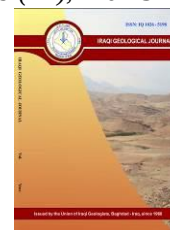




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Structural and Tectonic Analysis of Fracture Systems and Paleostress Orientation Inference in Western Iraq

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Abstract

Structural and tectonic analysis was conducted on the fractures in western Iraq, specifically in the areas of Heet, Suhailiya, Dolab, and Anah, which lie on the dividing boundary between the stable and unstable shelves within the AbuJir Faults and the Anah Graben. The field-based fracture analysis and systematic classification of joint and shear fracture sets were conducted. Fracture categorization indicates the prevalence of joint sets (hol), (okl), and (hko), together with shear fracture systems (hol) acute with respect to the tectonic axis a and (hol) acute with respect to the tectonic axis b. The measured fracture orientations and kinematic analysis indicate that deformation is predominantly governed by regional compressional tectonics. Paleostress analysis revealed primary compressional stress orientations, NW-SE, which are the dominant stress regimes causing fracture generation at the studied sites. These stress patterns are in accordance with the tectonic structure of western Iraq within the Arabian Plate's Stable Shelf (Inner Platform), showing that the platform's interior reflects systematic deformation despite having less folding than the Zagros Fold–Thrust Belt. Regional variations in fracture patterns reflect a multiphase deformation history affected by stress reorientation and local disruption. Stations near Heet, Sahliyah and Al-Baghdadi in particular, showed significant structural impact from the Abu Jir-Euphrates Fault Zone, which acts as a long-lived reactivated basement structure that accommodated right-lateral strike-slip deformation and inversion-related deformation during the Cenozoic. The results indicate that the NW–SE compressional component reflects inherited basement control and the reactivation of significant tectonic structures, such as the Rutbah Uplift and Anah Graben, particularly during Middle Miocene Late Alpine compression. Strike-slip fault deformation, positive flower structures, and isolated inversion characteristics within the Miocene deposits are examples of structural data that imply recurrent tectonic reactivation. Overall, the findings show that, in spite of its platform setting, western Iraq underwent multiphase brittle deformation governed by basement-related structural inheritance and regional convergence, placing new constraints on the tectonic evolution and paleostress development of the western Iraqi platform.

Keywords: Abu Jir Fault; Heet; Paleostress ; Strike-slip; Fracture

1. Introduction

Paleostress fields in the Earth's crust are deduced from various stress event indicators, such as earthquakes, landslides, and faulting/fracturing (Delvaux and Seperner, 2003). Brittle structures, including faults and fractures, resulting from tectonic forces, are used to reconstruct the orientations of past active stresses (Kaven et al., 2011; Igwe and Okonkwo, 2016). The main result of tectonic stresses DOI: <https://doi.org/10.46717/igi.2026.59.1F.10>

is expressed in rock fractures and joints fractures and joints, which are important and dependable markers of the paleostress and stress patterns in deformed sedimentary rocks (Bellahsen et al., 2006; Lacombe et al., 2011). Evidence of the ancient stress recorded in rock deformation can be found in the fracture or their interaction (Hugman and Friedman, 1979). The dynamic evaluation of joints in the folded strata facilitates the extrapolation of paleostress trajectories on the structure map. The folding process mechanism as a ductile deformational behavior resulting from the tectonic stresses, is considered the primary cause of the formation of systematic geological joints. The origin of joints has been a topic of contention for an extended period. De Sitter (1964), Hancock (1985) and Pollard and Martel (2020) demonstrated that joints were formed during syn-deformational tectonism. The study area is located in western Iraq along west bank of Euphrates River from Heet to Anah within the geographical coordinates (41°-43°)N to (33°-34°50'E) (Fig.1).

The Western part of Iraq is characterized by a Phanerozoic sequence that is relatively thin and covers the basement complex of Precambrian. The region generally lacks significant Alpine-related compressional structures. The exposed Mesozoic and Cenozoic formations display a predominant dip towards the N, NE, and E, with the exception of the extreme western portion, where the strata exhibit a westward dip (Fouad 2007). Numerous geological and tectonic studies have examined the western region of Iraq, especially the section extending between Heet and Anah, due to its complex structural features and contact between the main tectonic units such as the Anah anticline located between two major tectonic zones as described by Sissakian et al. (2021). The indicators included water gaps, wind gaps, arcuate valleys, sloped valleys, and whaleback formations. Fouad (2007) studied tectonic structure of western Iraq, and divided the platform into two parts: stable, represented by the western desert, and unstable north and east sides by Abu Jir Fault. The main goal of the study is to provide a more comprehensive recognition of the paleostress condition and structure and tectonic analysis of the study area.

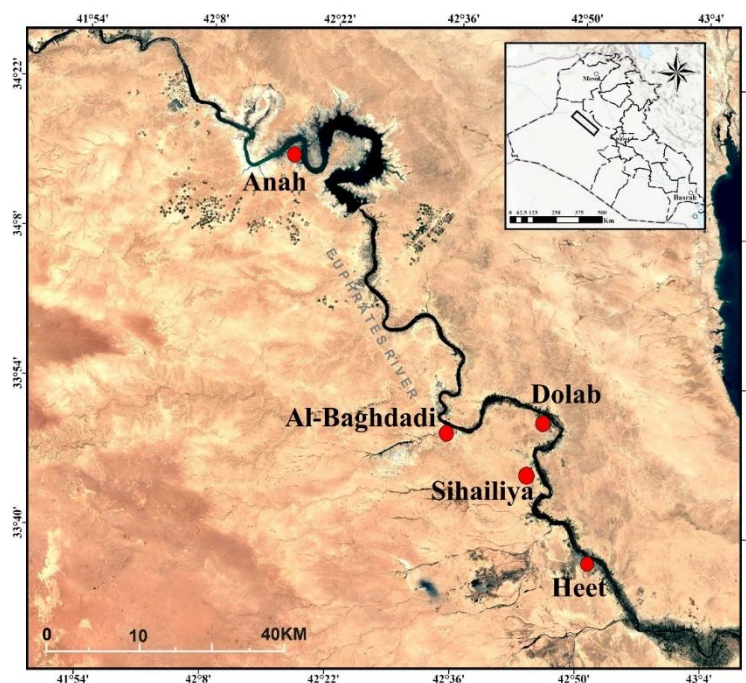


Fig. 1. Satellite image (landsat8, USGS Earth Explorer) showing location of the study area

2. Geological Setting of the Study Area

Tectonically, the Stable Shelf a relatively stable monocline and only slightly affected by Tertiary and Late Cretaceous deformation. The arrangement of the basement rocks and faults influenced the

orientations of structures in this tectonic unit, the Mesozoic arching, and the Paleozoic epirogenic events (Jassim and Goff, 2006). The Anah graben and Abu Jir Fault divide the less subsided terrains to the west from the subsided foreland basin of Zagros to the east. According to Fouad (2015), the Abu Jir Fault serves as border between the inner and outer platforms of the Iraqi territory. Al-Bassam et al. (1997) studied that, a part from a few fault system falike the Hauran and Nukhaib systems, the Western Desert of Iraq is devoid of surface structures.

