Bulletin of Pure and Applied Sciences.
Vol.38 F (Geology), No.1, 2019: P.65-79

Print version ISSN 0970 4639
Online version ISSN 2320 3234
DOI 10.5958/2320-3234.2019.00004.0

Available online at www.bpasjournals.com

Original Article

Analysis of Major Surface Structural Features in Marib Sector, Sab'atayn Basin, Yemen: Implications of Tectonic Evolution

Saleh A. Ghareb[1], Syed Ahmad Ali[2], Hamdi S. Aldharab[3], Javed Ikbal[4]*

Author's Affiliations:
[1,2,3,4]Department of Geology, Aligarh Muslim University, Aligarh, Uttar Pradesh 202002, India.

***Corresponding Author: Saleh A. Ghareb**, Department of Geology, Aligarh Muslim University, ligarh, Uttar Pradesh 202002, India.

E-mail: salehgh7586@gmail.com

(Received on 30.03.2019, **Accepted on 20.04.2019**)

ABSTRACT

This study includes major surface structural features in Marib Sector of Sab'atayn Basin. Detailed field investigations of the study area have revealed a tectonic setting characterized by faults, folds, joints, and dykes. Data of faults indicate that the study area has affected by the tectonics of Najd fault, the rift of the Gulf of Aden, and the rift of the Red Sea respectively. The folds in Al-Balaq area were formed as a result of local deformation which most probably has been occurred during the Jurassic time. In Ath Thaniyah area, folds were formed as a result of Pan-African tectonics in the study area. Folds in Jabal Al-Milh area have been developed locally due to salt tectonics; folds in this area were found upon the upturned flanks of the Nayfa Formation. Joints were found in two sets, first dominated set oriented to NW-SE whereas the second trend to ENE-WSW. Subordinate trends of joints are WNW-ESE and NNE-SSW. Dykes, in the area, are trending to ENE-WSW, parallel to the trend of the Gulf of Aden. Gulf of Aden has taken an old trend between Arabian Plate and Somalia Plate. The dykes are older than the Gulf of Aden trend which indicates that the Gulf of Aden developed along Precambrian weak zones between Arabian Plate and Somalia Plate.

KEYWORDS: Marib Sector,Sab'atayn Basin, Yemen.

INTRODUCTION

The area that forms the scope of this study lies in the Marib sector of Sab'atayn Basin (Figure 1). Marib sector is located to the west of the center of the Sab'atayn Basin. Sab'atayn Basin is divided into three geographic sectors, the Marib-Al-Jawf, the Shabwah, and the Hajar sector (Beydoun et al, 1996). This basin is an aborted Jurassic rift basin located in the southern part of the Arabian Peninsula (Redfern and Jones, 1995). Sab'atayn Basin formation was a consequence of an extensional phase related to the separation of India from Africa-Arabia (Ziegler, 2001).

Surface structural features which were found and analyzed are faults, folds, joints, and dykes. Faults were found in Al-Balaq, Al-Kanayis, Al-Alam, and AthThaniyah area. Folds also were found in Al-Balaq, Al-Alam, AthThaniyah, and Jabal Al-Milh area. Dykes present in Al-Aalam and Rwaik area. Minor joints were found in Al-Balaq, Al-Alam, and AthThaniyah area.Major joints were found in Rwaik and Al-Alamarea. The present study aimed to gain a full idea about tectonic evolution in Marib Sector of Sab'atayn Basin.

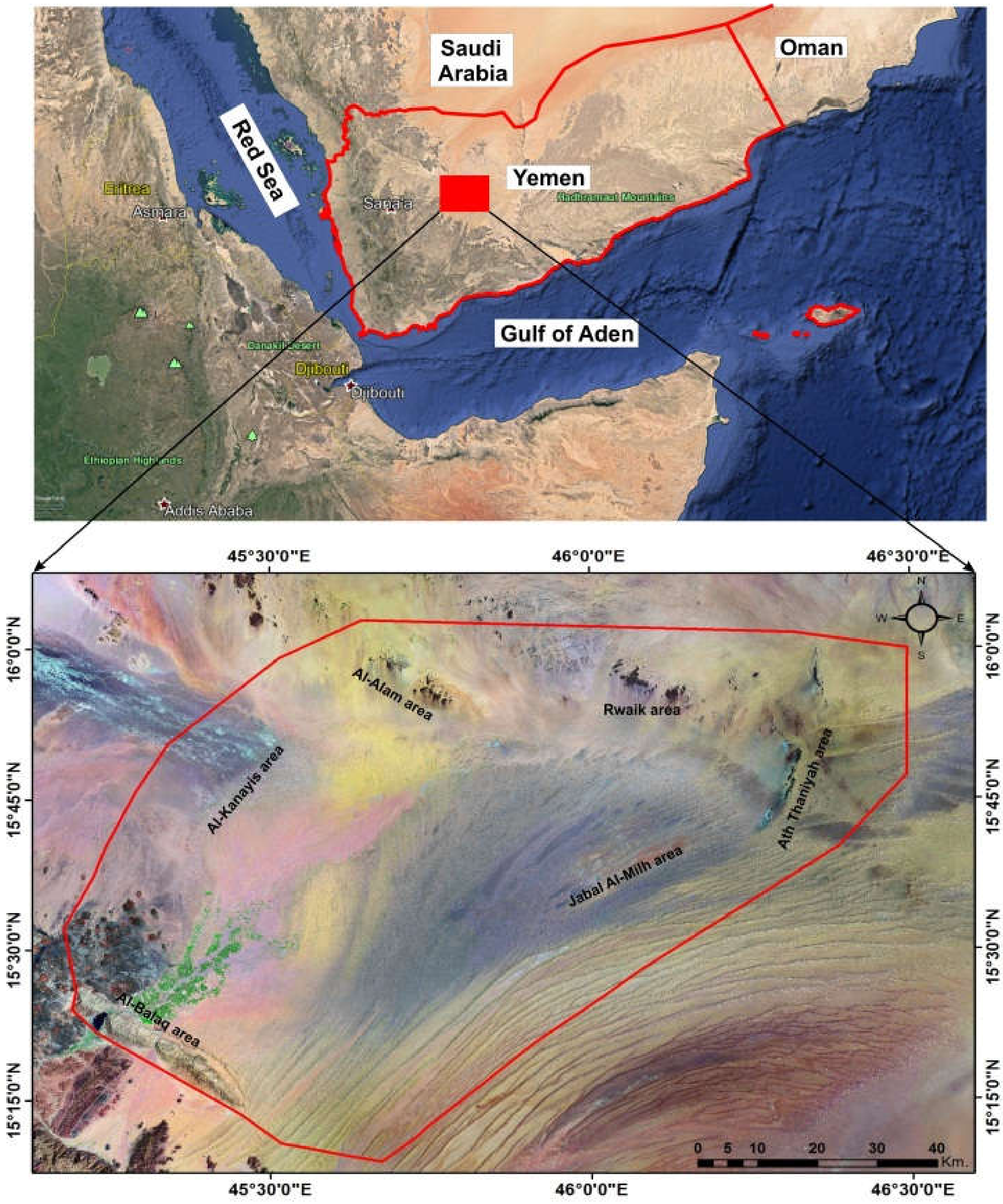


Figure 1: Showing location map of the study area

Geological setting: (Regional Setting and Geology)

The NW-trending Sab'atayn Basin (also called Marib-Shabwa-Hajar Basin) is a Mesozoic rift basin in the Arabian Peninsula that follows a deep-seated Proterozoic structural trend (Redfern and Jones, 1995). Basin formation was a consequence of an extensional phase related to the separation of India from Africa-Arabia (Redfern and Jones, 1995; Martin, 2001).

Pre-rift sediments are represented by Kuhlan Formation which is non-marine to shallow-marine clastic rocks (Sandstone) (Beydoun et al., 1998) overlain by shallow-marine carbonates (Shuqra Formation). The Shuqra Formation grades from massive limestone/lime mudstones, which are locally dolomitised and contain minor anhydrides, tolimestones and lime mudstones. According to Al-Wosabi and Wasel, (2011) the age of both formations is the latest Triassic to Middle Jurassic.

