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STRUCTURAL CONTROL ON LANDFORMS IN MARIB - SIRWAH VOLCANIC FIELD AS DEDUCED FROM REMOTE SENSING DATA IN MARIB GRABEN, YEMEN

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The Marib - Sirwah volcanic field is structurally represented by major graben. The Marib Graben is a relatively narrow deeply subsided structure lying between the Gabal Hilan in the northwest and the Gabal Al-Balaq Ridge in southeast area.
Remote sensing techniques with DEM were applied to delineate lithological and structural features of the area around Marib area, Yemen. Landsat Enhanced Thematic Mapper Plus (ETM+7) Satellite data have been used to identify the Marib - Sirwah volcanic field in Marib graben.
The results revealed that the Marib area is covered by three different rock types related to three different ages: basement rocks, Amran limestone and volcanic rocks. Lineaments of the Marib area were grouped in three domains according to rock units and show maximum direction in NE–SW followed by NW–SE.

Keywords**:** Marib, Sirwah, volcanic field, graben, remote sensing, Yemen

INTRODUCTION

Remote sensing integrated with GIS is widely used in mapping as a lithological discrimination technique [1-9].

Landsat ETM remote sensing imaging allows precise coverage of vast regions with basic data for geological exploration while significantly reducing exploration costs. These data provide valuable information for geological mapping and mineral exploration through highlighting geological structures such as lineaments, faults and lithological contacts [10]. Such equipment has been widely used in environmental studies [11-13].

The Yemen landscape comprises various rock types ranging in age from Precambrian to Cenozoic [14-16].

With the opening of the Gulf of Aden and the Red Sea during the Cenozoic era the western part of Yemen and parts of the coastal plain of the Gulf of Aden as well as some islands in the Red Sea were covered by subaerial extrusive lava flows (Yemen Volcanics) [17-20].

The present paper aims to elucidate the geological and structural aspects of the Marib – Sirwah area to display the relationships between the distribution and shape of Marib - Sirwah volcanic field and Marib graben, by using the Landsat ETM+ techniques available data.

The study area around Marib city, 180 km east of Sanaa, Yemen, is confined between Latitudes 15° 08 and 15° 36 N and Longitudes 44° 56 and 45° 30 E (Fig. 1 & Fig. 3). It covers about 3120 Km^2. The outcropping rock units range between the Precambrian basements to recent rock. The area has a humid climate, mountainous and desert topography beside soil and dense vegetation cover.

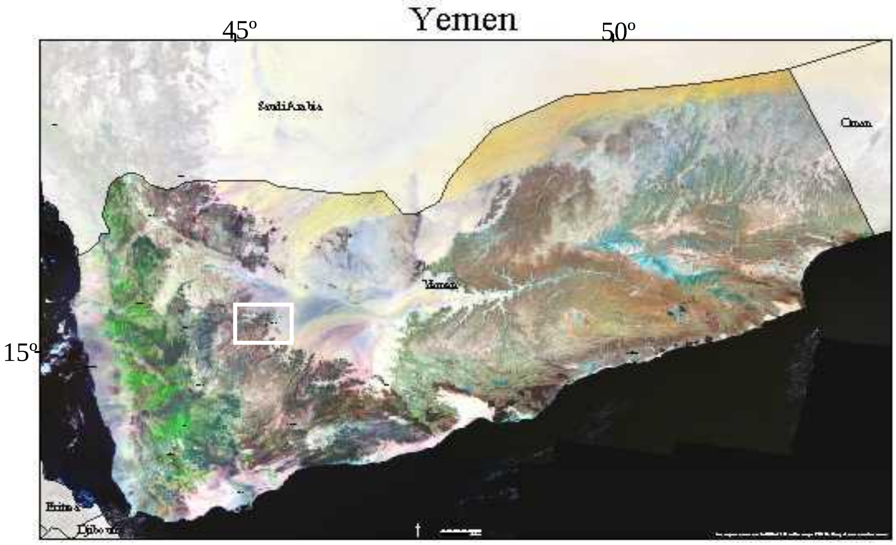

Fig. 1. MODIS satellite image of the Yemen. The Marib area (large white rectangle) is found to the south of major structure of the Wadi Al-Jawf trough northern Yemen,

Geological setting

The area of Marib - Sirwah is characterized by the prevalence of some rock units which can be classified into:

1- Basement rocks (Precambrian)

2- Amran limestone (Jurassic)

3- Volcanic rocks (Quaternary)

4- Quaternary cover deposits

The distribution of these rocks is shown in Fig. (3).

1- Basement rocks

The outcrops of the basement rocks, occupy most of the land surface of the study area. They are composed of medium to high grade regionally metamorphic rocks consisting of migmatites, schist, paragneisses, marble, metadolomite and graphite schist.

The granitic rocks are represented by intrusive granite porphyry, gneissose granite and mylonitized alkali granite associated with pegmatitic granite [21].

They form mountainous terrains as well as low-lying inliers in the southeastern sandy plains. They are unconformably overlain in the eastern and northern parts by the Amran limestone.

2- Amran limestone

Exposures of the Amran limestone constitutes the elongate ridges of Gabal El-Balaq and of Gabal Hilan extending in the NW-SE direction lying in the eastern and the northern parts of the study area.

[21] divided Amran group in the Marib area into five lithologic units arranged from base to top as follows: sandy limestone, fossiliferrous limestone, marly limestone, chalky limestone and stromatolitic limestone. Limestone outcrops are bounded by normal faults against the uplifted basement rocks and form the southwestern shoulder of El-Jawf graben.

3- Volcanic rocks

These volcanics are from the Quaternary volcanic phase characterized by central eruptions with volcanic cones scattered in the field of lava flows.