Stratigraphically, the exposed stratigraphic sequence in the study area includes are Anah Formation (upper oligocene), Euphrates Formation (Early Miocene), Fatha Formation (Middle Miocene), Nfayil Formation (is identical to Fatha Formation) (Fig. 2). Anah Formation is composed of massive, recrystallized, brecciated, gray, and coralline limestone and is exposed in the study area (Bellen et al., 1959). Euphrates Formation, which comprises a lower level of basal conglomerate that follows ten meters of fossiliferous limestone, can be seen along the Euphrates River between the areas of Heet and Al-Qaim. Hard limestone and pseudoplastic limestone are mixed at the top of the formation (Jassim and Goff, 2006). Fatha Formation appears in two locations near the arise reas of Dolab and Heet. In most cases, gypsum, bedded limestone, and green marl cycles comprise the formation. The southern and eastern parts of the study area contain Nfayil Formation, comprising green marl and gray fossiliferous limestone (Jassim and Goff, 2006).

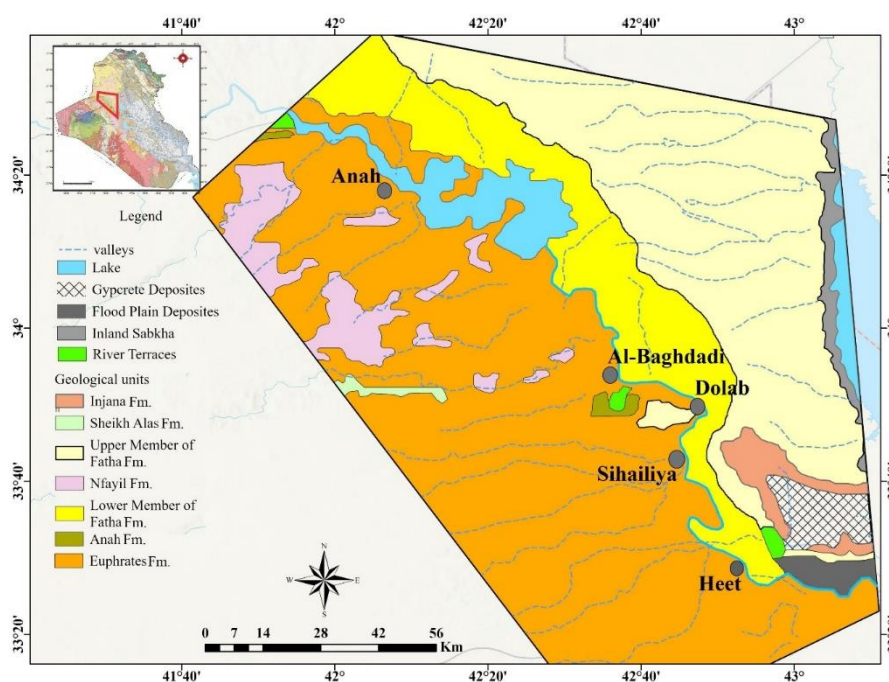


Fig 2. Geological map of the study area modified (after Sissakian and Fouad, 2015)

3. Materials and Methods

The fieldwork stage was the initial step undertaken to comprehend and identify the characteristics of the joints and faults and their tectonic implications. After reconnaissance of the study area, four locations were selected from Heet to Anah cities. GPS data were recorded and plotted on a digital elevation model to show the study area (Fig. 3). The average of joints was measured at each 34 attitudes were recorded as 10 readings for per location by Silva compass. In order to determine the paleostress orientations, the measured joint attitudes were geometrically and dynamically classified using Stereonet software (version11.3), which was also utilized to describe orientation the structural characteristics for this inquiry. The map geology of study area was produced using ArcGIS Pro (v3.5) and validated using satellite imagery. The WinTensor (Delvaux and Sperner., 2003) was used tool to determine paleostress

orientation. that uses Right Dihedron and Optimization methods it applies the Right Dihedron and optimization methods to analyze fault-slip data, fractures, and focal mechanisms for stress inversion.

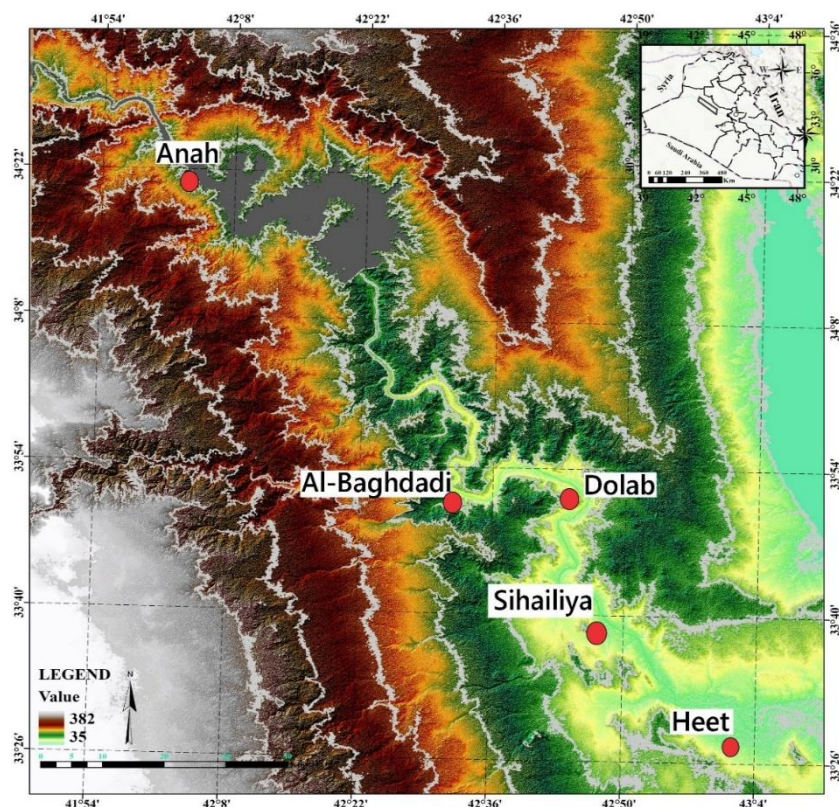


Fig.3. Digital elevation images for location of the study area from the (USGS)

4. Results

4.1. Fracture Analysis

Joints are among the most prevalent geological characteristics. Every rock outcrop contains several types of joints. They define the history of tectonic processes, which led to the formation of the joints and the physical properties of the rocks in which they are found (Weinberger et al., 2010). However, research on rock joints reveals that their geometry is self-similar, meaning that regardless of whether they are viewed at a microscopic, outcrop, or regional scale exhibit similar geometric patterns and spatial distribution (Weinberger et al., 2010). The tectonic interpretations of joints in the research region were derived through geometrical classification, followed by a dynamic investigation of these joints. The paleostress attitudes at four stations were referenced as part of the dynamic analysis. A Schmidt stereographic projection net was used to display the interpreted paleostress directions (Fig. 13), which were also extended to a geological map.

