS images of the Simpson Desert of Australia, the Kalahari Desert of South Africa (fig. 3a), the Empty Quarter of Saudi Arabia (fig. 3b) and the Sahara of North Africa (fig. 3c). Variants of the linear form are the feather type in Saudi Arabia and the wide intradune type in the Sahara (fig. 3d)

Parallel wavy or crescentic megadunes consist of nearly parallel rows of cuspate segments as represented in the Kara Kum Desert of the U.S.S.R. (fig. 4a), and in the Nebraska Sand Hills of western United States. Variants of the simple basic type are referred to as the fishscale type of the Great Eastern Erg of Algeria (fig. 4b), the giant crescent or megabarchan type of Saudi Arabia (fig. 4c), the bulbous warty type of the Gobi Desert in China, and the chevron or basket-weave type of the Takla Makan Desert, China (fig. 4d).

Star or radial megadunes commonly attain great height and include a few to many arms that project out from a central cone in various directions. The basic type, resembling a giant pinwheel, is scattered at random in parts of the Great Eastern Erg of Algeria (fig. 5a). In other parts of Algeria and in the Gran Desierto of Sonora, Mexico, chains of star dunes are characteristic (figs. 5b, 5c), whereas in the Empty Quarter of Saudi Arabia star dunes of graduated size, grading from small to very large, occur (fig. 5d).

Parabolic dunes that typically develop U shapes with arms drawn out on the sides are common in areas where vegetation or moisture or both tend to anchor the arms, while the center is blown out and its sand moves forward. These dunes are well illustrated in the Thar Desert of Pakistan (fig. 6a) and at White Sands, New Mexico (fig. 6b).

In some sand seas definite geomorphic forms fail to develop and the sand accumulates in flat sheets as near Lima, Peru. Elsewhere it may form stringers extending downwind without appreciable relief.

GENETIC IMPLICATIONS

Factors believed to control and to determine the size and form of dune bodies are the wind direction, variability, and strength, the underlying topography, vegetation, moisture, distance from source, and the amount of sediment available. Of these factors, the wind regime is by far the most important.