The volcanic field covers about ~ 825km^2 (55 X 15 Km), mainly extending in NE direction crowded with volcanic cones which are mainly arranged in parallel NE-SW lines.

Generally, they vary in thickness between few meters along their borders with the older rocks of the basement rocks and about several tens of meters at the central part. Some volcanic cones are isolated; the slopes of the cones are variable. These volcanics are mostly subaerial. Basalts and extensive welded tuff units predominate while andesites and rhyodacites are far less abundant.

These volcanics are intermittently extruded by several central eruptions which can be classified on the basis of their internal structural into explosive calderas having circular forms, volcanic necks, hornitos and cinder cones.

4- Quaternary deposits

Quaternary deposits cover almost the eastern part of the study area, to the north of Marib town. They are composed essentially of wadi deposits, sand dunes and sheets.

a- Wadi deposits

Wadi deposits are located in the northeast area. These are almost flat and covered by scattered vegetation. Clasts of these deposits include alluvium sediments, composed of gravels of different sizes, generally derived from the surrounding volcanics and sedimentary rocks. Clasts of these deposits are embedded in sandy, silty and clayey matrix. The fanglomerates are well represented on the upstream near the high lands.

b- Wind dune deposits

The majority of the Quaternary sediments appear in the east and north Marib area are represented by vast fields of sand dunes, backs or sand levees. They are characterized by their flat-toped sand ridges which extend parallel to the prevailing wind and lack the collapsing fronts.

Structures

The area is dissected by a series of extensional high angle normal faults which are wholly pertaining to brittle deformation and entirely postdating the deposition of the Amran Limestone. ETM+ evidences indicates that these faults took place during two subsequent periods. The faults of the early period trend NW-SE whereas the younger one strikes ENE-WSW. These faults might act as feeders along which the Marib – Sirwah volcanics were explosively erupted.

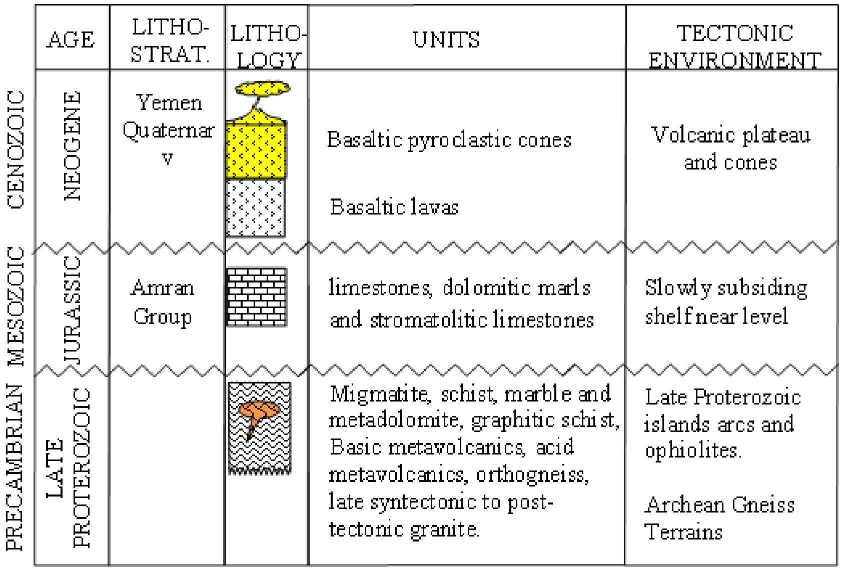

Fig. 2: Simplified stratigraphic column of the study area.

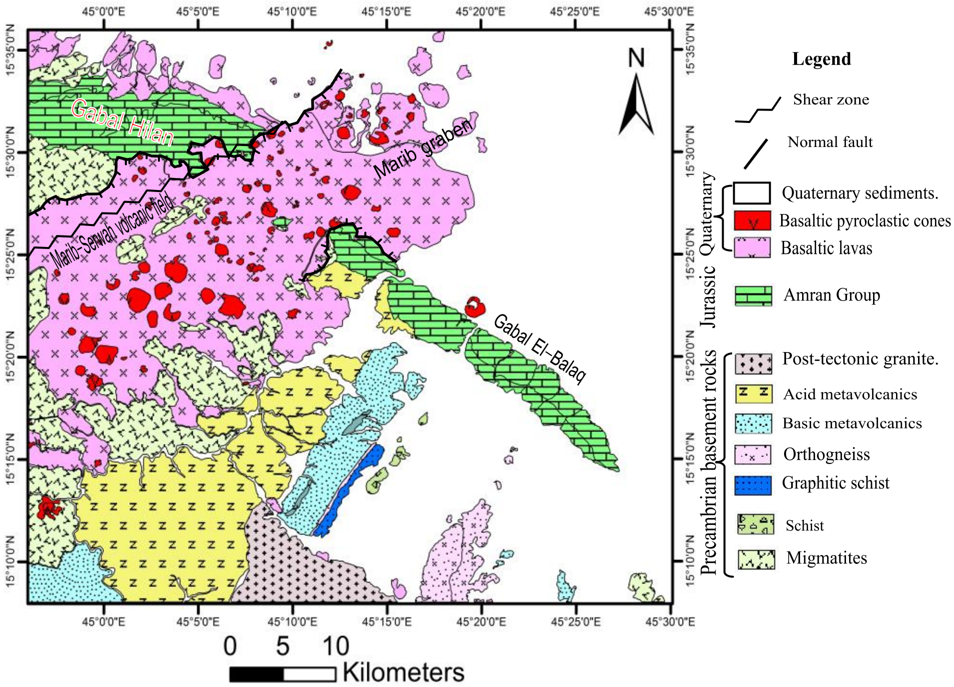

Fig. 3:Geological map of the Marib area. Modified after Robertson Group, 1992

MATERIALS AND METHODS

Two types of geologic maps are used in this study. Geological map of Republic of Yemen, western sheet Geologic map scale 1: 1000, 000, and two geological maps of scale 1:250 000 namely Marib, and Sanaa, [22].