Madbi Formation has considered as syn-rift deposits because of variations of its thickness, it is in subsurface exceeding 4000 m in the study area whereas it is around 25 m in Al-Alam area and about of 350 m in Al-Balaq Al-Qibili and 120 m in Al-Balaq Assharqi. Madbi Formation subdivided into a lower Meem Member and an upper Lam Member (Beydoun et al., 1998). Madbi Formation mainly comprises of muddy limestones and chalks with shaly horizons (Sachsenhofer et al., 2012). An occasional rich, but low-diversity nannofossil/dinocyst assemblage supports a relatively deep, partly restricted environment (Brannan et al., 1999).

During late stages of the syn-rift phase, ocean circulation in the study area as well as in the Sab'atayn Basin became restricted, and an evaporitic succession represented the Sab'atayn Formation with an estimated original thickness of about 300 m was deposited (Seaborne, 1996). Sab'atayn Formation subdivided into four members from below to up Yah, Seen, Alif, and Safir Members. This formation is comprised of Massive halite occurs in the basin center, whereas anhydrite and clastic rocks prevail along the basin margins (Seaborne, 1996). Interbedded thin shales are rich in organic matter (Brannan et al., 1999). The present thickness of the Sab'atayn Formation is strongly controlled by salt tectonics.

Post-rift sediments in the study area represented by Tawilah Group. This group consist of cross-bedded, white, well sorted, fine to coarse grained fluvial sandstones with gravel and shale interbeds. It is unconformably covered by either Quaternary basalts or unconsolidated Quaternary alluvial or eolian deposits.

METHODOLOGY

During fieldwork, working has been held on four outcrops: Al-Balaq, Al-Alam, AthThaniyah, Rwaik, and Jabal Al-Milh area. All geometry of the structural features have been measured from north azimuth, also maps have been produced with tied to the north azimuth. Special distribution, orientation, and size of structural features were analyzed using Arc GIS 10.2, RockWorks 16, Global Mapper 18, Map Maker 15, AutoCAD 2018, GEOorient 9.2, Rose net, and Stereonet-7 software.

RESULT AND DISCUSSION

Faults:
Faults are any surfaces or narrow zones with visible shear displacement along the zone. A fault is a surface or narrow zone in the crust of the earth along which one side has moved related to the other in a direction parallel to the surface or zone. A fault is a term of shear features or zones that extend of meters or longer. In the study area faults were found in Al-Balaq area (Figure 2a), Al-Kanayis area (Figure 2b), Al-Alam area (Figure 2c), and AthThaniyah area (Figure 2e).Faults in Al-Balaq and Al-Alam area, are clearly visible as shown in (Figure 2a,b).

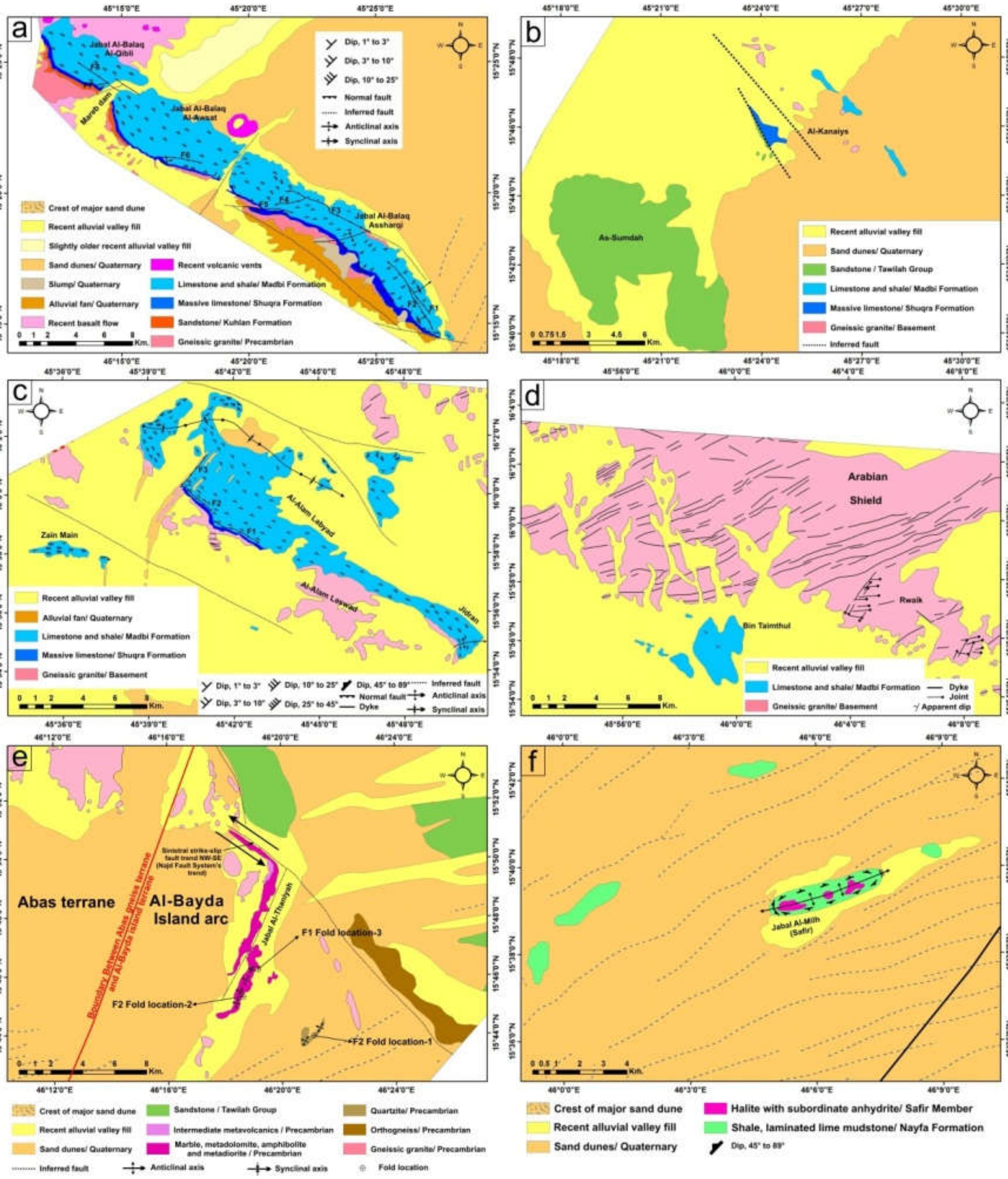


Figure 2: Geological and tectonic map of (a) Al-Balaq area, (b) Al-Kanayis area, (c) Al-Aalam area, (d) Rwaik area, (e) AthThaniyah area, and (f) Jabal Al-Milh area.

