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LANDSAT SATELLITE MAPPING IN EGYPT AND ITS POSSIBLE APPLICATIONS IN PETROLEUM AND NATURAL GAS EXPLORATION

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ABSTRACT

The most significant investigations on a global scale for earth resources sensing were initiated by the launching of the first Earth Resources Technology Satellite (ERTS-1 later renamed LANDSAT-1) in July 1972. Due to its special features LANDSAT imagery has greater advantages especially in regional mapping as compared to aerial photographic and other techniques. The Remote Sensing Center (RSC) - established in Cairo, Egypt in 1971 as a cooperative venture between Oklahoma State University, U.S.A., the National Science Foundation, U.S.A. and the Academy of Scientific Research and Technology, Egypt - has the unique chance to be one of the few institutions in the world to start LANDSAT satellite mapping at a very early stage. Apart from the mapping activities in other Arab countries, approximately three quarters of Egypt (some 750,000 km^2) is already covered by geological, structural lineation and drainage maps normally on 1:500,000 scale based on LANDSAT imagery interpretation combined with adequate field work and laboratory analysis. The greatest coverage of Sinai Peninsula has been mapped, however, only by LANDSAT imagery interpretation. Additional lineation and drainage density maps have been produced for some areas based on the computation of the structural lineation and drainage maps respectively. On the request of the users, soil and vegetation cover maps are constructed for certain areas of Egypt, while petroleum, mineral and construction materials as well as groundwater potential maps are done for specific areas based on LANDSAT investigations and combined with pertinent previous data.

The techniques of interpretation of LANDSAT satellite imagery used range from visual to semi-automatic to automatic. In the latter case, interpretation is carried out through the available highly advanced multispectral data analysis system M-DAS using computer compatible tapes. At present, mapping is concentrating on the regional interpretation of LANDSAT imagery on scales of 1:500,000 or 1:250,000 to decipher the regional

synoptic picture, however, the capacity of the M-DAS system interpretation goes even to a scale of 1:30,000.

The mapping so far carried out has revealed important geological and structural features in Egypt which are significant for regional petroleum and natural gas exploration. Examples are given in this paper to illustrate the mentioned features. It is hoped that in the immediate future with the cooperation of the petroleum concerns, LANDSAT satellite mapping and investigations of the individual structures possessing petroleum and natural gas potential will be carried out in Egypt on more detailed scales ranging from 1:250,000 to 1:30,000 in order to make full utilization of the advantages gained by the spaceborne observation technology.

LANDSAT MAPPING TECHNIQUES AND RESULTS

LANDSAT-1 has been launched by the U.S. National Aeronautics and Space Administration (NASA) in July 1972, while LANDSAT-2 has been launched in January 1975 to assure the continuity of data after the equipment of LANDSAT-1 ceased to acquire all the desired data and to supplement the coverage of the first satellite as long as its sensors were still operating (National Academy of Sciences, 1977).

The LANDSAT is a 950 kg spacecraft, travelling at an altitude of 920 km in a circular near polar sun- synchronous orbit. The satellite in question makes 14 orbits per day and covers any specific point on the earth's surface at about 9.30 a.m. local time every 18 days. At present both LANDSATs cover any specific point every 9 days.

The instruments on the LANDSAT consist of a Multispectral Scanner (MSS) and three Return Beam Vidicon (RBV) cameras in addition to two Data Collection System (DCS) receivers and two video tape recorders. The MSS scans the earth's surface and registers the intensity of energy reflected by the earth's features and objects in four wavelength bands of the electromagnetic spectrum both in the visible and infrared regions.

There are considerable advantages in surveying natural resources by multispectral sensing from space which include the synoptic view, the repetitive coverage, and the uniformity over time and over extensive areas. In addition the availability of the sensed data of the earth's natural resources and environment data in digital form lends them to rapid processing and treatment in suitable computers, while the acquiring of the data in part of the infrared region of the electromagnetic spectrum is beyond the scope of normal optical cameras used in either airborne or spaceborne photography.

The utilization of the imagery of LANDSAT-1 - which is the first U.S. spacecraft dedicated wholly to earth resources sensing - has been undertaken by the Remote Sensing Center at a very early stage of the acquisition of data from this satellite, and scientists and other staff of the Center have since gained unique experience in this respect. LANDSAT imagery mapping and interpretation have been accordingly carried out which range from the visual/manual examination of the images to the automatic digital analysis of the sensed data registered on computer compatible tapes, with intermediate steps involving optical or digital enhancement of the photographic products and their examination with optical equipment of various degrees of complexity.

The Multispectral Data Analysis System M-DAS produced by Bendix, U.S.A., is used at the Center for the automatic processing of the data already registered on LANDSAT satellite computer compatible tapes. In fact, even the automatic data processing so employed is an interaction between the scientist and the machine, where the scientific and technical experience and skill still play a great role in the interpretation of the spaceborne imagery.

The Multispectral Scanner carried on LANDSAT is a four channel radiometer which registers the energy reflected from the features and objects on the earth in four bands of the electromagnetic spectrum namely bands 4, 5, 6 and 7. It has been found out by experience that bands 5 and 7 are generally the most useful for the purpose of the mapping carried out and under the prevailing natural conditions in Egypt. In Table 1 a comparison is given of the main characters and uses of the MSS bands of LANDSAT-1 satellite (El Shazly, Abdel-Hady and El Kassas, 1977).