These maps have been used in digitizing and tracing the different rock units and used as reference data for verification of rock units discrimination by remote sensing data.

Landsat Enhanced Thematic Mapper Plus (ETM+7) imageries are available and free of charge via the /USGS Global visualization Viewer (http://glcfapp.glcf.umd.edu:8080/esdi/index.jsp).

The selection of the imageries was based on the acquisition date, availability and spatial resolution as well as the user need. ETM+ scenes of landsat-7 have been utilized in this study (path 165, raw 49, date 20- 03-2006). The selected bands include band 1 through band 5 and band 7 (Visible & Reflected Infrared “VNIR”) that characterized with 30 m spatial resolution. In addition to band 8 as the Panchromatic band (15 m). The thermal Infrared band 6 has been excluded for its low spatial resolution (60 m).

During this study four different software packages are used since there is not single software that will process all steps in the analyses.

ENVI 4.5 (the Environment for Visualizing Images) and ERDAS IMAGINE 9.2 (Earth Resources Data Analysis System), Ilwis 3.6 (Integrated Land and Water Information System) and Arc GIS 10 (geographic information system) mantle software packages are both used in digital processing to enhance the quality of the satellite raw digital data and produce image suitable for visual geological interpretation

Digital processing of ETM+ image for the study area generated several products ranging from subsetting, histogram equalization, false color composite (FCC), principal components analysis (PCA), and band ratio composite (BRC).

Subsetting is the process of breaking out a portion of a large image file into one or more smaller files. The whole stitched scene was subsetted to obtain the interested study area. The flow chart of the steps followed in the present work is visualized in Fig. 4.

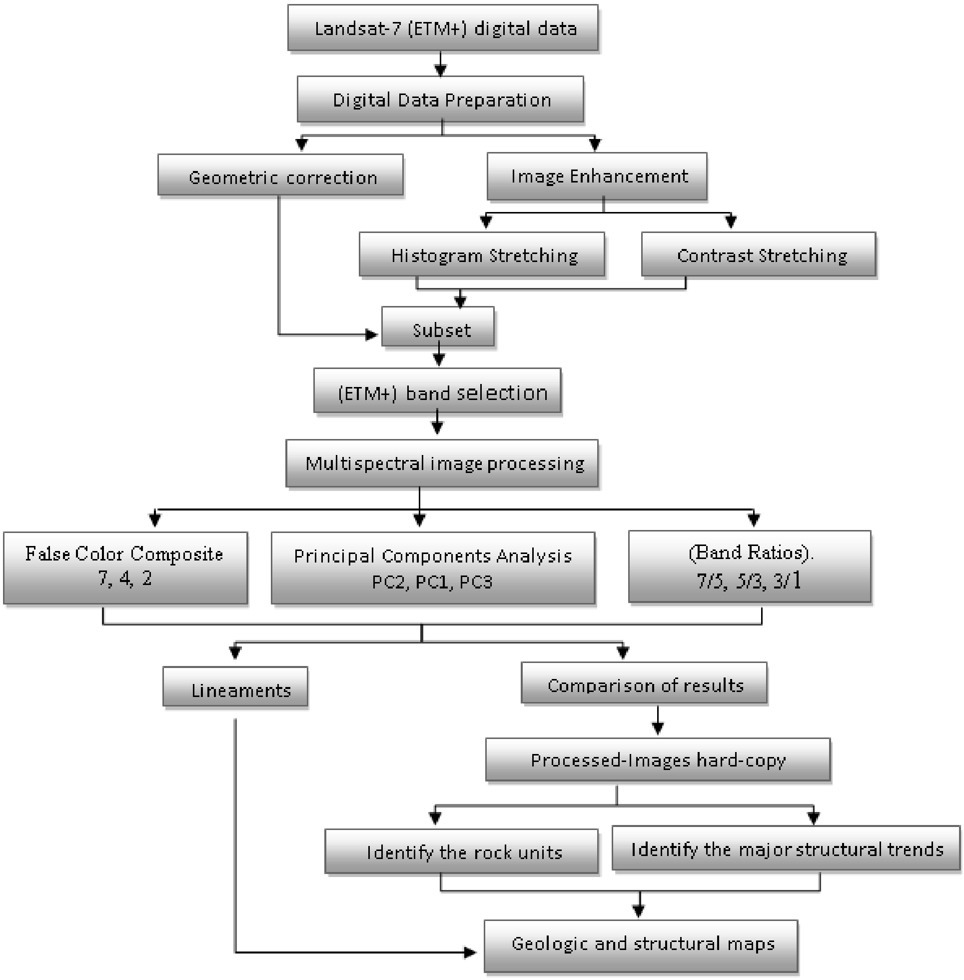

Fig. 4: Schematic diagram of methodology used in the present study.

False color composite images

The produced false colour composite image (bands 7, 4 and 2 in R, G and B respectively) has much better contrast and spectral resolution for geological information.

Visual inspection of the FCC image (Fig. 5) shows that the outcrops of old rocks around the Marib - Sirwah volcanic field are well discriminated into metavolcanics correspond to light red color, the granites correspond to Light brown color, the Amran group corresponds to gray color, basaltic lavas correspond to dark cyan colour while the basaltic pyroclastic deposits sheets corresponds to red colors.