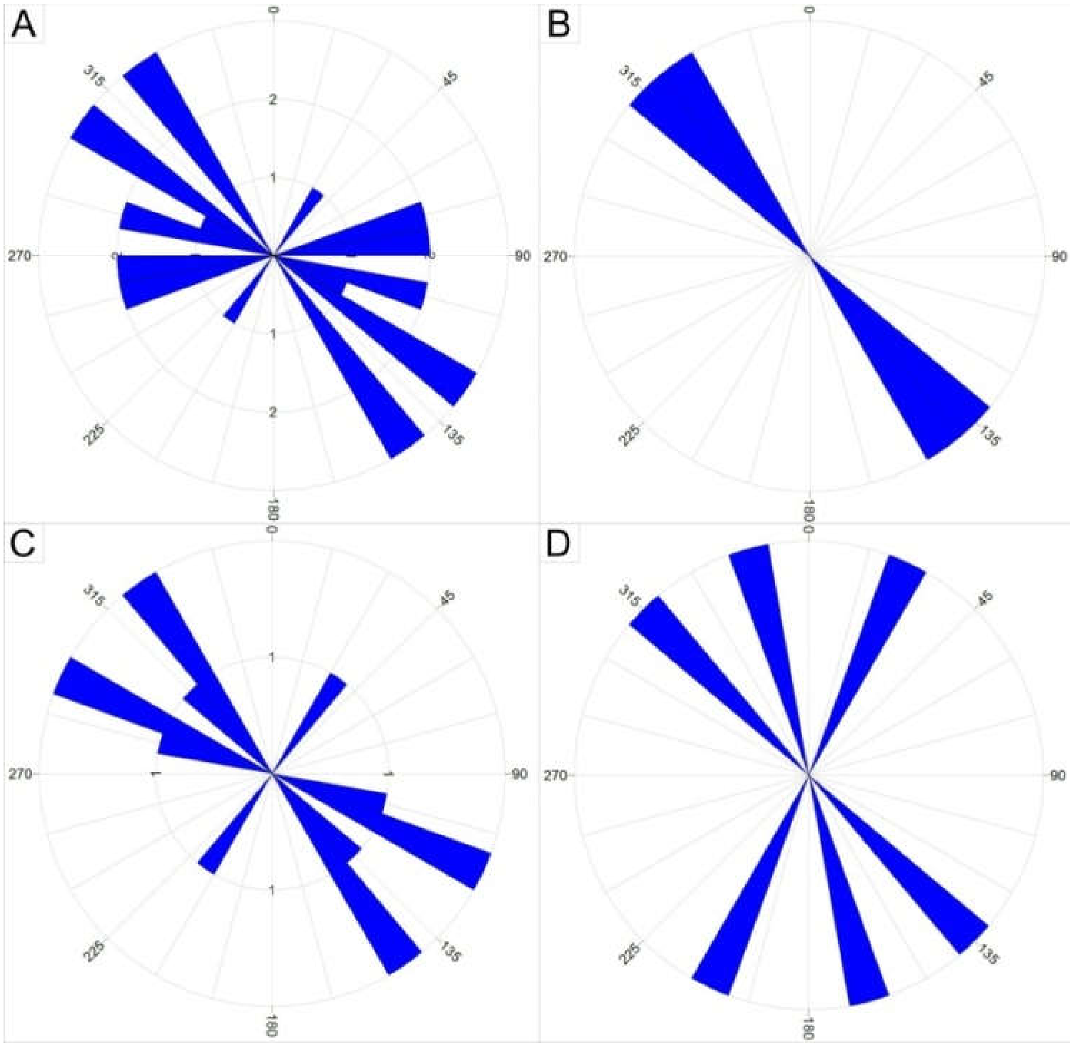


Figure 3: Showing rose diagram of (A) faults in Al-Balaq area, (B) faults in Al-Kanaiys area, (C) faults in Al-Alam area, and (D) faults in AthThaniyah area.

Geometric data of faults were collected to identify the orientation of these faults and correlated them with the tectonic events in the study area. The rose diagrams of faults in four locations in the study area show three trends with a subordinate trend to NE-SW direction (Figure 3). The NW-SE and/or WNW-ESE trends are following the Precambrian faults that called Najd Fault System in the area; the NW-SE trending of Najd Fault System has been changed to WNW-ESE trend due to the reactivation of Najd Fault System during the Jurassic time. The NE-SW trend is the direction of the rift of the Gulf of Aden whereas the NNW-SSE trend is the direction of the rift of the Red Sea.

Folds:
Folds were found in Al-Balaq, Al-Alam, AthThaniyah, and Jabal Al-Milh area. In Al-Balaq and Al-Alam areas, the folds in Amran Group (Shuqra and Madbi Formations). In these areas, the folds have formed as a result of local deformation in the area which most probably has been occurred during the Jurassic time. The orientation of axial plane of folds in Jabal Al-Balaq area is NE-SW which implies that the main compression was in the NW-SE direction (Figure 5 and 6).

AthThaniyah area has been mapped by Furgo, (2008) as part of Al-Bayda island arc (Figure 2e). Folds in AthThaniyah area were found in the metamorphic rock (Al-Thaniyah Group. / Basement). According to Heikal et al., (2014) the first phase of deformation, D1 of the basement rocks of Yemen, is considered to be pre-Pan-African (pre-thrust) and represented F1 folds in Al-Bayda island arc and second phase of deformation, D2, is related to thrust structures, which most probably occurred during early Pan- African and is dominated by compression, refolding (F2).The orientation of axial plane of F1 Folds ranging from N40ºE/S40ºW to N55ºE/S55ºW which implies that the main compression was in NW-SE. The orientation of axial plane of F2 folds ranging from N20ºW/S20ºE to N45ºW/S45ºE which implies that the main compression was in the NE-SW direction (Figure 7 and 8).

Folds in Jabal Al-Milh area have been developed locally due to salt tectonics. The folds in this area were found upon the upturned flanks of the Nayfa Formation. The folds upon the upturned flanks of the Safer Anticline have vertical and sub-vertical axes (Figure 4IV), plunging in all directions, this related to the tectonics of the salt. The direction of the axis of the Safer Anticline is parallel to the trend of the Gulf of Aden, this implies to that the salt diapir in Jabal Al-Milh area exposed on the surface through the weak zone which may be has caused by the tectonics of the Gulf of Aden.

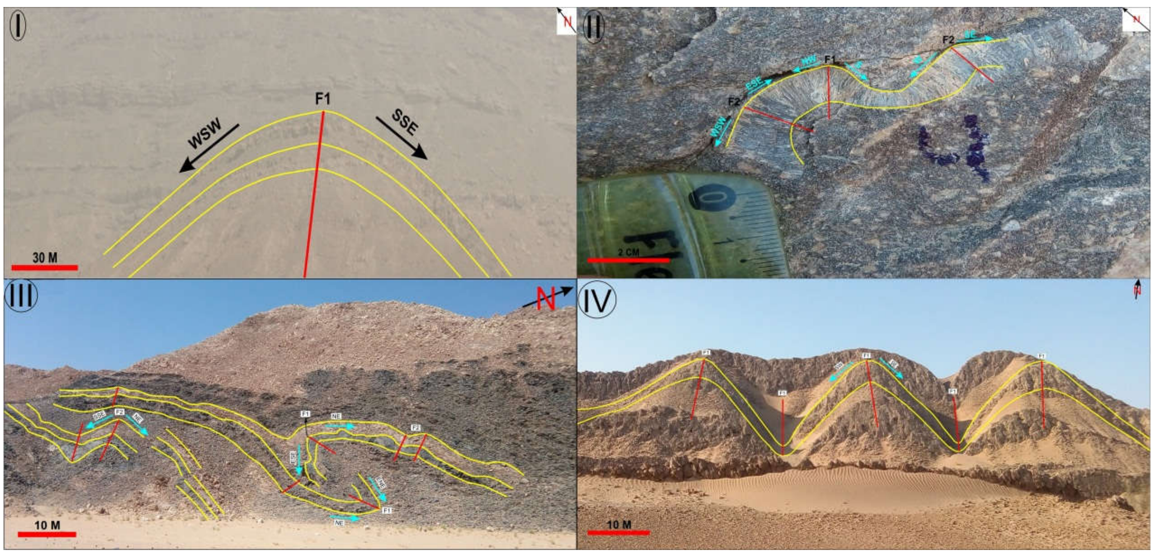


Figure 4: Shows (I and II) folds in Al-Balaq area, (III) folds in AthThaniyah area, and (IV) folds in Jabal Al-Milh area.

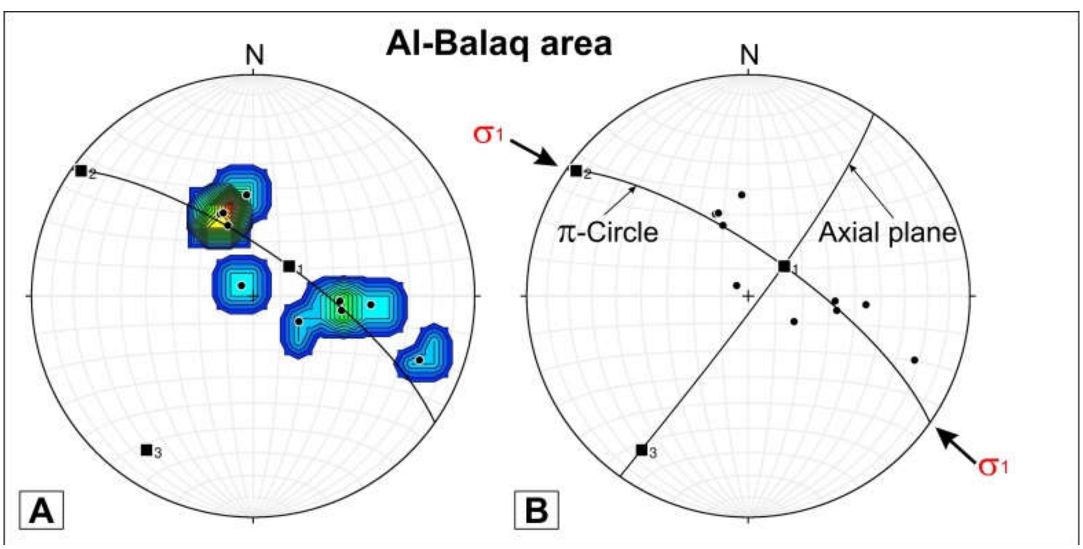


Figure 5: {A} Synoptic orientation diagram of poles and contours of folds, {B} The Maximum compressional stress direction of Al-Balaq area.