Table 1. Comparison of Main Characters and Uses of LANDSAT-1 MSS Bands

Band No. / Feature	4	5	6	7
Wave length (μ)	0.5-0.6	0.6-0.7	0.7-0.8	0.8-1.1
Spectral range	green	red	near IR	near IR
Tonal contrast	C*	A	B	B
Drainage patterns	B	A	C	B
Water bodies	C	B	B	A
Topographic features	C	A	B	A
Geologic units	C	A	C	B
Structural lineaments	C	A	B	A

* A: Excellent, B: Good, C: Poor.

At present, about 75% of the land coverage of Egypt - which amounts to some 750,000 km^2 - has been already mapped on scales of 1:500,000 to 1:250,000 through the interpretation of LANDSAT imagery regarding the geological, structural lineation and drainage maps (Figure 1). Adequate field checking and investigations as well as laboratory analyses of the samples collected have been carried out as an integral part of the satellite mapping programme, except in cases where it has not been possible to carry out this segment of the work in most of the Sinai Peninsula. The rest of the coverage of the territories of Egypt which is approximately 250,000 km^2 is being currently mapped by the same technique.

Other types of maps are also produced but they are only available for certain parts of the previously mentioned coverage depending on the requirements of the users. These include maps of petroleum, mineral and construction materials potential, groundwater potential, lineation density, drainage density, drainage basins, structural analysis, drainage analysis, soil, vegetation cover, and thematic maps. It is of interest to mention that a petroleum, mineral and construction materials potential map has been already constructed for the Sinai Peninsula (Figure 2).

EXAMPLES OF LANDSAT IMAGERY APPLICATIONS IN PETROLEUM AND NATURAL GAS EXPLORATION

The present stage of investigations on LANDSAT imagery is marked by its regional character in which a synoptic view is attained covering all Egypt. Examples are given in the following to illustrate how such mapping may be used in petroleum and gas exploration on a regional scale. It should be also remembered that this mapping is very quick and cheap in comparison to other exploration techniques. The examples cited come from northern Egypt extending from Sinai Peninsula eastwards through the Gulf of Suez, through the Nile Delta and the Nile Valley and finally reaching the Western Desert westwards.

The forthcoming stage - which the Remote Sensing Center hopes to carry out in close cooperation with the petroleum concerns will pay special attention to the detailed interpretation of LANDSAT imagery on scales ranging from 1:250,000 to 1:30,000. The objectives of the second stage are to decipher the characteristics of the individual petroleum - and natural gas - bearing structures.

Sinai Peninsula and the Nile Delta:

LANDSAT imagery interpretation has given a new outlook to the geology and structure of the Nile Delta and the Peninsula of Sinai which reflects on their petroleum and natural gas potential.

The mapping of the geological units and structural lineaments bounding the Nile Delta and the Gulf of Suez (El Shazly Abdel-Hady, El Ghawaby, El Kassas and El Shazly, 1974; El Shazly, Abdel-Hady, El Ghawaby, El Kassas, Khawasik, El Shazly and Sanad, 1975; El Shazly Abdel-Hady, El Shazly, El Ghawaby, El Kassas, Salman and Morsi, 1975) demonstrated that the Nile Delta has originated by Alpine diastrophism as a down faulted structure extending along the Red Sea and the Gulf of Suez structures. On the other hand, the River Nile itself to the south of its delta has developed as a structure not extending along the same line as the Red Sea and the Gulf of Suez structures though in many instances parallel to them. The petroleum and natural gas potential of the Nile Delta is thus considered to be comparable though not identical to the Gulf of Suez and the Red Sea. The depositional history of the Nile Delta begin to deviate greatly from the Gulf of Suez and the Red Sea starting from the Late Pliocene following the flooding of the River Nile into the Mediterranean and the deposition of Nile sediments together with marine sediments in the Nile Delta. Before this date greater similarity in the conditions of deposition exists between the Nile Delta as compared to the Gulf of Suez and the Red Sea. This may be illustrated with the discovery of petroleum accumulations to the west of Qantara within the domain of the Nile Delta and the nature of the Miocene section there.

The extreme northern part of Sinai termed the Mediterranean foreshore area (Figure 2) has been separated by ENE-WSW fault systems identified by LANDSAT imagery interpretation (El Shazly, Abdel-Hady, El Ghawaby, El Kassas and El Shazly, 1974) from the folded Mosozoic - Paleogene area to its south. The mentioned fault systems have been found to be continuous with those bounding the Nile Delta southeastwards. Accordingly, the part of Sinai to the north of the ENE-WSW fault systems has been considered as the most eastern extension of the Nile Delta and as comparable to the latter in its petroleum and natural gas potential. The Mediterranean foreshore area as delineated has been given second priority for petroleum and natural gas exploration (Figure 2) while the area to its south has been given third priority in this respect.

A map for petroleum, mineral and construction materials potential has been constructed for Sinai Peninsula on scale of 1:500,000 by the interpretation of LANDSAT imagery(Ibid, 1974). The area of first priority for petroleum and natural gas exploration has been given to the Gulf of Suez rift area (Figure 2). Its western boundaries have been delineated in Sinai Peninsula by the NNW-SSE and NW-SE fault systems separating the Phanerozoic sedimentary rocks from the sterile igneous-metamorphic basement rocks and the younger sedimentary rocks from the older sedimentary rocks further northwards. In addition, the geological units in the Gulf of Suez rift area have been mapped by LANDSAT imagery interpretation (Ibid, 1974) as well as the folds and fractures superimposed on them. These units are ranging in particular from the Paleozoic to the Neogene, and they include various rocks which play an important role in the generation,accumulation and preservation of petroleum and natural gas.