The Quaternary volcanic rocks, mainly exposed in the central part of the study area, are deeply eroded and crop out as low surface exposures. They can be differentiated by their tones

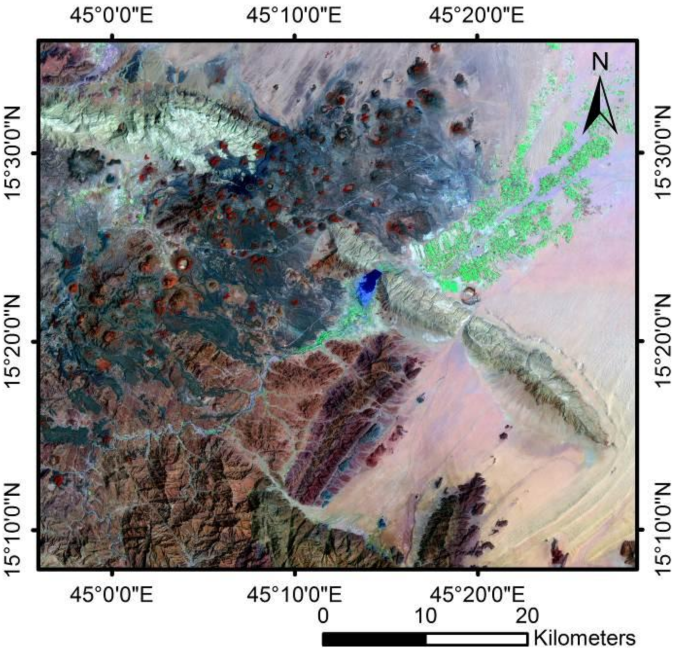

Fig. 5: A Landsat 7 ETM+ false color composite image (bands 7, 4, 2 in R, G, B).

Principal component analysis (PCA) and band ratios composite (BRC)

PCA is a statistical technique that can be applied to multispectral images to suppress the irradiance effects of all bands and therefore enhancing spectral reflectance of geological features [23].

It is generally accepted that the first three principal components analysis (PCA1, PCA2, PCA3) have over 98% of the spectral information. The results show that lithological units in the study area were discriminated and the contacts were identified on the PCA imagery (PCA2, PCA1, PCA3) in red, green, and blue (R, G, B) (Fig. 6). Lithologic mapping (Fig.6) is essentially based on the interpretation of these data. There are high contrast between the basement rocks, sedimentary rocks and the Quaternary volcanics.

Metavolcanics have magenta colors, granites have red magenta colors, Amran group have greenish yellow colors, basaltic lavas has a blue color, and the basaltic pyroclastic deposits are identified by magenta color. Wadi deposits light green colors in the eastern part where the valleys are filled with recent deposits.

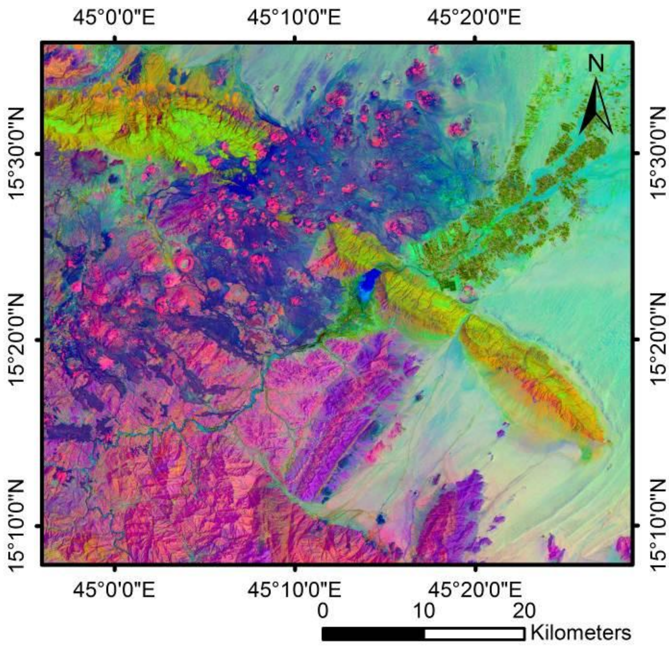

Fig. 6: Principal component analysis of Landsat 7 ETM+ image (PC2, PC1, PC3 in R, G, B) of the study area.

The best results of Landsat images processing is band ratio composite, that has been applied in the study area, (7/5, 5/3 and 3/1) in RGB, which were able to discriminate features and forms inside the volcanic field.

Accordingly, it is possible to discriminate between different rock units, in addition to some rock units that can be discriminated in this band ration more another as follow: the metavolcanic rocks exhibit yellow color, differing from the intrusive granite which displays greenish yellow color, the limestone of Amran group display green. Basaltic lavas shown in brown colour while the basaltic pyroclastic cones and sheets correspond to light yellow colors (Fig. 7).

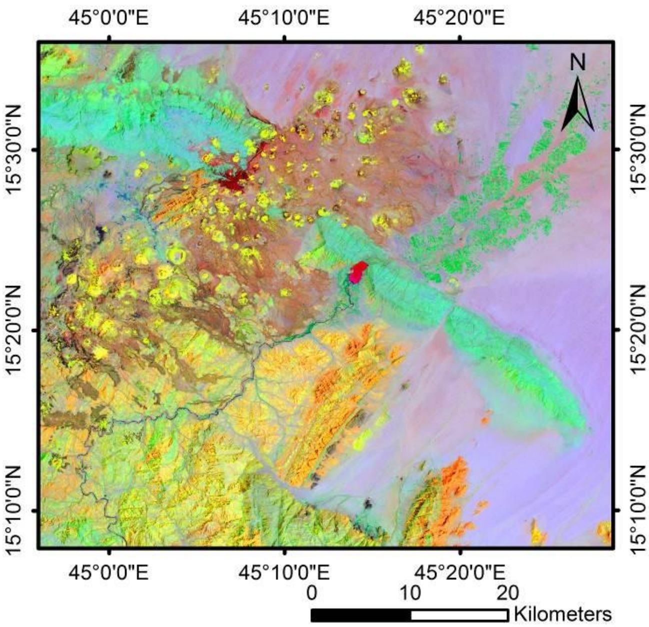

Fig. 7: Landsat ETM+ band ratio image 7/5, 5/3 and 3/1 in R, G and B, respectively.

