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A STUDY OF MORPHOLOGY, PROVENANCE, AND MOVEMENT OF DESERT SAND SEAS* IN AFRICA, ASIA, AND AUSTRALIA

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ABSTRACT

This study is designed to describe and classify major types of sand seas on the basis of morphologic pattern and lineation. For analyzing patterns of deposits on ERTS images, where the visible forms are mostly dune complexes rather than individual dunes, several steps are being used:

A. Enhancement of ERTS imagery by rephotographing 70mm transparencies using (1) different types of negative film, (2) overdevelopment of films in high-energy developers, and (3) printing on high-contrast papers. These methods can enhance the contrast between light and shadow to provide sharper pictures of the patterns under study.

B. Differentiation of dune sand from other objects within a sand sea by comparing images in all four spectral bands and composite color for each test site.

C. Recognition of atmospheric conditions, the effect of varying sun angles, and possible other seasonal influences upon interpretation of ERTS imagery by comparing images from numerous passes that show differing conditions on different dates.

Further analyses and final checks are made by comparative studies of air photos or ground data available for each site. After completion of thematic maps portraying the pattern and lineation of sand bodies, data on directions and intensity of prevailing and other winds are plotted on corresponding bases, as a preliminary to determination of internal structures through ground truth.

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1. INTRODUCTION

Principal objectives of this investigation are to compare the major sand seas of the world by recording types of geomorphic forms and trends developed in these sand bodies, to determine relations of their trends to wind and other meteorological controls, to vegetation, water, and topographic influences and, finally, to show the type of internal structure (stratification) characteristic of each geomorphic form. The structures may ultimately be used in determining the genesis and geometry of ancient eolian sandstones.

Development of a classification of large sand-desert deposits of the world is the initial step of the investigation. ERTS imagery is uniquely valuable for this purpose, providing coverage and revealing patterns of landform development on a scale heretofore unavailable. ERTS images are being studied from repeated passes over sixteen selected areas--eleven large foreign test sites and five small areas in the U.S.A., included largely to provide ground truth. The areas under study are:

1. Western North Africa including Algeria, Spanish Sahara, and Mauritania.
2. The Sahara Desert of Libya, Niger, and Chad.
3. The Kalahari and Namib Deserts of South Africa, Bechuanaland, and South-West Africa.
4. The Takla-Makan Desert of Sinkiang, China.
5. The western Inner Gobi Desert of China-Mongolia.
6. The Thar Desert of India-Pakistan.
7. The Kyzylkum ("Red Sands") and Karakum ("Black Sands") of the U.S.S.R.
8. The Great Sandy Desert of Australia.
9. The Great Victoria and Simpson Deserts of Australia.
10. The An Nafud of northern Saudi Arabia.
11. The Empty Quarter of southern Saudi Arabia.
12. White Sands, New Mexico.
13. Great Sand Dunes, Colorado.
14. Little Colorado Valley, Arizona.
15. Yuma Desert, California and Mexico.
16. Henry Mountains area, Utah.

2. INITIAL PROCEDURE

Upon receipt of ERTS imagery, data for each image are compiled on a work-sheet (fig. 1) devised by Carol Breed of this project for cataloguing primary information about each test site. Tabulated for each image are the ERTS number of the image, its center point coordinates, the type of retrospective data requests to be made, and some initial observations on the quality of the image and the significance of observed geomorphic features and patterns, as well as the date of accession of the image.

Next, each image center point is plotted on an index map of the appropriate test site (fig. 2). These small index maps provide quick reference to the type of coverage obtained. On these maps all ERTS images that show features pertinent to the study (with adequate resolution) are indicated in red, whereas other images that seem not to have significance to the project, or whose quality is not adequate, are marked in blue and probably will be eliminated from further consideration.

In the preparation of some ERTS images for study an additional step is taken. It consists of the enhancement of images (figs. 3, 4, 5) that show features considered of key importance to the investigation. This enhancement involves rephotographing of the 70mm ERTS transparencies using (1) various types of negative film, (2) overdevelopment of films in high-energy developers, and (3) printing on high-contrast papers. A detailed description of these procedures is given in a paper entitled "The use of photographic methods in contrast enhancement of ERTS images" prepared for the symposium by Lawrence F. Harris (1973).

