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# A GEOLOGIC REMOTE SENSING OF THE AREA SOUTHWEST OF ALFUJAIRAH, UNITED ARAB EMIRATES

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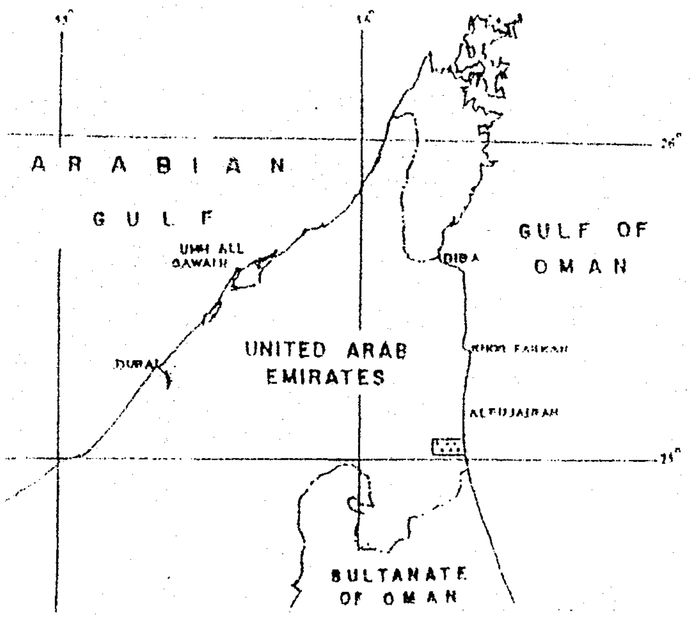
## ABSTRACT

*The area southwest of AlFujairah City, U.A.E. has been geologically mapped in this study at a scale of 1 : 25, 000 through aerial photographic interpretation, Indsat digital analysis and ground truth data collection.*

*It is classified into the following lithologic units : metagabbroid complex, and basic metavolcanics of the ophiotitic nappe, wadi and fan alluvium, sabkha deposlts, and coastal sand. Lineaments were also mapped and analyzed. Peak azimuths are 0°, 270°, 320°, 55°, and 290°.*

## INTRODUCTION

The study area (Figure 1) is about 80 Km2 in the southeastern part of the United Arab Emirates. It is bounded by the following coordinates : 25° 00′ 20′′ - 25° 04′ N and 56° 15′ - 56° 22′ E. Ground surface elevation ranges from zero on the eastern sid at khor Kalba and the Gulf of Oman shoreline to 976m at Jabal Qitab in the southwestern part of the study area. The eastern thrid is covered by Quaternary sediments, whereas the ophiolitic mountains dominate the rest of the area. Three wadis, Rumth, Hamad, and Yifan drain the ophiolitic mountains, and run easterly toward Gulf of Oman. The following landforms are recognizable from east to west : the coastal plains, the sabkha, the bajada, the wadis, and the mountains. Khor Kalba, Kalba, and AlFujairah are important urban centers on and near the eastern side of the study area. The area is accessible from the UAE eastern coast asphalt road, and from Hatta through a mountaineous road.




The purpose of the present study is to map the geology of the area at a scale of 1 : 25000 from Landsat multispectral scanner (MSS) imagery and aerial photographs. Field and laboratory works were accomplished to solve problems, and supplement information extracted from images and photos. Lineament analysis was performed to determine the structural setting with respect to the regional tectonics.

The term "wadi" is used here to mean a stream channel, usually dry except during the rainy season (Bates and Jackson, 1980).

## DATA AND PROCESSING

Many workers have used Landsat digitaly processed data to discrminate among various rock types (Rowan & others, 1974; Goetz & others, 1975; Hunt & Salisbury, 1978; Blodget & Brown, 1982; Rothery, 1984; Ashmawy, 1987).

The main sources of data for the present work were Landsat MSS imagery, color and B & W photography, and rock specimens.

A) The Landsat MSS data, used in the present study, was acquired by Landsat 5 on Februray 4, 1985. A subscene on a magentic floppy disk was produced by EROS Data centre from the recorded CCT of the scene # E-50340-06104. The floppy disk contains the four MSS bands 1,2,3 and 4. The image of the present study area was interactively processed using the Remote Image processing System (RIPS). The digital processing included RATIO, SMOOTH, SLICE, TRAIN and Class programs. (U.S. Geological Survey, 1985).

With some experimentation, the ratio 3/2 gave more meaningful results. On the ratio image (Fig.6), light tone indicates areas where ratio numerator is greater than the denominator and vice versa.

SMOOTH program executes smoothing by moving a specified size window. A 3x3 window has been used in the present work.

CLASS program classifies a multichannel disk file using signatures produced by the TRAIN software.

B) Color and B & W aerial photographs, scale 1 : 25000, of the study area were taken by Hunting Survey Limited in May and June, 1975. The photographs were very useful during the field investigation, and the stereoscopic laboraatory study of various geologic features such as definition of boundaries among rock units and extraction of lineaments.