GEOMORPHOLOGICAL FORMS OF MARIB - SERWAH VOLCANIC FIELD

Many of the geomorphological forms that were formed by volcanic activity crop out in the Marib-Serwah volcanic field and can easily distinguish them on the ETM+ image. More than 100 volcanic feature of varying forms are distinguished.

The FCC combination has been approved in five geomorphological configuration selected areas in the Marib - Serwah volcanic field to understand its ability to discriminate different geomorphological configurations from each other. The results show that several techniques of image processing are very helpful in the identification and discrimination between different land forms as well as the variation in their composition. The following features were easily classified in Marib - Serwah volcanic field:

1- ***Volcanic cones***

Volcanic cones are the most prominent feature of this volcanic field and there are either contiguous or spaced nozzles showing either circular or

crescent cones arranged mainly in a NE-SW trend, with some are aligned NW-SE. Volcanic cones are either symmetrical with equal radial slopes or asymmetric with varying degree of slopes in different sides of the cone (Fig. 8A).

2- Calderas

Large number of calderas occur in the field generally formed by violent explosive volcanic eruptions and consist of large volcanic circular form, with depressed inner parts and surrounded by highly elevated walls. They show steep angle of outward slope and are composed essentially of pyroclatics (Fig. 8B).

3- Volcanic arcs

This consists of volcanic forms at the exit of lava of incision arc, with high long crescent-shaped volcanic crater -like arcs (Fig. 8C).

4- Volcanic wedges

These are similar to the explosive caldera type but there sidewalls undergone intense erosion differential (Fig. 8D).

5- Volcanic plateaus

Volcanic plateaus and benches appear in the form of flat topped or broad volcanic cones with low angle of slope indicating slow outpouring of low viscous basic lava from fissures rather than central routs (Fig. 8E).

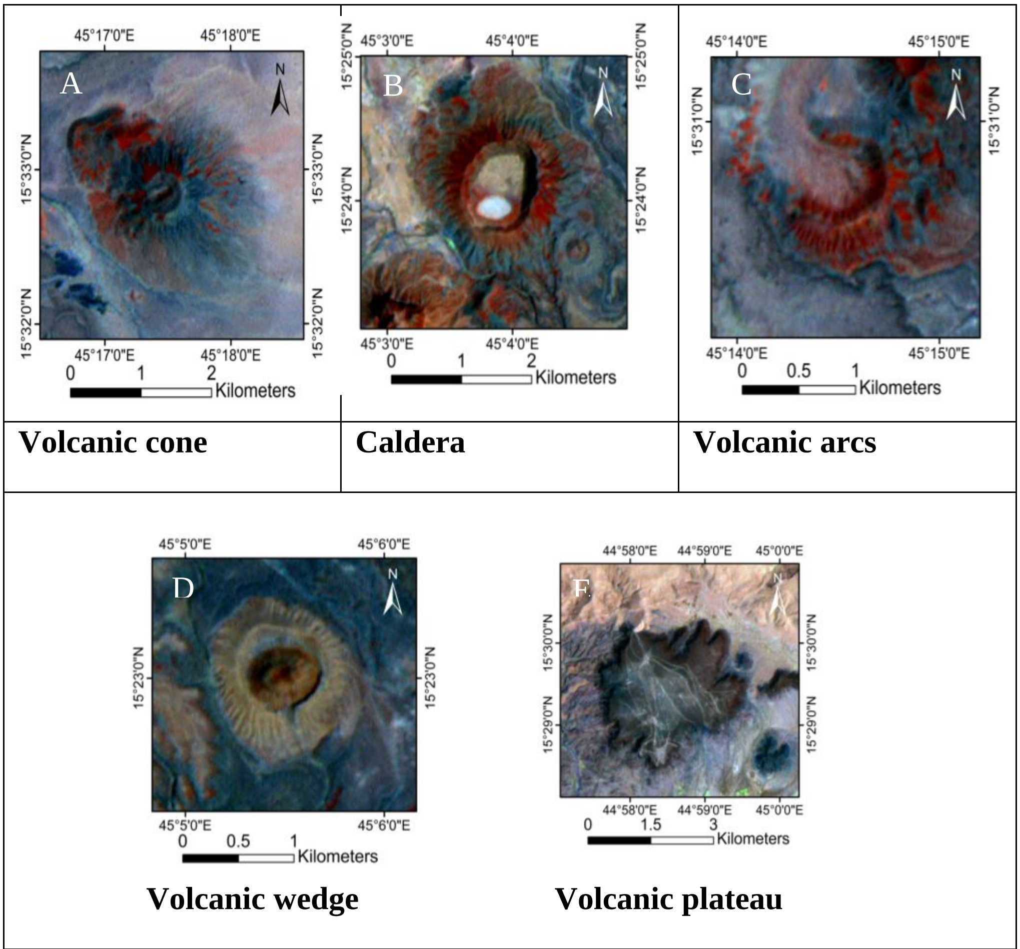

Fig. 8: Landsat images of some geomorphological shapes in Marib - Serwah volcanic field as seen on Landsat ETM+ 7 image.