As scanning of the transparencies continues, retrospective data requests are sent to Goddard Space Flight Center for black-and-white and color prints (fig. 6) of images in key areas marked for further study. One complete set of prints covering each test site will ultimately be assembled into a photomosaic using as a base the U.S. Coast and Geodetic Survey/U.S. Air Force Operational Navigation Charts (ONC) which are at the same scale (1:1,000,000) as the ERTS images. At this scale, as suggested in the recent abstract of A. P. Colvocoresses (1973), the ERTS MSS bulk imagery matches the ground control reasonably well. From the photomosaics, thematic maps of desert geomorphic trends will be derived. These maps will, we hope, help us to develop and illustrate a classification of dune array types in the sand seas of the world.

3. INTERPRETATION OF BAND DIFFERENCES ON BLACK AND WHITE ERTS IMAGERY

Commonly, significant differences in appearance of desert landforms and water bodies occur from spectral band to spectral band of the same image. For example, figure 7 shows marked difference in the appearance of several lakes in the Simpson Desert of Australia, which could affect interpretation. The near-infrared band 7, which shows water as black, reveals that the lakes all contain water rather than being dry, which might be assumed from observation of the same features on band 4 (green). The light tone of the lakes on band 4 is therefore interpreted as sediment in water, rather than being a salt pan or other reflective, dry material. Vegetation is apparent on band 4. Band 6, near-infrared, (middle picture) gives probably the most valid picture of any one band, for this area.

Another example of the importance of comparing images in all bands is given by figure 8, the Rann of Cutch area in Pakistan. The Indus River is on the west, the great dune area is in the east center and the partly water-covered Rann itself lies to the southeast. Figure 9 shows a lake clearly defined in band 7, whereas sediment in the water appears as light tones in the lake in other bands. Band 4 characteristically shows vegetation along the river course, whereas band 7 clearly defines the wet river. In figure 10 channels in the Rann are well defined in band 6, but are very weak in bands 4 and 5, probably because of sediment. Sand dune areas to the north are uniformly visible in all bands; this uniformly bright appearance of the sand is evident in all bands.

An unusual example of band differences in a sand area occurs in the Empty Quarter of Saudi Arabia (fig. 11). In band 4 the interdune areas are dark and the dunes are light, whereas in band 7, the dunes are dark and the interdune areas are light. The reasons for these differences are not definitely known, but probably can be determined from low-altitude photography or other form of ground truth.

4. USE OF BULK COLOR COMPOSITE PRINTS

The value of bulk composite color prints furnished by Goddard Space Flight Center is apparent. In figure 6 (ERTS number 1057-06193) in the Empty Quarter of Saudi Arabia, a color composite print shows the sand dunes bright yellow, and the interdune areas blue-green. The same area is illustrated in each of the three parts of figure 5, where the left picture is an ERTS positive print, the center picture is an enhanced photograph of the same image, and the right picture is a photocopy (by xerography) of the enhanced photograph. The purpose of this enhancement is to define more sharply the patterns that reveal the geomorphic forms of the various sand bodies, and to aid in measurements of these bodies. The color composite print (fig. 6) of the same image confirms that the patterns were formed by moving sand.

The yellow color of sand bodies in general seems to be consistently characteristic of all of the deserts for which we now have some color coverage, i.e. western North Africa, Saudi Arabia, and Australia. This consistency may mean that color prints of key areas can solve some problems of interpretation, where black-and-white imagery may be ambiguous. Two examples are noteworthy:

(1) Where the nature of some linear features is not certain from black-and-white prints, a color print of the same image may show these linear features to have the characteristic yellow of sand bodies. Illustrations were observed on color composite prints from near the Senegal River, southern Mauritania.

(2) Sand bodies are sometimes confused with cloud formations, drifting snow, or salt deposits, all of which appear similarly bright on black-and-white images. On color composite prints, sand appears as yellow, whereas those other features are clearly white.

5. CLASSIFICATION

After the distribution of principal sand areas has been established for each study area under investigation, and methods have been perfected for distinguishing between modern active dunes on the one hand, and stabilized old dunes or erosional (nondepositional) sand bodies, on the other, this study will concentrate on tabulating and analyzing the principal patterns represented in the various areas. Six dune patterns (fig. 12), from six areas indicated by number below, are at the same scale and show marked morphologic differences. The areas represented (fig. 12) are: (6) Takla-Makan, China, (1) Mauritania, (15) Empty Quarter, Saudi Arabia, (3) Libya, (2) Algeria, and (14) An Nafud, Saudi Arabia.