Gulf of Suez-Nile Valley Area:

This area has been mapped on a scale of 1:500,000 using LANDSAT imagery. It is of special interest from the petroleum exploration point of view to outline here some structural features of the area under consideration as illustrated by its folds and its fractures-faults analysis.

Folds mapped by LANDSAT imagery in the Gulf of Suez-Nile Valley area belong to two main superimposed systems with the following main trends: ENE-WSW and NNW-SSE (El Shazly, Abdel-Hady, Salman, El Rakaiby and El Aasy, 1977). The ENE-WSW folds (Figure 3) strike generally in a N65°E-S65°W direction and plunge mainly to SSW. These folds are assymetric with their northern limbs mostly steeper as compared to their southern limbs. Some of them are of large magnitude such as the anticline of Wadi Araba and the syncline of El Galala El Qibliya, however, they appear also on smaller scales. On the other hand, the NNW-SSE folds (Figure 3) strike in a N35°W-S35°E direction and are often associated with very conspicuous faulting, They are well represented in the southeastern part of the considered area, along El Maaza Plateau and to the southeast of El Minya, the latter is an open syncline.

Interesting circular and semi-circular features are well represented in the southeastern part of the discussed area where the basement rocks are outcropping and along the western coastal plain of the Gulf of Suez (Figure 3) where the Miocene and post Miocene sediments are the main exposed rocks.

The lineaments mapped in the Gulf of Suez-Nile Valley area by LANDSAT imagery interpretation which correspond to fractures and faults are statistically analyzed according to trends taking their length proportion into consideration (Figure 4). It is demonstrated in this way that five domains: A, B, C, D and E are represented in the considered area. Domain A covers the area of basement outcrops where the N35°W-S35°E fracture set is predominating. Domain B includes Wadi Araba which is covered mainly by Cretaceous and Carboniferous sediments, there the N55°E-S55°W set is predominant. Domain C, on the other hand, is best represented at Wadi El Asyuti and Wadi Qena in the southwestern part of the area under discussion where the Early Eocene sediments are exposed, and where the most important fracture set is striking N35°W-S35°E. In domain D the same fracture set is the most common and its faults show occasionally strike slip features. This domain is represented by a wide coverage of El Maaza Plateau where the Middle Eocene rocks are commonly exposed. Finally, Domain E occupies the northern part of the area where Middle Eocene, Late Eocene, Oligocene and Miocene sediments are outcropping. The most predominating fracture set in this domain attains a N45°W-S45°E strike, with some of the faults belonging to it showing right lateral strike slip movements.

The previously mentioned folding and fracturing patterns have controlled in various degrees the accumulation and migration of petroleum and natural gas in the Gulf of Suez-Nile Valley area. The detailed analysis of these features should be carried out in conjunction with the petroleum concerns which are conducting other exploration techniques in the same area with the purpose of integrating the results of all these investigations and making full use out of them. This is illustrated by the fact that at least three folding systems have influenced the Gulf of Suez from the Sinai Peninsula side and from the Eastern Desert side. These fold systems have developed under the Hercynian, Laramide and Alpine diastrophisms. The Alpine diastrophism has influenced the Miocene rocks which are the source rocks as well as reservoir and cap rocks in the Gulf of Suez rift area, while the older Laramide and Hercynian diastrophisms acted on the pre Miocene rocks which are very important reservoir rocks. At the same time, the diastrophisms have been accompanied by fractures and faults belonging to several generations and assuming various trends, although the NNW-SSE trend is the most common in the Gulf of Suez (Figure 4). It has been stated by Brown (1976) that Ramadan Oil Field structure consists of a series of northeast dipping pre Miocene fault blocks separated by NW-SE trending down to the west normal faults. It is obvious from the above that both pre Miocene and post Miocene tectonics play important roles in the localization of oil fields. Due to the difficulty of applying structural analysis to the subsurface data due to scarcity of points of observations, it is necessary to carry out structural analysis on a regional scale as well as more detailed scales applying LANDSAT imagery to compliment the data arrived at by other techniques in order to arrive at the best tectonic picture of the Gulf of Suez area,which will enhance considerably oil exploration in this important area.

North Western Desert:

The application of LANDSAT imagery interpretation in the Western Desert has led to the quick regional mapping of most of the area coverage of this vast expanse of land in a relatively short time from the geological, structural lineations and drainage points of view, as well as other sides of investigations. This is particularly true in view of the fact that the Western Desert has certain locations which are difficult to pass through, for example, the floor of the Qattara Depression, the Great Sand Sea, etc...

The northern part of the Western Desert which is important for petroleum and gas exploration is already completely covered by geological, structural lineation and drainage maps on a scale of 1:500,000. Other maps are available for certain areas which include lineation density (Figure 6), drainage density, drainage basins, soil, groundwater potential, iron ore and vegetation cover maps. Apart from revealing the geology, structure and other natural features of the north Western Desert, the latter has been regionally connected with the salient features eastwards across the Nile Valley and Nile Delta, Eastwards across the Nile Valley and Nile Delta, Eastern Desert, Gulf of Suez and Sinai Peninsula.

