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Analysis of Joints Trends in the area between Al-Rawnah and Al-Huriyah, Northwest of Taiz City, Yemen

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Abstract: This paper presents the results of systematic analysis of joints trends in the rock masses exposed in the stretch between Al-Rawnah and Al-Huriyah areas, northwest of Taiz city, Yemen, using Fabric-8 software technique. From the field investigations and structural relations between the various lithounits, the exposed rock masses in the study area are classified into four litho-tectonic units viz., from bottom to the top:1) basement rocks, 2) Amran limestone rocks, 3) Al-Tawillah sandstone rocks and 4) volcanic rocks. Results of the study indicate that the rock units of the study area are cut and deformed by NNW-SSE, NE-SW, WNW-ESE, N-S, and E-W trending joints. NNW-SSE and NE-SW trends are the most predominant trends influencing the rock units of the study area. The dominant and major NNW-SSE trend correlates to the direction of the maximum extensional stress associated with the Red Sea rift system, while the second one (NE-SW) is perturbed regional stress field related to the direction of the stress generated during the opening of the Gulf of Aden. The basement rocks are commonly affected by both vertical and conjugate joints. The conjugate joints are represented by X and Y types, although T and H types were also recognized. Amran limestone rocks are affected by subvertical joints in addition to asymmetric with symmetric joints of veins filled by calcite minerals. Orthogonal cross joins, conjugate joints, polygonal joints and exfoliation joints were documented in Al-Tawillah sandstone rocks. Columnar jointing, plumose structures, horsetail fractures, kink joints and exfoliation joints are commonly observed in the volcanic rocks. This study indicates that the fracture spacing, orientation and thickness of the rock mass and patterns of fractures are controlled by lithology and structural evolution of the study area.

Keywords: Joint types, Fabric-8 software technique, Taiz city, Rose diagram.

INTRODUCTION

Jointing is a major deformation process in a rock body, variously occurring in all rock types and tectonic settings. Joints are fracture surfaces across which the material has lost cohesion and no appreciable movement has occurred [1, 2]. Joints and other fractures represent brittle failure that forms in response to an applied stress, often of tectonic origin [3-7]. Fracture sets provide information on the full stress orientation. Conjugate fracture sets provide information on the full stress orientation. However, extensional fractures form perpendicular to the minimum principal stress ($\sigma3$). Such fractures, therefore, do not provide information on the orientations of the intermediate ($\sigma2$) and maximum ($\sigma1$) compressive stress [4].

Joint sets are characterized by consistency of orientation over wide areas. As a result, they have been extensively used to map regional stress trajectories [8, 3, 4, 9-16]. The objectives of the present study are: (1) identification and delineation of the main lithologic units, (2) description of the joint patterns in the investigated area and (3) interpretation of the development of the joints trends.

STUDY AREA

The study area is about 30 Km to the northwest of Taiz city in the southwestern part of Yemen (Fig-1). Topographically, the study area is well represented by high mountains, steep slopes, flat low lands and undulating eroded lands with major Wadis. Elevations of the geomorphic units reaches up to 2550 meters above mean sea level. Morphologically, Wadis vary from steep narrow in the foothills to wide gently sloping in flat low lands. They are mostly rectilinear reflecting prominent structural control, developed on structural lines (joints and faults) traced in the studied area.

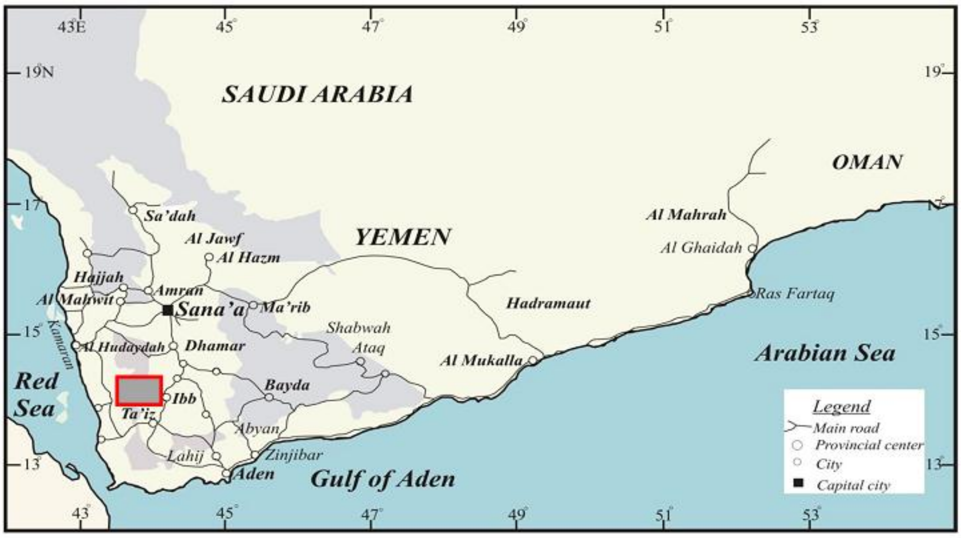

Fig-1: Republic of Yemen map showing the study area (small red rectangle)

Geologically, the area between Al-Rawnah and Al-Huriyah is covered with diversified rocks