Patterns of sand areas are being recorded and plotted as a basis for developing a classification and will be used in preparing thematic maps of the areas being compared. They will ultimately be given designations for reference purposes and attempts will be made to analyze each. Interpretation of many patterns can be made through the use of low-altitude air photography, in which individual dune forms can be recognized even though at the same places, at the scale of ERTS imagery, only sand complexes can be detected. Illustrations from the Algerian desert show linear patterns in an ERTS image (fig. 13) that are seen in an aerial photograph kindly furnished by Dr. H.T.U. Smith as strings of star dunes (fig. 14); likewise, a reticulate pattern in an ERTS image (fig. 15) appears as clusters of star dunes (fig. 16) in another aerial photograph by Dr. Smith.

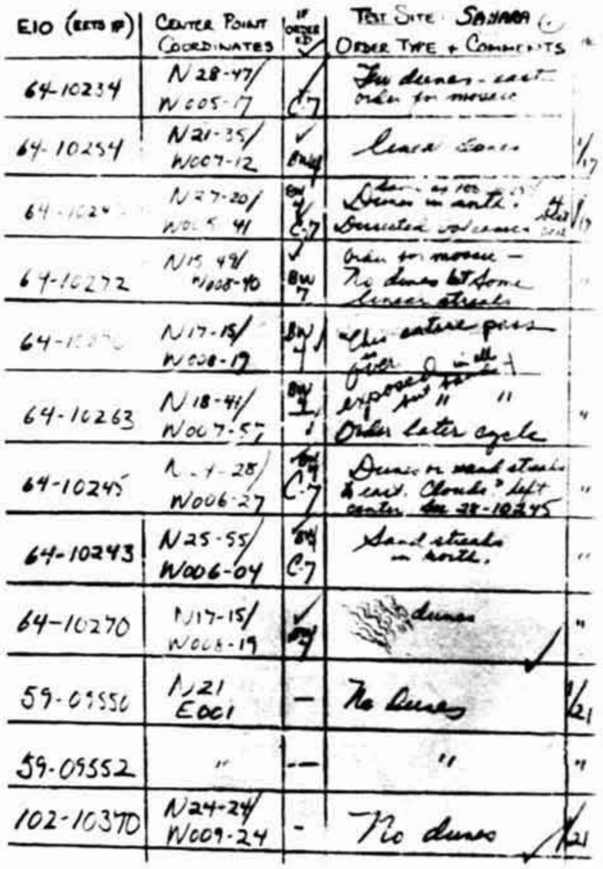
6. GROUND TRUTH

A future part of this project is to determine, where possible, the causes of particular dune-complex patterns and of lineation. Meteorological data are currently being compiled to establish probable relationships of wind direction and wind velocity to dune form and trends. Finally, an attempt will be made to gather ground truth on internal structures of sand bodies in relation to their form and pattern in order to establish their genesis and to recognize their presence in the geologic record.

7. REFERENCES CITED

Colvocoresses, A. P., 1973, Overall evaluation of ERTS imagery for cartographic application /abs./, in NASA Earth Resources Survey Program weekly abstracts: U.S. Dept. Commerce Natl. Tech. Inf. Service, p. 7-8 (Jan. 22, 1973).

Harris, L. F., 1973, The use of photographic methods in contrast enhancement of ERTS images: ERTS-1 Symposium Proc.



EIO (ERTS #)	Center Point Coordinates	If Order ed ✓	Test Site: Sahara ① Order Type + Comments	
64-10234	N 28-47/ W005-17	✓ C-7	Few dunes - east. Order for mosaic	
64-10254	N21-35/ W007-12	✓ BW	Linear dunes	1/17
64-[illegible]	N27-20/ W005-41	BW 4/ C-7	Dunes in north. Dissected volcanics	1/17
64-10272	N15 48/ W008-40	✓ BW 7	Order for mosaic - No dunes but some linear streaks	"
64-[illegible]	N17-15/ W008-17	BW 4 ✓	This entire pass [illegible] exposed [illegible]	
64-10263	N 18-41/ W007-57	BW 4	" " Order later cycle	"
64-10245	N[illegible]-28/ W006-27	BW 4 C-7	Dunes or sand streaks to east. Clouds? left center. See 28-10245	"
64-10243	N25-55/ W006-04	BW 4 C-7	Sand streaks in north.	"
64-10270	N17-15/ W008-19	✓ BW 4	dunes ✓	"
59-09550	N21 E001	—	No dunes	1/21
59-09552	"	—	"	"
102-10370	N24-24/ W009-24	-	No dunes ✓	1/21

Figure 1.--Sample copy of worksheet

Figure 2.--Sample of test-site plots on base map from Air Force Operational Navigation Chart; sites to be studied are shown in red; those probably to be eliminated in blue.