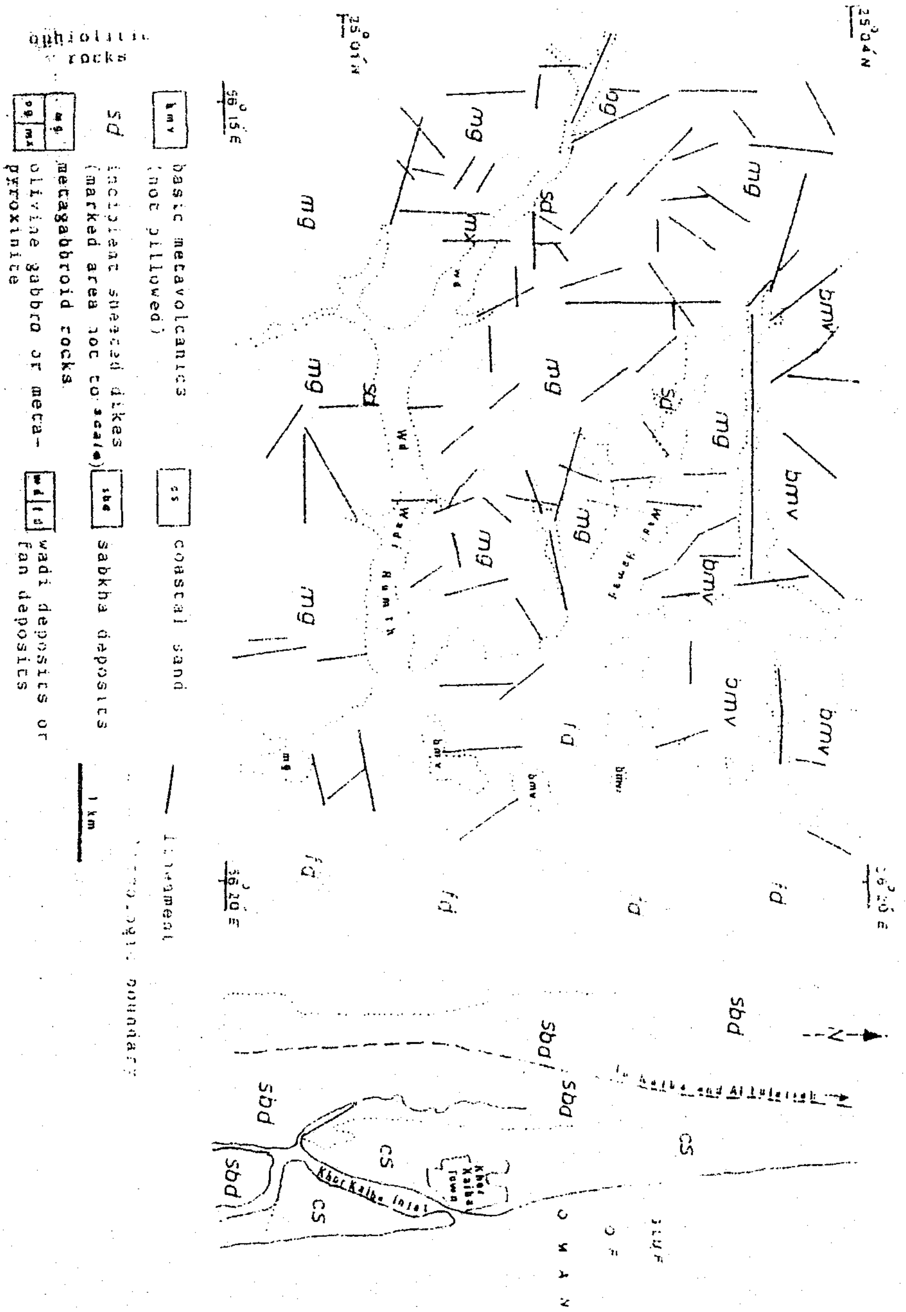
C) Fifty rock specimens from different rock units were collected and studied. Forty thin sections were prepared from the rock specimens and studied petrographically.

## GEOLOGIC UNITS

The geologic units (Figure 2) that have been identified in the present work according to the North American Stratigraphic Code (NACSN, 1983) are : 1) metagabbroid complex with incipient sheeted dikes; 2) basic metavolcanics; 3) wadi and fan alluvium; 4) sabkha deposits; and 5) coastal sands. These units are discussed below.

Glennie *et al.*, 1974 had been mapped a structural sketech map of the Oman Mountains in a regional scale (1 : 100,000), including the area study. They described in breif words the most common lithologic units therein.

The ophiolitic metagabbroid rocks cover most of the study area. They are diversified, and contain a wide variety of metagabbro, olivine gabbro, and minor occurrences of metapyroxenite, amphibolite, diorite and trandhjemite. The field characteristics and relationships of these rocks are as follows :


ophiolitic rocks
bmv basic metavolcanics (not pillowed)
sd incipient sheared dikes (marked area not to scale)
mg metagabbroid rocks
pg mx olivine gabbro or meta-pyroxinite
cs coastal sand
sbd sabkha deposits
wd fd wadi deposits or fan deposits
lineament
geological boundary
1 km
Khor Kalba Inlet
Khor Kalba Town
N

1. They maintain massive form, fractured by faults and irregular joints (Figure 3 A).

2. Bounderies among the different rock types of the metagabbroid complex are mostly indefinite and indistinguishable with the exceptions mentioned below.

3. Contacts between metagabbro and olivine gabbro are tectonic, and marked by faults, as the olivine gabbro triangle in the upsteram section of Wadi Rumth, and the limited exposure in the upstream reach of Wadi Hamad.

4. Contacts between the metagabbroid rocks and the basic metaacolcanics also seem to be tectonic, as in Wadi Yifan and in the downstream nothern side of Wadi Hamad.

5. The metagabbro is foliated along faults and sheaar zones. Dark mineraals are arranged in a subparallel form.

6. In a few local outcrops, as near the contact between the metaagabbro and the olivine gabbro in the upstream part of Wadi Rumth, the metagabbro is fine-grained and layered. Layers, up to 15cm thick are formed of alternate dark and light minerals (FIgure 3B). They are similar to what has been mentioned by Hassan and Al-Sulaimi (1979).

7. Local kaolinization is well recognized in Wadi Rumth (Figure 3C). Laterization in noticeable in Wadi Hamad (Figure 3D).

8. Metapyroxenite, amphibolite, and leucocratic rocks outcrops are very limited. Metapyroxenite is recorded near the

peripheral parts of the metagabbroid complex. Amphibolite and diorite from small fragments and patches within the trondhjemite (Figure 3E).