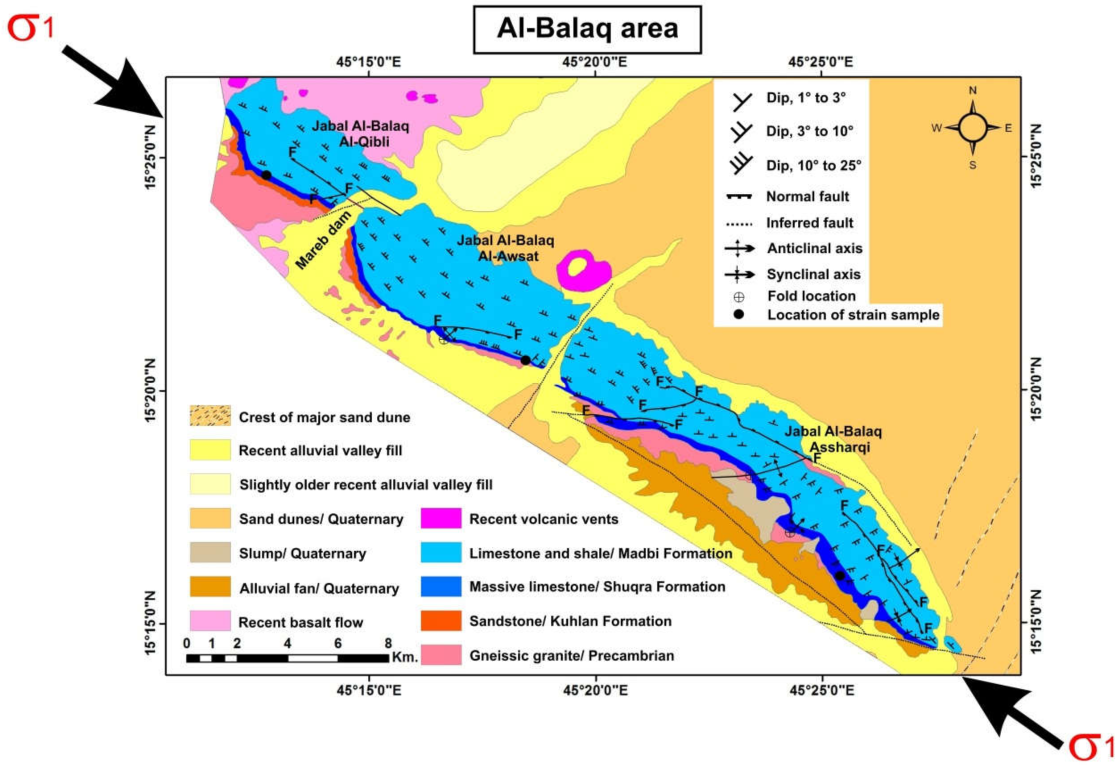


Figure 6: Maximum compressional stress direction (σ1) that dominating in the development of foldsofJabal Al-Balaq area.

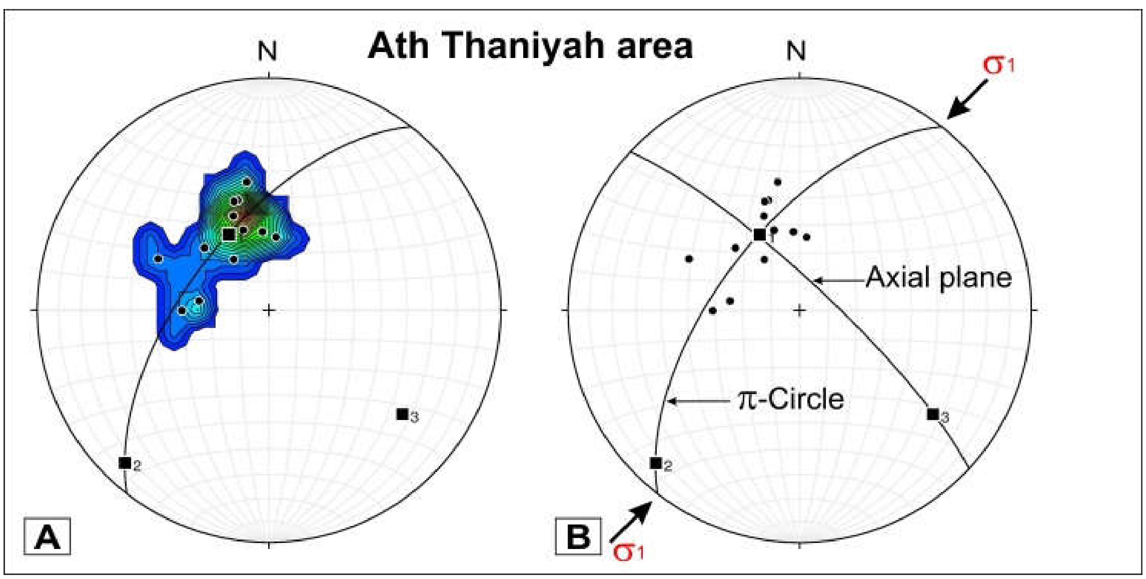


Figure 7: {A} Synoptic orientation diagram of poles and contours of folds, {B} The Maximum compressional stress direction of AthThaniyah area.

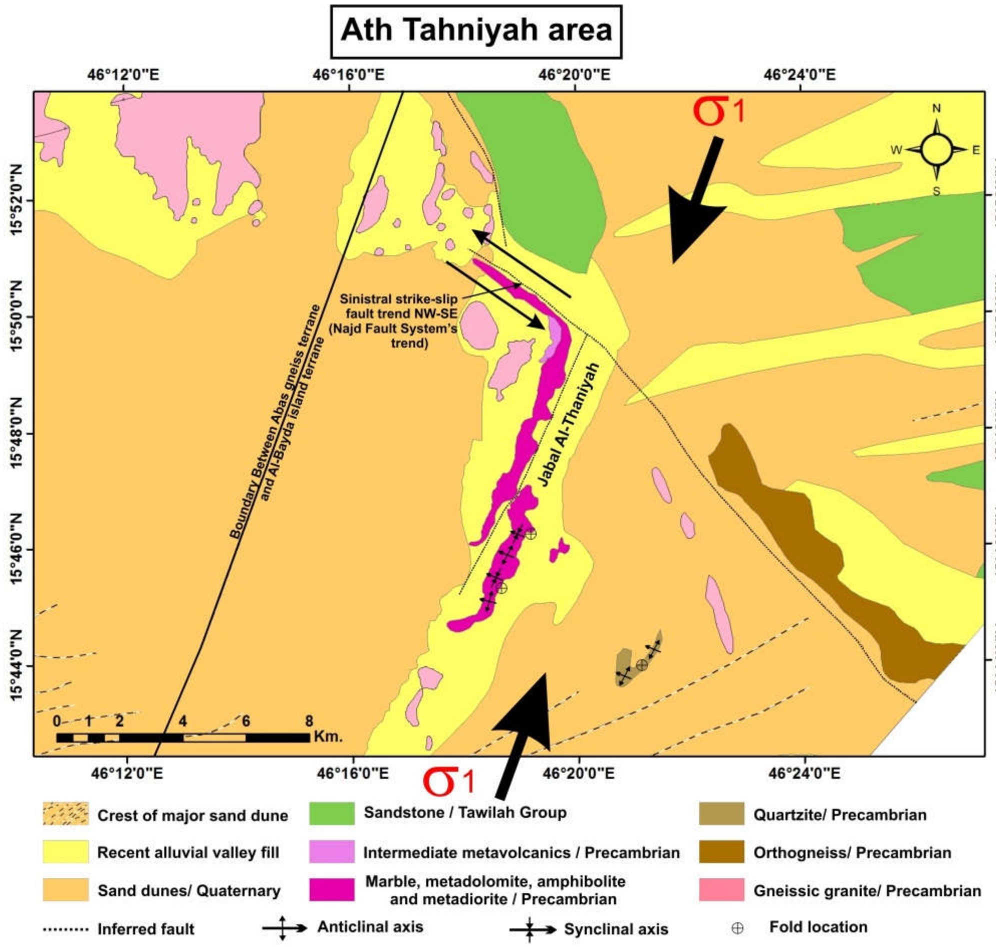


Figure 8: Maximum compressional stress direction (σ1) that dominating in the development of folds of AthThaniyah area.