The geometrical classification of systematic joints is based on their relationships to hypothetical orthogonal tectonic axes a, b, and c (Fig. 4). Bronu Sander developed these axes between 1926 and 1930 (Ramsey and Huber, 1987). It is suggested that the axis a be parallel to the bed's dip direction, the axis b be parallel to the bed strike direction, and axis c be parallel pole to bedding plane. The joints were then categorized into sets and systems by several geologists, including Turner and Weiss (1963), Hancock (1985) and Fossen (2016) based on their geometrical correlations with those three axes. Joint sets are categorized as ab, ac, and bc, and joint systems as okl, hko, and hol. For example, the joint set type ac indicates that its plane is parallel to the a and c axes, whereas the joint system hko indicates that the joint cuts two tectonic axes a and b but is parallel to the tectonic axis c where ($l=c$, $h=a$, $k=b$). The letter l is

assigned the number 0 when the fractures are parallel to the tectonic axis c , and the same is true for other systems.

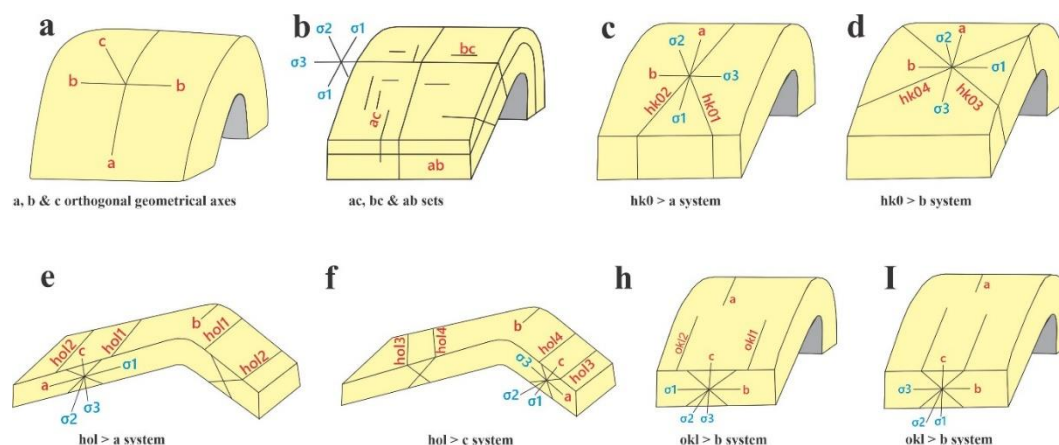


Fig. 4. Geometrical classification of the joint after Hancock (1985)

4.1.1. Station 1

The first investigated area was located within Fatha Formation in Heet outcrop with coordinates (33°35'29.61"N, 42°50'7.86"E). This outcrop, which belonging to the Fatha Formation (Middle Miocene), and is composed of bedded limestone, gypsum, and green marl. The bedding plane dip 065/07° NE. Over ten fracture plane data points were collected, as shown in Table 1 and Fig.5. The results show that hko joints are the most common and well developed joint set in the field of study. The stereonet digram analysis shows two primary sets of high- to near-vertical joints (S1 and S2). The distinct overlap of the two sets at the diagram's center at the center of the stereonet signifies the prevalence of high-dip shear fractures. These fractures likely formed under horizontal compressive stress and are indicative of strike-slip movement within the Abu-Jir fault zone. Additionally, hydrocarbon seepage is observed along highly fractured gypsum layers (Fig.6).

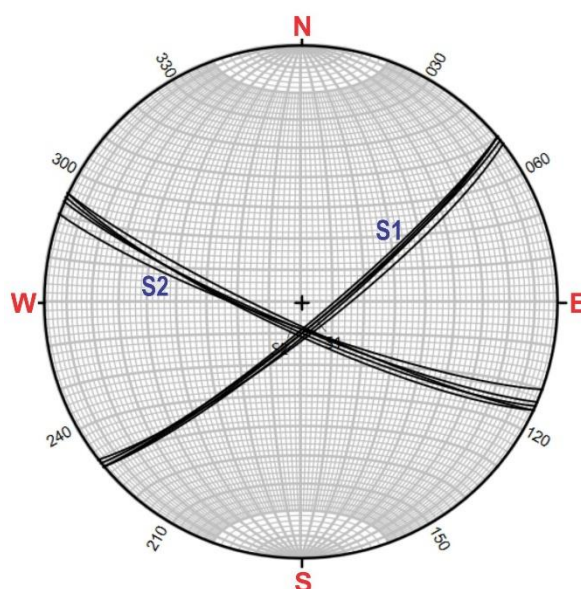


Fig. 5. Stereographic projection shows joint sets of station 1

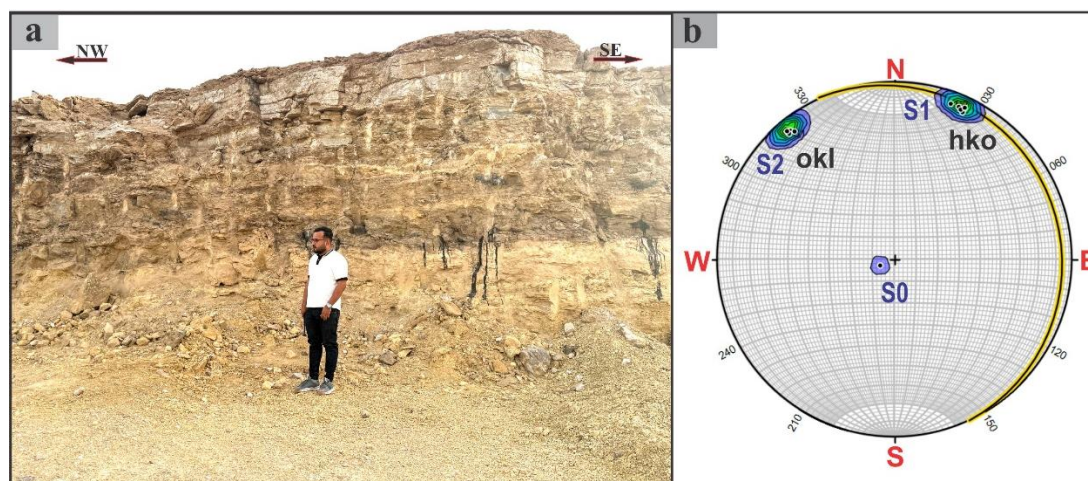


Fig.6. a) Shows the fractures at station 1 in Heet outcrop of the study area; b) Stereographic projection of the fractures at station 1

4.1.2. Station 2

The second investigated area is located within Euphrates Formation in Sahliyah outcrop, which is situated in the northwest of the Heet outcrop ($33^{\circ}43'23.16''\text{N}$, $42^{\circ}42'21.11''\text{E}$). Only the upper section of Euphrates Formation is shown in this outcrop. Euphrates Formation is composed of well-bedded, chalky, shelly recrystallized limestone at the type locality (Bellen et al., 1959). Over ten fracture plane data points were collected, as shown in Table 1 and Fig. 7. The results show that the hol>c type can be found in the lower Sahliyah outcrop as a conjugate system (Fig.8). This system consists of two intersecting sets (S1 and S2), the bedding plane 065/20, these planes intersect the tectonic axes a and c, and are parallel to axis b. The NW-SE (S1) set has dip direction and dip amount of 241/60, while (S2) set has dip and dip amount of 61/64 toward NE, respectively.