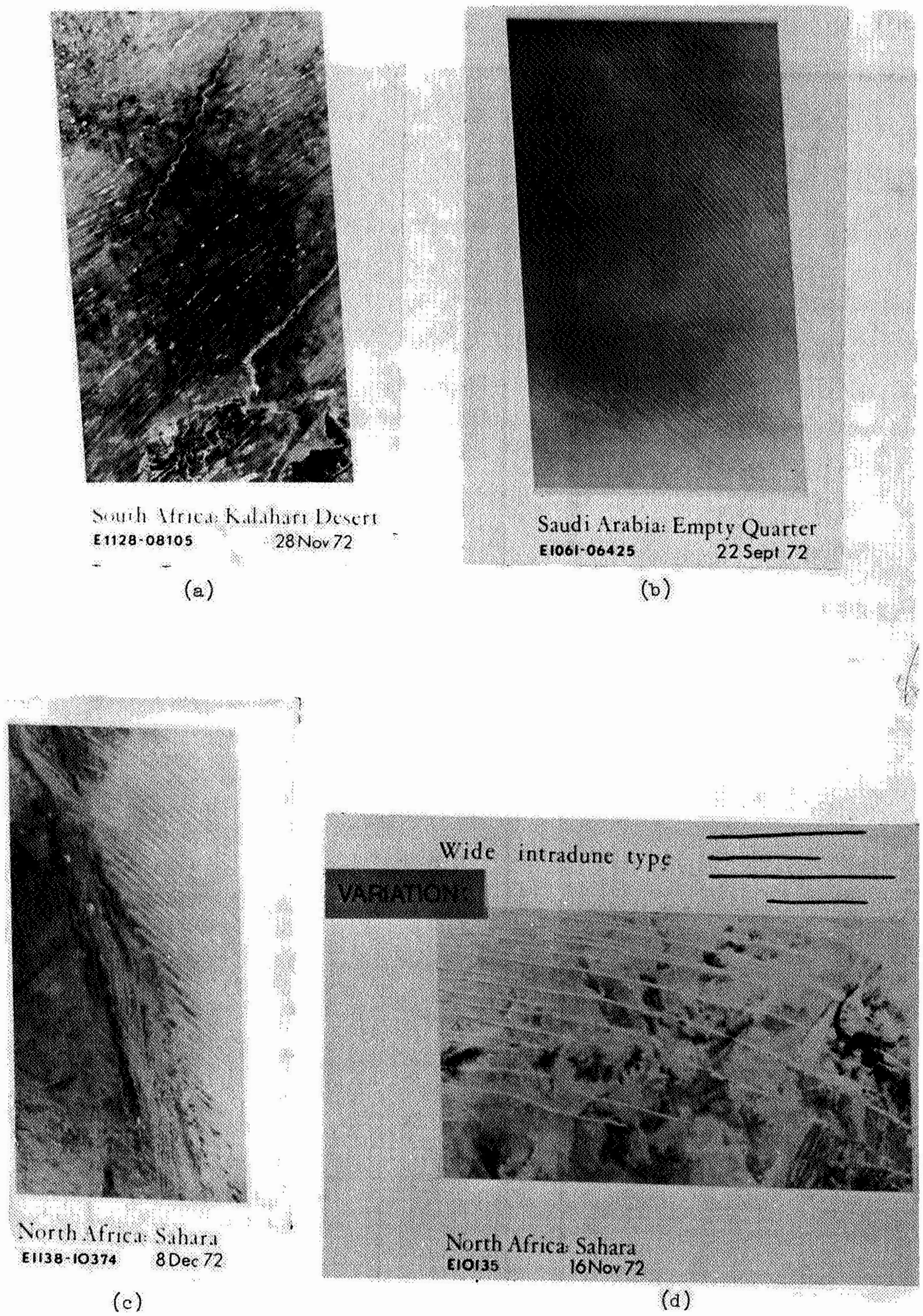


Figure 3.--Parallel straight (linear) megadunes: (a) Kalahari Desert, South Africa; (b) Empty Quarter, Saudi Arabia; (c) Sahara Desert, North Africa; (d) Sahara, North Africa (wide intradune variety).

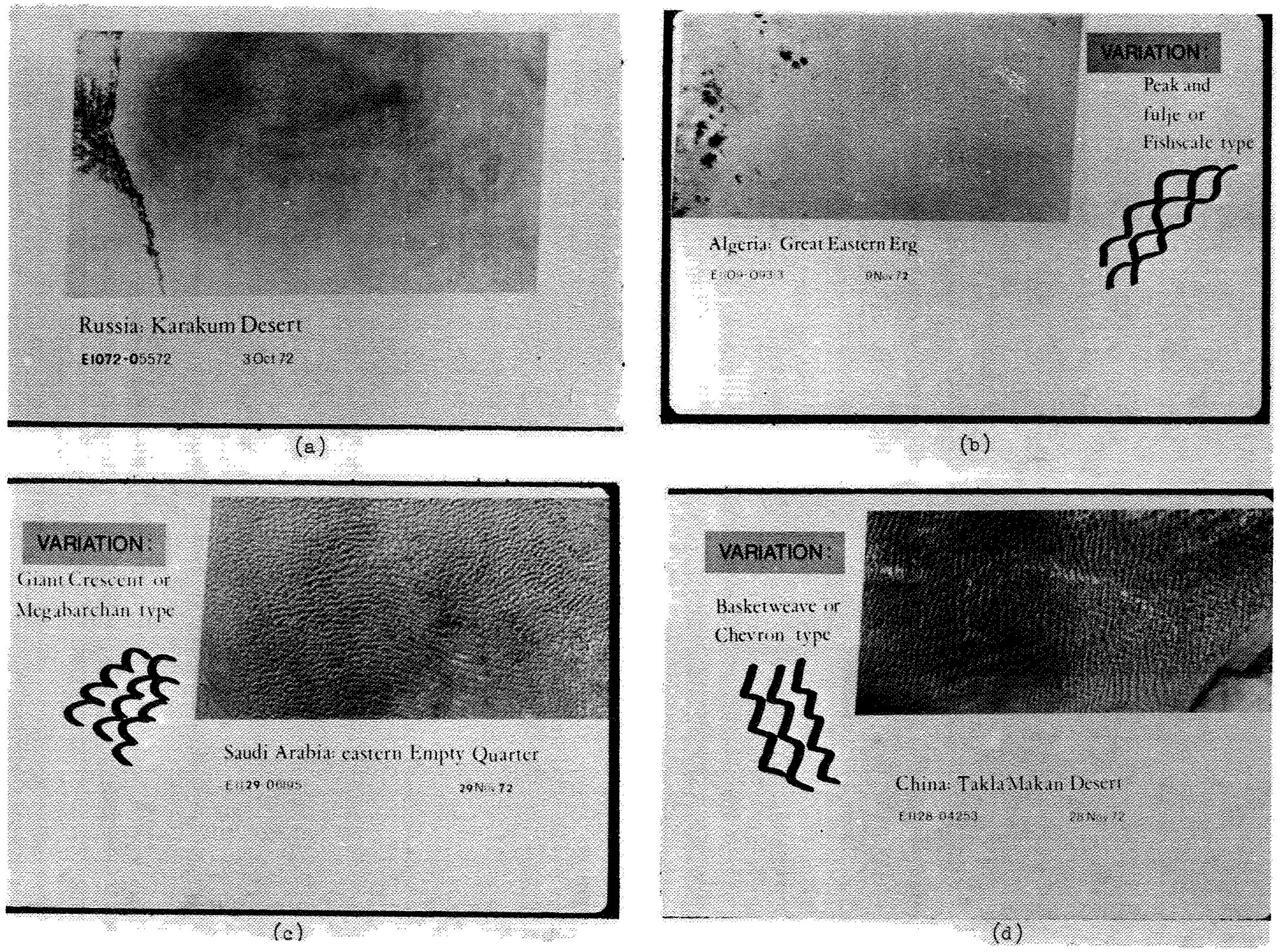


Figure 4.--Parallel wavy (crescentic) megadunes: (a) Kara Kum Desert, U.S.S.R.: (b) Great Eastern Erg, Algeria (fishscale type); (e) Empty Quarter, Saudi Arabia (giant crescent type); (d) Takla Makan Desert, China (basketweave type).