Figure 3.--Test site in Takla Makan desert, China. Illustrates results of contrast enhancement from ERTS positive. ERTS #1078-04481

Figure 4.--Test site in Tashkent area, Uzbekistan, U.S.S.R. Illustrates results of contrast enhancement from ERTS positive. ERTS #1070-05443

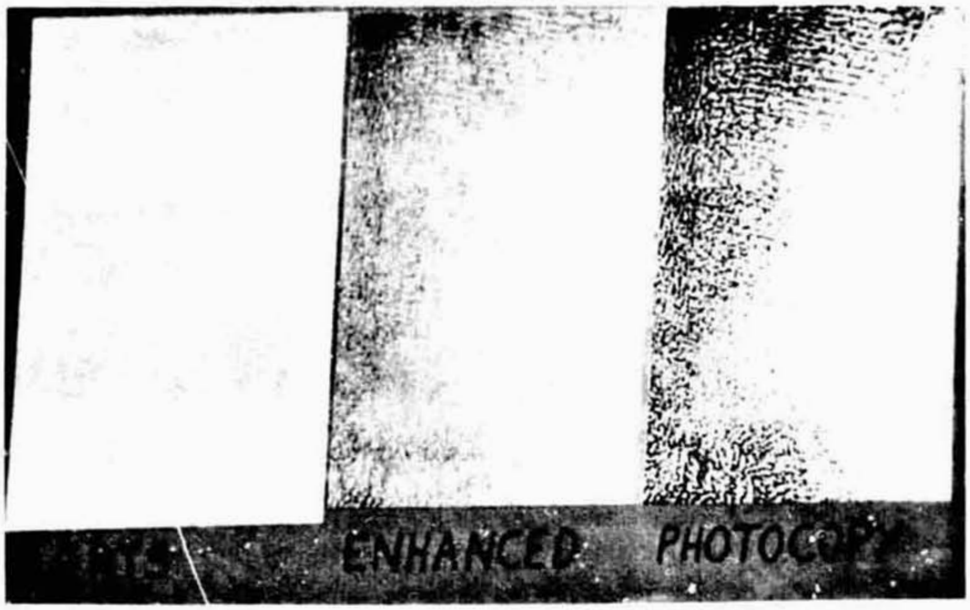


Figure 5.--Test site in the Empty Quarter, Saudi Arabia. Comparison between ERTS positive, contrast enhanced print and photocopy of enhanced print. ERTS #1057-06193

Figure 6.--Test site in the Empty Quarter, Saudi Arabia. Black and white print of color composite print by Goddard Space Flight Center in which sand appears yellow and interdune space blue green. ERTS #1057-06193

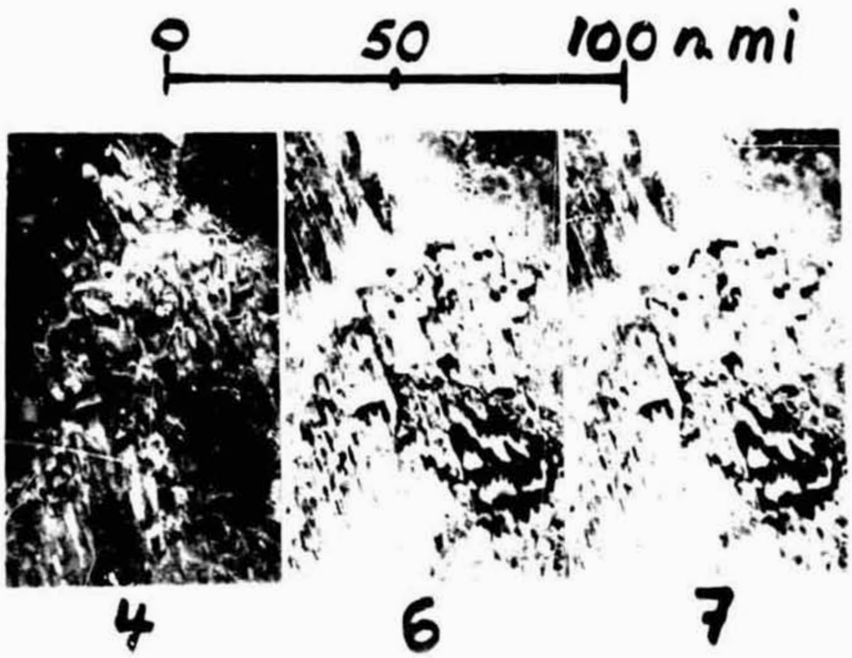


Figure 7.--Test site in Simpson Desert, Australia. Comparison of bands 4, 5, and 6. ERTS #1097-00034.