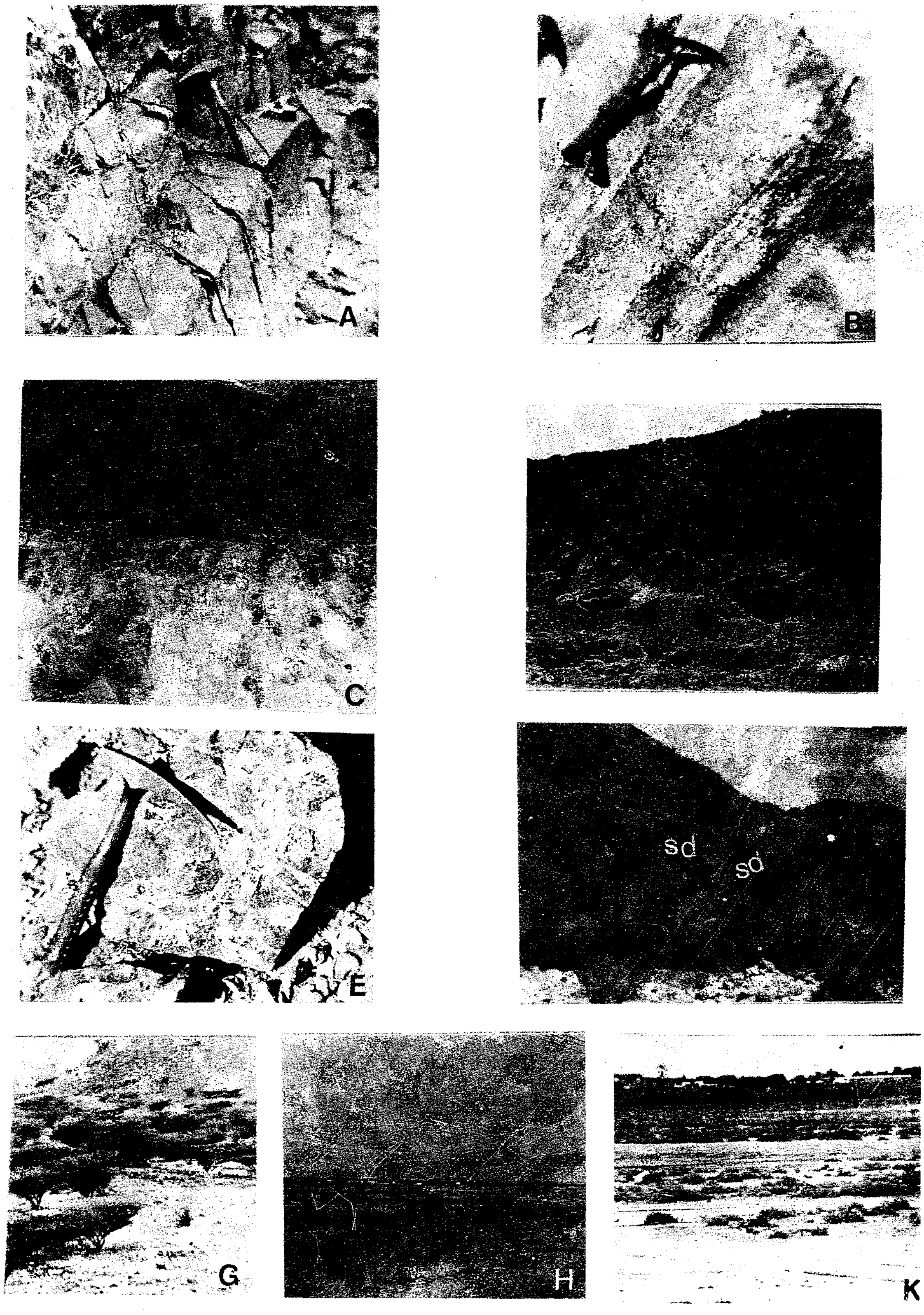
9. Sheeted dikes are found in a few places mostly injected and chilled against the massive metagabbroid rocks. Their exposures in Wadls Rumth and Hamad are extensively broken irregular fragments, 0.5 to 1m wide interslice the metagabbroid rocks (Figure 3F). They are formed of dark green to greyish green fine grained metadiabase. Sheeted dikes do not have a thick mappable lithologic extension in the study area.

The ophiolitic basic matavolcanic rocks in the study area are formed of non-pillowed low grade metamorphosed basic massive basalts. They are exposed as hills of moderate and low relief in Wadis Yifan and Hamad. They are either bounded by metagabbroid rocks where fault planes often form the contacts, or by Wadi and fan depodits. Rock texture is aphanitic to fine-grained. color is dark grey greenish grey. Weathered surface color is dark brown to brownish grey.

Wadi and fan alluvium occupies the montaineous drainage lines and the bajada (Figure 3G). Deposits of this unit are lenticular and complex; derived from the metagabbroid rocks and the basic metavolcanics of the Rumth, Hamad and Yifan drainage basins. Grain size changes gradually of sharply, both horizontally and vertically, The alluvium is mainly formed of gravel and sand. Silt and clay are less than 10%. During dry periods, finer sediments are removed by deflation, and may be redeposited in more sheltered areas blocking flow channels. As the Wadis flow again, water may overflow, and scours new, or modifies old channels (Glennie, 1970). The old alluvium, of probably Pleistocene-early Holocene age, is cemented and more weathered. The new alluvium, of late Holocene age, mostly overlies the old one. It contains, in part, reworked grains of the old alluvium. Some boulders may have received part of their rounding by exfoliation before transportation. Roundness is not a guaranteed indication of long transport (Glennie, 1970). Ophicolitic inselbergs rise above the bajada surface. Small ones will become partly or completely buried in the bajada alluvium as erosion and sedimentation carry on. This accounts for the extermely variable thickness of the Wadi and fan deposits.