An example is given here of folding structures which have been elucidated in the north Western Desert. It has been found out by LANDSAT imagery interpretation and structural analysis corroborated by considerable field observations that the old Laramide anticlinal structure of Bahariya Oasis which is superimposed on the Late Cretaceous and Paleogene sediments and which acquire an axial trace striking NNE-SSW has been modified by a younger folding with an axial trace striking NNW-SSE (El Shazly, Abdel-Hady, El Ghawaby and Khawasik, 1976). Further north at the Qattara Depression and El Diffa Plateau, Alpine folding is superimposed on the Neogene sediments. The axial trace of this folding at Qattara Depression syncline (Figure 5) is ENE-WSW and slighty plunging to W (El Shazly, Abdel-Hady, El Ghawaby, Khawasik and El Shazly, 1976).

As present oil fields and gas fields in the north Western Desert are known in the Cretaceous sediments (Deibis, 1976, etc.) while the Jurassic sediments are potentially petroleum- and gas-bearing. The interpretation of structural lineaments from LANDSAT on various scales together with field observations and structural analysis are necessary to decipher the structures which have acted on these mentioned sediments including Laramide and Alpine folding and faulting. The interaction between these studies and the data collected using other techniques will formulate the best model for carrying out exploration programmes in such vast and complicated terrain as the Western Desert.

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FIGURE CAPTIONS

FIGURE 1. MAP OF EGYPT SHOWING COVERAGE OF LANDSAT IMAGERY GEOLOGICAL, STRUCTURAL LINEATION AND DRAINAGE MAPPING CARRIED OUT BY RSC ON SCALE 1:500,000 (HACHURED). COVERAGE BEING MAPPED CURRENTLY (BLANK).

FIGURE 2. MAP OF PETROLEUM, MINERAL AND CONSTRUCTION MATERIALS POTENTIAL OF SINAI PENINSULA (SIMPLIFIED) ,BASED ON LANDSAT IMAGERY AND PREVIOUS WORK.

FIGURE 3. MAP OF FOLDS REVEALED BY LANDSAT IMAGERY INTERPRETATION, GULF OF SUEZ-NILE VALLEY AREA.

FIGURE 4. MAP SHOWING ROSE DIAGRAMS OF LINEAMENTS INTERPRETED FROM LANDSAT IMAGERY, GULF OF SUEZ-NILE VALLEY AREA.

FIGURE 5. STRUCTURAL LINEATION MAP OF QATTARA DEPRESSION AREA, WESTERN DESERT, BASED ON LANDSAT IMAGERY INTERPRETATION.

FIGURE 6. LINEATION DENSITY MAP OF QATTARA DEPRESSION, WESTERN DESERT, DERIVED BY COMPUTATION OF THE STRUCTURAL LINEATION MAP.