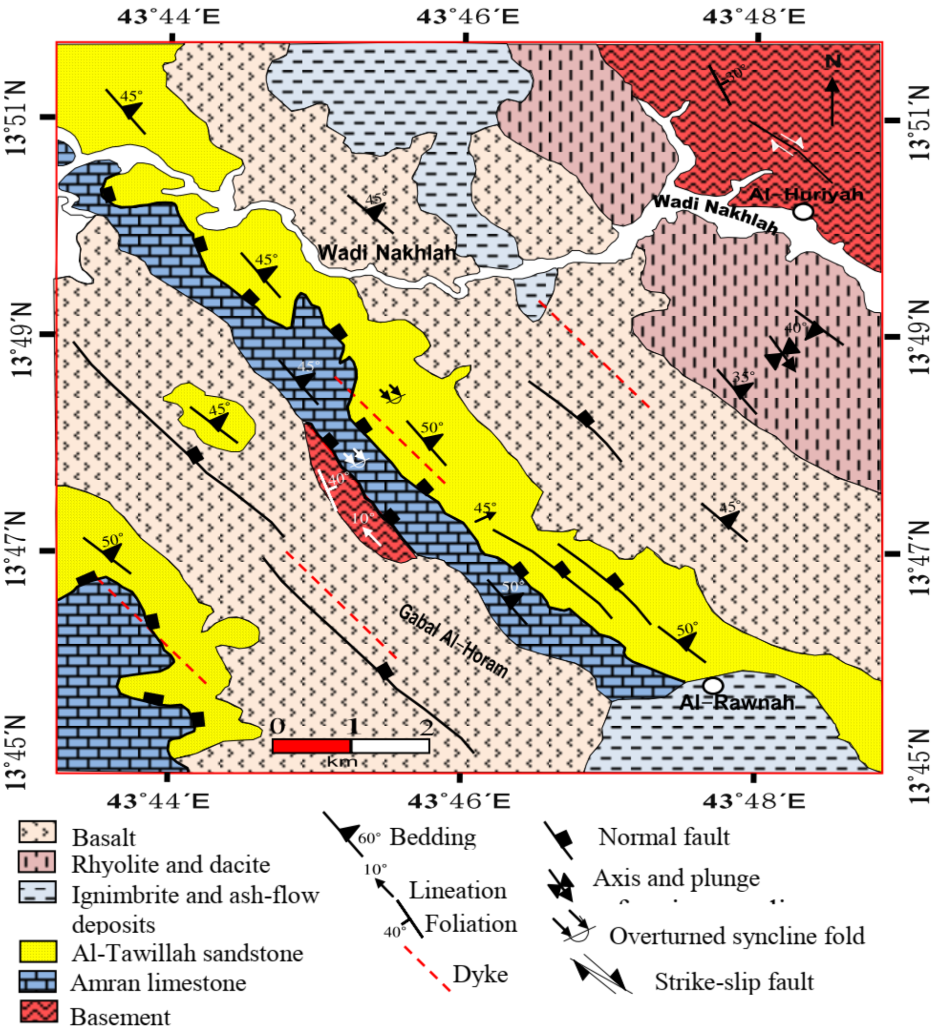

Fig-2: Geological map of the study area (modified after Robertson, 1992) [21].

RESULTS

During field geological mapping involving lithology, collection of samples and joint studies, four main litho-tectonic units were identified and mapped (Fig-2). They are from bottom upwards 1) Precambrian basement rocks, Mesozoic sedimentary formations represented by 2) Amran limestones and 3) Al-Tawillah sandstones. The top most lithounits are volcanic rocks of Tertiary age. The lithostratigraphy of the above mentioned sequence in the area between Al-Rawnah and Al-Huriyah is furnished in Table-1.

Table-1: Compiled tectono-stratigraphic sequence in the study area

AGE	GROUP	LITHOSTRATIGRAPHY
Tertiary	Volcanic rocks	Basalt Rhyolite and dacite Ignimbrite and ash-flow deposits
Cretaceous	Al-Tawillah sandstone	Sandstone
Jurassic	Amran limestone	Limestone
Precambrian	Basement	Gneisses, migmatites, granitic gneisses and amphibolites

Basement Rocks

Precambrian crystalline basement rocks outcrop in the northeastern corner and central part of the mapped area. In both the locations, the basement rocks contain banded gneisses, granitic gneisses, migmatites and amphibolites. The base of this unit is not recognized (Fig-3a). The Precambrian rocks are unconformably overlain by Phanerozoic platformal sedimentary rocks comprising Jurassic limestone, Cretaceous sandstone, Tertiary Yemen Volcanics and recent sediments [17]. Some xenoliths are highly elongated or ovoidal in shape and enclosed in Precambrian crystalline basement rocks. Migmatites occur in various shapes, associated with granite gneiss and amphibolites. Most migmatites seen in the field are stromatic migmatites, characterized by leucosome (Fig-3b) which may have been produced by partial melting and local melt segregation along the foliation. The migmatites vary from pods or bands that are elongated parallel to the regional foliation of the rock.

Structurally, the basement rocks are bounded by two normal faults dipping 20° to 40° to the northeast. Fracturing is well developed in the basement rocks and this together with the lithological heterogeneities, produced easily eroded weak zones in the basement rocks. They are mildly to strongly sheared, folded, showing well foliation and lineation. These shear zones are oriented along in NW-SE direction (Fig-3c).