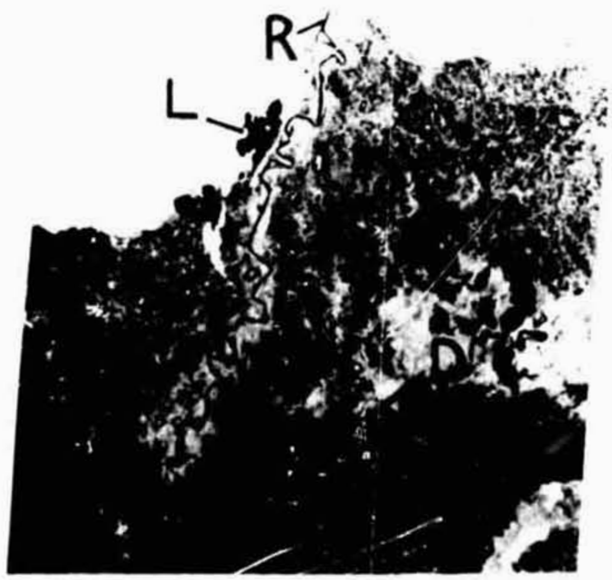


Figure 8.--Test site in the Rann of Cutch area, Pakistan and India. R, Indus River; L, lake; D, dunes; and the Rann (lower one third). ERTS #1066-05263

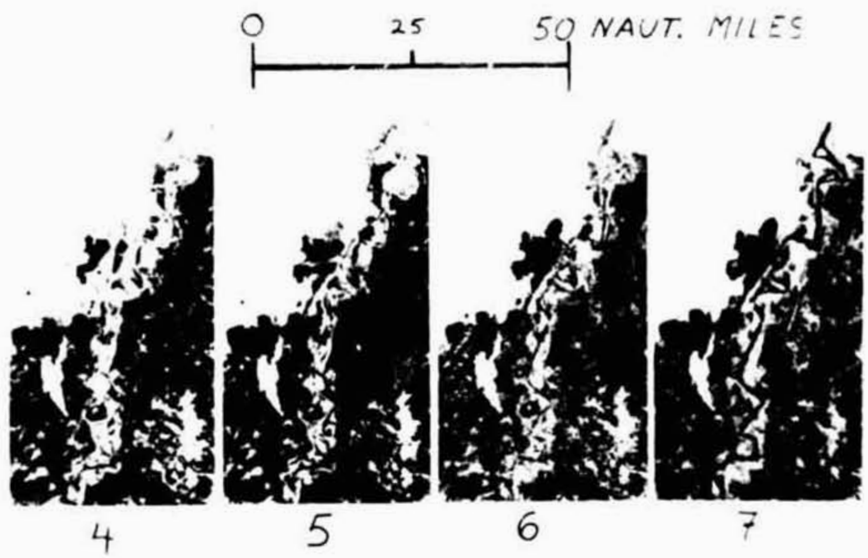


Figure 9.--Rann of Cutch area, Pakistan and India. Comparison of spectral bands 4, 5, 6, and 7 in vicinity of Indus River. ERTS #1066-05263, NW part.

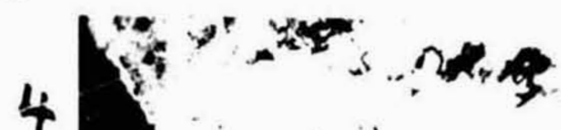


Figure 10.--Rann of Cutch area, Pakistan and India. Comparison of spectral bands 4, 5, 6, and 7 in vicinity of the Rann. ERTS #1066-05263, south part.

