ARTICLE
JOURNAL OF UNIVERSITY OF BABYLON
For Pure and Applied Sciences (JUBPAS)
Vol.33; No.4.| 2025

ISSN: 2312-8135 | Print ISSN: 1992-0652
info@journalofbabylon.com | jub@itnet.uobabylon.edu.iq | www.journalofbabylon.com

Structural Complexity of Folds in the Zagros Simple Folded Zone-northeast Iraq

Ali Hassan Mousa [1] and Ahmed A. Hasan [2 *]

[1, 2] Remote Sensing Department, College of Remote Sensing and Geophysics, AlKarkh University of Science, Baghdad, Iraq

ali.h@kus.edu.iq [1] ahmad.a.h@kus.edu.iq [2 *]

Accepted:	24/12/2025		Published:	31/12/20253

ABSTRACT

This paper examines the structural complexity of the Zagros Simple Folded Zone (ZSFZ), which covers northeast Iraq, with a significant major emphasis on geological units and fold morphology, as well as tectonic deformation processes occurring in that region. The Zagros Mountain Belt, which covers a large portion of northeast Iraq, formed as a result of plate convergence between Arabia and Eurasia.

The study area, which shows different fold styles such as symmetrical, asymmetrical, overturned, and fault propagation folds, depending upon lithology contrast or tectonic stress, is an arc-shaped region in the Kurdistan Region. Seismic reflection data were analyzed for subsurface information, which shows that the Foothill Zone, where most of the studied anticlines are found, shows structural control by various thrust faults, decollement planes, and episodes of back thrusting.

Important anticlines like Chamchamal, Dari, Qara Dagh, Pulkhana, and Chia Surkh were individually studied for their geometric characteristics and evolutionary development of folds, as well as the effects of major thrusting episodes. It appears from tectonic evolution that existing faults, as well as sediment layers, are of great importance for the development of folds.

This information offers key insight for hydrocarbon exploration, pinpointing structural elements of a trap as well as underground features that increase reservoir capacities. Knowledge about deformation processes in the Zagros Fold-Thrust Belt improves models for geophysical exploration. This work stresses that it is crucial to combine information about seismic studies, fieldwork, and structural geology to acquire a profound understanding of its tectonic settings.

Keywords: Folding, Faulting, ZSFZ, Iraq.

مجلة جـــامعة بـــابل للعلـــوم الصـــرفة والتطـــبيقية مجلة جـامعة بـابل للعلـــوم الصـرفة والتطـبيقية مجلة جـامعة بـابل للعلـوم الصـــرفة والتطـــبيقية

1 INTRODUCTION

The simple Zagros folded zone, or ZSFZ, refers to a major geographical feature that runs along the Zagros Mountain range, forming a major structural or tectonic boundary in northeast Iraq. This area has gotten a lot of attention from geologists, as well as various fields associated with resource exploration, owing to its unique folding features, as well as a host of complicated geological structures that define its structural behavior. Analysis of a simple Zagros zone would not only contribute, therefore, to tectonic studies but also help decode processes that influence deformation, with implications for resource exploration, such as oil or minerals [1].

The Zagros Mountain Range formed as a result of tectonic forces that are still in a state of progression as a result of convergence between the Arab and Eurasian plates [2]. This convergence resulted in a set of folds as well as impulse belts, with ZSFZ being a notable example of folds created as a result of such tectonic forces. The structural complexity of this bent zone exhibits different sorts of folds, such as symmetrical, asymmetrical and overthrown folds, which exhibit the intensity of tectonic force that caused stresses as well as tensions [3]. It requires a great level of morphology as well as different geographical locations to understand tectonic history as well as its subsequent effects related to landscape, sediment and metal deposits.

Considering deformation mechanisms, folds at ZSFZ may result from a combination of several factors, such as lateral extrusive forces, flexion sliding, or failed folds. Typically, a combination of this deformation mechanism results in a range of structures of different scales, which may further affect the physical properties of regional materials [4] [5].

Seismic Reflection Data Interpretation is a widely used technique for subsurface geology analysis, which uses processed seismic data [6]. This technique provides a clearer view of the subsurface geology structures. Seismic sections, time, as well as velocity contour maps, are used for structural trap identification and analysis of seismic stratigraphy and seismic facies. [7] [8].