Sabkha deposits are mainly formed of sand mixed with salt, silt, and clay. Percolation of sea water, supplied by Khor Kalba inlet, through the sabkha surface, is the main source of salt. Ground surface elevation ranges from 4 to 8m. Ponded water (Figure 3H) indicates poorly soil. Natural vegetation is scarce to absent. Khor Kalba inlet is a stage of a lagoonal feature formed by near-shore marine deposition.

Coastal sand occupies the eastern side of the study area (Figure 3K). It consists of carbonate and terrigenous sand. Grain size ranges from coarse to fine. Land surface elevation ranges from 0 to 4m. The coastal sand has been built up in the form of bar by waves. The bar was separated from the land to the West by a lagoon. As sedimentation continued, it became connected with the main land. Formation of this unit exemplifies the interplay between wind-and Wave-transporated sand in the coastal enviroment.


A
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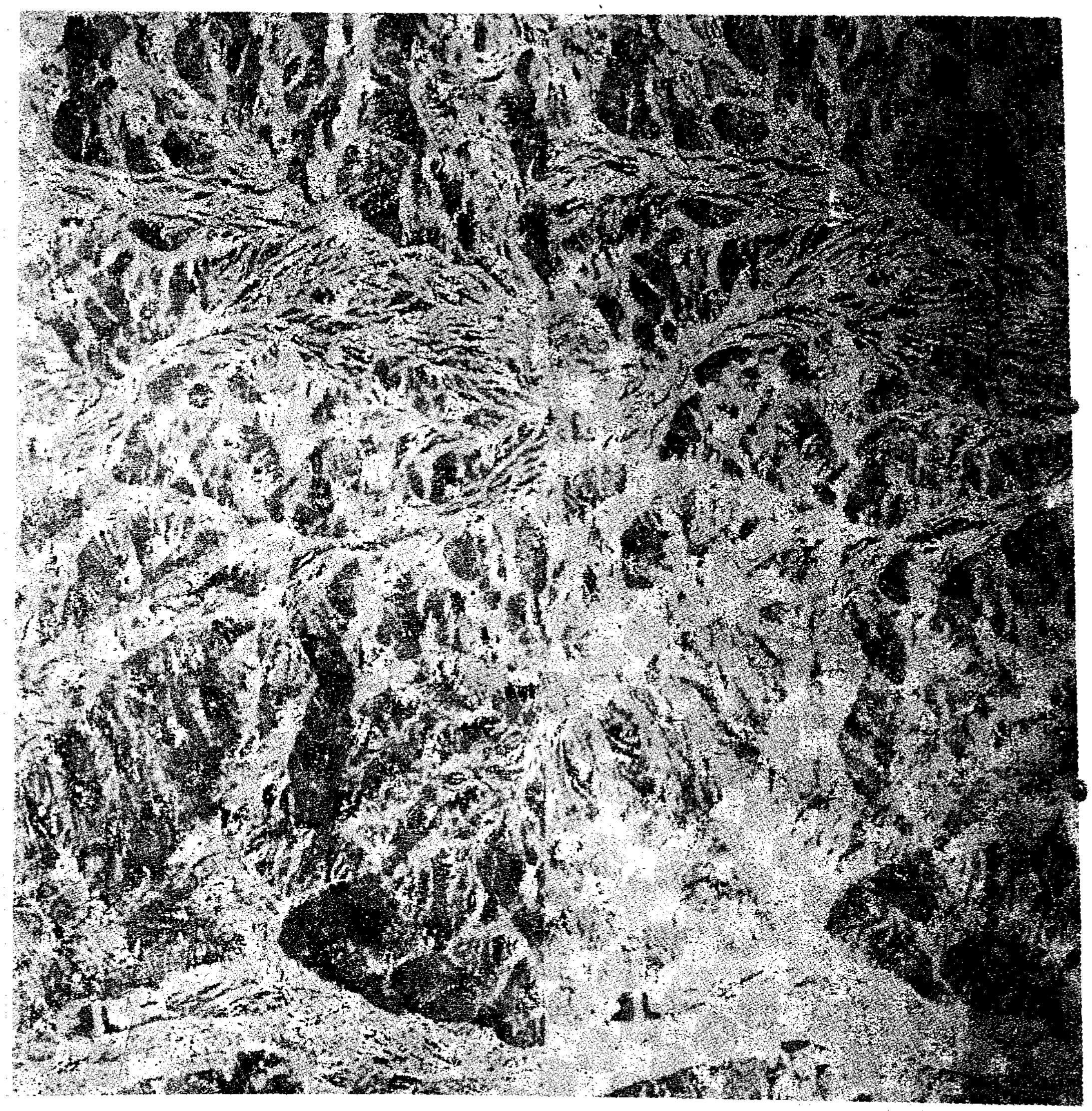
## PHOTO AND IMAGE INTERPRETATION

The following discussion includes topograhy, drainage, tone, and boundaries of the different geologic units in the study area as they have been interpreted from the aerial photographs and the Landsat MSS digital data.