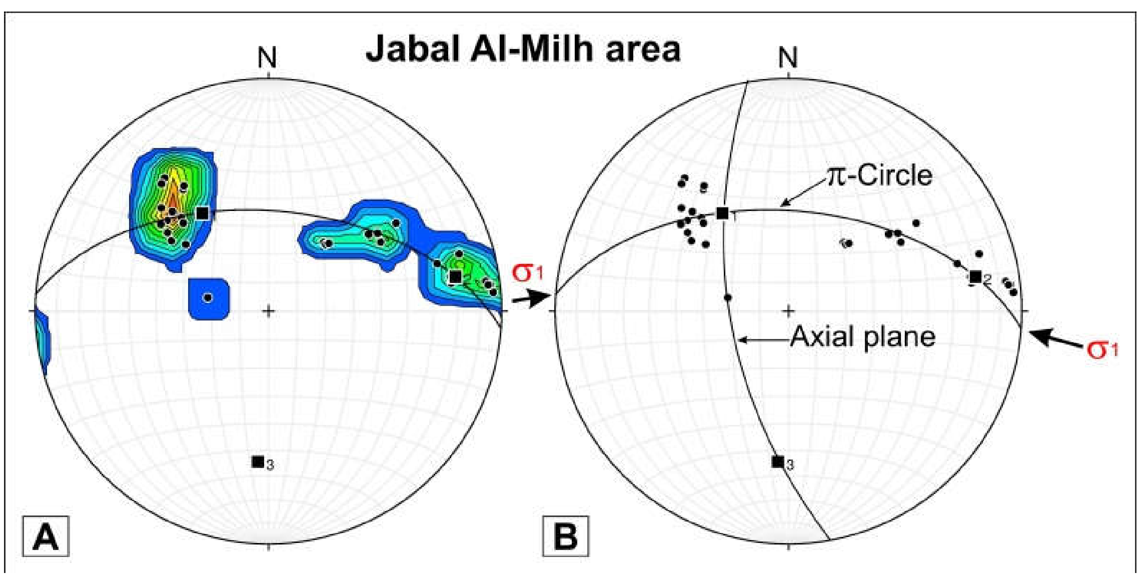


Figure 9: {A} Synoptic orientation diagram of poles and contours of folds, {B} The Maximum compressional stress direction of Jabal Al-Milh area.

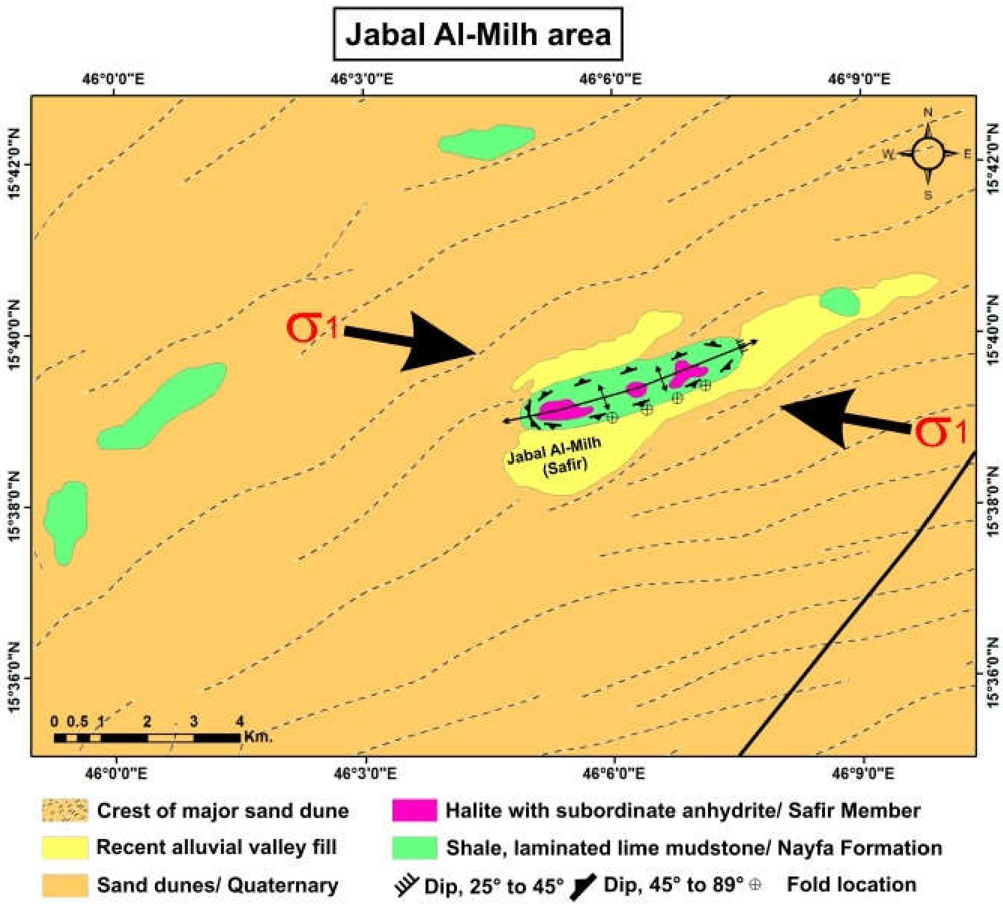


Figure 10: Maximum compressional stress direction (σ1) that dominating in the development of folds of Jabal Al-Milh area.

Joints:

The open fractures that developed in the brittle rock masses as a result of deformation in the crust of the earth are called joints (Engelder, 1987; Pollard and Aydin, 1988) with no or little shear displacement parallel to the fracture plane (Narr and Suppe ,1999). The joints also can be called tensile fracture or crack due to lack of shear involvement in the joint formation (Van der pluijm and Marshake 2003). Joints can be defined as fracture surfaces across or along which the movement is negligibly small (Ghosh, 1993). Individual joints are planar to curvy-planar surfaces that intersect the tops and flanks of outcrops as lines (Davis et al., 2012). Joints are present everywhere and can be utilized strongly as markers for paleostress (Pollard et al., 1982). Joints are a sensitive indicator of the paleostress field and can be used to infer the regional stress field orientation along with its special and temporal elevation (Engelder, and Geiser, 1980; Dyer, 1988; Olson and Pollard, 1989).

The joints that are in a systematic form have observed in the Shuqra Formation in Al-Balaq area (Figure 11A and B) and in quartzite rocks in AthThaniyah area (Figure 11E, F, and G), non-systematic joints were found in Al-Alam in the Basement rocks (dyke and host rocks) (Fig. 11C), it also found in AthThaniyah area (Figure 11G). The complex joints were found in the basement in zone-3 (Figure 11D). The conjugate joints develop in the compressive stress field (Omosanya et al., 2013). The systematic and non-systematic conjugates of joints were found in AthThaniyah area (Figure 11E and F).