The main goal of seismic interpretation is to create a general image of subsurface geology, with emphasis on structural trap mapping with respect to reservoir tops [9]. It also assesses hydrocarbon prospects with respect to a given site, as it generates a site for drilling [10]. Seismic information is also useful for determining geology, such as faults or folds, beneath a geographical site [11] [12].

For this research, seismic data has been utilized for identifying as well as for creating a map of structural geology in the studied region. It should be noted that the studied region, which falls under Kurdistan in northeast Iraq, is about 70 km south and southwest of Sulaimani Governorate, with a covered area of 15,140 km² (Fig. 1). This research will use high-resolution 3D seismic data for interpretation related to subsurface structures, such as anticlines, as well as faults.

The complexity of the Zagros simple fold zone has structural ramifications that go beyond academic research. For instance, it has been noted that simple fold structures such as that of Zagros are of significant importance in regard to oil exploration since folding mechanisms often result in ideal conditions for oil entrapment, such as in the Zagros Uplift [13]. Geological mapping of structural features, which forms a significant aspect of studying structural information, for example, ZSFZ, plays a crucial role in optimizing oil exploration endeavors as structural

ISSN: 2312-8135 | Print ISSN: 1992-0652
info@journalofbabylon.com | jub@itnet.uobabylon.edu.iq | www.journalofbabylon.com

ISSN: 2312-8135 | Print ISSN: 1992-0652
info@journalofbabylon.com | jub@itnet.uobabylon.edu.iq | www.journalofbabylon.com

information helps in understanding regional development, which guides future oil exploration endeavors [14].