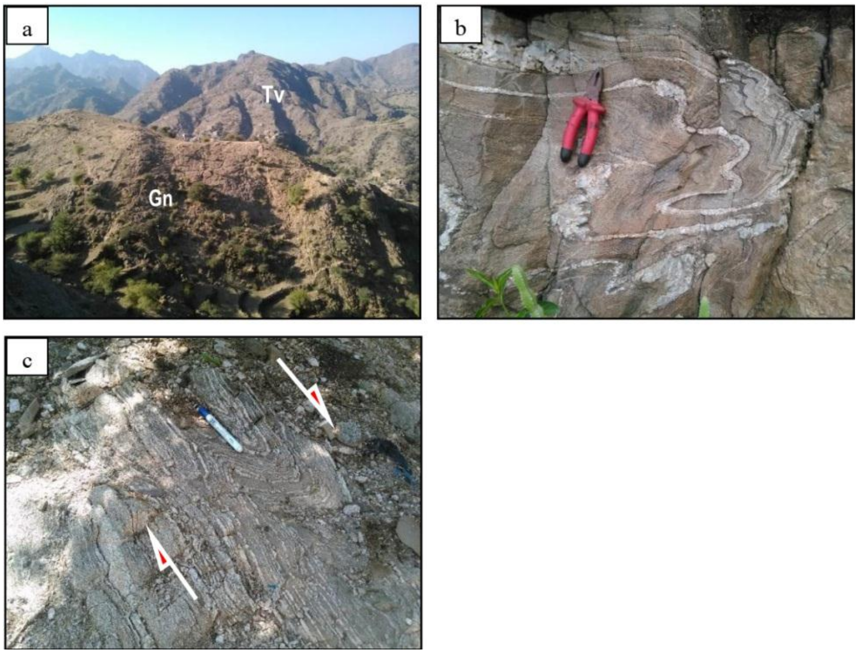

Fig-3: (a) Field photographs showing gneissose rocks (Gn) (lower part of the photo), unconformably overlain by Tertiary volcanic rocks (Tv) (upper part of the photo) (b), stromatic migmatites consisting of thin light colored leucosomes alternating with thicker dark color melanosomes rich in ferroma-gmesian minerals (c), Z-fold formed during progressive shearing and displaying right-lateral shear sense of movement in mylonite rocks

The most common rock types constituted of shear zones are represented by different varieties of the ductile and few brittle fault rocks. The ductile varieties include protomylonite, mylonite, ultramylonite, and minor phyllonite and striped granitic gneisses and migmatites, while the brittle rock varieties are comprised of cohesive cataclasites and cohesive breccias.

Amran Limestone

The Amran limestone is encountered in the central part of the studied area. The beds extend in NW-SE direction. Another small outcrop of limestone is seen in the southwestern corner of the mapped area (Fig-2). Amran limestone is mainly composed of fine- to coarse-crystalline limestone interbedded with dolomite, shale and marl with gypsum in the lower part. Some limestone is cataclasite and consists of angular to rounded, variably sized fragments of calcite, quartz and dolomite. It is compact and dark grey to light brown in color. Texturally, it is generally homogeneous.

The limestone in the study area is bounded by Tertiary volcanics and partly basement rocks, and Al-Tawillah sandstone rocks from the southwest and northeast respectively. It rests unconformtably over the Precambrian basement outcrops and structurally underlain by Al-Tawillah sandstone. The contact between them is sharp and deformed (Fig-4a).

Structurally, minor folds and faults have locally developed in the limestone rocks (Fig-4b). They are extensively fractured and cut by numerous basic and acidic dykes which are probably responsible for marblization. The trends of these dykes are mainly along N-S and NNW-SSE directions. The top of the limestone section is characterized by silicified stromatolitic limestone beds (Fig-4c). The silicified stromatolitic limestone beds trend in NW-SE direction and dip towards NE at low to moderate angles. Limestone blocks are also recorded as grey alternated beds attaining a total thickness of about 260m.

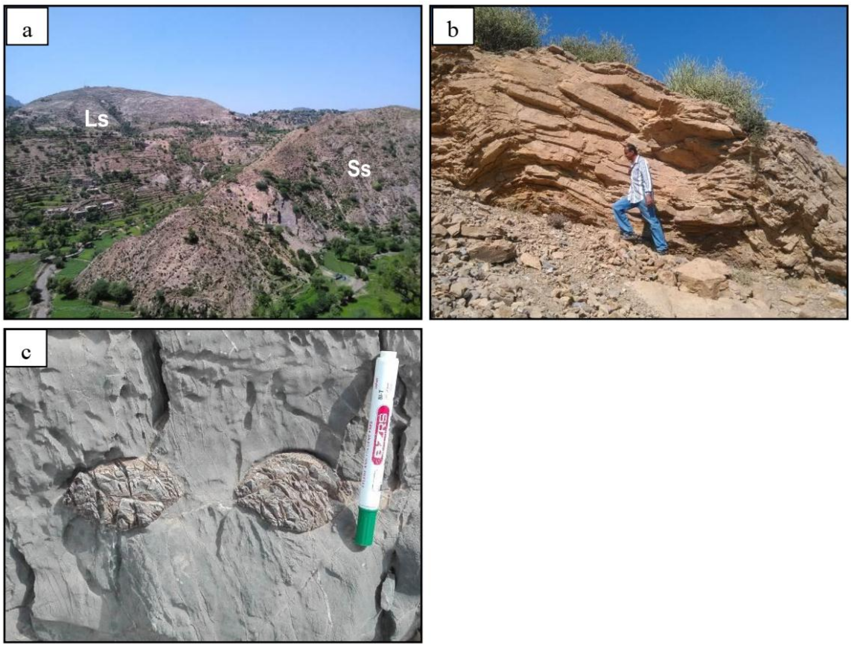

Fig-4: Field photographs showing (a) contact between Amran limestone (Ls) and Al-Tawillah sandstone (Ss), (b) minor folds in Amran limestone rocks, (c) silicified stromatolitic carbonate oncoids in Amran limestone rocks

Al-Tawillah Sandstone

Al-Tawillah sandstone rocks in the study area are exposed along middle zone extending from the northwest to southeast as well as in the southwest of the mapped area (see Fig-2). Small sandstone rock masses with *oval-like shape* are intruded into Tertiary volcanic rocks. Thickness of these rocks in the investigated exposures varies from less than 120m to over 200 m.

Al-Tawillah rocks are mainly composed of white to light grey coloured very fine to coarse grained sandstone. The degree of grains sorting of sandstone varies from poorly to well sorted. It is moderately to well sorted in the upper parts, whereas is moderately to poorly sorted in the middle and lower parts. The degree of roundness of the sand grains ranges from angular to subrounded.