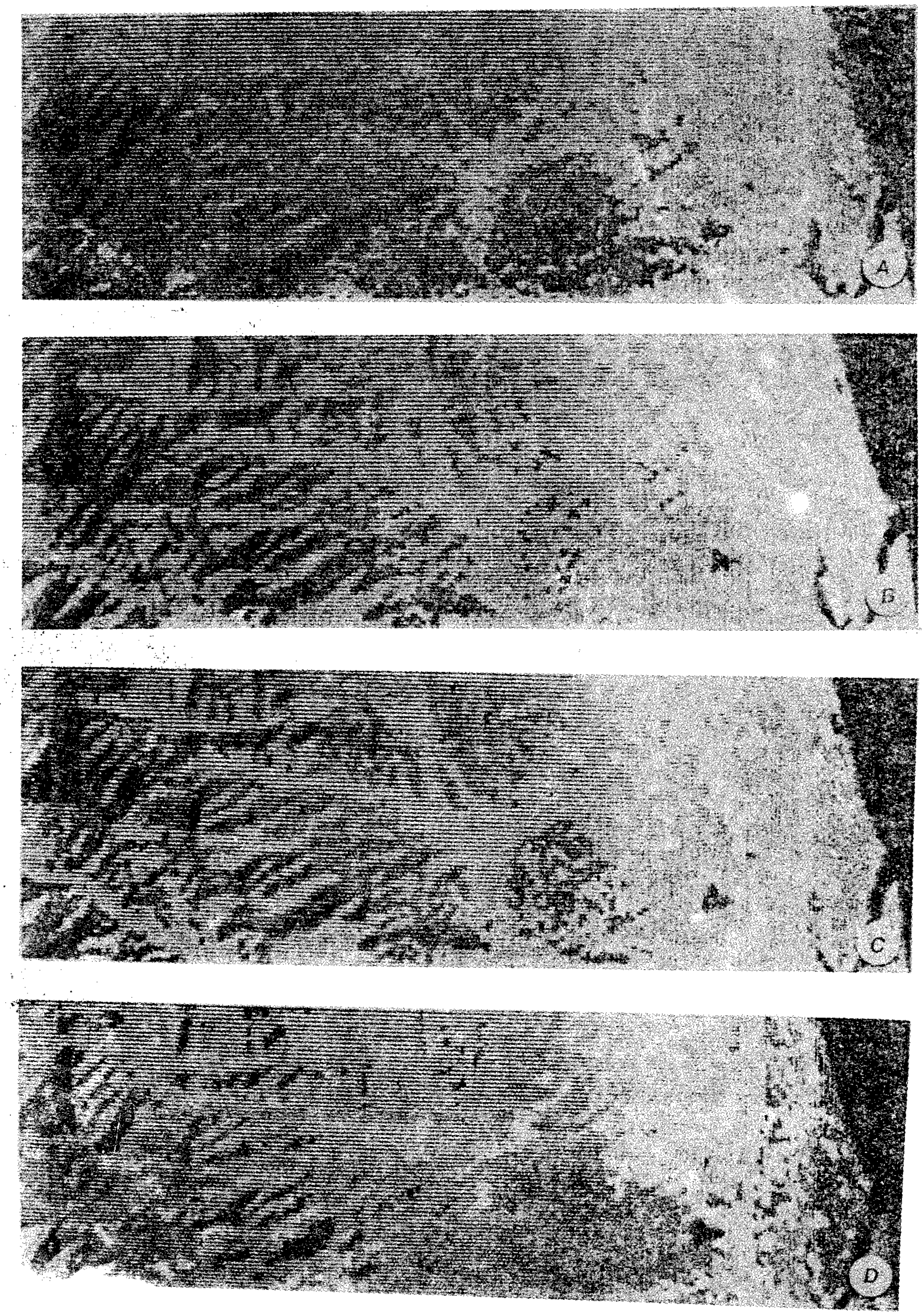
The metagabbroid rocks display massive mountaineous and hilly areas on aerial photographs (Figure 4). Drainage divides are mostly sharp. Slopes are moderats to steep. Gullies are mostly straight, shallow, and mostly controlled by fractures. The regional drainage pattern of the metagabbroid rocks is dendritic. Locally it is parallel, rectangular, or angular. The metagabbroid rocks show variable grey tones on the B & W aerial photographs. Colors are also variable from greenish to brownish on the color aerial photographs. Change in tone and color is mainly caused by difference in illumination angle, and photographic processing. On the Landsat image, gray tone is obviously darker on the shaded sides of mountains. Boundaries are either tectonic such as the boundary between the metagabbroid rocks and the basic metavolcanics, or unconformities as the contact between the metagabbroid rocks and the Quaternary deposits. On Landsat imagery (Figure 5) the metagabbroid rocks are distinct from the Wadi and fan deposits. Bands 2, 3 and the sliced images display more discrimination between metagabbroid rocks and Wadi and fan deposits than bands 1 and 4 images. The dark shaded sides of the mountains in bands 1, 2, 3 and 4 almost disappear by ratio and smooth processing.