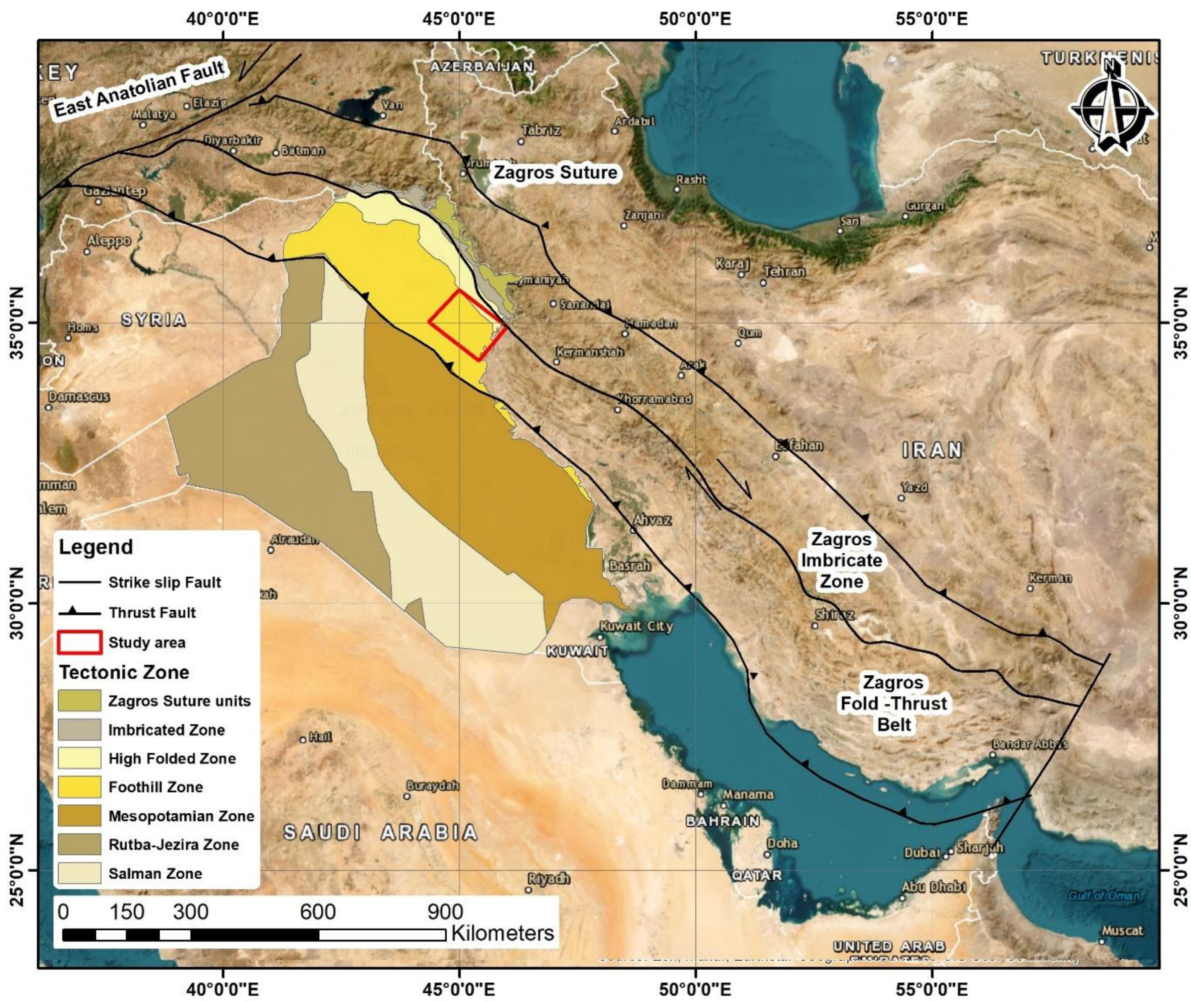


Figure 1: Tectonic map illustrating the location of the study area [15].

2 GEOLOGIC SETTING:

The Arabian Plate, which is a component of the young and active Zagros orogeny that makes up the structure under investigation, has a complicated tectonic history with both active and passive borders. The ZFTB, which is a component of the Alpine-Himalayan belt, is the Arabian plate's distorted NW margin, which was created by the plate's continuous convergence with the Eurasian plate. About 2000 km long, the collisional belt of the Zagros orogeny begins in southeast Turkey, travels through the KRI and east of Iraq before heading west of Iran, and ends in the southeast at the Hormuz Strait and the Oman Mountains [16][17][18][19][20][21][22].

The Zagros Suture, the Imbricated Zones, the High Folded Zone (which is the counterpart of the Simply Folded Belt in the Iranian portion of the Zagros), and the Foothill Zone are the four NW-SE striking tectonic units that make up the fold-thrust belt in northern Iraq [23]. Foothill Zone [24] [23] [18] is where the research area is located. The foothill zone's anticlines are running E-W in the northwest and NW-SE in the southeast. This subzone contains thick Pliocene-aged molasses sediment and clearly visible deep and lengthy synclines [23].

The region of study, which falls under the simple fold zone of Zagros, covers a large geographical domain in northeast Iraq (Fig. 1), with a high structural complexity. Analysis of this complexity in relation to its folds, as well as deformation mechanisms, helps shed more insight into tectonic deformation, which has been linked to resource availability [25].

Sedimentary deposits with high thickness, including sandstone, dolomite, lutite, and limestone, under high compression during the late Cenozoic era, forming the geologically complexes Zagros Simple Fold Zone (ZSFZ), characterize this region. It is noteworthy that as a result of this compression, which generates symmetric as well as asymmetric features like anticlines and synclines, conditions for generating stratigraphic traps that must exist for hydrocarbon storage have been established. Analysis of hydrocarbon resources, including estimation of conditions at depth, has been largely reliant on structural complexity [26].

Bakhtiani, Pabdeh, and Gurpi formations are among the units of ZSFZ that formed under different conditions during different times of the Mesozoic to Cenozoic era [27][28][3]. As a result of tectonic compression, deformation, and forces, units may possess different qualities, for example, different lithologies, as a result of faulting or fracture. This indicates that the geographical features, which formed as a result of colliding plates, that is, Arabian, as well as Eurasian plates, possess a significant influence on ZSFZ units.

Some key formations include the Bija formation, which indicates a transition towards more terrestrial deposits, as well as the Pindá, which dates from the late Jurassic to early Cretaceous periods, serving as a reservoir as well as a source for hydrocarbon deposits. The Cenomanian Balambo and Albian Gercus formations demonstrate further complexities in deposition, which are affected by tectonic uplift as well as changes in sea level. Basic structural configuration, as well as carbonate sedimentation, occurs under the influence of upper stratigraphic units such the Fatha, Shiranish, and Kometan formations [25].