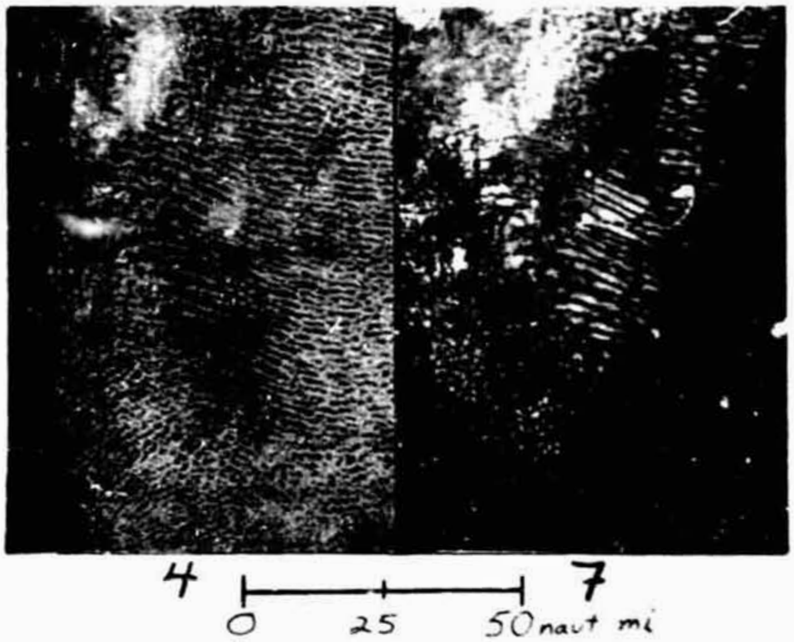


Figure 11.--Test site in the Empty Quarter of Saudi Arabia. Comparison of bands 4 and 7. ERTS #1057-06190

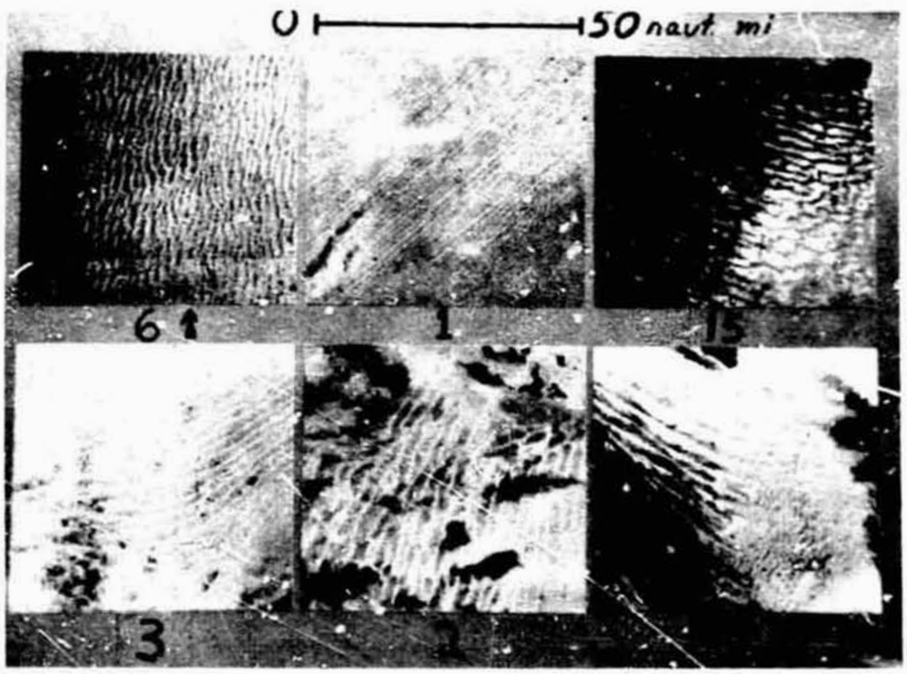


Figure 12.--Varieties of patterns in various sand seas: Takla Makan, China (6), Mauritania (1), Empty Quarter, Saudi Arabia (15), Libya (3), Algeria (2), An Nafud, Saudi Arabia (14).