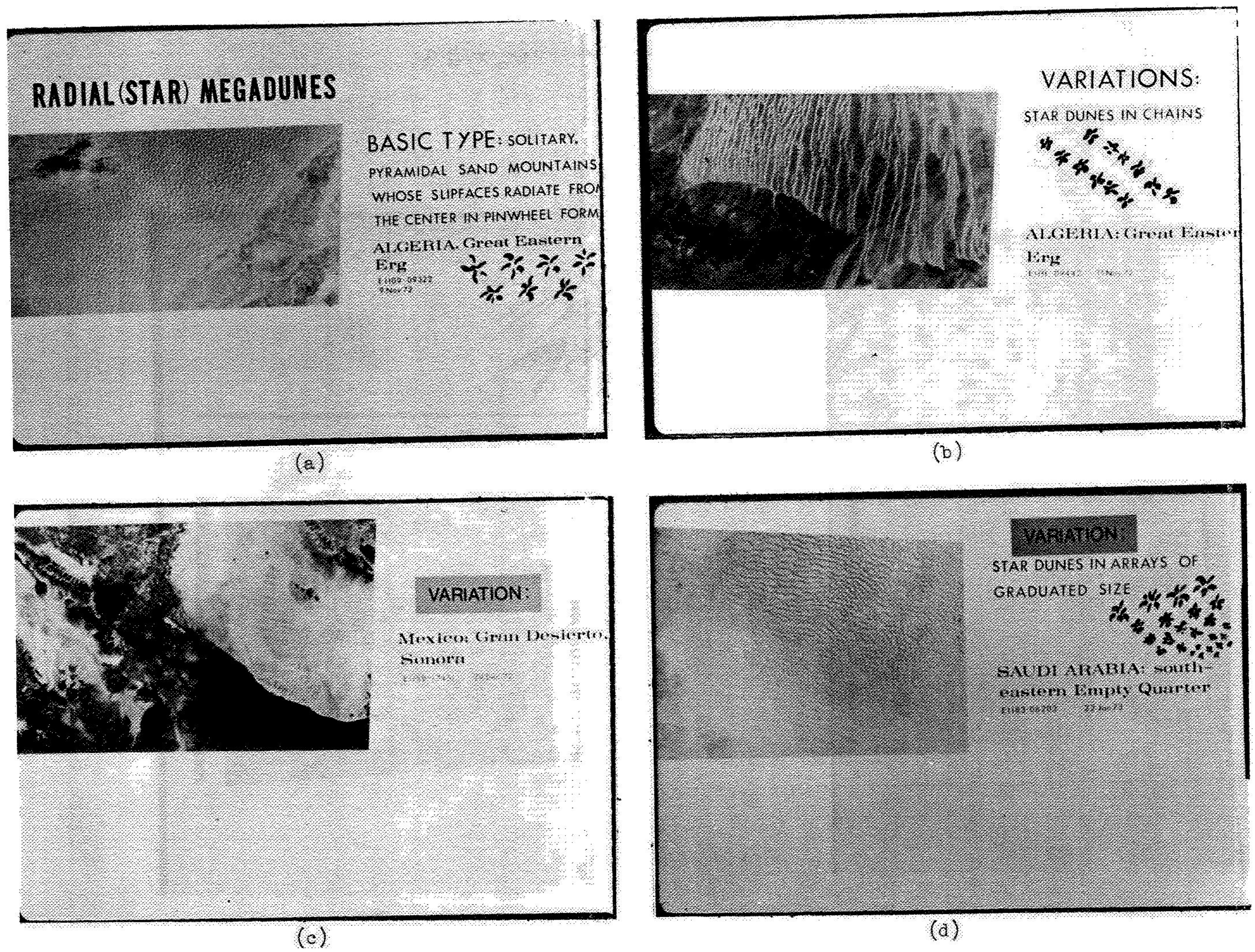
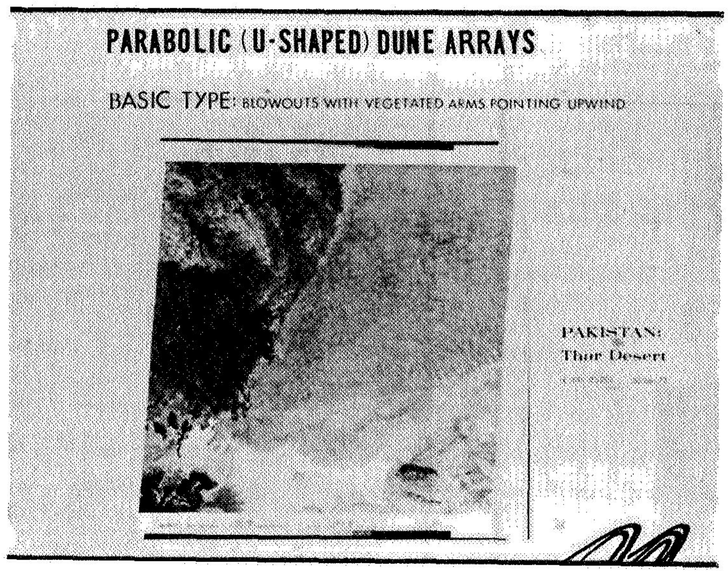
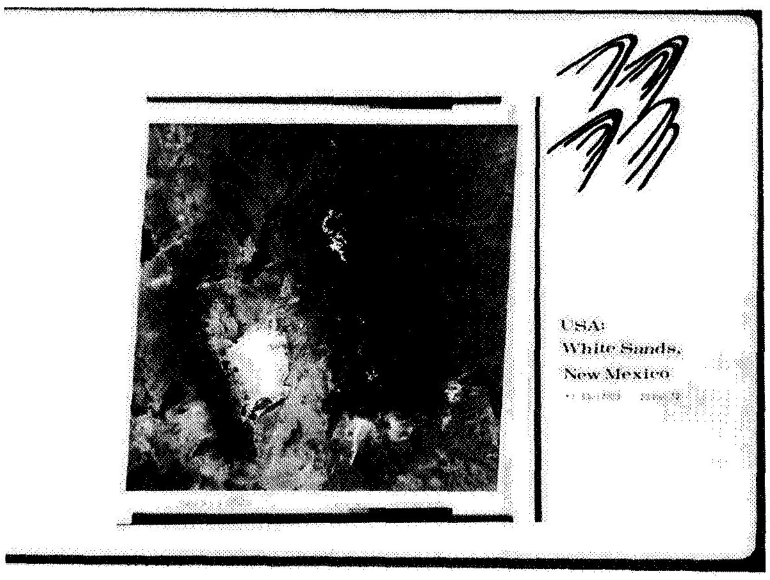