Hydrocarbon potential, as well as structural dynamics of the region, is affected by other major formations such as Injana, Hazar-Marad and Pilaspi. It should be noted that structural complexities existing in the region are a result of tectonic as well as sedimentational forces, where mechanical properties of such formations control deformation processes such as faulting as well as folding. Overall, structural complexity of ZSFZ is imperative in understanding tectonic evolution, as well as hydrocarbon development, of this region [29].

ISSN: 2312-8135 | Print ISSN: 1992-0652
info@journalofbabylon.com | jub@itnet.uobabylon.edu.iq | www.journalofbabylon.com

مجلة جامعة بابل للعلوم الصرفة والتطبيقية مجلة جامعة بابل للعلوم الصرفة والتطبيقية مجلة جامعة بابل للعلوم الصرفة والتطبيقية

info@journalofbabylon.com | jub@itnet.uobabylon.edu.iq | www.journalofbabylon.com ISSN: 2312-8135 | Print ISSN: 1992-0652

3 METHODS AND MATERIALS

This study relied primarily on the interpretation of a comprehensive geophysical dataset and geological and tectonic maps, including ten seismic sections at the locations shown in Figure 1, to study the complexity of the low folded zone, specifically within the study area.

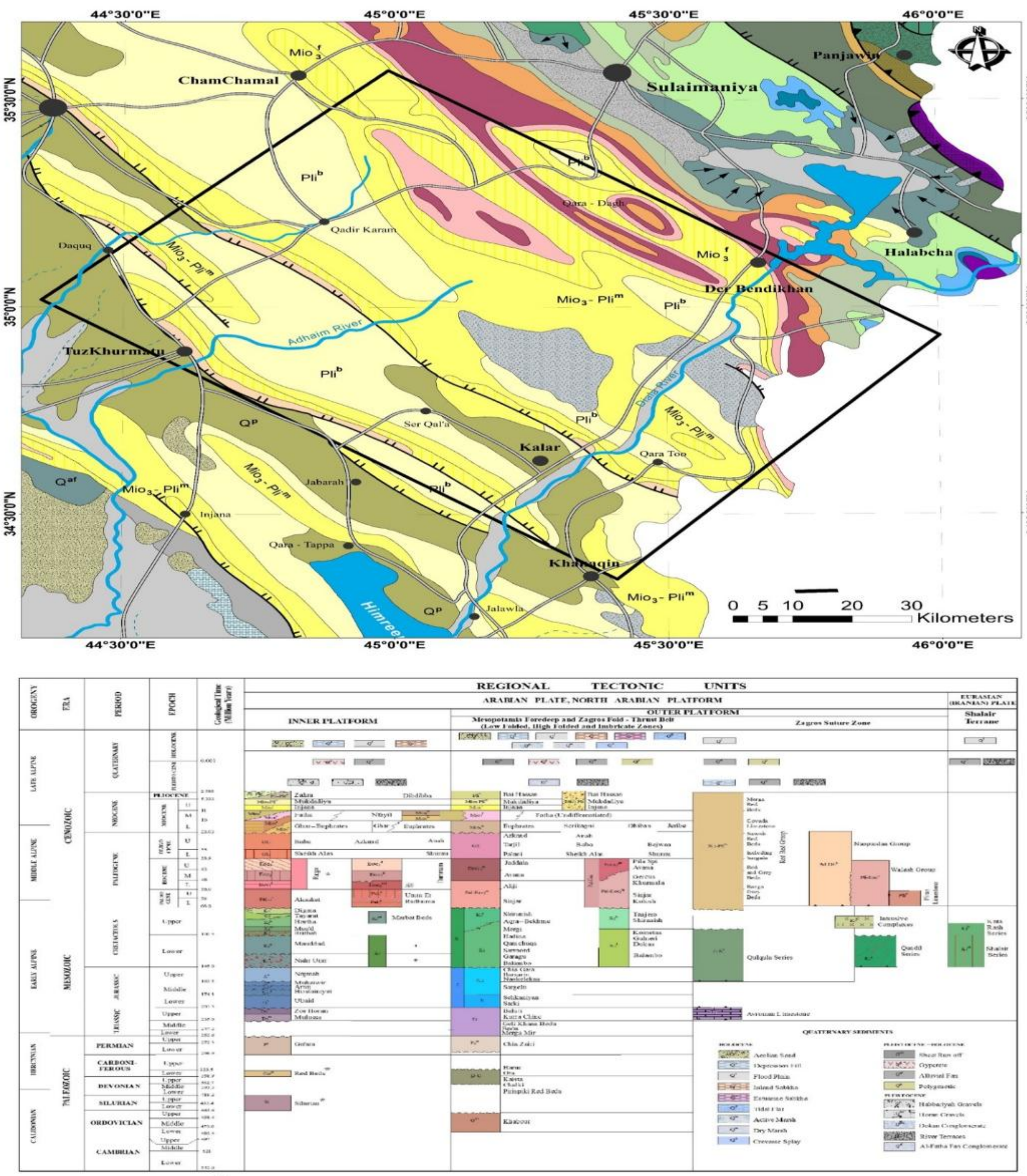


Figure 2: Geologic map of the studied area (GEOSERV-Iraq).

مجلة جامعة بابل للعلوم الصرفة والتطبيقية مجلة جامعة بابل للعلوم الصرفة والتطبيقية مجلة جامعة بابل للعلوم الصرفة والتطبيقية

4 RESULTS AND DISCUSSIONS

Traditionally, structural analysis has been carried out in the field by looking at real rocks and how they deform. Analog model research has been the alternative strategy [30]. Conversely, reflection seismic technology is already developing to the point where seismic segments will serve as the virtual geological field. The geologic structure history can also be uncovered using other data sets, including as well prospective field data, which are typically utilized to support reflection seismic data.

The folds in the study area can be classified mainly into various structural types: symmetric and asymmetric, and each type is influenced by the mechanical properties of the strata involved. The symmetrical folds, characterized by uniform extremities with respect to the axial plane, are often developed in more ductile layers, such as the carbonate sequences found in the upper Jurassic formations. These folds commonly reflect a less intense degree and are associated with gradual and uniform shortening during the tectonic load process.

On the other hand, there are asymmetric folds that display a complicated morphology with varied angles as well as varying lengths of limbs. This usually reflects an intensification of contrast in competition between rock units, thus favoring directions of folding owing to contrasts in strength. One example seen in the Zagros region includes asymmetric folds seen in amalgamated sandstone belonging to the upper Cretaceous as well as shaly formations, where steeper dives with larger deformation features are demonstrated by units of more competent material as opposed to units of less competent material.