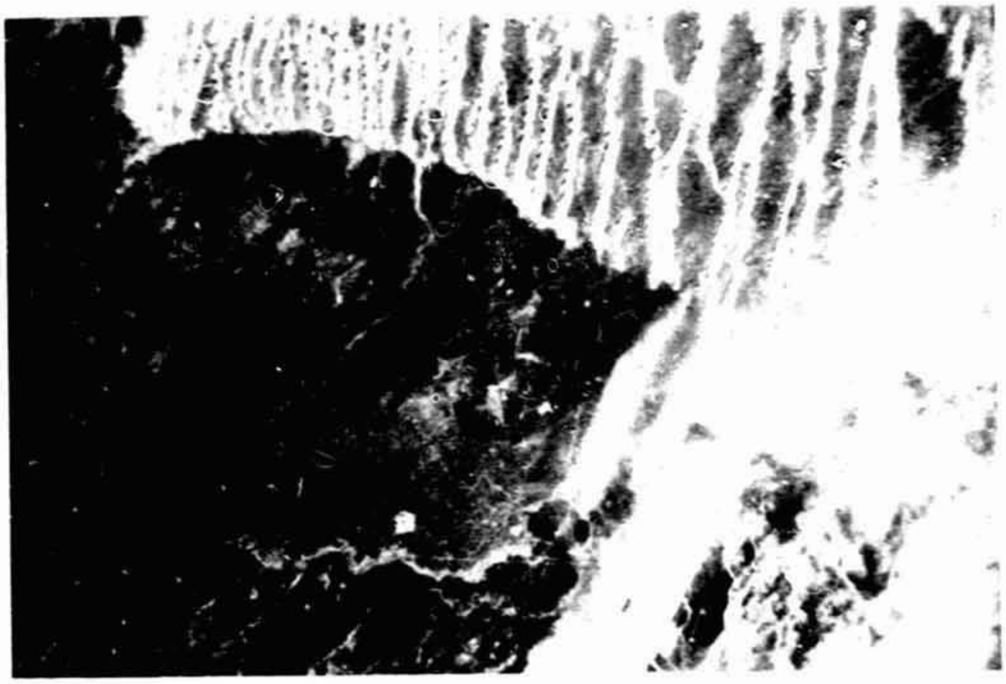


Figure 13.--Linear pattern in sand of Algerian desert shown in ERTS image. Formed by rows of star dunes. ERTS #1111-09442

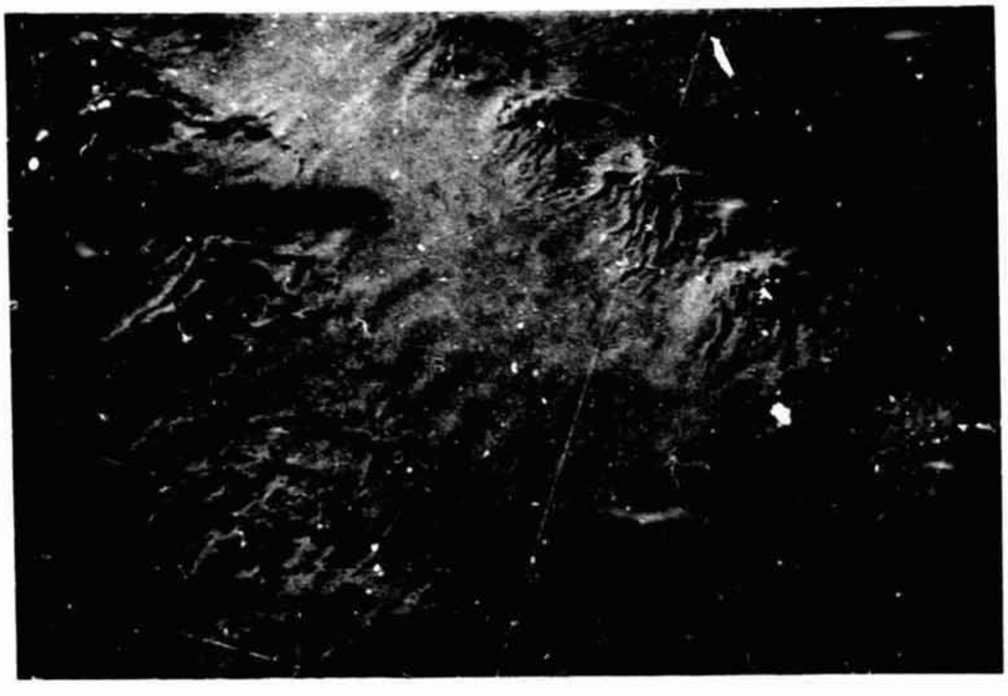


Figure 14.--Rows of star dunes in Algerian desert as seen in aerial photograph. Photo by H.T.U. Smith.