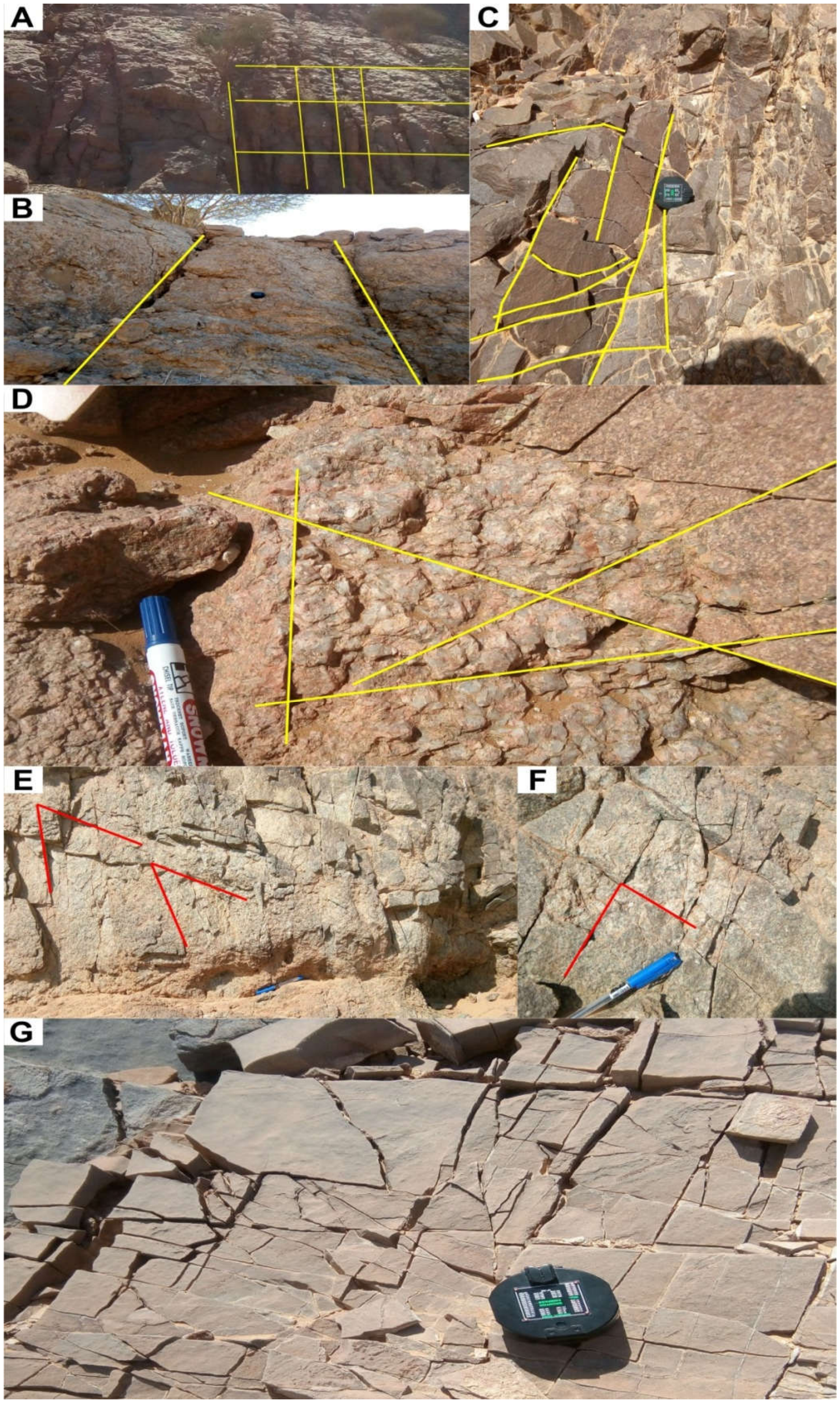
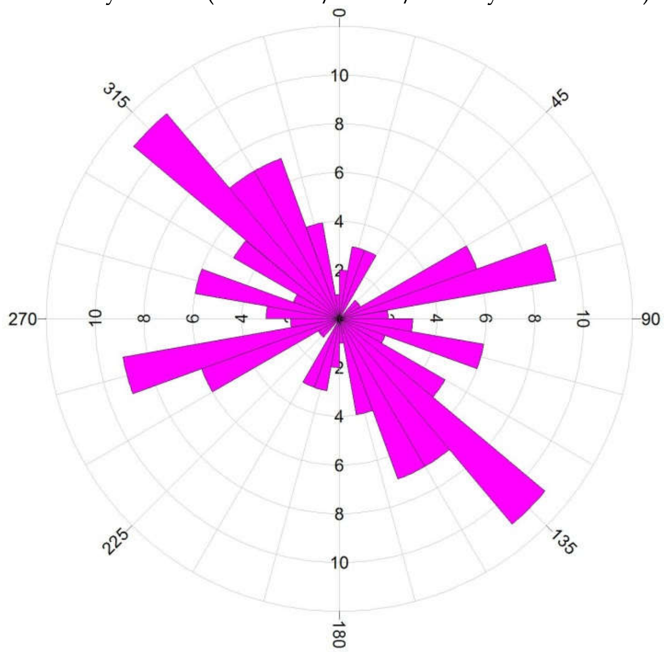


Figure 11: Different types of joints (A and B) in Shuqra Formation Al-Balaq area, Systematic (C) Non-systematic in the Basement rocks of Al-Alam area (D) Complex in the Basement rocks in Al-Alam area (E) Non-Systematic conjugate in the Basement rocks (Quartzite) in AthThaniyah area (F) Systematic conjugate in the Basement rocks in AthThaniyah (G) Non systematic in the Basement rocks in AthThaniyah area.

Two or more sets of joints have been identified in the study area. First dominated set orientation is NW-SE same to the orientation of Najd Fault System in the study area, whereas the second dominated set trends to ENE-WSW which is most probably trend of the Gulf of Aden (Figure 12). Subordinate trends are WNW-ESE which also may be affected by the Precambrian weak zones (Najd Fault System), and NNE-SSW which is may be following the trend of the Red Sea Rift. Studied joints are in Jabal Al-Balaq area (Shuqra Formation), Al-Alam area (Basement rocks/ AbasTerrane), and AthThaniyah area (Basement/ rocks/ Al-Bayda island arc).



Statistical Summary	
Calculation Method:	Frequency
Class Interval:	10.0 Degrees
Azimuth Filtering:	Deactivated
Data Type:	Bidirectional
Population:	73
Total Length of All Lineations:	146.0
Maximum Bin Population:	11.0
Mean Bin Population:	4.29
Standard Deviation of Bin Population:	2.93
Maximum Bin Population (%):	7.53
Mean Bin Population (%):	2.94
Standard Deviation of Bin Population (%):	2.01
Maximum Bin Length:	11.0
Mean Bin Length:	4.29
Standard Deviation of Bin Lengths:	2.93
Maximum Bin Length (%):	7.53
Mean Bin Length (%):	2.94
Standard Deviation of Bin Lengths (%):	2.01
Vector Mean:	123.2 Degrees
	303.24 Degrees
Confidence Interval:	33.8 Degrees
	(95 Percent)
R-mag:	0.27

Figure 12: Rose diagram of all joint sets.

Major joints were found in the NW of the study area (Figure 13). Those joints in the Basement rocks (Abasterrane), oriented along NE-SW (Fig. 14), following the rift of the Gulf of Aden. Gulf of Aden has taken an old trend between Arabian Plate and Somalia Plate which is ENE-WSW. Subordinate trend oriented to NW-SE.