Figure 5.--Star or radial megadunes: (a) Great Eastern Erg, Algeria (random distribution); (b) Great Eastern Erg, Algeria (chain type); (c) Gran Desierto, Sonora (chain type); (d) Empty Quarter, Saudi Arabia (graduated size).



(a)



(b)

Figure 6.--Parabolic (u-shaped) dune arrays:
(a) Thar desert, Pakistan;
(b) White Sands, New Mexico.

Broad lineation and regional trends in sand seas are best recognized from ERTS images. Details of morphology which commonly reflect structure are shown best by Skylab photography and by airplane photos (fig. 7). Further details and ultimate confirmation of structural types must be established by ground truth, largely through the process of trenching.

The relations of wind strength and direction to dune form must necessarily be established by gathering data from meteorological sources where these are available. The data are then plotted on sheets as overlays to the ERTS imagery mosaics that display the dune patterns. Such overlays have been completed, in part, for South West Africa (fig. 8)and for White Sands, New Mexico (fig. 9), with air current information shown in the form of wind rose diagrams.

Considerable information on factors other than wind that affect dune form and size is furnished by ERTS imagery. The relation of vegetation and water bodies to dune sand in Mali (fig. 10a) and in Pakistan (fig. 10b) can be deduced from the color distribution in the false-color prints (vegetation appears red) from which the figure 10 pictures were made. Shifts in wind direction in Saudi Arabia (fig. 10d) are illustrated by the smoke of burning oil wells; the influence of topographic barriers on sand forms in Algeria is shown in figure 10d. A second example of wind-barrier effect is illustrated in figure 8 where a mountain system separates dunes of the Namib and Kalahari deserts.

In order to quantify data on the density of dune ridges as seen on ERTS images, visual counts are made,along a line,of the number of dunes per kilometer. From these counts isodensity maps are prepared showing possible relations of dune density to physical barriers or to wind roses. The isodensity map of Simpson Desert, Australia (fig. 11), has been compiled from 49 visual counts.

GROUND TRUTH

The acquisition of ground truth from field studies, especially data on the internal structure or stratification, represents the final and critical stage of sand sea investigation. This is best done by a direct approach consisting of wetting the sand, cutting trenches to expose stratification in three dimensions, and recording the patterns on rubber peels, scale drawings or photographs. Such field methods have been successfully tested in Libya, Saudi Arabia, U.S.A. and elsewhere. Although tedious and time-consuming, they furnish excellent records of the internal structures representative of each type of dune, thus enabling a reconstruction of subsurface patterns critical to various geological interpretations.

Ground truth should assist in establishing a new model for understanding eolian sand bodies. A general concept in the past has been that dunes are basically the result of sand migration by the processes of saltation and avalanching under the influence of a prevailing wind. This concept doubtless still applies in some regions, but a revised model incorporating the effects of multidirectional and variable winds that produce a complex of dune forms, with growth both vertically and laterally, is needed. Many aspects of this model are being tested in the present study.