Moreover, being characterized by reclined structures, they usually indicate strong forces of compression, as well as being believed to occur in specific tectonic events or deformation phases. In ZSFZ, such structures are related to major periods of tectonic reactivation with a strong connection to thrust failure, which usually occurs at the front or edge of major fold structures. On the other hand, the major lateral shortening indicated by such upper folds offers information about the period of compression in the fold belt, indicating areas with high deformation rates, which in turn produce specific mechanisms related to resource entrapment.

The association of the bedding series of beds, such as the Adaiyah and Najma formations, to the different levels of ductility and breakability increases the complexity of the folding pattern. These rock units also influence fold thickness as well as the resulting felt folding mechanics. The greater ductility of the shale beds results in them being more effective decoupling layers during deformation and hence permits the development of more complex interfered folding styles, such as set-aside folds common in the study area.

Fold development is influenced by the interaction of the present faults and fractures that facilitate a local weakening of strata and thus transform the folding activity. The presence of such discontinuities can result in complex fold geometries like overturned and disharmonic folds that deviate from the classical models [31]. The structural complexity that develops as a result stresses the need for accurate geomechanical investigations to determine the interaction of folding activities and defect formation.

ISSN: 2312-8135 | Print ISSN: 1992-0652
info@journalofbabylon.com | jub@itnet.uobabylon.edu.iq | www.journalofbabylon.com

مجلة جامعة بابل للعلوم الصرفة والتطبيقية مجلة جامعة بابل للعلوم الصرفة والتطبيقية مجلة جامعة بابل للعلوم الصرفة والتطبيقية

Apart from that, the kinematic processes are also of significant contribution in the folding evolution of the simple zagros folded zone. The deformation is compressive and is responsible for several mechanisms of folding, namely flexion shift and similar deformation. The flexion shift occurs when the layers slip past each other but still remain intact, occurring on the axial surfaces where litter plans slide over litter plans for layer rotation [32]. It results through inducing huge changes in the amplitude of the folds and the wavelength, which reflects the distribution of deformation present in the fold structures.