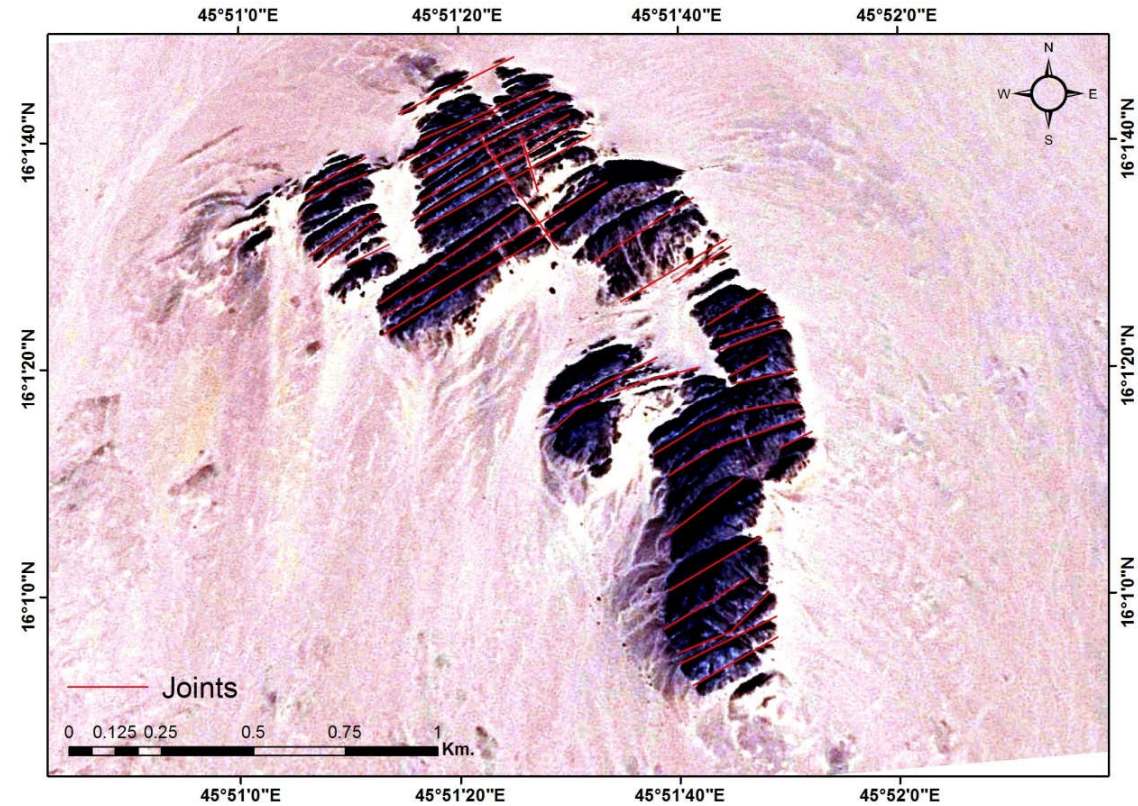
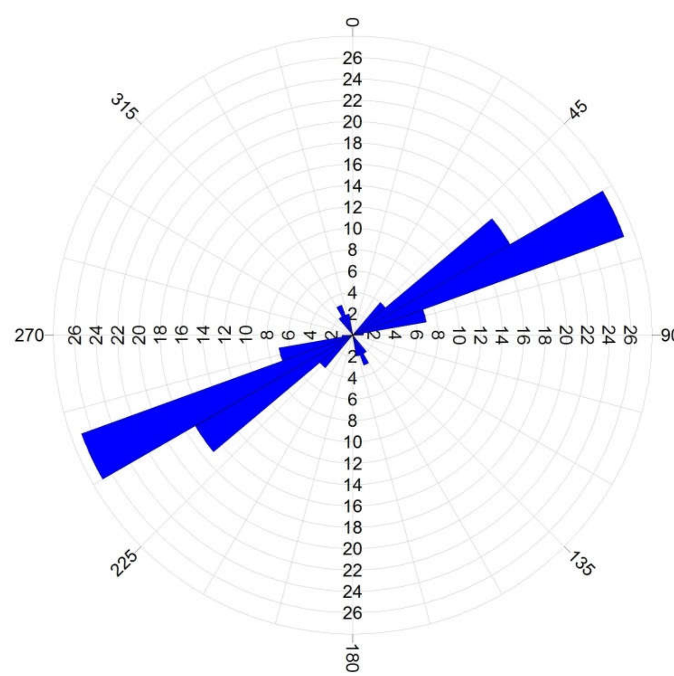


Figure 13: High resolution satellite image of major joints in the NW of the study area.



Statistical Summary	
Calculation Method:	Frequency
Class Interval:	10.0 Degrees
Azimuth Filtering:	Deactivated
Data Type:	Bidirectional
Population:	63
Total Length of All Lineations:	126.0
Maximum Bin Population:	27.0
Mean Bin Population:	7.88
Standard Deviation of Bin Population:	8.98
Maximum Bin Population (%):	21.43
Mean Bin Population (%):	6.25
Standard Deviation of Bin Population (%):	7.13
Maximum Bin Length:	27.0
Mean Bin Length:	7.88
Standard Deviation of Bin Lengths:	8.98
Maximum Bin Length (%):	21.43
Mean Bin Length (%):	6.25
Standard Deviation of Bin Lengths (%):	7.13
Vector Mean:	62.1 Degrees
	242.12 Degrees
Confidence Interval:	10.6 Degrees
	(95 Percent)
R-mag:	0.75

Figure 14: Rose diagram of major joints in the NW of the study area.

Dykes:

Dykes are tabular bodies of igneous rock that cut across the structure of older formation. A simple dyke is the result of a single intrusion of magma. A multiple dike is a result of two or more intrusions of the same kind of magma. A composite dyke is the product of the intrusion of two or more kinds of magma. A differentiated dyke is one that was intruded a homogeneous magma, but from which two or more varieties of rock have formed in situ.

Data of dykes were collected from Al-Alam and Rwaik area (Figure 2c,d) both are in Abasterrane. Dykes that were observed are only in Precambrian rocks (Basement), Jurassic rocks were not cut by those dykes as shown in (Figure 15). Dykes are ranging in the length form several hundred meters to a few kilometers (Figure 2c,d).

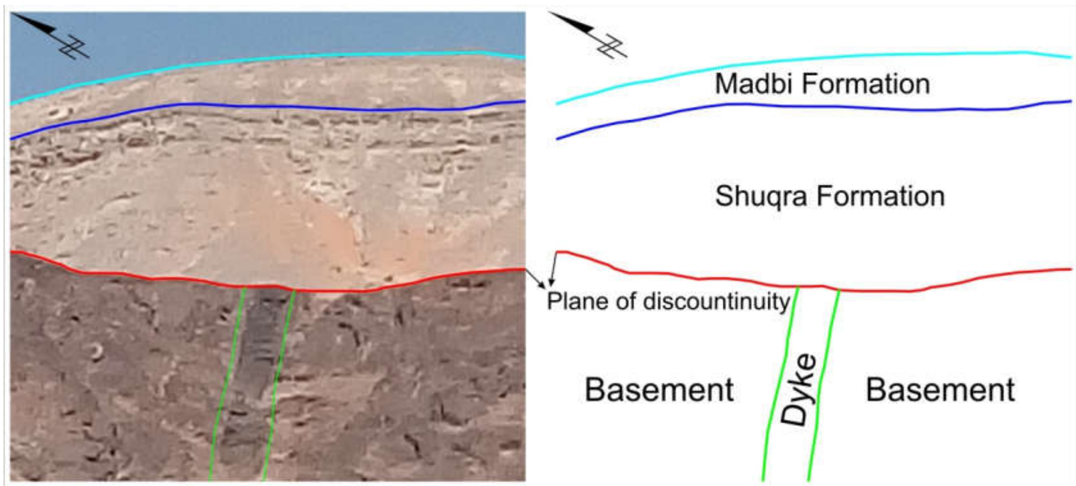
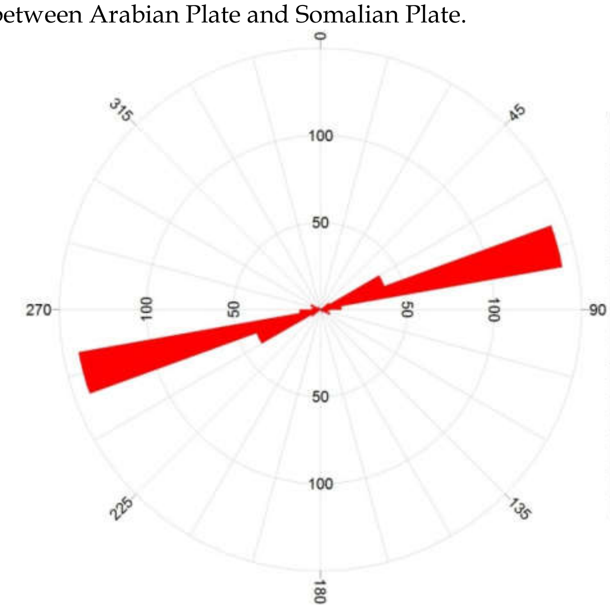


Figure 15: Field photograph and sketch showthe dyke and its situation in Al-Alam area.

Dykes, in the area, are trending to ENE-WSW (Figure 16), parallel to the trend of the Gulf of Aden but it older. When the rift of Gulf of Aden initiated in Early Tertiary time. Gulf of Aden has taken an old trend between Arabian Plate and Somalian Plate.



Statistical Summary	
Calculation Method:	Frequency
Class Interval:	10.0 Degrees
Azimuth Filtering:	Deactivated
Data Type:	Bidirectional
Population:	215
Total Length of All Lineations:	430.0
Maximum Bin Population:	141.0
Mean Bin Population:	26.88
Standard Deviation of Bin Population:	46.02
Maximum Bin Population (%):	32.79
Mean Bin Population (%):	6.25
Standard Deviation of Bin Population (%):	10.7
Maximum Bin Length:	141.0
Mean Bin Length:	26.88
Standard Deviation of Bin Lengths:	46.02
Maximum Bin Length (%):	32.79
Mean Bin Length (%):	6.25
Standard Deviation of Bin Lengths (%):	10.7
Vector Mean:	75.2 Degrees
	255.23 Degrees
Confidence Interval:	2.9 Degrees
	(95 Percent)
R-mag:	0.93

Figure 16: Rose diagram showing the orientation of studied dykes in the study area.