The basic metavolcanics form massive topography with

FIG·4



# FIG·5

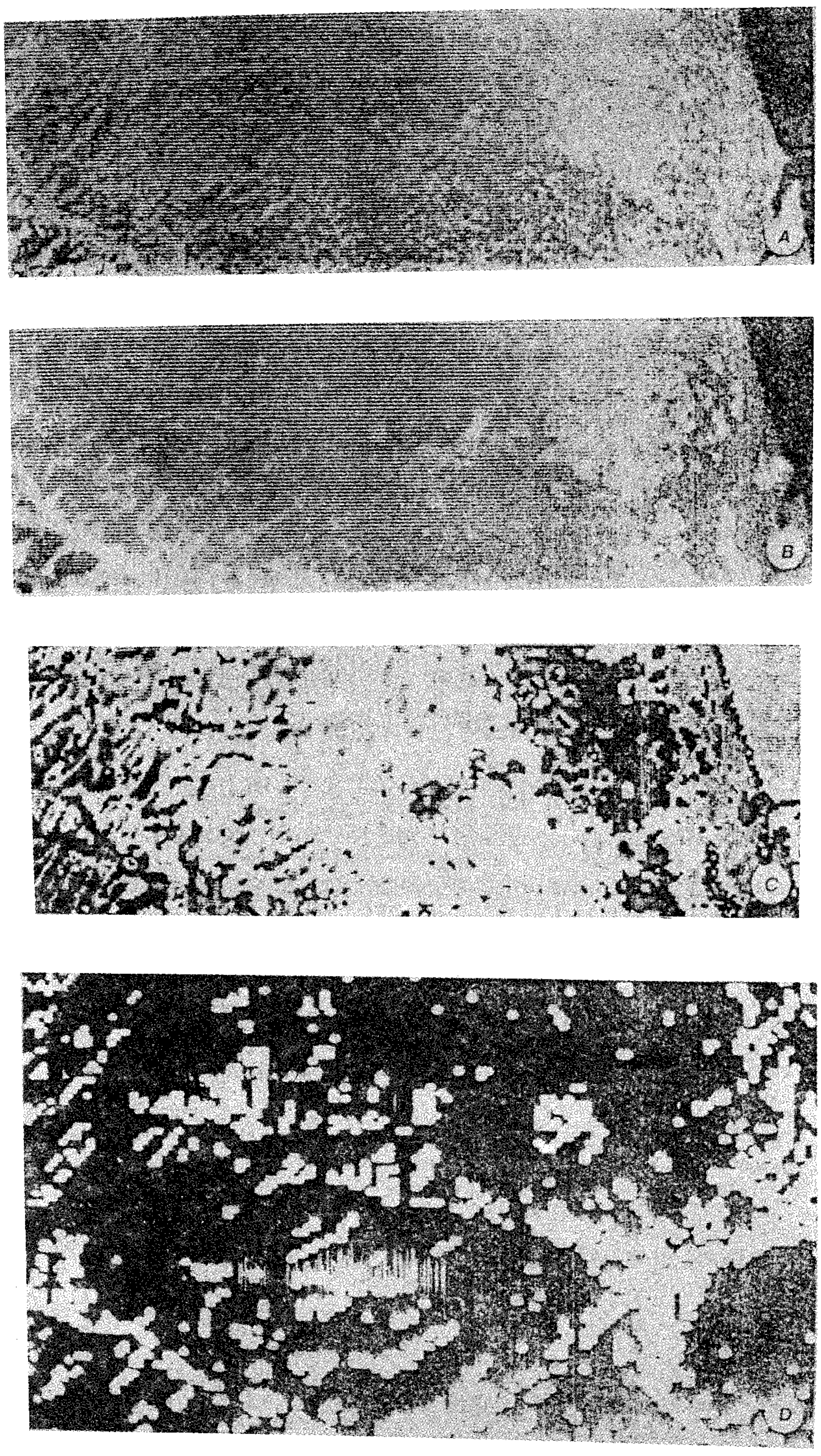


moderate rellef. On aerial photographs, slopes are moderate to steep, and tops are clear. The basic metavolcanics are dissected by shallow short gullies. Many of these gullies are structurally controlled giving local angular drainage pattern. Basic metavolcanics tone is dark gray on B & W aerial photos, and dark brown on color photos. Tone and color differences between the basic metavolcanics and metagabbroid rocks are fairly good basis to draw the boundary between them. On Landsat imagery (Figures 5 and 6) the basic metavolcanics are defined from the Wadi and fan deposits. However, the difference between basic metavolcanics and metagabbroid rocks is not obvious on the above mentioned figures. This is because the reflected waves, received by the MSS detectors, come from almost similar weathered surfaces of the two mentioned rock units. The slight difference between the two rock units is not detectable on the 79 x 58 m MSS resolution cell which has 0.5 - 1.1 m spectral awave length range.

The Wadi and fan unit shows dendritic drainage pattern on the mountaineous western and central parts, and radial on the eastern (bajada) part. This unit appears light grey on the B & W aerial photos, and yellowish beige on the color ones. Darker parts mark out old alluvium, whereas lighter areas designate new alluvium. Wadis as a whole are wadi and shallow (Holmes, 1965). Braided channels characterize both the wadi and fan surfaces. Those channels have low sinuosity designated by successive branching and rejoining around alluvial islands. Axes of islands are parallel to flow. Surface slopes range from more than 6° in the intramountaineous wadi segments to less than 1° on the eastern part of the bajada. Trees of

## FIG·6

*A Geologic remote sensing of the area southwest..............*



Acacia tortills are scattered with some concentration along previous channel courses. Thickness of the wadi and fan deposits varies; but, generally increases toward the fan distal part in the eastern side of this of this unit, close to the boundary with sabkha seposits. Tree clusters along the western side of the mentioned boundary are obvious on aerial photos. Natural vegetation concentration along the surface periphery of the fan indicates zone of maximum supply of tolerable salinity water. On Landsat digital imagery (Figure 5B & C), wadi and fan unit is brighter than the surrounding rocks. The eastern boundary of this unit, rich in natural vegetation, shows very light area on band 2 and 3 images. Ratio 3/2, smooth, slice, and Train and Class processings (Figure 6) display clear definition of the wadi and fan unit.

The sabkha and coastal sand units occupy the eastern part of the study area. The coastal sand is light brown on aerial photos, and the sabkha color is pale yellow. Poor drainage of the sabkha area causes some water ponding after rain. The northwestern arm of khor Kalba inlet runs in the sabkha part, whereas the northeastern arm flows in the coastal sand unit. These two units are not separated on Landsat imagery (Figure 5). Only the ratio smoothed sliced image (Figure 6C) shows the coastal sand distinguishable from the sabkha. Figure 5C & D and Figure 6A & B show the northeastern arm of khor Kalba inlet bright due to more spectral return from vegetation in band 3, 4, and 3/2 ratio images. Khor Kalba town is obvious on the 3/2 ratio image (Figure 6A & B) also due to ratio enhancement.