Lineament extraction using remote sensing of study area

Lineaments may reflect surfaces of discontinuity in the rocks or may reflect geological structures or topographic features or human made features.

The study area is subdivided into three domains according to the type of exposed rocks (basement rocks, sedimentary rocks, volcanic rocks), for the identification of possible local variations in the structural behavior. The area is characterized by rectilinear and curvilinear lineament structures. A total number of 768lineaments with total length of 1383.4 km was detected and mapped (Table 1 and Fig. 9).

The linear features plotted in the mapped area correspond to linear geomorphologic features (wadis, cliffs, sheets and ridges), fractures (joints, dykes, faults and major shear zones). The lineaments of volcanic flows indicate paleogeographic slopes controlling lava flow direction. The lineaments were statistically analyzed according to their azimuth, number (N), length (L) and orientation. The azimuth frequency diagrams of the analyzed lineaments for the basement rocks, Amran limestone, volcanic rocks and totally for, the whole area are shown in (Fig.10). The lineaments map and rose diagrams reflect prevalence of two main structural trends.

The distribution of the surface fracture trends as deduced from the rose diagrams of N% and L% in different sectors together with both total and the major fractures reveal the followings:

The first prevailing lineaments set is NE - SW which constitutes an the elongated belt and probably controlled the flow of lava during formation of Marib - Sirwah volcanic field.

The second predominant trend of the lineaments express fractures that extend NW-SE nearly parallel to major fault trend which bounds the morphotectonic ridges of Gabal Al-Balaq. This trend nearly coincides with the Wadi Al-Jawf trough that dates to Mesozoic time [24]. The localization of this volcanic field seems to be controlled by intersection of two major regional deep fracture trends parallel to the Red Sea (NW) and Gulf of Aden (NE).

Table 1: Frequency distribution of lineaments in Marib area.

	Azimuth Intervals	Basement rocks				Amran rocks				Volcanic rocks				Total			
		N	L (km)	N %	L%	N	L (km)	N %	L%	N	L (km)	N %	L%	N	L (km)	N %	L%
NE/SW	0: <10	19	40.1	4.32	4.73	9	8.794	3.673	3.23	0	0	0	0	28	48.9	3.65	3.54
	10: <20	17	27.7	3.86	3.27	14	11.66	5.714	4.28	2	5.7	2.41	2.17	33	45.1	4.3	3.26
	20:<30	42	72.4	9.55	8.54	22	21.83	8.98	8.02	5	23.4	6.02	8.89	69	118	8.98	8.5
	30: <40	57	136	13	16.1	30	34.4	12.24	12.6	13	39.4	15.7	15	100	210	13	15.2
	40: <50	30	50.3	6.82	5.94	30	32.65	12.24	12	23	72.3	27.7	27.5	83	155	10.8	11.2
	50: <60	25	53.8	5.68	6.35	15	14.59	6.122	5.36	15	32.8	18.1	12.5	55	101	7.16	7.32
	60: <70	26	49.4	5.91	5.83	17	20.27	6.939	7.45	9	27.5	10.8	10.4	52	97.2	6.77	7.03
	70: <80	32	68.9	7.27	8.13	11	12.46	4.49	4.58	3	13.1	3.61	4.98	46	94.4	5.99	6.83
	80: 90	26	56.8	5.91	6.71	11	9.28	4.49	3.41	0	0	0	0	37	66.1	4.82	4.78
NW/SE	0: <10	12	20.9	2.73	2.47	11	11.3	4.49	4.15	0	0	0	0	23	32.2	2.99	2.33
	10: <20	9	14.7	2.05	1.74	12	12.5	4.898	4.58	1	6.1	1.2	2.32	22	33.3	2.86	2.41
	20: <30	7	13.1	1.59	1.54	12	14.7	4.898	5.38	1	3.6	1.2	1.37	20	31.3	2.6	2.27
	30: <40	17	35	3.86	4.14	14	11.9	5.714	4.38	3	11.8	3.61	4.48	34	58.8	4.43	4.25
	40: <50	38	75.3	8.64	8.89	9	18.9	3.673	6.95	4	16.2	4.82	6.16	51	110	6.64	7.99
	50: <60	28	41.8	6.36	4.93	10	11.2	4.082	4.1	3	8.4	3.61	3.19	41	61.4	5.34	4.44
	60: <70	18	31.6	4.09	3.72	8	13.3	3.265	4.89	0	0	0	0	26	44.9	3.39	3.24
	70: <80	19	34	4.32	4.01	5	5.6	2.041	2.06	1	2.9	1.2	1.1	25	42.5	3.26	3.07
	80:90	18	25.4	4.09	2.99	5	6.95	2.041	2.55	0	0	0	0	23	32.3	2.99	2.34
sum.		**440**	**847**	**100**	**100**	**245**	**272**	**100**	**100**	**83**	**263**	**100**	**100**	**768**	**1383**	**100**	**100**