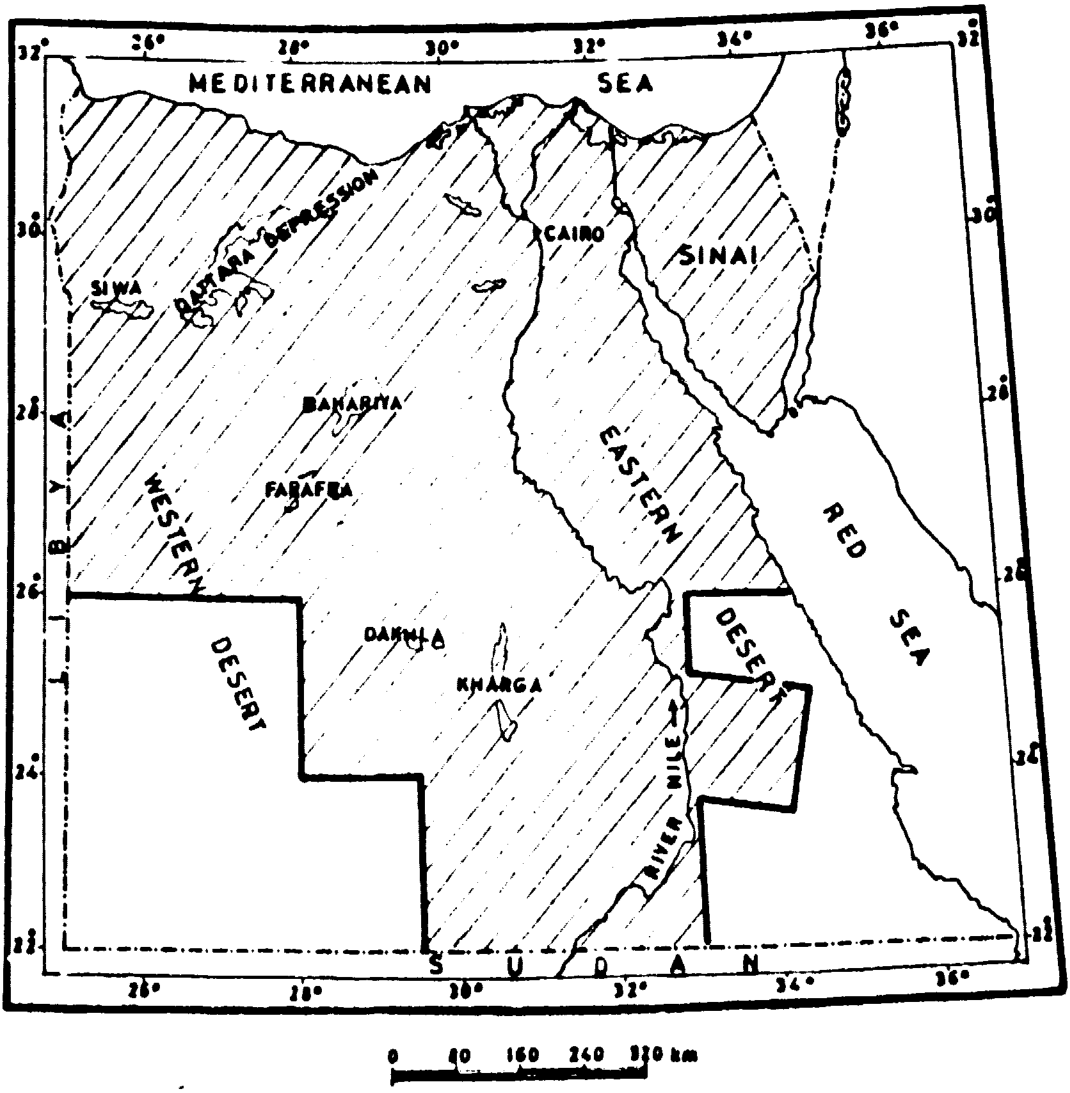


FIGURE (1) MAP OF EGYPT SHOWING COVERAGE OF LANDSAT IMAGERY GEOLOGICAL, STRUCTURAL LINEATION AND DRAINAGE MAPPING CARRIED OUT BY RSC ON SCALE 1 : 500.000 (HACHURED) COVERAGE BEING MAPPED CURRENTLY (BLANK).

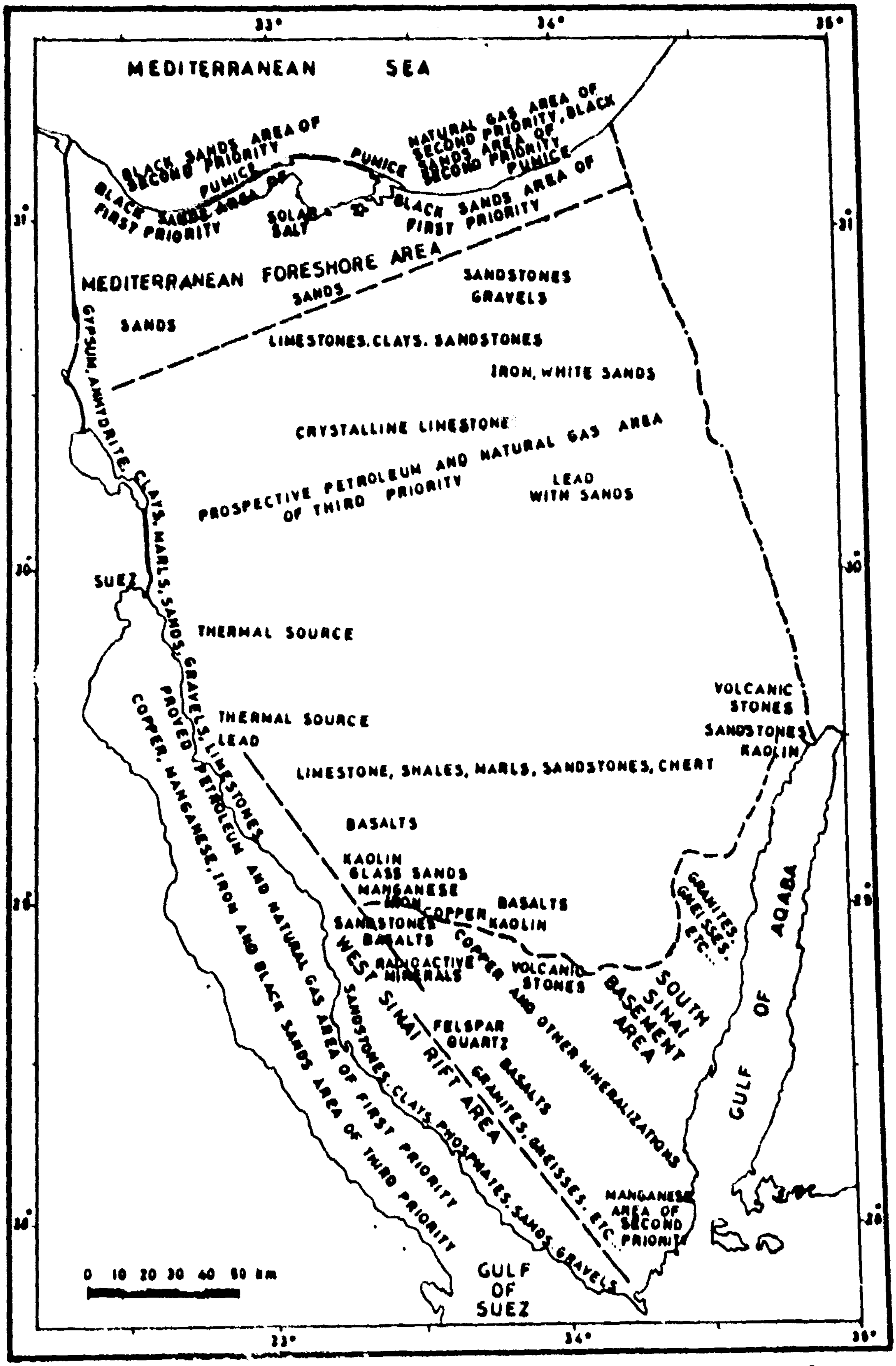


FIGURE (2) MAP OF PETROLEUM, MINERAL AND CONSTRUCTION MATERIALS POTENTIAL OF SINAI PENINSULA (SIMPLIFIED) BASED ON LANDSAT IMAGERY AND PREVIOUS WORK.