CONCLUSION

Faults in the study area, are tending to three main directions, NW-SE, NE-SW or ENE-WSW, and NNW-SSW. The NW-SE is the trend of Najd Fault System, the NE-SW or ENE-WSW is the trend of the Gulf of Aden, and NNW-SSW most probably is the trend of the rift of the Red Sea in the study area. Folds were found in Al-Balaq, AthThaniyah, and Jabal Al-Milh area. In Al-Balaq area folds have been formed as a result of local deformation. Folds in AthThaniyah area were formedas results of Pan-African tectonics in the study areaand present in two generations. Folds in Jabal Al-Milh area have been developed locally due to salt tectonics. Two to three sets of joints were found in the study area, the dominance of three sets of joints oriented along NW-SE, ENE-WSW, and NNE-SSW. Dykes in Al-Alam and Rwaik area filled the fractures that oriented along ENE-WSW direction. Dykes were found in Basement rock's fractures. The dykes are older than the Gulf of Aden which indicates that the Gulf of Aden developed along Precambrian weak zones between Arabian Plate and Somalia Plate.

ACKNOWLEDGEMENT

The authors are more grateful to the chairman of department of geology, Aligarh Muslim University, India to providing facilities to complete this research. Thanks are due to Geological Survey of Yemen, for providing geological Map and Landsat satellite data. The authors also would like to sincerely thank the editors and all of the anonymous reviewers for their careful and useful comments that improved the revised manuscript.

REFERENCES

1. Ali, S. A. (2000). Trend surface analysis of Microlineament in Parsoli-Bichor area of Vindhyan Basin, Rajasthan. *Indian Journal of Petroleum Geology*, *9*(2), 37-48.
2. Ali, S. A., Alhamed, M., & Ali, U. (2016). Morphometric analysis of Abdan Basin, Almahfid basement rock, Yemen: using remote sensing and GIS. *Int J Adv Remote Sens GIS*, *5*(3), 1605-1617.
3. Ali, S. A., & Ali, U. (2015). Litho-structural mapping of Sind catchment (Kashmir Basin), NW Himalaya, using remote sensing & GIS techniques. *Int J Sci Res*, *4*(7), 1325-1330.
4. Ali, S. A., & Ali, U. (2017). Evaluating linear geological structures in seismogenic compressional setting, Kashmir basin, NW-Himalaya. *Spatial Information Research*, *25*(6), 801-811.
5. Ali, S. A., (2000). Lithofacies of Debari Group, Jaisamand Area, Udaipur District, Rajasthan, Rajasthan. Bull. Indian Geologists Association, 33 (2), 11-17.
6. Ali, S. A., Khan, A., Rais, S. (2003). Record of Syneresis Structures from Nithar Sediments of Bayana Sub-Basin, Delhi Supergroup, Rajasthan. Indian Journal of Petroleum Geology, 12 (2), 59-63.
7. Ali, S. A., (2000). Bedding characteristics of conglomerate of Debari Group, Aravalli Super Group Udaipur district, Rajasthan. Indian Minerals, 54 (1&2), 79-84.
8. Al-Wosabi, M., &Wasel, S. (2011). Lithostratigraphic subdivision of the Kuhlan Formation in Yemen. *Arabian Journal of Geosciences*, *4*(7-8), 1323-1335.
9. Beydoun, Z. R. (1997). Introduction to the revised Mesozoic stratigraphy and nomenclature for Yemen. *Marine and Petroleum Geology*, *14*(6), 617-629.
10. Beydoun, Z. R. (1997). Introduction to the revised Mesozoic stratigraphy and nomenclature for Yemen. *Marine and Petroleum Geology*, *14*(6), 617-629.
11. Beydoun, Z. R., & As-Saruri, M. L. (1998). The Phanerozoic depositional basins and inter-basinal highs of Yemen: their structural framework and sedimentary cover. *Zeitschrift fur GeologischeWissenschaften*, *26*, 517-530.
12. Beydoun, Z. R., As-Saruri, M. L., &Baraba, R. S. (1996). Sedimentary basins of the Republic of Yemen: their structural evolution and geological characteristics. *Revue de l'InstitutFrançais du Pétrole*, *51*(6), 763-775.
13. Beydoun, Z.R., Al-Saruri, M., El-Nakhal, H., Al-Ganad, I.N., Baraba, R.S., Nani, A.S.O., Al-Aawah, M.H., 1998. International Lexicon of Stratigraphy, second ed., vol. III. International Union of Geological Sciences and Ministry of Oil and Mineral Resources, Republic of Yemen, Republic of Yemen.

14. Brannan, J., Sahota, G., Gerdes, K. D., & Berry, J. A. (1999). Geological evolution of the central Marib-Shabwa basin, Yemen. *GeoArabia*, *4*(1), 9-34.
15. Davis, G. H., Reynolds, S. J., Kluth, C. F., 2012. Structural Geology of Rocks and Regions (3nd Edition), John Wiley & Sons, p 839.
16. Dyer, R. (1988). Using joint interactions to estimate paleostress ratios. *Journal of Structural Geology*, *10*(7), 685-699.
17. Engelder, T. (1987). Joints and shear fractures in rock. *Fracture mechanics of rock*, *Academic press*, London, pp. 27-69.
18. Engelder, T., &Geiser, P. (1980). On the use of regional joint sets as trajectories of paleostress fields during the development of the Appalachian Plateau, New York. *Journal of Geophysical Research: Solid Earth*, *85*(B11), 6319-6341.
19. Heikal, M. T. S., Al-Khirbash, S. A., Hassan, A. M., Al-Kotbah, A. M., & Al-Selwi, K. M. (2014). Lithostratigraphy, deformation history, and tectonic evolution of the basement rocks, Republic of Yemen: an overview. *Arabian Journal of Geosciences*, *7*(5), 2007-2018.
20. Martin, A. Z. (2001). Late Permian to Holocene paleofacies evolution of the Arabian Plate and its hydrocarbon occurrences. *Geo Arabia*, *6*(3), 445-504.
21. Numan, N., & Azzawi, N. (1993). Structural and geotectonic interpretation of vergence directions of anticlines in the foreland folds of Iraq.
22. Olson, J., & Pollard, D. D. (1989). Inferring paleostresses from natural fracture patterns: A new method. *Geology*, *17*(4), 345-348.
23. Pollard, D. D. (1987). Theoretical displacements and stresses near fractures in rock: with applications to faults, joints, veins, dikes, and solution surfaces. *Fracture mechanics of rock*, 277-349.
24. Pollard, D. D., &Aydin, A. (1988). Progress in understanding jointing over the past century. *Geological Society of America Bulletin*, *100*(8), 1181-1204.
25. Redfern, P., & Jones, J. A. (1995). The interior rifts of the Yemen-analysis of basin structure and stratigraphy in a regional plate tectonic context. *Basin Research*, *7*(4), 337-356.
26. Redfern, P., & Jones, J. A. (1995). The interior rifts of the Yemen-analysis of basin structure and stratigraphy in a regional plate tectonic context. *Basin Research*, *7*(4), 337-356.
27. Sachsenhofer, R. F., Bechtel, A., Dellmour, R. W., Mobarakabad, A. F., Gratzer, R., & Salman, A. (2012). Upper Jurassic source rocks in the Sab'atayn Basin, Yemen: Depositional environment, source potential and hydrocarbon generation. *GeoArabia*, *17*(4), 161-186.
28. Sachsenhofer, R. F., Bechtel, A., Dellmour, R. W., Mobarakabad, A. F., Gratzer, R., & Salman, A. (2012). Upper Jurassic source rocks in the Sab'atayn Basin, Yemen: Depositional environment, source potential and hydrocarbon generation. *GeoArabia*, *17*(4), 161-186.
29. Seaborne, T. R. (1996). The influence of the Sabatayn Evaporites on the hydrocarbon prospectivity of the Eastern Shabwa Basin, Onshore Yemen. *Marine and Petroleum Geology*, *13*(8), 963-972.
30. Van der Pluijm, B. A., Marshak S., 2003. Earth Structure: An Introduction to structural geology and Tectonics (2nd Edition), W. W. Norton & Company Ltd., Castle House, 75/76 Wells Street, London W1T 3QT, p 656.