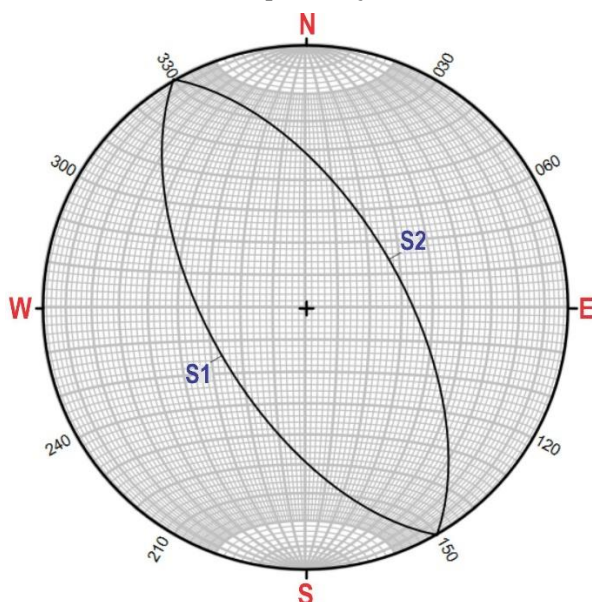


Fig.7. Stereographic projection shows joint sets of station 2

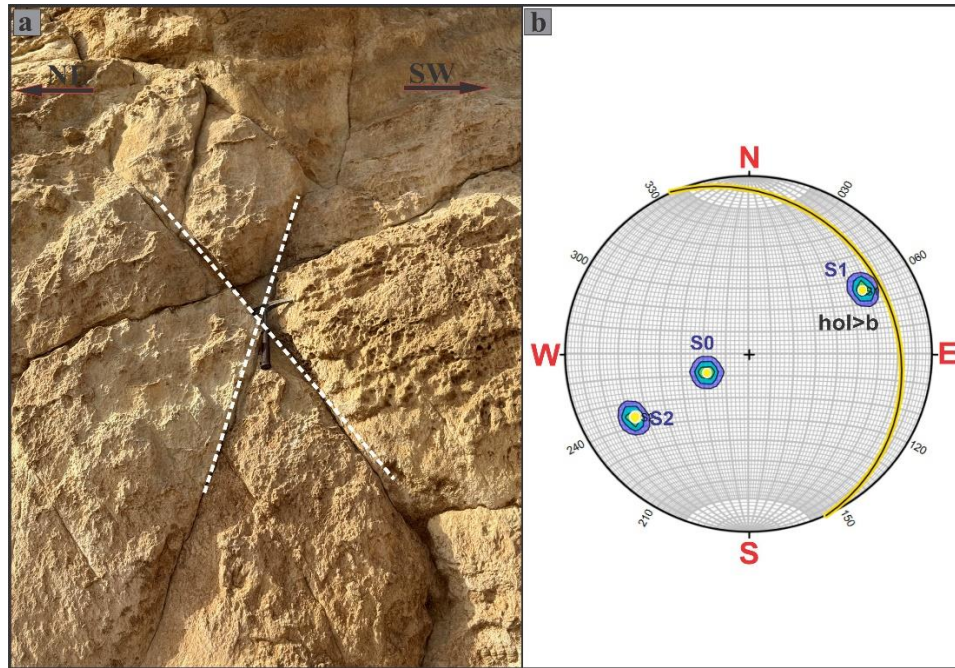


Fig. 8. a) Shows the fractures at station 2 in Sahliyah outcrop of the study area; b) Stereographic projection of the fractures at station 2

4.1.3. Station 3

The third investigated area is located within Euphrates Formation in the Al-Baghdadi outcrop which is situated to the northwest of the Sahliyah outcrop (33°51'36.70"N, 42°31'47.75"E). More than ten fracture plane measurements were collected, as shown in Table 1 and Fig. 9, has a conjugate fracture system formed of two primary sets (S1 and S2), that correspond to the (hol > a) type, based on the stereonet analysis of the investigated area Fig. 10.

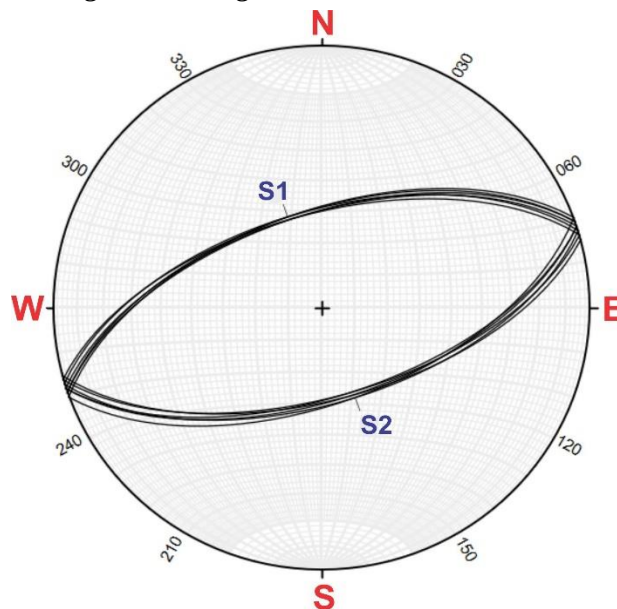


Fig. 9. Stereographic projection shows joint sets of station 3

The two sets of planes in this system are oriented parallel to the intermediate axis *b* and are connected to the tectonic axes *a* and *c*. The main structural trend in the station is shown by the first set (S1), which has a dip direction and dip angle of roughly 340/60 toward the (ENE). The second set (S2),

on the other hand, is oriented with a dip direction and dip angle of roughly $160/60^\circ$ toward the (SW), indicating a conjugate relationship with S1 but in the different direction. Overall, the results show the studied area was subjected to a constant compressional stress regime, that resulted in the formation of a well-defined conjugate fracture system, as shown by the distribution of strike and dip relationships on the stereonet.

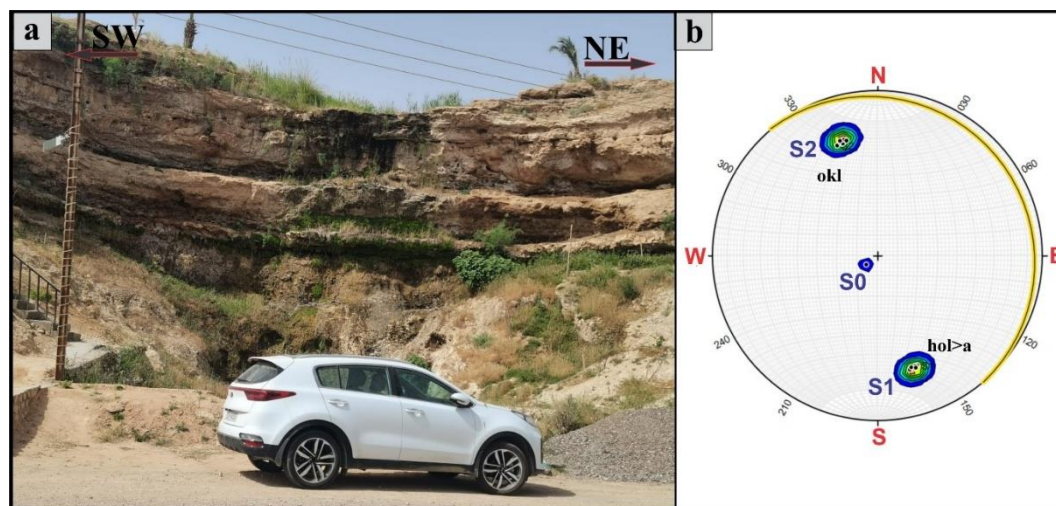


Fig.10. a) Shows the fractures at station 3 in Al-Baghdadi outcrop of the study area; b) Stereographic projection of the fractures at station 3

4.1.4. Station 4

The fourth investigated area is located within Anah Formation in Anah outcrop, which is situated in the northwest of the Heet outcrop ($34^\circ 20' 7.71''\text{N}$, $42^\circ 5' 39.58''\text{E}$). More than ten fracture plane measurements were collected, as shown in Table 1. Anah Formation in Iraq was initially described by Bellen, 1959; Noon et al., 2026), who also located the type section in Nahiyah village, approximately 15 km east of the Anah area in Western Iraq. This deposit is composed of light gray, detrital, fragmented, recrystallized, coralline limestone, up to 14 m thick. The results show that the hol>c type can be found in the Anah outcrop as a conjugate system (Fig. 11).