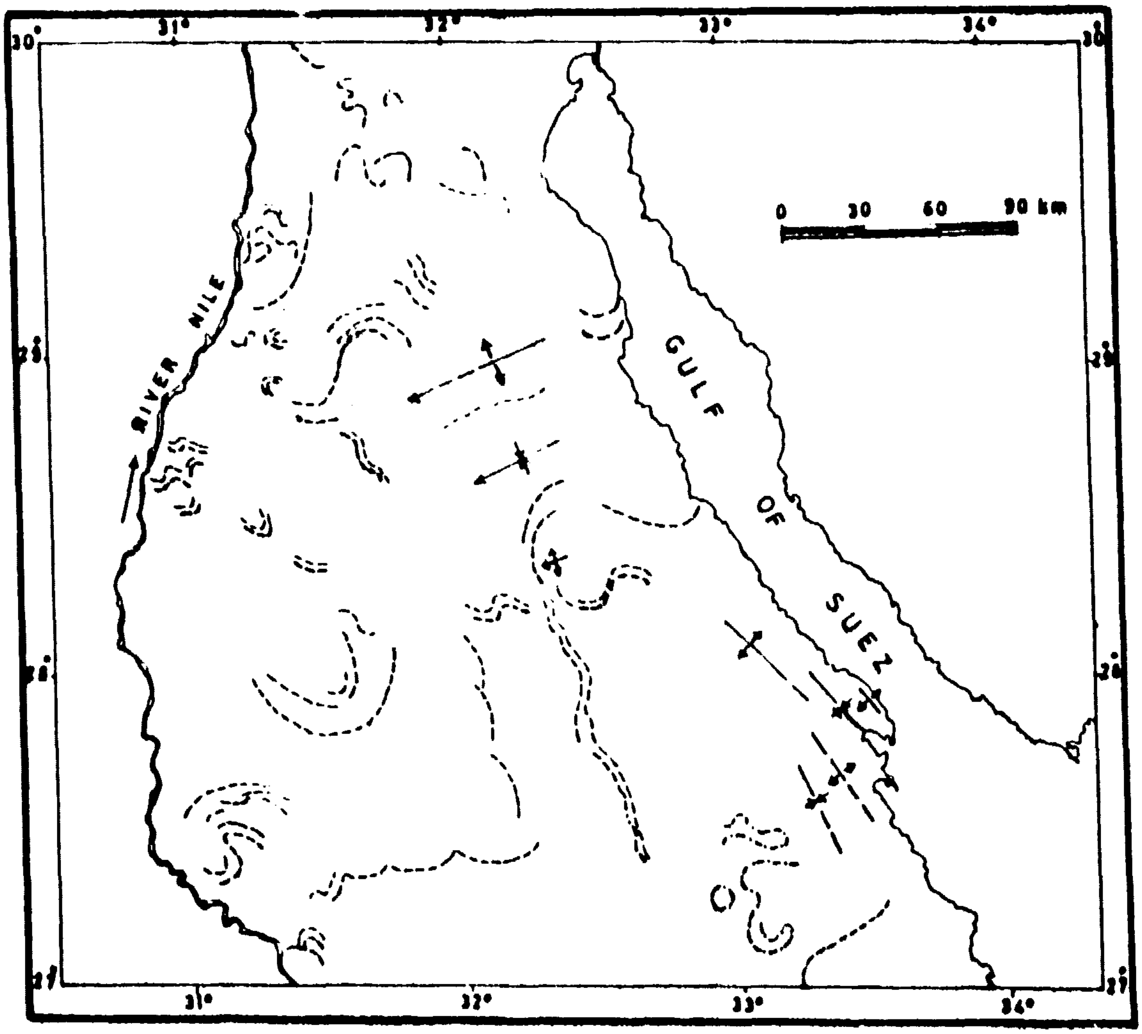


FIGURE (3) MAP OF FOLDS REVEALED BY LANDSAT IMAGERY INTERPRETATION. GULF OF SUEZ - NILE VALLEY AREA.