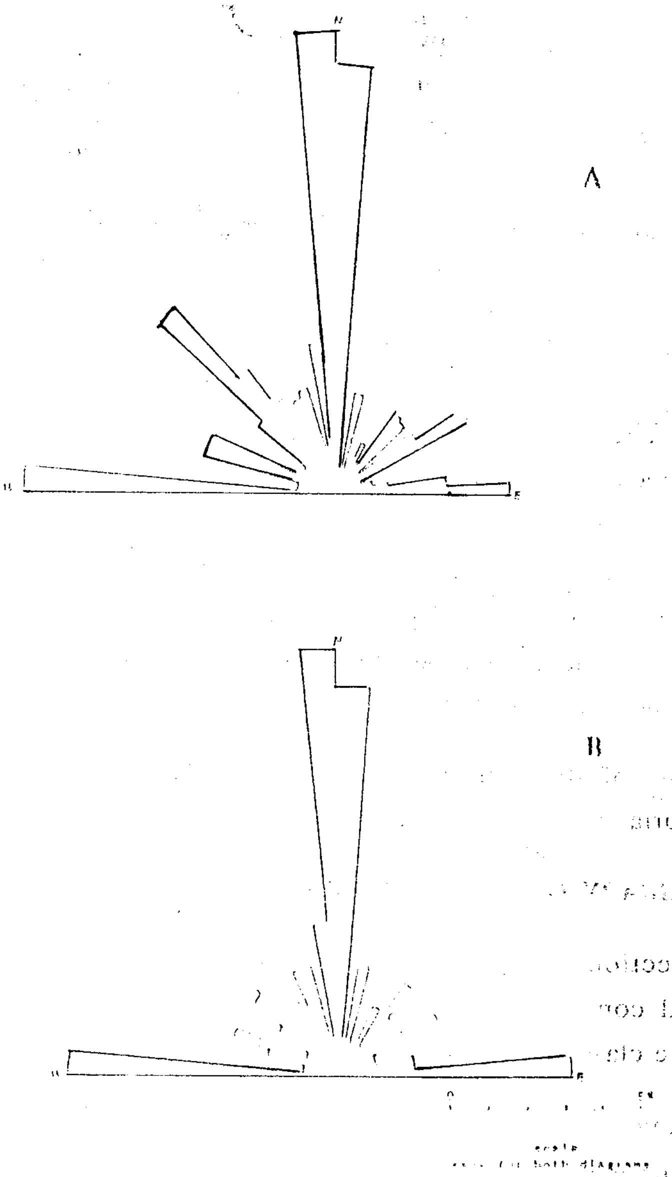
## V. LINEAMENT ANALYSIS

Hundreds of workers have observed, mapped and studied lineaments since the 19 th century. Hopkins (1841), Daubree (1879), and Hobbs (1904, 1911) introduced some of the pioneering work. O, Leary and others (1976) revised the term "lineaments" and related terms as used by various authors.

Lineaments have been mapped in the present work from aerial photographs on the basis of spectral signatures between the lineament and the immediate near area. They are expressed as linear features of different tones. In the field, they are weathered zones along faults and joints, linear topographic margins, straight stream or valley segments, or changes in soil nature.

The mapped lineaments were reviewed against topographic maps to cancel alignments related to manmade features such as roads. Lineaments are shown on the geologic map (Figure 2). The azimuth and length of each lineament were measured and used in the statistical analysis.

The staistical treatment included representation of azimuth frequency to find preferred orientations. Rose diagrams (Figure 7) were plotted to display azimuth frequency of lineaments. Angular classes of 5° interval were recorded, wider intervals may cause peak diffusion, and the data will be biased by averaging them. Less than 5° interval will present the confusion of smaller grouping. Diagnosis of significant peaks and troughs is based on departure from randomness. Lack of peaks and troughs in the frequency distribution implies that the orientation pattern of one variable


A
B
scale
both diagrams

changes randomly with respect to the other.

Figure 7 A and B shows 0°, 270°, 320°, 55°, and 290° azimuths as preferred lineament trends, mentioned in a decreasing order of significance. These trends are prominent, but not equally developed across the area. For example, the E-W trend is not observable on the downstream reaches of wadis Rumth and Hamad.

Four of the above mentioned trends are compatible with the tectonic trends identified in the neighboring areas. The north-south trend remarkably corresponds to Oman Line (Furon, 1941) which extends from Iran across the Gulf of Oman trending mainly N-S. The east-west trend correlates with central Arabia Arch and Hadramout Arch (Tiratsoo, 1976). The 320° trend corresponds to the Arabian peninsula faulting (Murris, 1980); and in particular wadi Ham Fault, about 10km north of the study area. The 55° trend coincides with Diba Line, 60km north of the study area. It seems that the tectonic pattern in the study area is old.

Elements of the pattern have been reactivated at different times with variable stress magnitudes and directions.

## VI. PETROGRAPY OF THE OPHOLITIC ROCKS

This section deals with the petrographic study of the metagabbroid complex and the basic metavolcanics in the study area. They are classified as follows :

1. metapyroxenite
2. olivine gabbro
3. metagabbro
   a massive metagabbro

b layered metagabbro

c sheared metagabbro

d uralitized gabbro

4. amphibolite
5. diorite
6. trondhjemite
7. metadiabase
8. metabasalt

Metapyroxenite occurs in minor amounts, and represents the ultramafic portion of the metaagabbroid complex. Microscopically, it conists of secondary amphibole (actinolite), with remants of pyroxene, a few opcques, and phlogobite.

Olivine gabbro is mainly composed of plagioclase, amphibole, pyroxene, and olivine. Accessories are ilmenite and magnetite. Olivine occurs as large subhedral crystals in cumulate texture (Figure 8A). It is characterized by fresh appearance; but, replaced by magnetite and iddingsite along internal partings.

Matagabbro froms more than 90% of the metagabbroid complex. The following varieties have been designated.

Massive metagabbro is predominant. Microscopically, it conists of amphibole and plagioclase with scarce amounts of pyroxene, chlorite, biotite, quartz, leucoxene, sphene, white mica, and apatite. Rellics of ophitic and subophitic textures are noticeable (Figure 8B).

Layered metagabbro has very limited outcrops. It exhibits a well developed small layered structure. The mineral constituents are segregated into alternate melanocratic and leucocratic lamine and layers up to 2.5cm showing a cumulate texture (Figure 8C). The melanocratic layers are formed of pyroxene relics and pseudomorphus amphibole; whereas the leucocratic layers are entirely formed of saussuritized plagioclase.