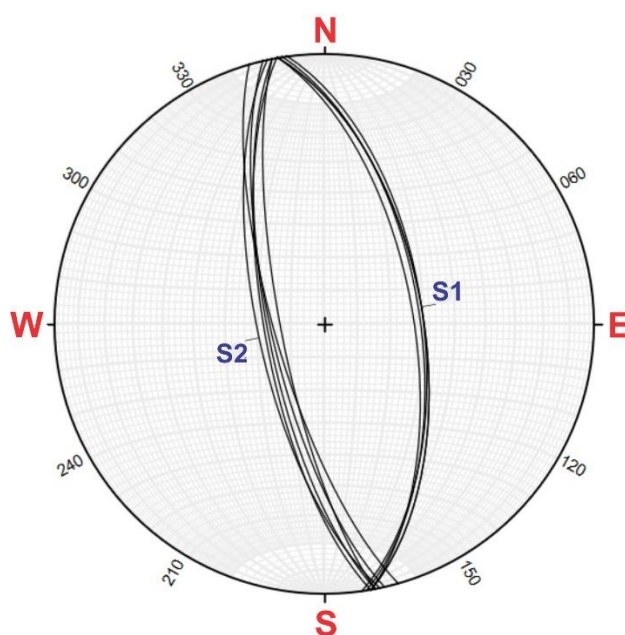


Fig.11. Stereographic projection shows joint sets of station 4

This system consists of two intersecting sets (S1 and S2) whose planes intersect tectonic axes *a* and *c* and run parallel to *b*. The stereonet diagram shows two main sets of semi-vertical joint orientations, generally north-south, with minor deviations towards NNE-SSW and NNW-SSE, suggesting that the region is influenced by a regional tectonic stress field characterized by a horizontal compressional component directed east-west (Fig. 12).

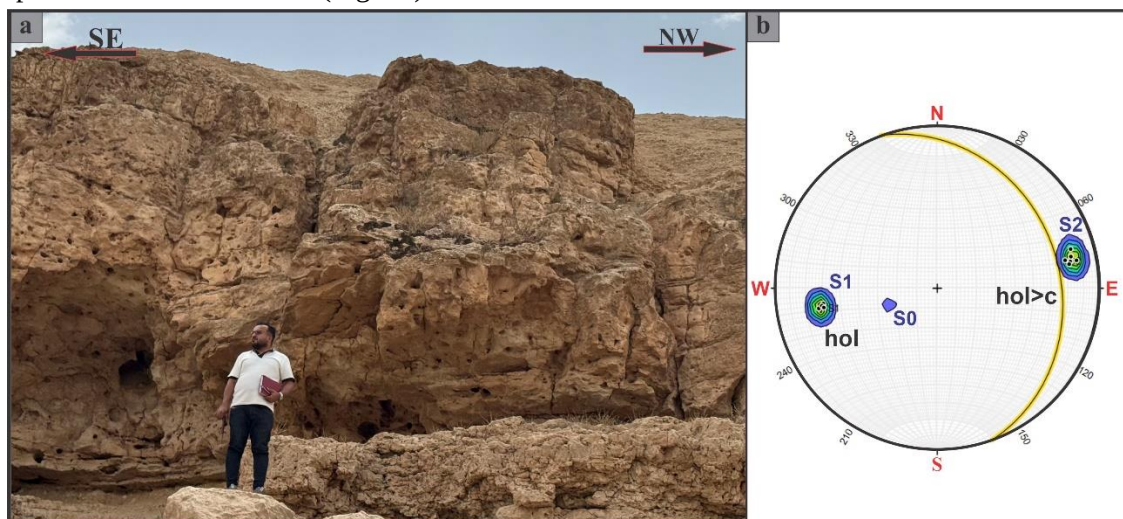


Fig.12. a) Shows the fractures at station 4 in Anah outcrop of the study area; b) Stereographic projection of the fractures at station 4

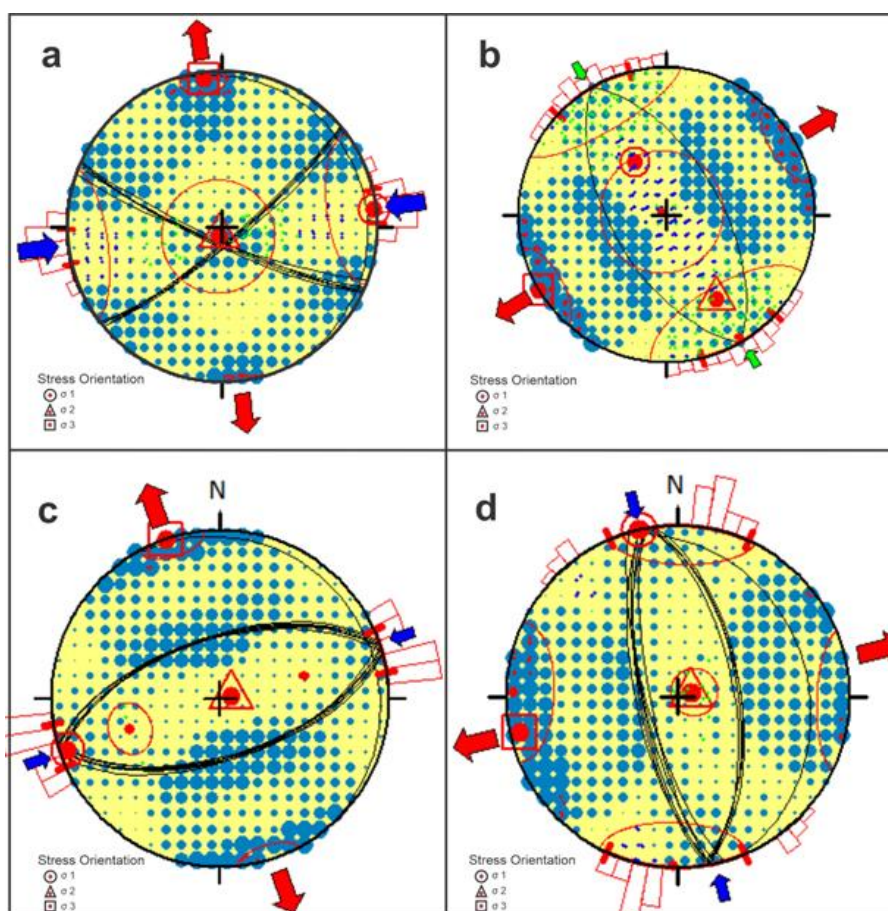


Fig.13. Paleostress orientation result by (Right Dihedron) along four station as: a) Station.1 Heet outcrop; b) Station.2 Sahliyah outcrop; c) Station.3 Al-Baghdadi outcrop; d) Station.3 Anah outcrop