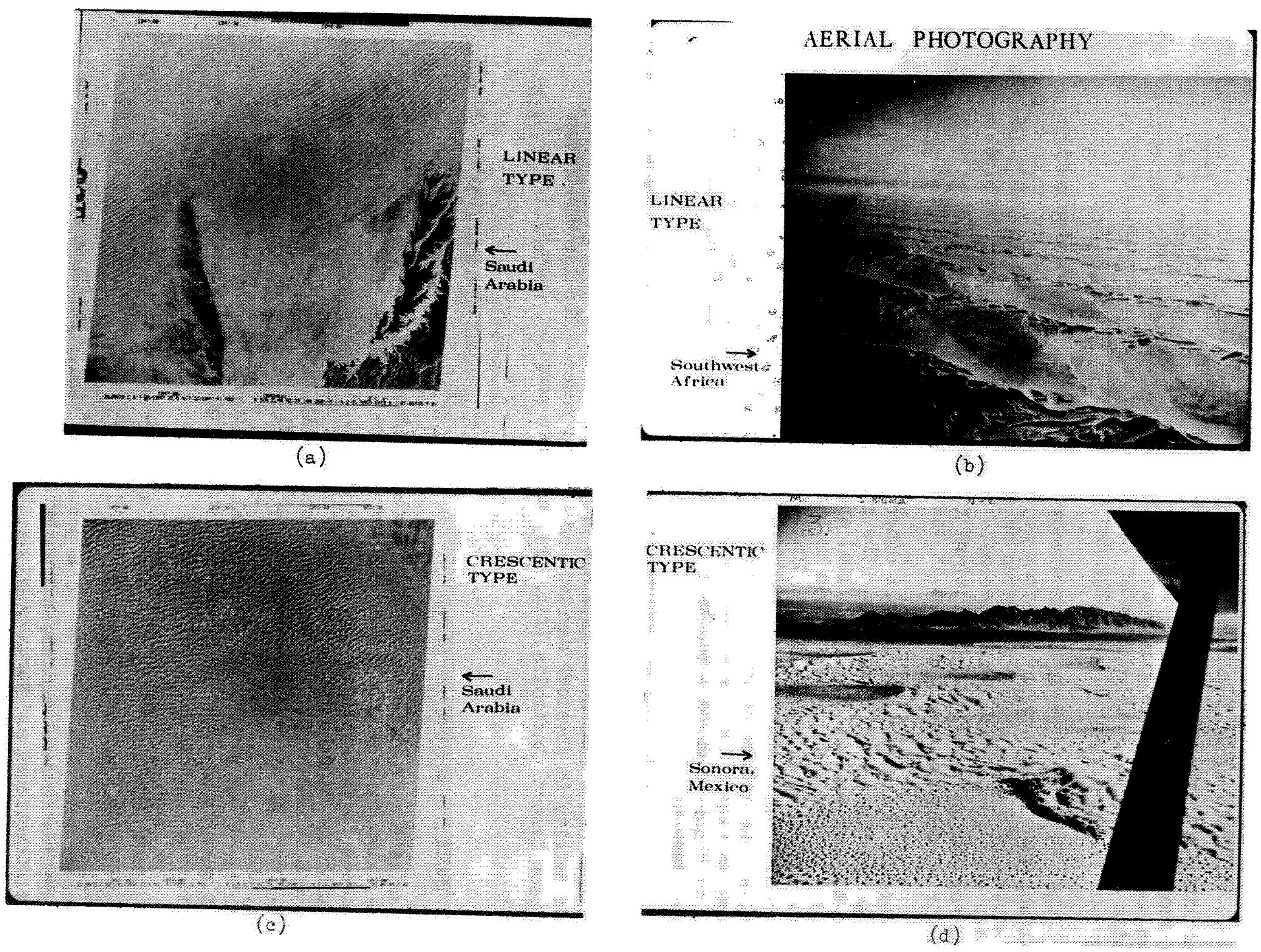


Figure 7.--Comparison of ERTS imagery and air photographs for two basic types of dunes: (a) Linear type, Saudi Arabia (ERTS imagery); (b) Linear type, South West Africa (Air photograph); (c) Crescentic type, Saudi Arabia (ERTS imagery); (d) Crescentic type, Sonora, Mexico (Air photograph).