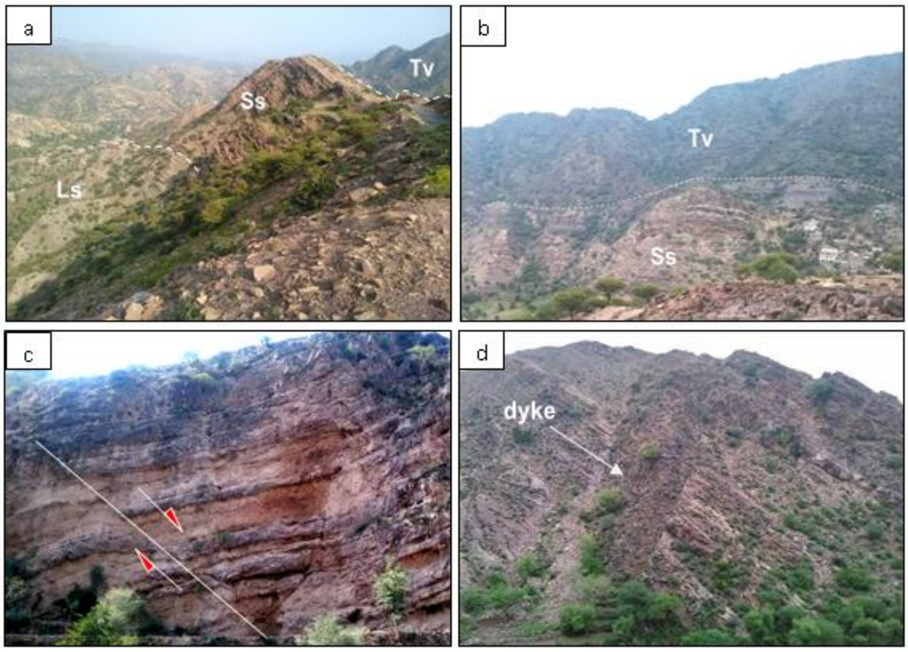

Fig-5: Field photographs showing; (a) Al-Tawillah sandstones (Ss) directly overlying the Amran limestone (Ls), which in turn is overlain by Tertiary volcanic rocks (Tv), (b) sharp and irregular contact between Al-Tawillah sandstone rocks (Ss), unconformably overlaid Tertiary volcanic rocks (Tv), (c) normal fault in sandstones rocks with a displacement of 30 m, (d) thick basic dyke in sandstone rocks; the dyke is about 13 m wide. Note the contacts of the dyke are sharp.

Al-Tawillah sandstone is frequently observed lying unconformably above the Amran limestone and overlain by the Tertiary volcanic rocks (Fig-5a). The unconformity is marked by a conglomerate bed, while in other locations, the contacts between Al-Tawillah sandstone and Amran limestone are sharp and irregular (Fig-5b).

Structurally, the Al-Tawillah sandstone rocks are generally striking NW-SE and gently dip to the northeast. Most sandstone rocks are traversed by several NNW-SSE-oriented normal faults set which seems to be genetically and kinematically related to the Red Sea rifting system (Fig-5c). They are also invaded by volcanic dykes and sills impressed in the sandstone strata up to 12 m thick. These dykes and sills are more resistant to weathering and erosion than the surrounding country rocks; so lithological ridges several maters in height are formed (Fig-5d).

Tertiary Volcanic Rocks

In the study area, the Cenozoic volcanic rocks and deposits have a greatest areal extent in comparison to all other units with an areal extent of 70% of total area. They occur as elongated outcrops extending from the northwest to southeastern parts of the mapped area (Fig-2). The Cenozoic volcanics are represented by alternating sequences of volcanic lava flows and volcaniclastic deposits of varying composition from mafic to acidic types (bimodal volcanic rocks). The volcanic rocks and deposits cover the Amran limestone and have an irregular sharp contact (Fig-6a).

Based on the field work, three main horizons of volcanic rocks and deposits were distinguished. These are:

- Ignimbrite and ash-flow deposits,
- Rhyolite and dacite, and
- Basalt

Ignimbrite and ash-flow deposits are of limited occurrence in the studied area. Two exposures of these deposits were observed and studied. The ignimbrite and ash-flow deposits in the first exposure (south of the mapped area) appears as half circular-like mass, while in the second one (north of the mapped area) these deposits are found as funnel- like body (Fig-2). These deposits are characterized by grey to violet colors and attain a thickness of over hundreds of meters.

The rhyolite and dacite rocks are not common compared with the other volcanic units. The rocks are covered by Precambrian crystalline basement rocks in the northeast and by basalt from the other sides. They occur as elongated mass body extending from the northeast to eastern part of the mapped area (Fig-2). This body with a moderate relief, varies in width from 2 to 4 km with an average length of about 8 km.

Basalt rock masses cover most part of the study area. They are predominantly represented by basalt lava flows and basaltic tuffs as well as pyroclastic flows with vari-colored and mafic/acidic composition. The basalt lava flows and basaltic tuffs are commonly found layered, topographically forming terrains of high relief relatively.

Texturally, the basalt flows consist of different varieties, fine grained, porphyritic, nonporphyritic, locally containing vesicles and amygdules (Fig-6b). The observed basalt fragments are generally varied in colors from dark brown in fresh rock surface to brownish colour on the weathered surface. The round spots or elongated fragments are commonly occur within the flows; however, large, sheet-like fragments are occasionally observed. Tuff sheets were observed at different levels within silicic volcanic rocks. Structurally, almost all the pervious volcanic rock units are affected by major NW and NNW trending faults.