Table 1. Fracture types and paleostress direction for all stations for the study area

Station Number	Set of joins	Bedding Plane Dip Direction/dip amount	Dip Direction	Dip amount	Joint type	Paleo stress direction	Type of applied stress
St.1	S1	065/07	140	82	hko>a	NW-SE	Compression
			141	82			
			142	80			
			140	81			
			140	83			
			200	82			
St.2	S2	065/20	205	80	okl	NW-SE	Compression
			203	82			
			204	81			
			205	83			
			241	60			
			61	64			
St.3	S1	050/7	160	30	hol>a	NNW-SSE	Compression
			162	29			
			161	30			
			164	29			
			163	30			
			161	29			
St.4	S2	070/25	340	30	okl	NNW-SSE	Compression
			342	29			
			343	30			
			344	28			
			345	29			
			342	28			
St.5	S1	070/25	80	60	hol>c	NNW-SSE	Compression
			80	63			
			82	60			
			81	61			
			80	60			
			258	70			
St.6	S2	070/25	259	73	hol	NNW-SSE	Compression
			254	75			
			260	72			
			259	77			

5. Discussion

The fracture analysis and classification revealed hol, okl, and hko as well as the shear systems hol acute about a, hol acute about the tectonic b axis in the study area. Table 1 shows that the main paleostress orientations are NE-SW and NW-SE. The joint and fracture analysis results show that brittle deformation patterns produced under regional compressional stress regimes predominate in the study area. This result is very similar to the tectonic structure of Western Iraq, which is part of the Arabian Plate's (Stable Shelf) (Jassim and Goff, 2006). The area is structurally impacted by inherited basement

Faults and important tectonic zones that regulate the distribution and orientation of brittle structures, despite being generally less deformed than the Zagros Fold-Thrust Belt in northern Iraq (Jassim and Goff, 2006; Fouad, 2015).

One of the predominant shear fractures in the research region is the hol acute concerning the tectonic axis. The shear fractures oriented at hol acute to the tectonic axis c, hol acute to about the tectonic axis a and okl suggest that these fractures may result from the extensional phase linked to NE-SW and NW-SE compressive stresses. This indicates that Zagros-related shortening extended behind the external fold-thrust belt advancing westward into the Platform (Stable Shelf) and resulting in systematic brittle deformation even in the normally stable Western Desert. The presence of a secondary NW-SE compressional trend represented by the first and fifth stations indicates a complex stress history characterized by stress reorientation and/or the superposition of deformation phases, likely influenced by pre-existing basement structures and the reactivation of significant regional tectonic features, including the AbuJir-Euphrates Fault zone, Rutbah Uplift, and Anah Graben.

Stations located within the Heet and Al-Baghdadi cities are affected by the Abu Jir fault, the joint and fracture patterns seen in the Heet area indicate substantial structural influence from the Abu Jir-Euphrates fault zone, a prominent tectonic feature in western Iraq. This fault zone is a lengthy, regionally continuous structural border that delineates the comparatively stable Inner Platform from the more deformed areas adjacent to the Mesopotamian foredeep, and has been frequently reactivated during the Cenozoic Era. The prevalence of systematic, steeply dipping joint sets, along with the identification of primary compressional trends (NE-SW). According to De Ruiter et al. (1994), the NW-SE trend of the Euphrates trough caused structural inversion based on the direction of stress in relation to the local N-S compressive field. This is similar to the principle of the Abu Jir fault (De Ruiter et al., 1994; Alsouki and Taifour, 2015). After a total inversion, Abu Jir Euphrates fault zone saw strike slip, lateral movement. Additional further that right lateral movement takes place on these fault zones includes sag ponds, pressure ridges that are separating, and associated floral formations. Fieldwork observations on the ridge indicate that the upper Euphrates and Fatha formations having a large listric positive inverted fault (Figs.14 and 15).

An upward-oriented positive flower structure is created by convex reverse fault and is related to small faults, and different from the surrounding areas, this structure contributes to the formation of localized topographic relief and show the existence of several Euphrates Formation outcrops (Fig. 14). In addition, between two fault blocks, a sedimentary dyke has been observed. The limestone that makes up this dyke originates from either the carbonate rocks of the higher portion of the Euphrates Formation or the first cycle of the Fatha Formation. Given that elements were deposit before lithification show that the highest Euphrates Formation undergone syn-sedimentary events like slumping or collapse structures (Fig. 15d). Additionally, as shown in Fig. 15a and 15b, a local graben structure has been identified in the top portion of the Euphrates Formation in the Dolab area. Furthermore, a layer of basal conglomerates was retained under the Euphrates Formation in the study region, indicating an unconformity surface between Euphrates Formation (Early Miocene) and the Oligocene formations. This layer was created when the Oligocene formations began to appear above sea level. Another extensive stretch of exposure is noticed and indicated the end of the Oligocene phase (Fouad, 2007).

The Anah station, according to the direction of stresses (northwest, and southeast), is affected by the upheavals that occurred in the Anah Basin. The inversion of the Anah graben, delineating the northern limit of the tectonically stable Stable Platform in Iraq, transpired due to the reactivation of pre-existing normal faults that define the graben's boundaries. During the Late Alpine compression (Middle Miocene), the normal faults along the graben border were reactivated as reverse faults, resulting in a partial inversion of the basin and the creation of a monoclinical structure above the old Anah Basin (Fouad, 1997; Fouad, 2007).

The prevalent structural patterns observed throughout the African and Arabian shields are in NE-SW, NW-SE and N-S orientations. The later two have generally been dubbed the Hejaz and Najd Orogenies in Saudi Arabia (Brown and Coleman, 1972). Additionally, the observed variation in dip angles from subvertical to moderate dips, may represent variations in fracture mechanisms, from tensile joints to fractures impacted by a small shear component, especially in the vicinity of reactivated fault systems during Neogene tectonic inversion events recorded in Western Iraq. Overall, the fracture data show that Western Iraq has experienced several compressional stress phases even though it is part of a stable platform. The primary regional stress regime associated with Zagros shortening is probably represented by NE–SW compression, whereas secondary phases and/or localized structural influences associated with basement reactivation are likely represented by NW–SE compression (Jassim and Goff, 2006; Fouad, 2015).