The Zagros' Orogenic system has been shaped by a series of compression events driven mainly by the collision of Arab and Eurasian tectonic plates. This collision has not only led to the formation of a large folding belt, but also caused a significant uplift and surge. The underground rocks, mainly composed of crystalline metamorphics and igneous intrusions, have variable rheological properties which influence the way in which the above-mentioned strata react to the compression forces. The presence of these heterogeneous underground rocks leads to a differential deformation of the sedimentary coverage, often causing the development of complex fold models that are not consistent in the region.

The ZSFZ is characterized by a series of well -defined folds, largely resulting from the compression associated with the collision between the Arab and Eurasian tectonic plates [33]. As the tectonic forces acted in the region, the pre -existing sedimentary strata underwent significant deformation, including folding, flaws and other associated processes.

The folds in the study area have geometries and variable orientations, that derive from different deformation mechanisms. The complexity of these structures is often attributed to the interaction of tectonic forces, sedimentary processes, and variations in the mechanical properties of the lithological units. The location of the deformation along weak layers can lead to the development of narrow folds and folds of propagation of faults.

4.1 Folding and Faulting:

The many anticlines are developed within the Foothill Zone; their axes run in the NW-SE direction (Figure 3). The oldest exposed rocks belong to the Fat'ha and Pila Spi formations. The Fat'ha Formation forms the bulk of the core. The 2D seismic data of anticlines in the studied area illustrate the structural styles of these anticlines. The structures are examples of simple anticlines and examples of sub-thrust structures below a detachment at the Miocene evaporite level.

The Dari anticline is developed within the Foothill Zone. It lies in the southwestern corner of the studied area. Its axis runs in a NW-SE direction, in which the Bai Hassan Formation is exposed. Its surface length is about 36 km [34]. The Dari anticline is an asymmetrical, linear fold with a rounded hinge, doubly plunging. The northwestern plunge is within the map area on Wadi Beber.

The Chamchamal anticline (Sangaw structure) is a brachy, asymmetrical, non-cylindrical that is form doubly plunging [35]. The core of the Chamchamal Anticline is built up of two dome structures: the Qara Wais and Ajdagh domes, which are arranged in echelon form and separated structurally and topographically by a low saddle. The oldest exposed rocks belong to the Pila Spi Formation. Its length is 16.35 Km, with a steeper southwestern flank and a gentler northeastern

ISSN: 2312-8135 | Print ISSN: 1992-0652
info@journalofbabylon.com | jub@itnet.uobabylon.edu.iq | www.journalofbabylon.com

one. The oldest exposed rocks belong to the Pila Spi Formation. The crest of the Chamchamal anticline is deeply eroded to a level that leads to exposure of the Pila Spi Formation.