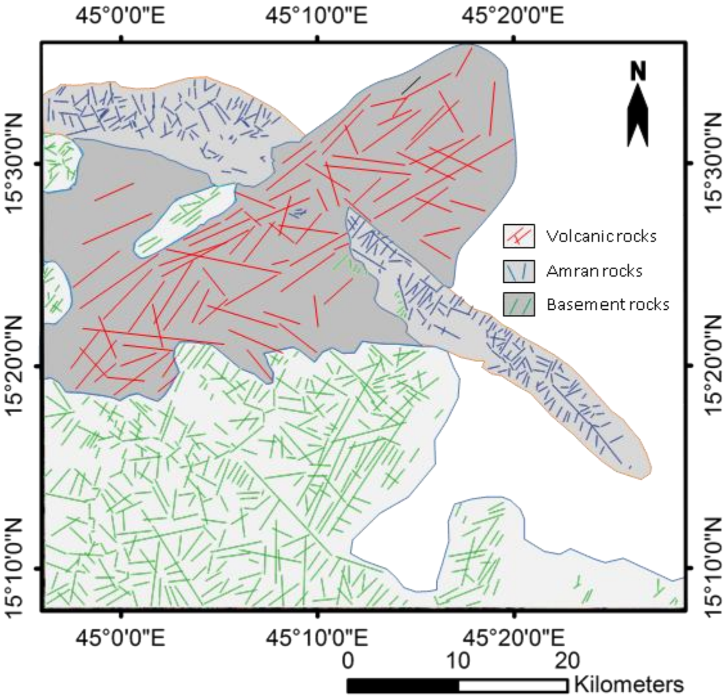

Fig. 9: Lineaments of Marib area picked from Landsat image, red lines are lineaments in Quaternary volcanics field, green lines are lineaments in the basement rocks while blue lines are lineaments in Amran rocks.

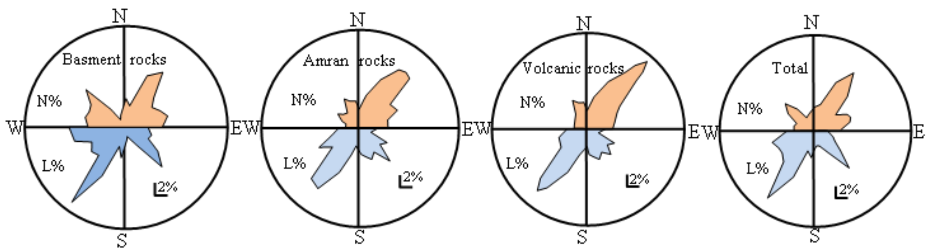

Fig. 10: Rose diagrams of the lineaments in the Marib area

Marib graben

The Marib Graben is a relatively narrow deeply subsided structure lying between the Gabal Hilan in the northwest and the Gabal Al-Balaq Ridge in southeast area bounded by normal faults trending NE-SW with down faulted blocks of Jurassic Amran limestone in between. It measures about 10 Km long and 6 Km wide (Figs. 11,12,13).

The graben is located in the northern part of the appareled shear zone effecting the basement rocks in a perpendicular direction to the Jawf rift of NW-SE trend in the North east Yemen. This graben is occupied completely by the Quaternary volcanics of Marib-Serwah field. Deep bounding faults and associated fractures played the main role as conduits (pass ways) for volcanic activity as control of fissure eruptions in the field.

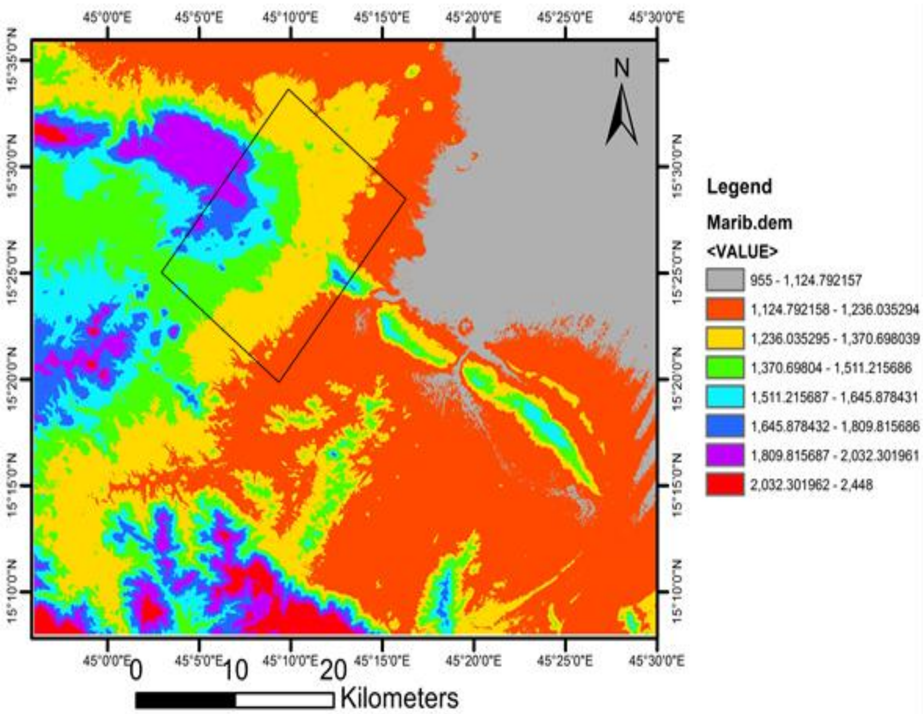

Fig. 11: DEM showing the topography of Marib area.

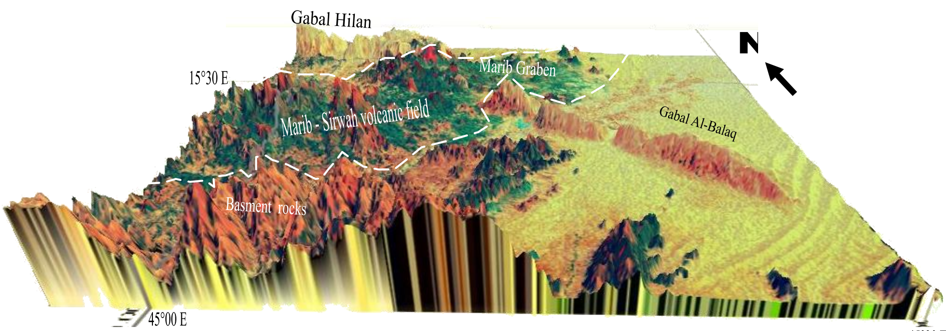

Fig. 12: 3D diagram showing the topography of graben between Gabal Al-Balaq and Gabal Hilan also shown are Marib-Serwah volcanic field.