LEGEND

Folds

Axis of plunging anticline, dashed where inferred

Axis of plunging syncline, dashed where inferred

Circular feature

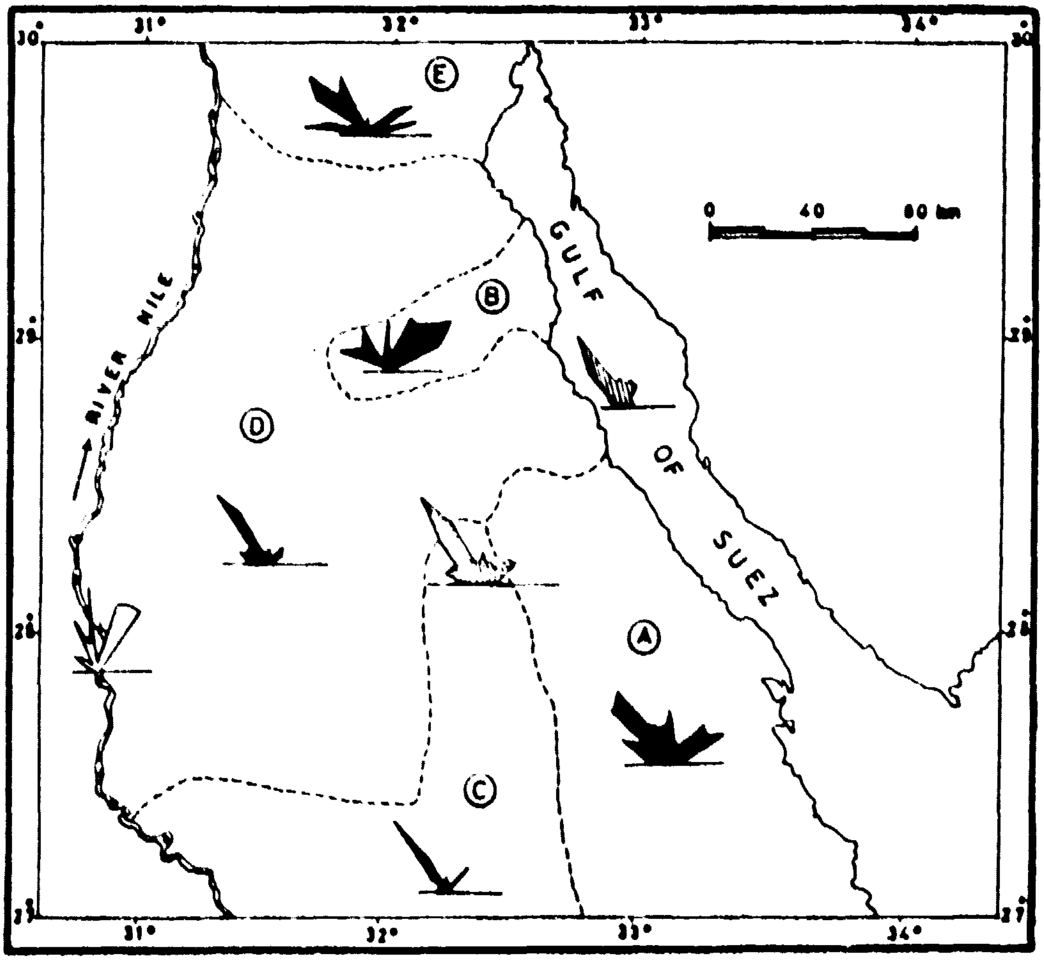


FIGURE (4) MAP SHOWING ROSE DIAGRAMS OF LINEAMENTS INTERPRETED FROM LANDSAT IMAGERY, GULF OF SUEZ - NILE VALLEY AREA.

LEGEND

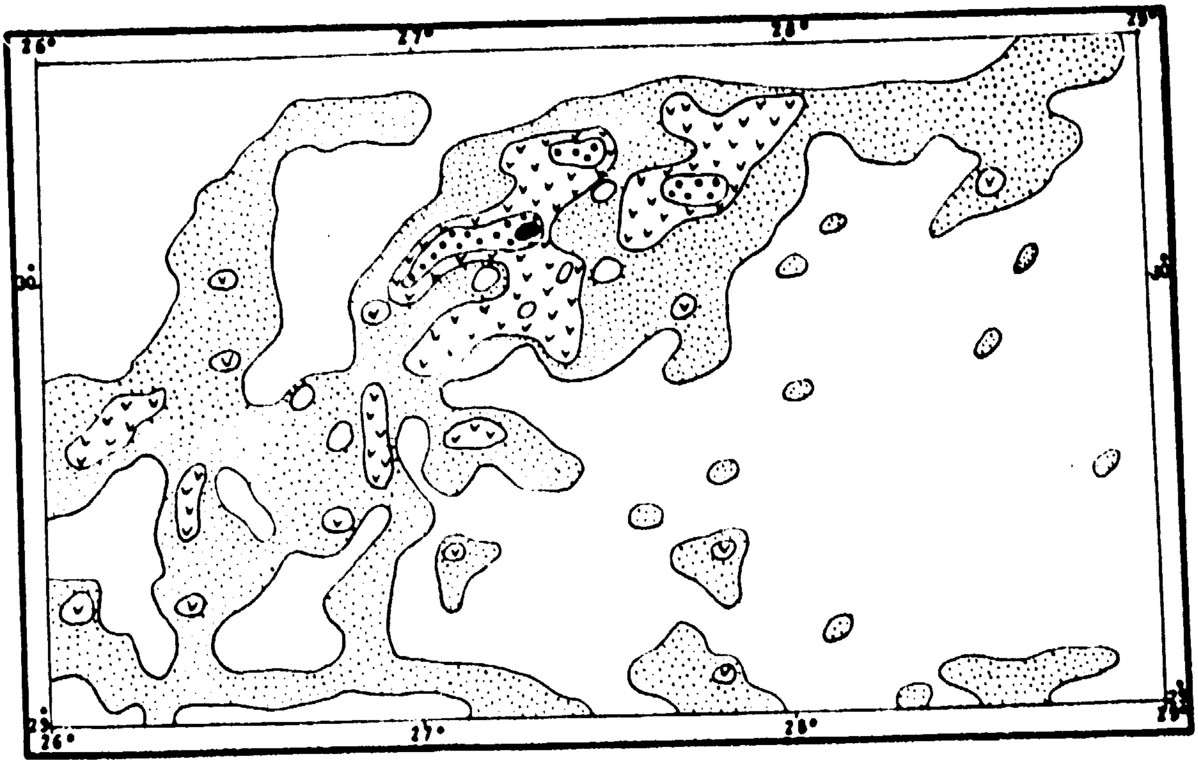
Rose diagram for lineaments in whole area