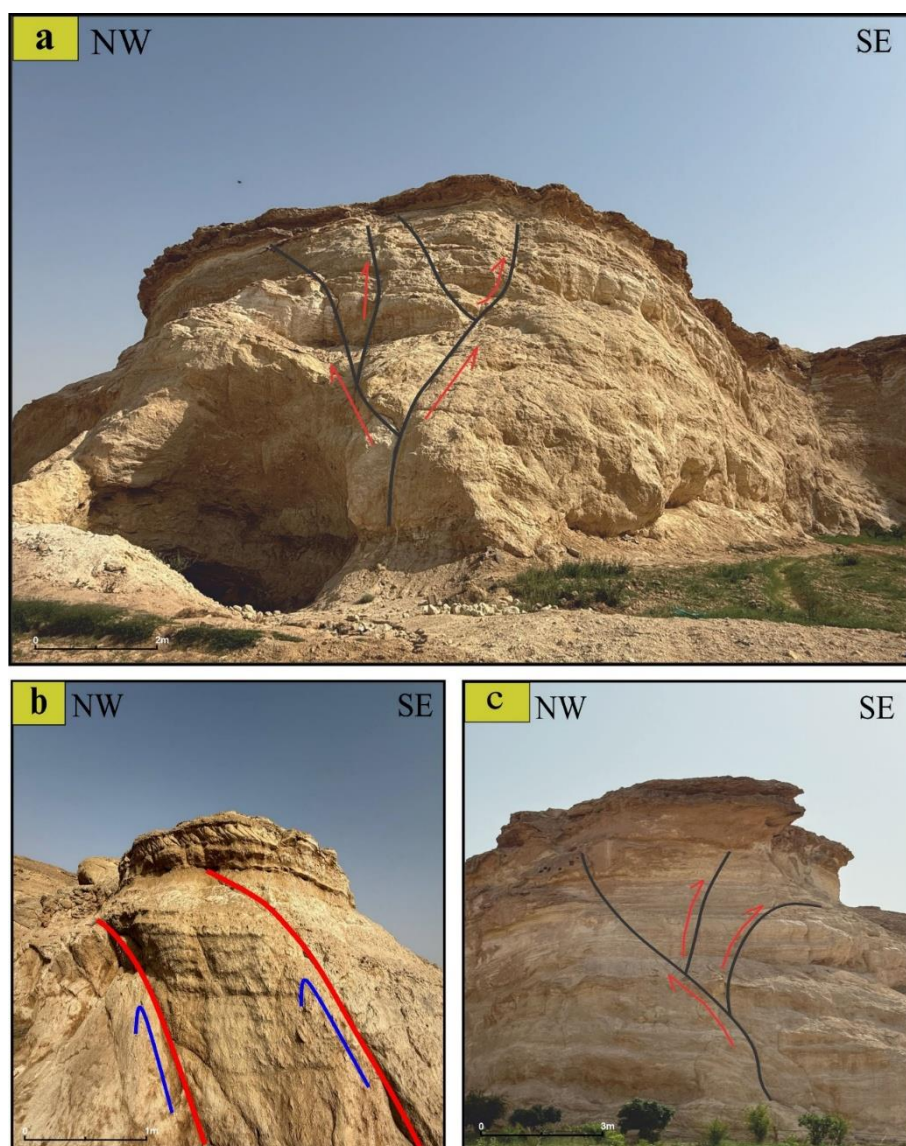


Fig.14. a) Positive flower structure Dulab outcrop's; b) Positive Flower Structure in Sahliyah outcrop's; c) Positive flower structure Dulab outcrop's

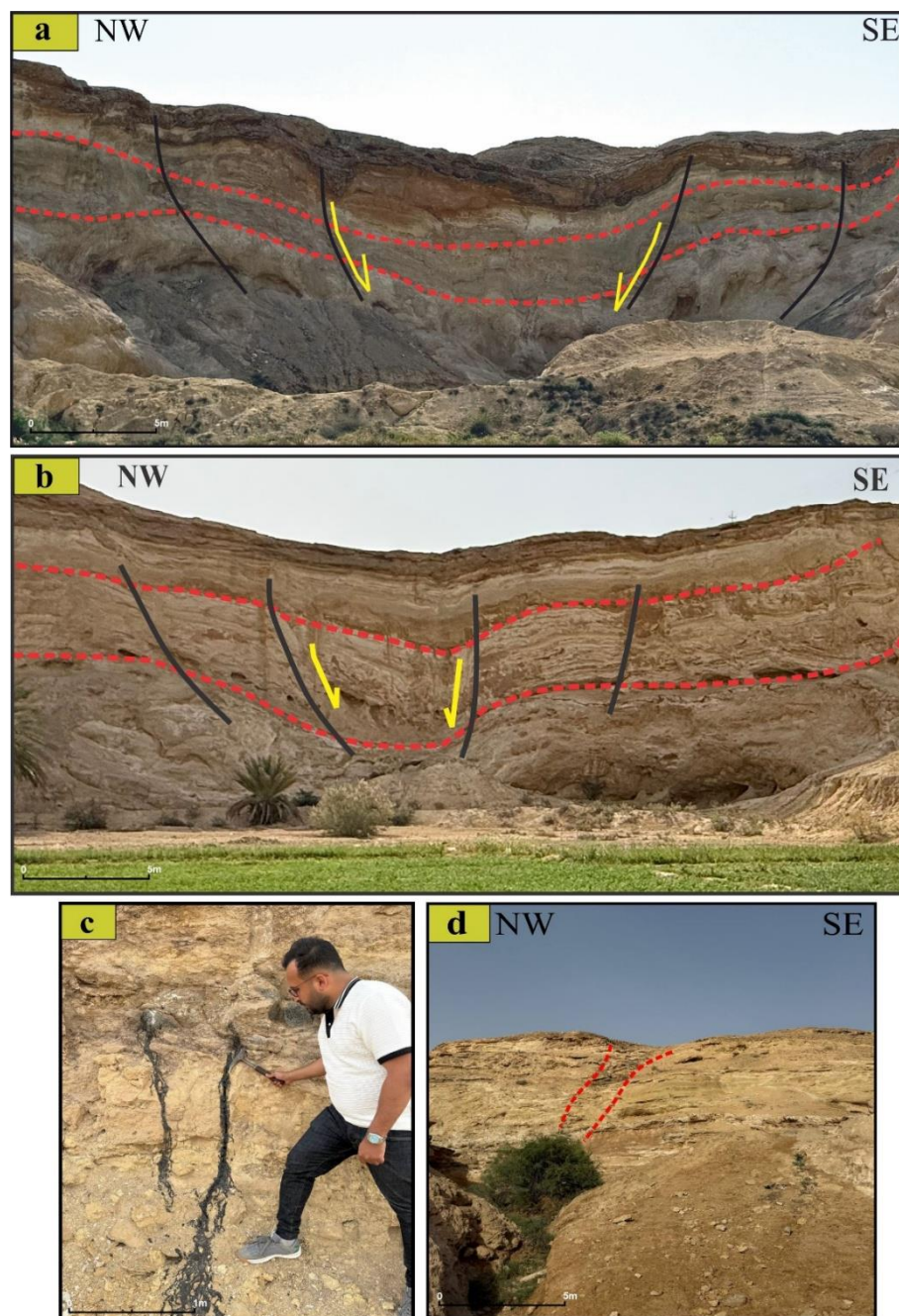


Fig.15. a and b) Graben in the Dulab outcrop's; c) Hydrocarbon seepage Heet outcrop's; d) Sediment dike and undulation in the Sahliyah outcrop's

6. Conclusions

This study provides an integrated structural-tectonic explanation of deformation in Western Iraq Heet–Sahliyah–Dulab–Al-Baghdadi–Anah using fracture classification and paleostress analyses. The detected joint sets hol, kl, and hko, together with the predominant shear systems hol acute about a and hol acute about c, suggest that deformation in the region is primarily dominated by regional compressional stress regimes. The paleostress study indicates NW–SE compressional orientations, which reflect the main tectonic stress fields that caused the formation of the observed fractures. The stress analysis trends align with the regional tectonic framework of western Iraq within the Stable Shelf (Inner Platform) of the Arabian Plate, showing that the platform interior has experienced considerable deformation, despite exhibiting a lower degree of folding in comparison to the Zagros Fold–Thrust Belt.