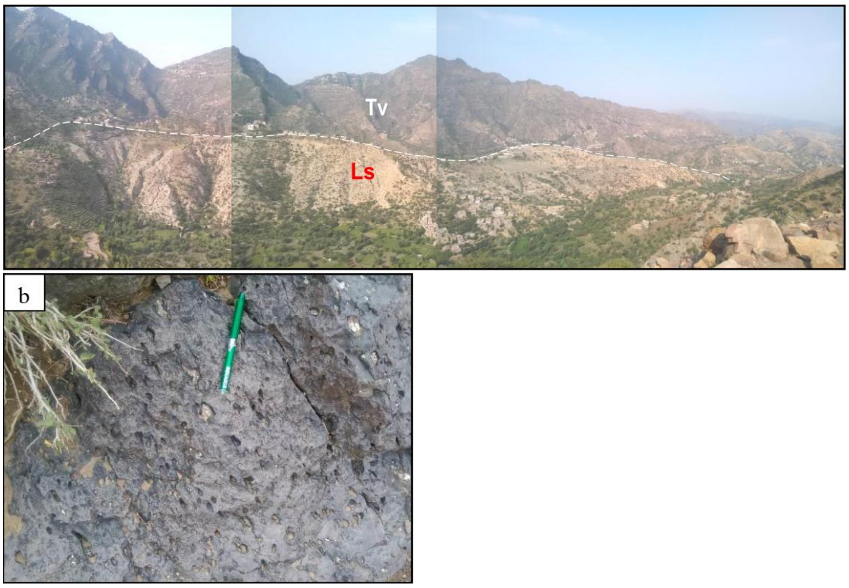

Fig-6: Field photographs showing; (a) Tertiary volcanic rocks (Tv) resting over Jurassic limestone rocks (Ls), (b) vesicles and amygdules in basaltic rocks

JOINTS IN THE STUDY AREA

Joints are very common secondary planar structures in the study area. A total of 1470 joints developed in relatively less weathered 114 diverse rock outcrops were documented. The recorded joints are statistically treated and structurally analyzed. Accordingly, the study area was subdivided into four domains as follows:

Joints in Basement Units

In the study area, the basement rocks are strongly fractured by joints which range in size from small to large with gaps and deeply eroded and crushed walls. Small-scale joints are more abundant. A total of 371 joints were recorded on the outcrops of basement units. On these outcrops, the following characteristics of joints were observed: 1) both vertical (Fig-7a) and conjugate joints (Fig-7b) are widespread with steep to orthogonal dip and extend to a great depths through the rock mass, 2) the angles between the two main joint sets are variable in different outcrops but generally less than 60º, 3) the conjugate joint patterns in the studied rock outcrops are represented mainly by the X and Y types; however, T and H types were also recognized (Fig-7c), 4) the most common joints show NE-SW and NNW-SSE trends; however, some joints also exhibit other intermediate trends, 5) the joints are characterized by smooth and planar surfaces; however, a few striated surfaces of joints were observed which may have developed due to later movement along the joints. The spacings of joints are commonly between 0.01cm and 0.5 cm; but may also reach 2 m, depending on thickness of the bed. Most of the measured joints in these rocks have gaps/aperture varying in width from 0.7 cm to about 10 cm.

Joints in Limestone Units

Based on field investigations and analysis of 311 joints in limestone rock units, the following salient features of joints and their characteristics were made out: 1) Limestone rock units are dissected by joints of all scales; large-scale joints with low frequencies are the prevalent ones, 2) Two joint sets approximately parallel and perpendicular to the bedding direction are recognized; however, the subvertical joints which are grouped in several sets (Fig-8a) and asymmetric joints (Fig-8b) were also observed, 3) The strike directions of prevalent joint sets are predominately in NNE-SSW, NW-SE, N-S and E-W directions, which correspond to the strike directions of regional structures or faults, and 4) The joints are characterized by smooth and planar surfaces; the spacing typically range from 10 cm to 1 m with gaping spaces ranging from 1 to 8 cm apart. In some locations, joints show several opening phases with symmetric veins filled with calcite minerals (Fig-8c). The maximum values of opening reach up to 1 m in the NW–SE trending joint set.

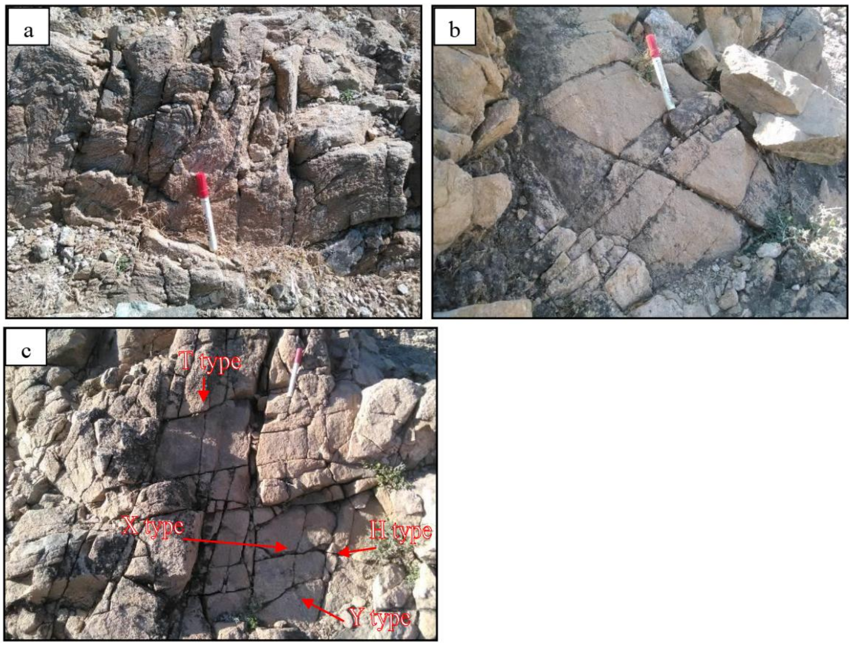

Fig-7: Field photographs of the gneiss rocks outcrops showing: (a) Well developed vertical systematic joints; (b) Two (orthogonal joint) sets of conjugate systematic joints intersect at an angle of 80°; (c) X, Y, T and H types