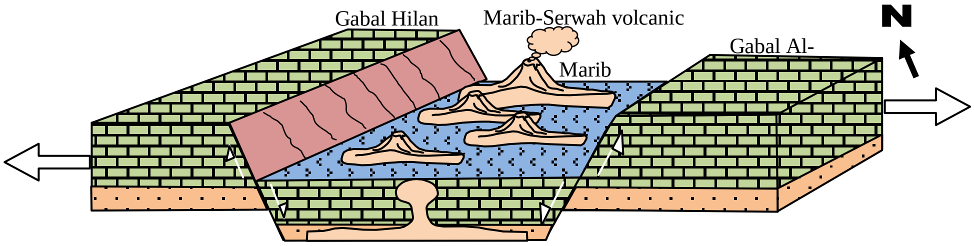

Fig. 13: Sketch showing the graben between Gabal Al-Balaq and Gabal Hilan also shown are Marib-Serwah volcanic field.

Geologic history

Through analysis of satellite images is clear that the study area was effected by different tectonic events experienced by successive geological periods beginning at the Precambrian to the Recent.

Three development stages could be recognized:

- Pre-configured graben
- Graben Configuration phase
- Graben post configuring stage

Pre-configured graben phase

This phase of an extended pre-Cambrian until the Jurassic and tectonic events which include effected the basement rocks shown in the southwestern part of the area well pronounced by in shear zones which trend northeast - southwest

Graben Configuration phase

This phase represented in extension trend northwest - southeast and shows clearly in the Amran group rock. This has resulted to the extension the high and low parts of the Amran group rock.

Graben post configuring phase

This is the most important stages where the initiation of the latest Marib - Serwah volcanic field. It is most probably related to the phases of the Red Sea - Gulf of Aden openining, which led to the configured fissures and faults parallel to the extension of volcanic field and trend northeast - southwest and these fissures formed in the body graben got development of

these fissures which led to the weakness of the Earth's crust and thus allowed extrusion of basaltic lava which flowed to long distances. has got the beginning of lava out in the last million years of the Quaternary [25] was the beginning of the volcanic activity in the south-western part of the volcanic field.

It is noticeable that the volcanic activity in this field passed several periods of activity and quiet.

CONCLUSIONS

In the present work, the lithologic, structural discrimination and lineament analysis of digital data of Landsat Enhanced Thematic Mapper Plus (ETM+7) data have substantially improved visual interpretation for detailed mapping of the area around Marib area, Yemen.

The main image analysis techniques involved in this study were false color composite (FCC), principal component analysis (PCA) and band ratioing.

The exposed Precambrian basement rocks are migmatites, schist, paragneisses, marble, metadolomite and graphite schist. The Jurassic Amran limestones constitute two elongate ridges lying in the eastern and the northern parts of the study area and comprise sandy limestone, fossiliferrous limestone, marly limestone, chalky limestone and stromatolitic limestone of Gabal El-Balaq and Gabal Hilan, Marib.

The central part of the study area is covered mainly by basalts volcanic rocks and extensive welded tuff units predominate while andesites and rhyodacites are far less abundant.

The area is dissected by a series of extensional high angle normal faults which are wholly pertaining to brittle deformation and entirely postdating the deposition of the Amran Limestone delineating El Jawf rift of NW-SE. A younger faulting period strike ENE-WSW formed the new transverse Marib graben. The bounding faults might act as feeders along which the Marib – Sirwah volcanics were explosively erupted.

The structural lineament analyses confirms the structural control of the major fracture system and the volcanic activity of Marib - Sirwah volcanic field. The NE-SW trend is an inherited predominant regional structural lineament trend from the basement structural grain.

It can be concluded that the main extensional tectonic forces affecting the study area had the NW-SW direction, which probably caused Marib graben which caused the formation the Marib - Sirwah volcanic field.

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استخدام بيانات الاستشعار عن بعد لتحديد التحكم التركيبي لحقل مأرب – صرواح البركاني المتكون في إخدود مأرب – اليمن

فـؤاد بجــاش

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تم تطبيق تقنيات الاستشعار عن بعد مع النموذج الرقمي للاتفاعات (DEM) لتحديد الملامح الصخرية والظواهر التركيبية للمنطقة المحيطة بمدينة مأرب، اليمن. وقد تم استخدام صور وبيانات الاقمار الصاعية المحسنة (ETM + 7) لتحديد حقل مأرب – صرواح البركاني في اخدود مأرب.

أظهرت النتائج أن منطقة مأرب تغطيها ثلاثة أنواع الصخور المختلفة التكوين والأعمار: صخور القاعدة المتكونة في عصر ما قبل الكامبري ومجموعة عمران المتكونة في عصر الجوراسي والصخور البركانية المتكونة في العصر الرباعي.

وقد تم تحليل التراكيب الخطية لمنطقة مأرب وتم تقسيمهم حسب نوع الصخور ووجد أن معظم التراكيب الخطية تكون ذات إتجاهين الإتجاه الاول شمال شرق – جنوب غرب وبينما الإتجاه الاخر شمال غرب – جنوب شرق

ويتكون حقل مأرب – صرواح البركاني في إخدود كبير وهذا الإخدود يقع بين جبل هيلان في الشمال الغربي وجبل البلق في جنوب شرق المنطقة.