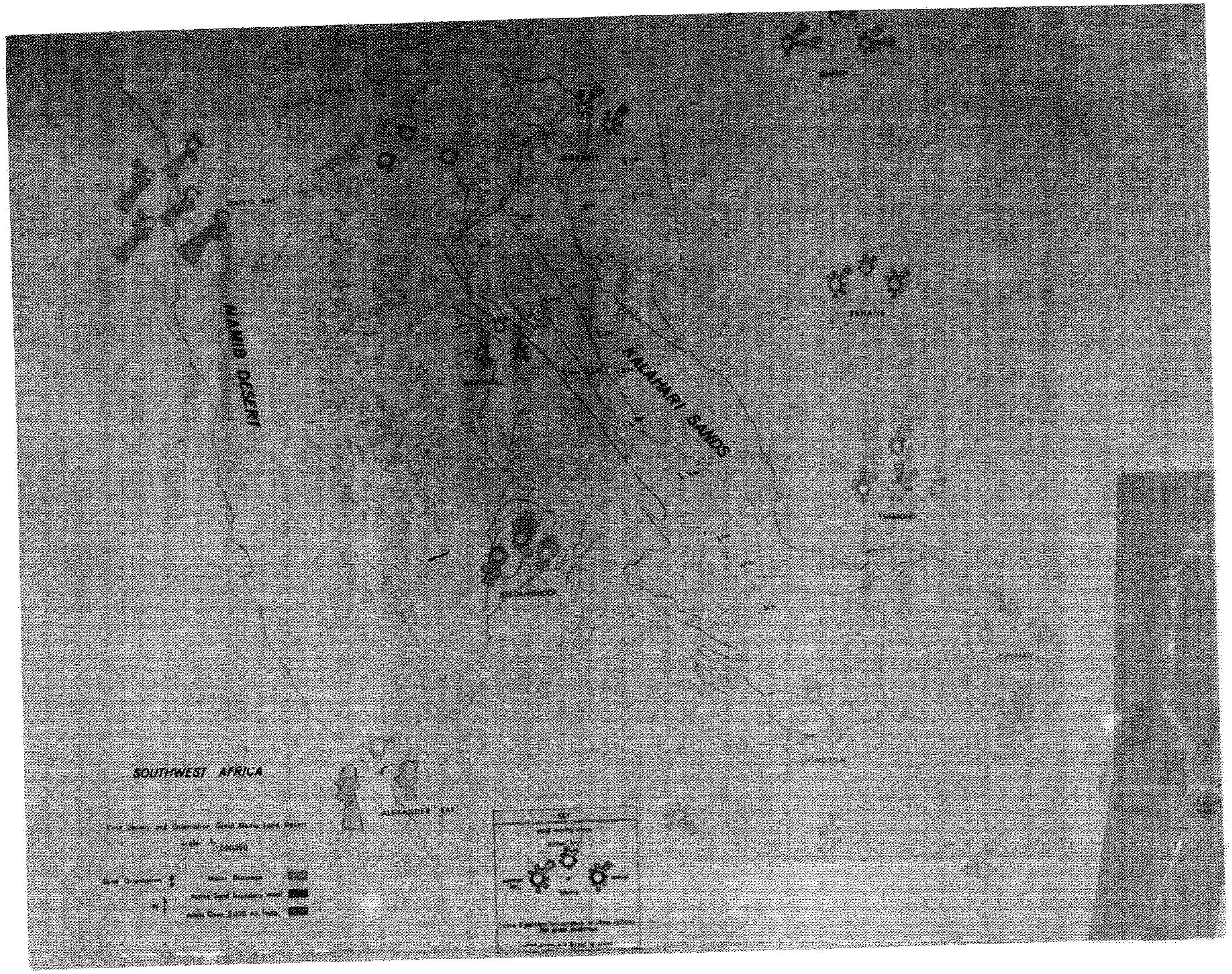


Figure 8.--Map of South West Africa showing dune density and orientation, Namib and Kalahari deserts.