Sandstone rocks are strongly affected by systematic and non-systematic joints in different directions. A total 392 joints are measured and recorded in the field which were later statistically treated and structurally analyzed. The studies established NNW-SSE, NE-SW, N-S and E-W trending directions for the prevailing joint sets. Of them, two joint sets are trending parallel and perpendicular to the bedding planes. They form the master joint set which are characterized by a linear fracture traces with lengths of several meters. Spacings range from 2 to 14 cm and the joint openings are sometimes filled by mineralized veins or dykes. The acute angle enclosed by the two subsets is between a few degrees and 75º, with an average of 40º, and the acute bisector is normal to bedding. Orthogonal cross joins extend across intervals between systematic joins in brittle sedimentary strata and abut the systematic joints at about 90º angles (Fig-9a). The conjugate joints are also recorded in the sandstone rocks. These joints are completely vertical and the dihedral angle between the two sets is about 80º. Hancock [4] concluded that when the dihedral angle between two sets of joints, ranges from 10º to 50º the system is termed conjugate hybrid joints, while conjugate shear joints enclose angles of 60º or greater. Accordingly, the conjugate joints in sandstone units of the study area are can be considered as conjugate shear joints. Polygonal joints pre-date the joint arrays, and appear to have been filled by veins before the arrays formed. They cut the bed into polygons, commonly over 0.5 m diameter (Fig-9b).

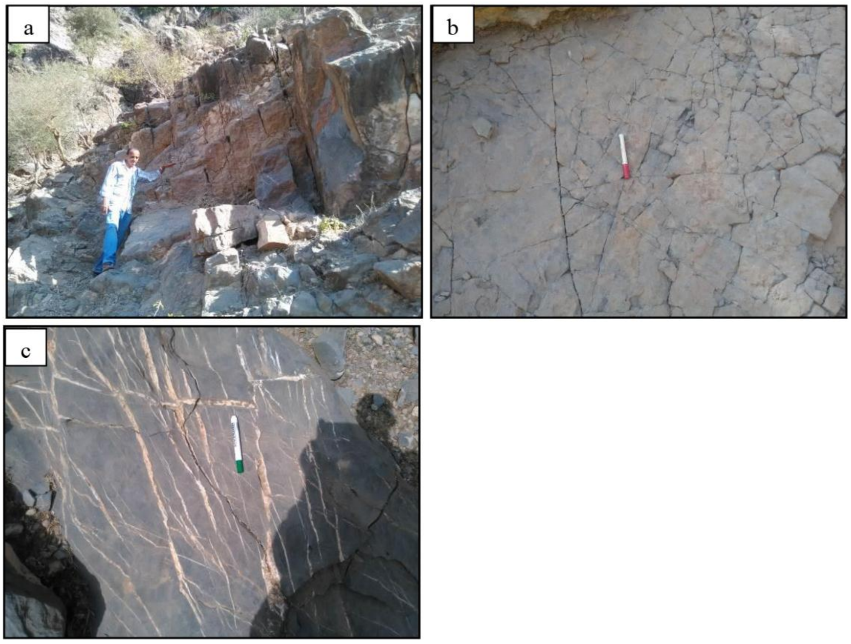

Fig-8: Field Photographs of limestone rocks showing; (a) vertical systematic joints, (b) conjugate joints, (c) parallel and conjugate k- calcite veins

The sandstone rocks are intensively weathered, usually form high-lying lands and are characterized by the development of exfoliation features (Fig-9c). Dome exfoliation fractures are inferred to form under unloading conditions, and they differ from joints that are associated with burial or tectonic processes which generally occur under decreasing loading. Some joints with striated surfaces were observed.

Fig-9: Field photographs of Cretaceous sandstone outcrops showing; (a) orthogonal cross joins, (b) polygonal joints, (c) highly exfoliation fractures

Joints in Volcanic Rocks

Well developed joints were observed in the volcanic rocks of the study area and chosen 396 joints were measured on the outcrops. In some sites, well developed, systematic continuous, planar, parallel, evenly spaced NE-SW joint set accompanied by secondary (younger) NW-SW cross joints abutting the former (mean azimuths 60º-70ºand 330º-340º, respectively) were distinguished. Typically, they have lengths of several meters to tens of meters. Joint spacings are variable, although generally are between 2 and 7 m. The joints measured in this part range from small to large scales with gaping width ranging from 0.5 to 8 cm. The angle between the two joint sets that define the extremes of the joint spectrum ranges from 60 to 85º. In other sites, a primary (older) N-S set with E-W cross joints (mean azimuths 0º - 10º and 80º- 90º) were recognized. The columnar jointing structures known as colonnade and entablature are commonly observed in the study area (Fig-10a). Columnar jointing is clearly seen in the volcanic lavas resting on terrace deposits in the central part of the area. The jointed volcanic rocks are quarried for local building purposes.

The plumose markings, wherever observed, are always on the NW-SE trending cross joints; this trend is also the major trend of joints in the study area (Fig-10b). According to Pollard and Aydin [18], plumose markings always develop during Mode-I (extension) mode of fracturing and are oriented perpendicular to the direction of least principal stress σ_3.

Some NE-SW joints show change in their strike direction by an angle of about 60º (Fig-10c). This phenomenon is called kink because its trend is abruptly different from that of the joints. Cruikshank *et al*., [19] mentioned that the sense of kinking indicates the sense of shear during faulting: a kink that turns clockwise with respect to the direction of the main joint is the result of right-lateral shear and a kink that turns counter-clockwise is the result of left-lateral shear. Accordingly, the NE-SW kinked joints have obviously developed as a result of right-lateral shear (Fig-10c).