Rose diagrams (length proportion) for lineaments in domains Ⓐ to Ⓔ

Rose diagram (length proportion) for lineaments of Gulf of Suez boundaries

Rose diagram (length proportion) for lineaments of River Nile course

Domain boundaries



FIGURE(6) LINEATION DENSITY MAP OF QATTARA DEPRESSION, WESTERN DESERT, DERIVED BY COMPUTATION OF THE STRUCTURAL LINEATION MAP.

0 10 20 30 40 50 km

LEGEND

Density of lineation
(km / km^2)

[black]	> 0.4000
[dots]	0.3001-0.4000
[v marks]	0.2001-0.3000
[fine dots]	0.1001-0.2000
[blank]	0.0000-0.1000

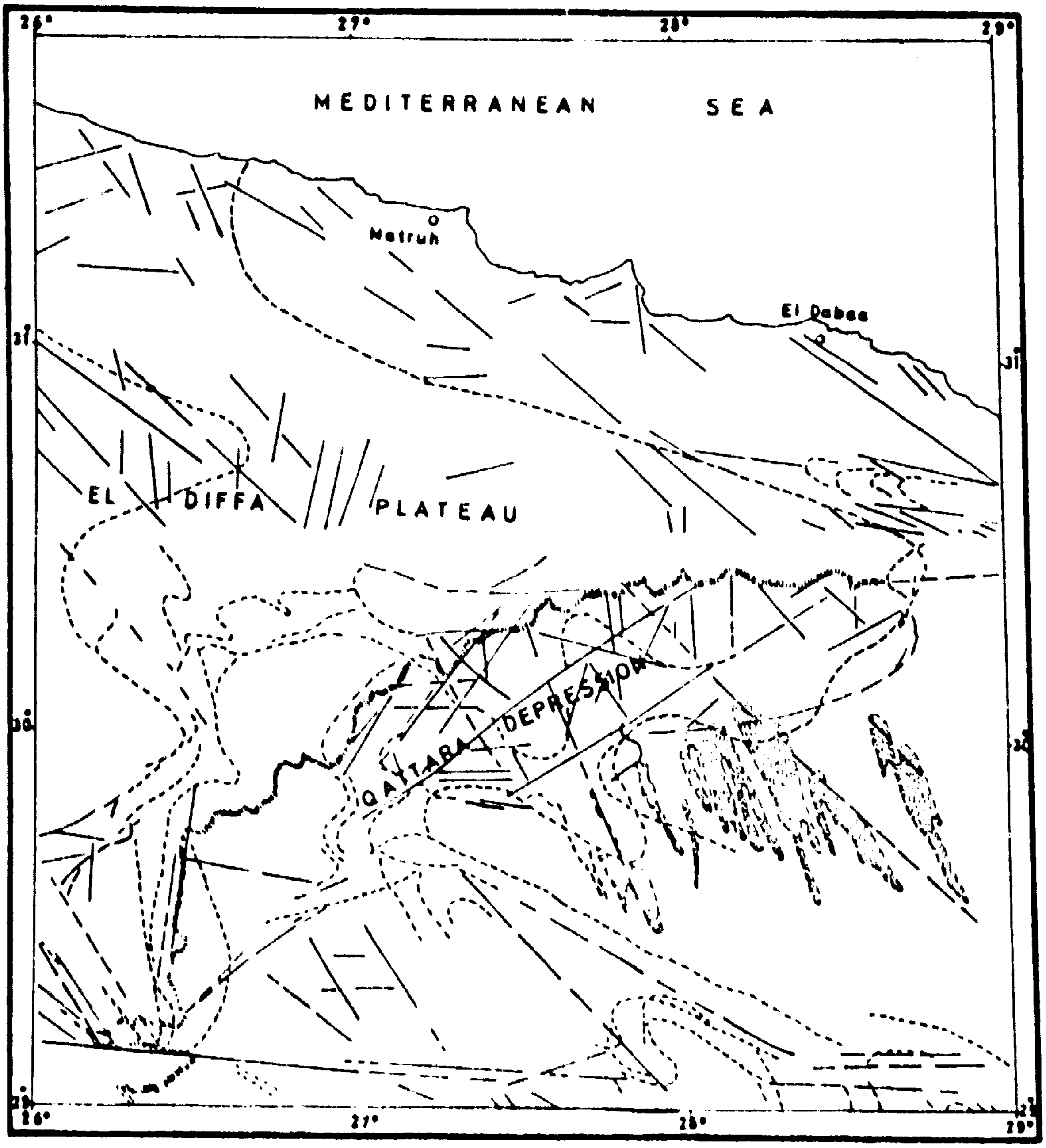


FIG 5. STRUCTURAL LINEATION MAP OF QATTARA DEPRESSION AREA, WESTERN DESERT, BASED ON LANDSAT IMAGERY INTERPRETATION.

0 10 20 30 40 50 km

LEGEND

Sand dunes

Fold traces

Fractures including faults

Other lineaments

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