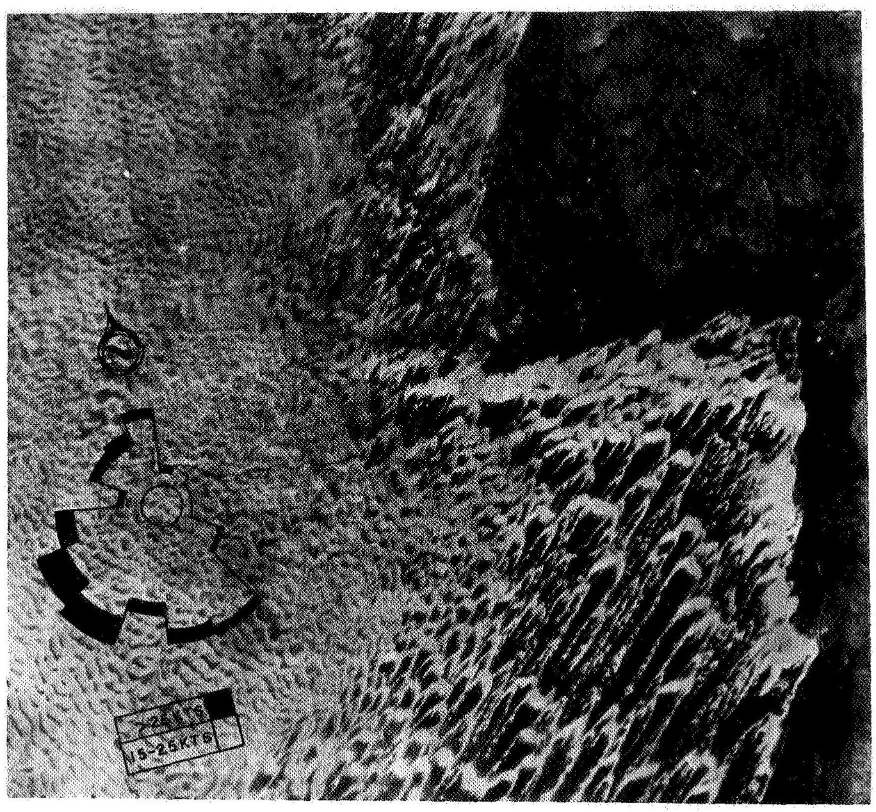


Figure 9.--White sands, New Mexico: wind rose diagram for comparison with dune orientation. (Enlarged image processed from ERTS-1 computer compatible tape).

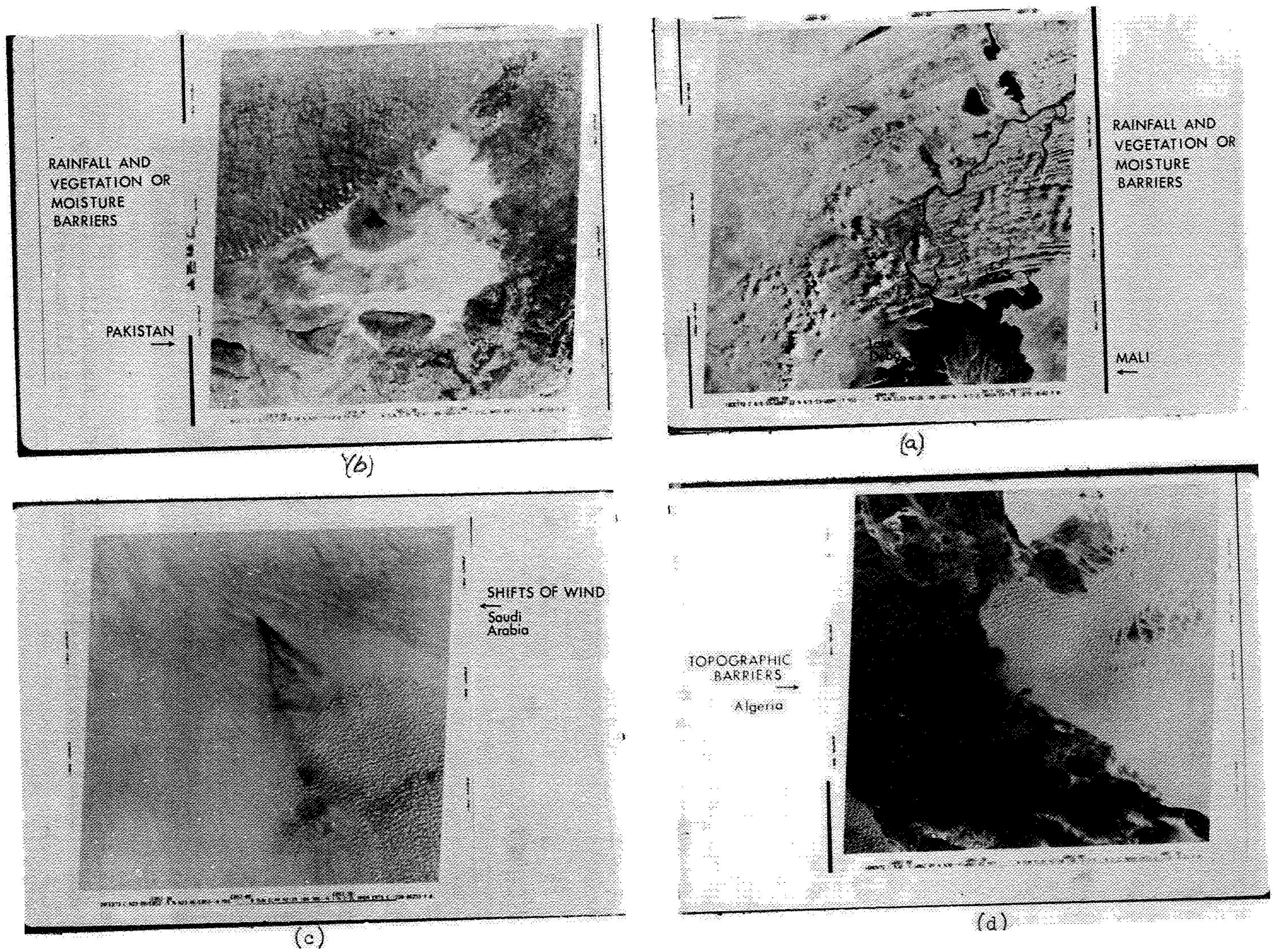


Figure 10.--Physical features affecting size and shape of dunes and megadunes in sand seas: (a) Mali (water and vegetation); (b) Pakistan (water and vegetation); (c) Saudi Arabia (shifts of wind); (d) Algeria (topographic barriers).