There are groups of semi-parallel fractures near the end of some joints which branch out from the joint something like the hairs in horses' tail (described along faulted joints in granite by Davies & Pollard [20]. In the study area, this type of fractures (horsetail) up to 1 meter long of many extension joints that trend in N60^{0}E was observed in volcanic rhyolite rocks (Fig-10d).

These rocks form a low-lying country and show well developed, weathered boulders and spheroidal exfoliation (Fig-10e). A few exfoliation joints occur parallel to each other on the outcrop. Each pair of the adjacent joints contains a rock `slice' between them which is sub-parallel to the outcrop.

Tectonic Trends

A close correlation is seen between the orientation of sets of joints and tectonic trends. Comparison of the frequency (rose) diagrams of the joints represented for the different rock units of the study area reveals the following (Table-2 and Fig-11):

- Basement rocks show joints trends along NNW-SSE, NW-SE and NNE-SSW directions.
- The recognized joints in the limestone rocks are of the NNW-SSE, NW-SE, N-S and E-W trends.
- The NNW-SSE, NW-SE, N-S and E-W joints sets have the most predominant trends in the sandstone rocks.
- The predominant oriented joints sets in the volcanic rocks have NNW-SSE and NW-SE trends.
- Majority of the sets of joints were found to follow the NNW-SSE, NW-SE, N-S and E-W trends

The study on the trends of sets of joints reveals the followings:

The NNW-SSE trend (Red Sea trend)

The NNW-SSE trend comes in the first order of the predominated tectonic trend among the fracture patterns in the studied area. It is strongly represented and recorded in all rock types of the investigated area. This trend is running nearly parallel to the general trend of the Red Sea. The Red Sea rift system formed due to horizontal compressive stress (nearly N20°W-S20°E) is considered one of the major breaks systems affecting the study area. This trend is commonly observed from Pre-Cambrian times and well developed during the Red Sea rifting.

The NE-SW trend (Gulf of Aden trend)

The NE-SW trend is strongly predominant among the total fractures in the studied area, especially in the basemen rocks and sandstone rocks. This trend coincides with the general trend of the Gulf of Aden trend and is attributed to the opening of the rift. It represents the second prevalent trend after the NNW-SSE trend.

The WNW-ESE trend

The WNW-ESE trend represents the most well pronounced direction in joints. It comes in the third order of predominance, especially in the basemen rocks. The WNW-ESE trend was created during the Precambrian age and reactivated in the subsequent times.

The N-S trend (East African trend)

This N-S trend has wide extension and is a predominant trend among the total joints in the studied area. Statistically, it comes in the fourth order of predominance and more pronounced in the limestone rocks.

The E-W trend is considered one of the main joints characterizing the Pre-Cambrian basement rocks and the limestone rocks. This trend comes in the fifth order among the investigated joints in the rocks of the study area.

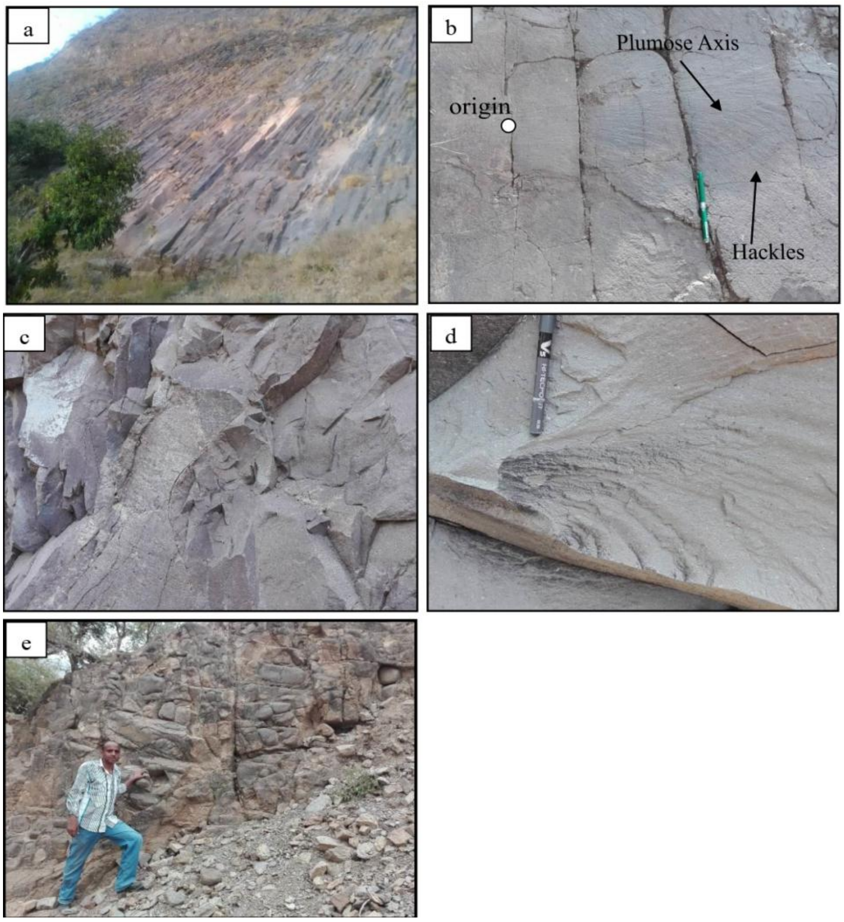

Fig-10: Field photographs showing; (a) colonnade columnar jointing in the basalts rocks, (b) plumose structures in the basalts rocks, (c) kink joint in rhyolite rocks, kink angle is 85º, (d) horsetail fractures at the end of the NE-SW joint in addition to horsetail fractures terminate within the NW-SE joint in rhyolite rocks; (e) spheroidal and oval exfoliation