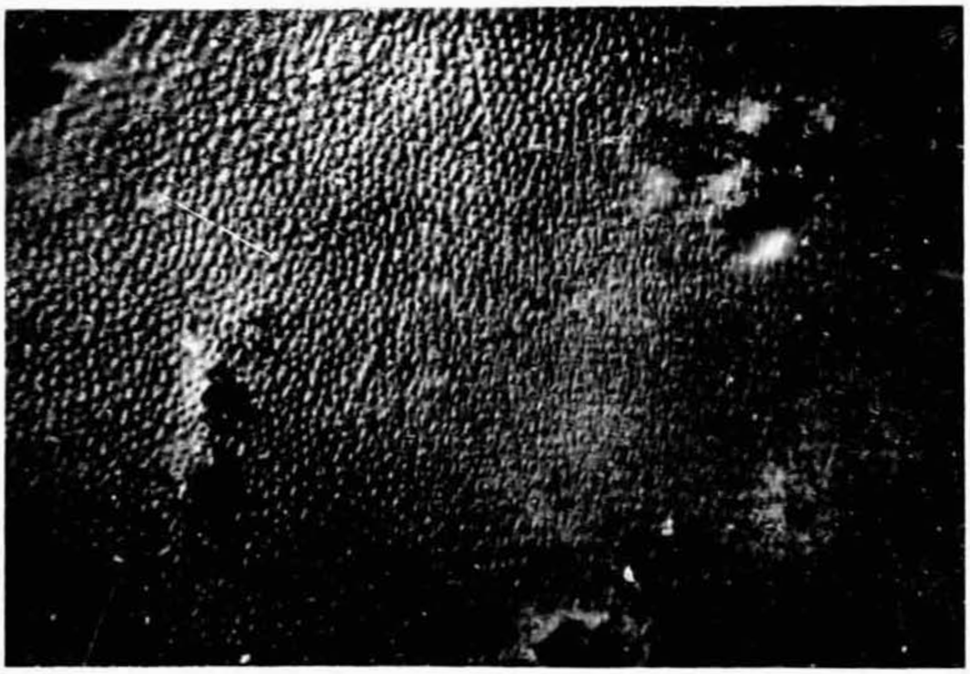


Figure 15.--Reticulate pattern in sand of Algerian desert shown in ERTS image. Formed by clusters of star dunes. ERTS #1109-09322

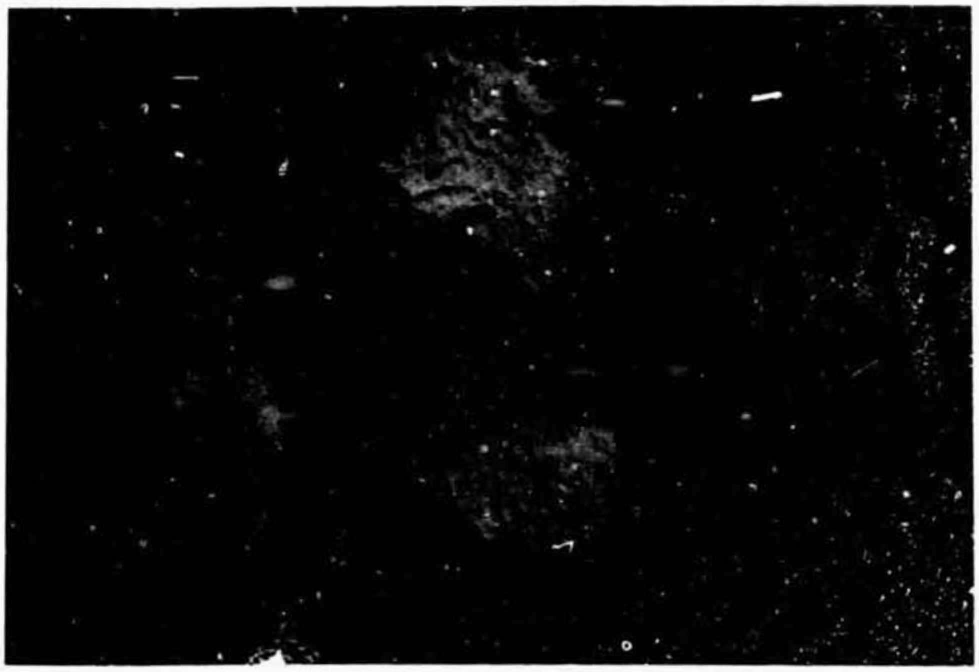


Figure 16.--Cluster of star dunes in Algerian desert as seen in aerial photograph. Photo by H.T.U. Smith.