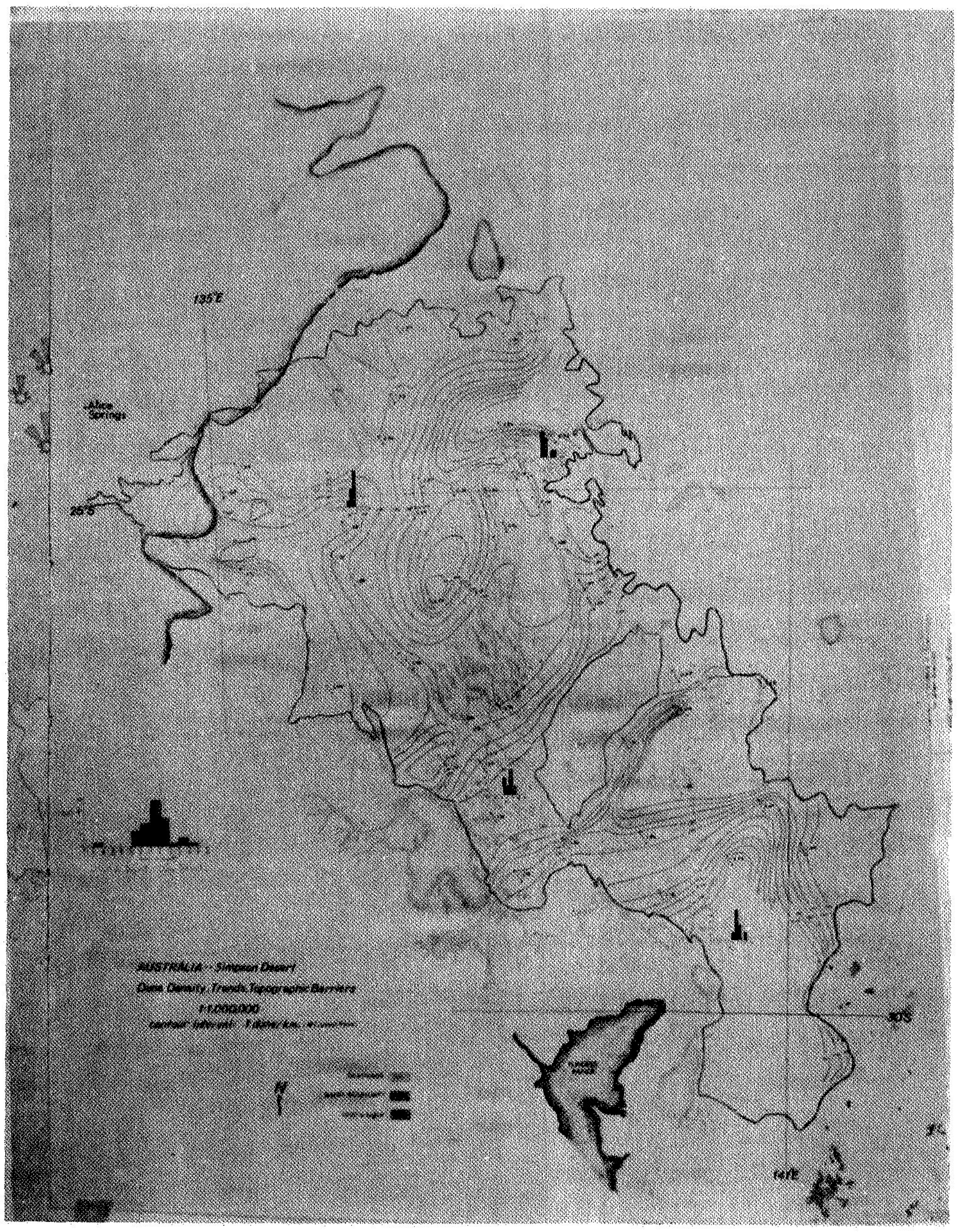


Figure 11.--Isodensity map of Simpson Desert, Australia. (Density lines show number of dune ridges per kilometer).

ULTIMATE GOAL OF INVESTIGATION

Long-term objectives of this study are to obtain an understanding of the overall structures in sand seas and by means of these structures to differentiate between various types of dunes. An understanding of major rock formations as the Navajo Sandstone and Coconino Sandstone of Western United States and many others considered to be of eolian origin, has economic application because such widespread sandstones control the underground movement of many fluids and locally serve as reservoirs. Ore-bearing fluids and also oil and gas migrate through such permeable rocks making a knowledge of their structural trends important in exploration programs.

Further benefits to be derived from a better understanding of windblown sands and their accumulations relate to the many problems of their encroachment on and burial of roads, agricultural areas and other developments of man. Adequate methods of controlling dune movements require a good knowledge of the factors that determine their growth and movement.

Finally, recent pictures of features on Mars that are considered the result of deposition from very strong wind action, seem to have analogies in ERTS images and probably can be understood and explained by correct interpretation of corresponding earth features.