The results further show that the fracture pattern indicates a multi-phase deformation history in which regional far-field stresses associated with Zagros-related stresses were transferred westward into the Stable Shelf area, creating systematic jointing and shear fracturing.

Stress reorientation and/or episodic stacking of deformation phases are suggested by the appearance of a secondary NW–SE compressional trend, which is most likely controlled by the reactivation of inherited basement structures. This pattern is especially evident at the first and fifth stations. This study focuses on the major tectonic role of major structural elements, such as Abu Jir Euphrates Fault zone, Rutbah Uplift, and Anah Graben, which functioned as enduring deformation corridors that locally altered stress trajectories and increased fracture intensity. The measured data from stations between Heet and Sahliyah demonstrate that the Abu Jir fault system significantly influenced fracture geometry and deformation style. The deformation is characterized by right-lateral strike-slip movement with inversion-related structures, indicating Cenozoic reactivation.

Author contributions: CRediT

Abdullah A. Al-Mamouri: Proposing a research project, developing a research plan, and writing the manuscript Preparing the resulting maps and figures.

Jaffar H. Al-Zubaydi: Approving the research idea, choosing the study area, verifying the results, and verifying the manuscript writing.

Sa'ad R. Yousif: Contributing to the fieldwork in the study area, verifying the results, and contributing to writing the manuscript with linguistic editing.

Declaration of Competing Interest

The authors declare that they have no competing financial interests or personal relationships that could influence the work reported in this study.

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References

- Al-Bassam, K.S., Al-Bedaiwi, J.A., Al-Kadhimi, J., 1997. A study on the extension of Hail arch in Iraq: new findings from Al-Nukhaib region, S. Iraq. *Geoscience and Arab Development*, 1(2), 12-23.
- Alsouki, M., Taifour, R., 2015. The tectono-depositional evolution of the Syrian Euphrates Graben Area using the 3D seismic data. *Arabian Journal of Geosciences*, 8(9), 7577-7587. <https://doi.org/10.1007/s12517-014-1692-4>
- Bellahsen, N., Fiore, P., Pollard, D.D., 2006. The role of fractures in the structural interpretation of Sheep Mountain Anticline, Wyoming. *Journal of Structural Geology*, 28(5), 850-867. <https://doi.org/10.1016/j.jsg.2006.01.013>
- Bellen, R.C., Van, H.V. Dunnington, Wetzel, R., and Morton D., 1959. *Lexique Stratigraphique International*, Asia, Fasc., 10a, Iraq, Paris.
- Brown, G.F., Coleman, R.G., 1972. The Tectonic Framework of the Arabian Peninsula. *International Geological Congress*.
- De Ruiter, R.S.C., Lovelock, P.E.R., Nabulsi, N., 1994. The Euphrates Graben, Eastern Syria: a new petroleum province in the northern Middle East. In: M. Al-Hussieni (Ed.), *Geo.94, Middle East Petroleum Geosciences*, Gulf Petrolink, 1, 357-368.
- De Sitter, L. U., 1964. *Structural Geology* (2nd ed.). McGraw Hill, New York.
- Delvaux, D., Sperner, B., 2003. New aspects of tectonic stress inversion with reference to the TENSOR program. <https://doi.org/10.1144/GSL.SP.2003.212.01.06>

- Fossen, H., 2016. Structural Geology. Cambridge university press.
- Fouad, S. F. A., 1997. Tectonic and structural evolution of Anah Region, west Iraq. Ph.D. Theses, College of Science, University of Baghdad, Baghdad. Iraq.
- Fouad, S. F., 2007. Tectonic and structural evolution. Iraqi Bulletin of Geology and Mining, (1), 29-50.
- Fouad, S.F.A., 2015. Tectonic Map of Iraq Scale 1:1000 000 (3rd ed.). Iraqi Bulletin of Geology and Mining, 11(1), 1-7.
- Hancock, P.L., 1985. Joints and faults; the morphological of their origins. Proceedings of the Geologists' Association, 79(2), 141-151. [https://doi.org/10.1016/S0016-7878\(68\)80032-X](https://doi.org/10.1016/S0016-7878(68)80032-X)
- Hugman Iii, R.H.H., Friedman, M., 1979. Effects of texture and composition on mechanical behavior of experimentally deformed carbonate rocks. AAPG Bulletin, 63(9), 1478-1489. <https://doi.org/10.1306/2F9185C7-16CE-11D7-8645000102C1865D>
- Igwe, O., Okonkwo, I.A., 2016. Application of paleostress analysis for the identification of potential instability precursors within the Benue Trough Nigeria. Geoenvironmental Disasters, 3(1), 17. <https://doi.org/10.1186/s40677-016-0051-z>
- Jassim, S.Z., Goff, J.C., 2006. Geology of Iraq. Dolin, Prague and Moravian Museum, Brno.
- Kaven, J.O., Maerten, F., Pollard, D.D., 2011. Mechanical analysis of fault slip data: Implications for paleostress analysis. Journal of Structural Geology, 33(2), 78-91. <https://doi.org/10.1016/j.jsg.2010.12.004>
- Lacombe, O., Bellahsen, N., Mouthereau, F., 2011. Fracture patterns in the Zagros Simply Folded Belt (Fars, Iran): constraints on early collisional tectonic history and role of basement faults. Geological magazine, 148(5-6), 940-963. <https://doi.org/10.1017/S001675681100029X>
- Noon, M.A., Mohamed, A.A., Al-jibouri, A.S., 2026. Biostratigraphy and Paleocology of Azkand and Anah formations (Late Oligocene) in Wadi Al-Khazgha Algarbi, Anah area, West of Iraq. Iranian Journal of Earth Sciences. <https://doi.org/10.57647/j.ijes.2025.16943>
- Pollard, D.D., Martel, S.J., 2020. Structural Geology: A Quantitative Introduction. Cambridge University Press.
- Ramsey, J.G., Hubber, M.I., 1987. The Techniques of Modern Structural Geology. Vol.2, Folds & fractures Academic press. London, UK.
- Sissakian, V. K., Al-Ansari, N., Abdulahad, A. D., 2021. The Anah Anticline: An Outstanding Anticline between Two Major Tectonic Zones in Iraq. Geotectonics, 55(2), 250-260. <https://doi.org/10.1134/S0016852121020084>
- Sissakian, V. K., Fouad, S. F., 2015. Geological map of Iraq, scale 1: 1000 000, 2012. Iraqi Bulletin of Geology and Mining, 11(1), 9-16.
- Turner, F.J., Weiss, L.E., 1963. Structural Analysis of Metamorphic Tectonic, New York, 525.
- Weinberger, R., Eyal, Y., Mortimer, N., 2010. Formation of systematic joints in metamorphic rocks due to release of residual elastic strain energy, Otago Schist, New Zealand. Journal of Structural Geology, 32(3), 288-305. <https://doi.org/10.1016/j.jsg.2009.12.003>