Sheared metagabbro also has limited occurrence along faults and shear zones. It is slightly to moderately foliated. The mineralogic composition of this rock is similar to the massive metagabbro, but with secondary quartz, plagioclase and ferromagnesian minerals indicating dynamic deformation.

Uralitized gabbro crystals are olive green, and mostly speckled with white specks. Microscopically, it is mainly composed of plagioclase, with secondary amphibole (uralite), and pyroxene relics. Accessories are ilmenite, magnetite, and epidote, Uralite is variably altered to chlorite associated with expelled magnetite. It usually encloses fine laths of labradorite.

Amphibolite shows fine-to medium-grained granoblastic aggregates of hornblende and plagioclase. Quartz, chlorite, and epidote are scarce.

Diorite is composed of plagioclase, and amphibole, with subordinate quartz, epidote, white mica, sphene, and apatite.

Trondhjemite is a light-colored, containing less than 10% mafic minerals (Streckeisen, 1976). It is formed of oligoclase, quartz, chlorite, and allanite. It is homogeneous, with a hypidomorhic granular texture.

Metadiabase entirely forms the incipient sheeted dikes in the study area. The rock is mainly formed of labradorite, hornblende, and actinolite. Intergranular texture is common where amphiboles occupy angular interstices between plagioclase laths (Figure 8D).

Metabasalt is the main component of the basic metavolcanics.

It is composed of dense aggregate of albite, saussuritized plagioclase, hornblende, with suborinate chlorite, opaques, sphene, and leucoxene. Ophitic and subophitic textures are observed.

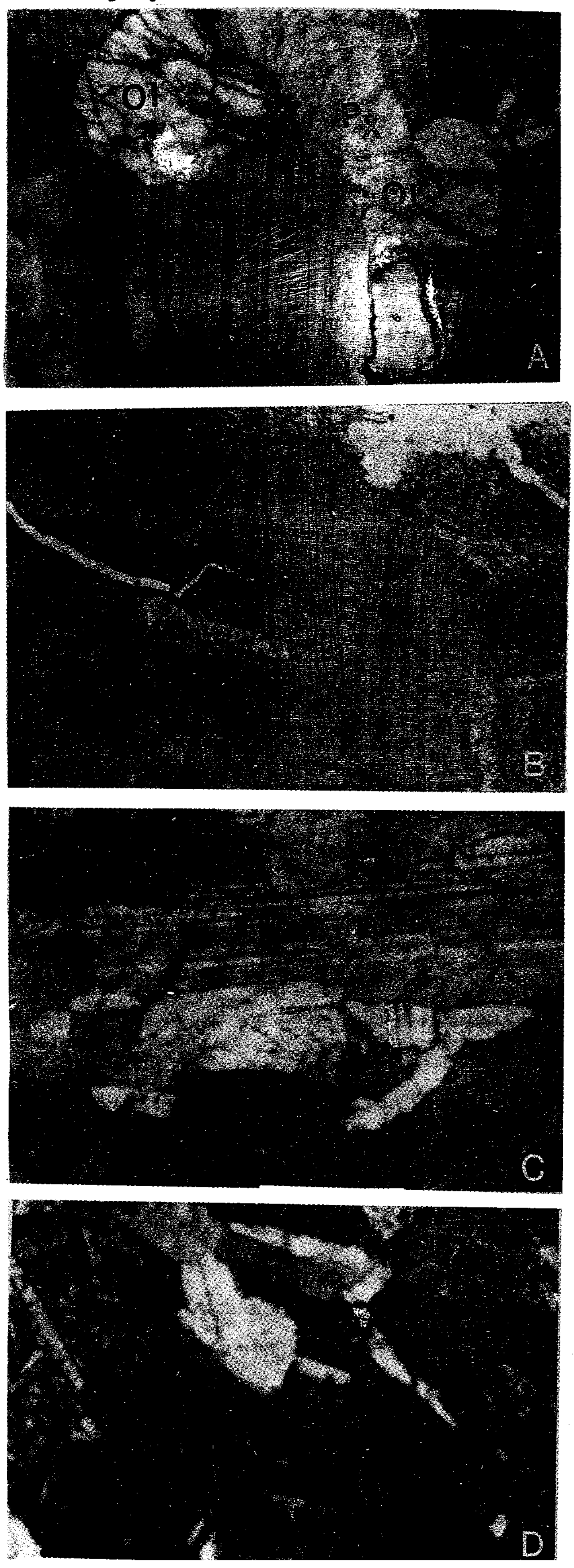
## VII. CONCLUSIONS

Remote sensing data, whether from air or provides basis for mapping geologic units. Aerial photographs at a scale of 1 : 25000 give more spatial delails than the Landsat MSS images. The latter provides more spectral and temporal information, in addition to a synoptic view of a large area, lucrative digital processing and enhancement of Landsat data are valuable improvement to visual interpretation.

The differences among spectral reflectances from various rock types are severely decreased by altertion, weathering, shadow and relief elements. Therefore, ground-truth collection and petrographic analysis are required supplements as represented in this study.

The five major lithologic units that have been identified in this study are : (1) metagabbroid complex including metapyroxenite, olivine gabbro, metagabbro, amphibolite, diorite, trondhjemite, and incipient sheeted dikes, (2) basic metavolcanics, (3) wadi and fan alluvium, (4) sabkha deposits, and (5) coastal sand. The field

FIG -8



occurrence of metapyroxenite suggests that it represents a transitional stage between mafic and ultramafic rocks.

Lineaments in the study area have preferred trends. Their azimutahs, in a decreasing order of significance, are : 0°, 270°, 320°, 55°, and 290°. The first four trends are compatible and consistent with the structural trends in the neighboring areas.

Availability of higher resolution satellite data, as TM and SPOT data should increase the extractable amount of information from space images required for geologic studies.

## ACKNOWLEDGEMENTS

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