Table-2: Frequency distributions of joints in study area

	Azimuth Intervals	Basemen rocks		Limestone rocks		Sandstone rocks		Volcanics rocks		Total	
		N	N %	N	N %	N	N %	N	N %	N	N %
NE/SW	00:10	15	4.043	7	2.250	12	3.061	8	2.020	42	2.857
	>10:20	10	2.695	16	5.144	16	4.081	13	3.282	55	3.741
	>20:30	12	3.234	11	3.536	15	3.826	7	1.767	45	3.061
	>30:40	19	5.121	23	7.395	25	6.377	20	5.050	87	5.918
	>40:50	16	4.312	24	7.717	42	10.714	25	6.313	107	7.278
	>50:60	37	9.973	28	9.003	38	9.693	34	8.585	137	9.319
	>60:70	45	12.129	24	7.717	12	3.061	48	12.121	129	8.775
	>70:80	11	2.964	6	1.929	18	4.591	13	3.282	48	3.265
	>80:90	15	4.043	12	3.858	9	2.295	12	3.030	48	3.265
NW/SE	00:10	15	4.043	9	2.893	9	2.295	8	2.020	41	2.789
	>10:20	12	3.234	13	4.180	18	4.591	11	2.777	54	3.673
	>20:30	30	8.086	31	9.967	41	10.459	54	13.636	156	10.612
	>30:40	42	11.320	29	9.324	38	9.693	43	10.858	152	10.340
	>40:50	16	4.312	20	6.430	30	7.653	36	9.090	102	6.938
	>50:60	30	8.086	19	6.109	20	5.102	26	6.565	95	6.462
	>60:70	23	6.199	15	4.823	17	4.336	19	4.797	74	5.034
	>70:80	15	4.043	13	4.180	18	4.591	11	2.777	57	3.877
	>80:90	8	2.156	11	3.536	14	3.571	8	2.020	41	2.789
Sum.		**371**	**100**	**311**	**100**	**392**	**100**	**396**	**100**	**1470**	**100**

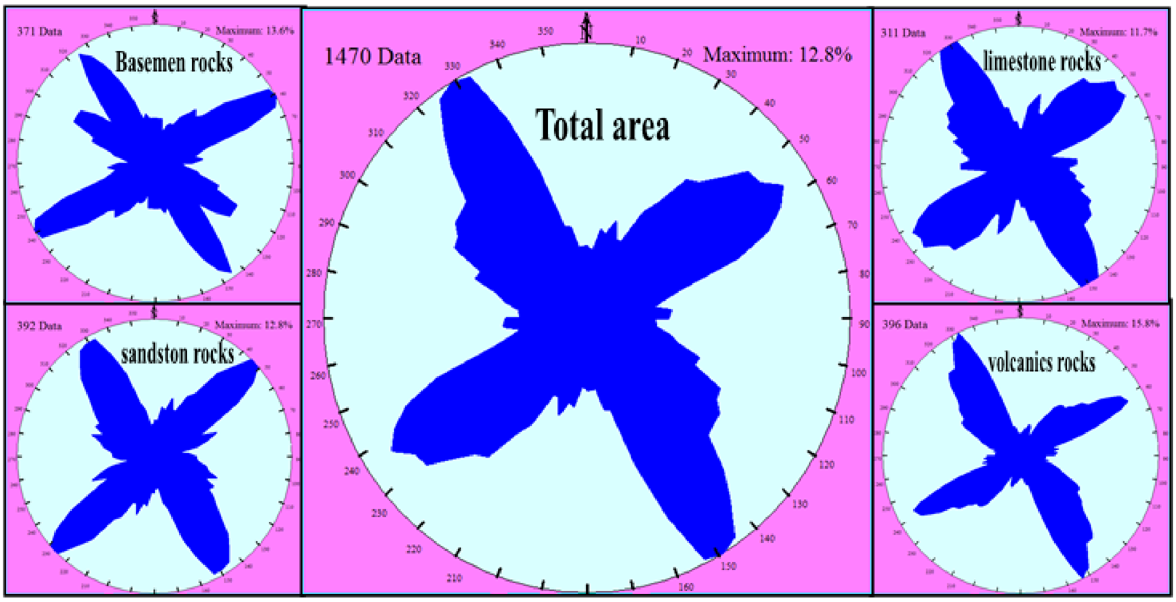

Fig-11: Rose diagram of number of joint affecting the rock exposures in the four rocks units and total of the study area

CONCLUSIONS

In the present study, the detailed field investigations of the area between Al-Rawnah and Al-Huriyah, northwest of Taiz city in Yemen, were carried out. A total of 114 high-quality rock outcrops were selected to be representative for different rock units. Exposed rock masses in the study area were classified into four litho-tectonic units based on the field investigations and the study on the structural relations between the various lithounits. They are from bottom to the top:1) basement rocks, 2) Amran limestone rocks, 3) Al-Tawillah sandstone rocks, and 4) volcanic rocks. All these rock units are cut and deformed by numerous systematic and non-systematic joint sets. A total of 1470 joints were investigated and documented. These joints range from small- scale to large-scale with gaping spaces/apertures ranging from 0.7 to 10 cm apart. Joints were represented and analyzed using Fabric-8 software technique. Two prevalent cross cutting joints systems were recognized and they show NNW-SSE and NE-SW trends in addition to WNW-ESE, N-S and E-W trends. These trends are nearly congruent to the Red Sea trend and Gulf of Aden trend tectonics. In basement rocks, the vertical and conjugate joints are widespread. The conjugate joints are largely represented by X and Y types; however, T and H types were also recognized. The subvertical, asymmetric and symmetric joints were observed in Amran limestone rocks. The orthogonal cross joins, conjugate joints, polygonal joints and exfoliation joints are commonly observed in Al-Tawillah sandstone rocks, while the columnar jointing, horsetail fractures, plumose structures, kink joints and exfoliation joints are more frequently encountered in the volcanic rocks.

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