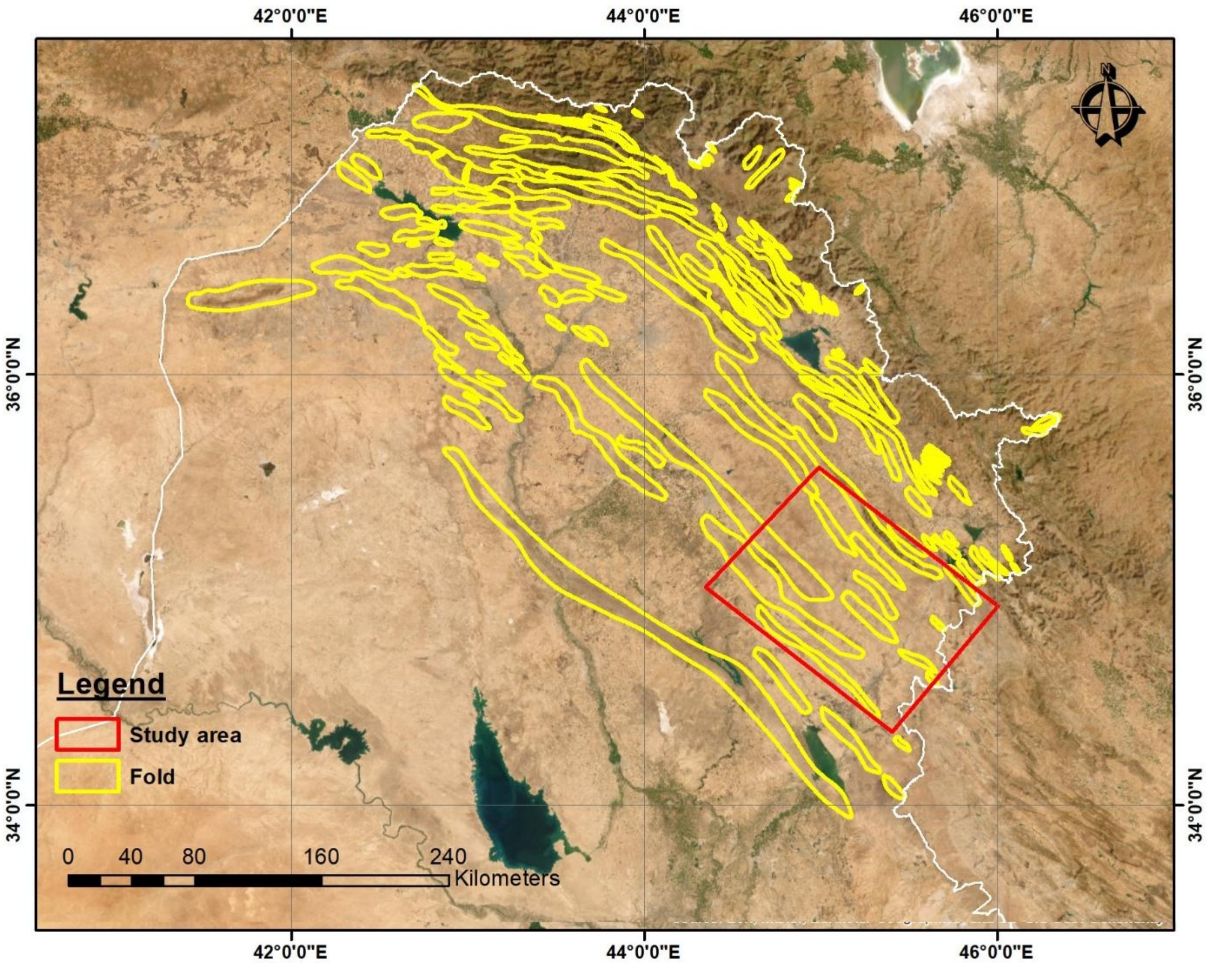


Figure 3: shows the trending of folds in the study area.

The 2D seismic data of the Chemchemal anticline illustrate the structural styles of this anticline and neighboring anticlines (Figure 4). The structure is an example of a simple anticline and an example of sub-thrust structures below a detachment at the Miocene evaporite level.

Seismic section structural interpretation verifies that the majority of the present-day structure was formed within the last 5 million years by a significant push. On the sides of the current structure, smaller-scale faulting and back thrusts were caused by thrusting that occurred earlier. This leads to complicated geometries that have not been completely elucidated. The presence of the predicted sub-surface anticline is confirmed by an apparent unconformity at the top Kolosh/base Pila Spi, which indicates the beginning of a time of fast sediment deposition. These sediments were undeformed until the last phase of considerable thrusting, which led to the formation of the present-day surface anticline.

info@journalofbabylon.com | jub@itnet.uobabylon.edu.iq | www.journalofbabylon.com ISSN: 2312-8135 | Print ISSN: 1992-0652

مجلة جامعة بابل للعلوم الصرفة والتطبيقية مجلة جامعة بابل للعلوم الصرفة والتطبيقية مجلة جامعة بابل للعلوم الصرفة والتطبيقية

مجلة جـــامعة بـابـل للعلـــوم الصـرفـة والتطـبيقيـة مجلـة جـامعة بـابـل للعلـــوم الصـرفـة والتطـبيقيـة مجلـة جـامعة بـابـل للعلـــوم الصـــرفـة والتطـــبيقيـة

info@journalofbabylon.com | jub@itnet.uobabylon.edu.iq | www.journalofbabylon.com ISSN: 2312-8135 | Print ISSN: 1992-0652

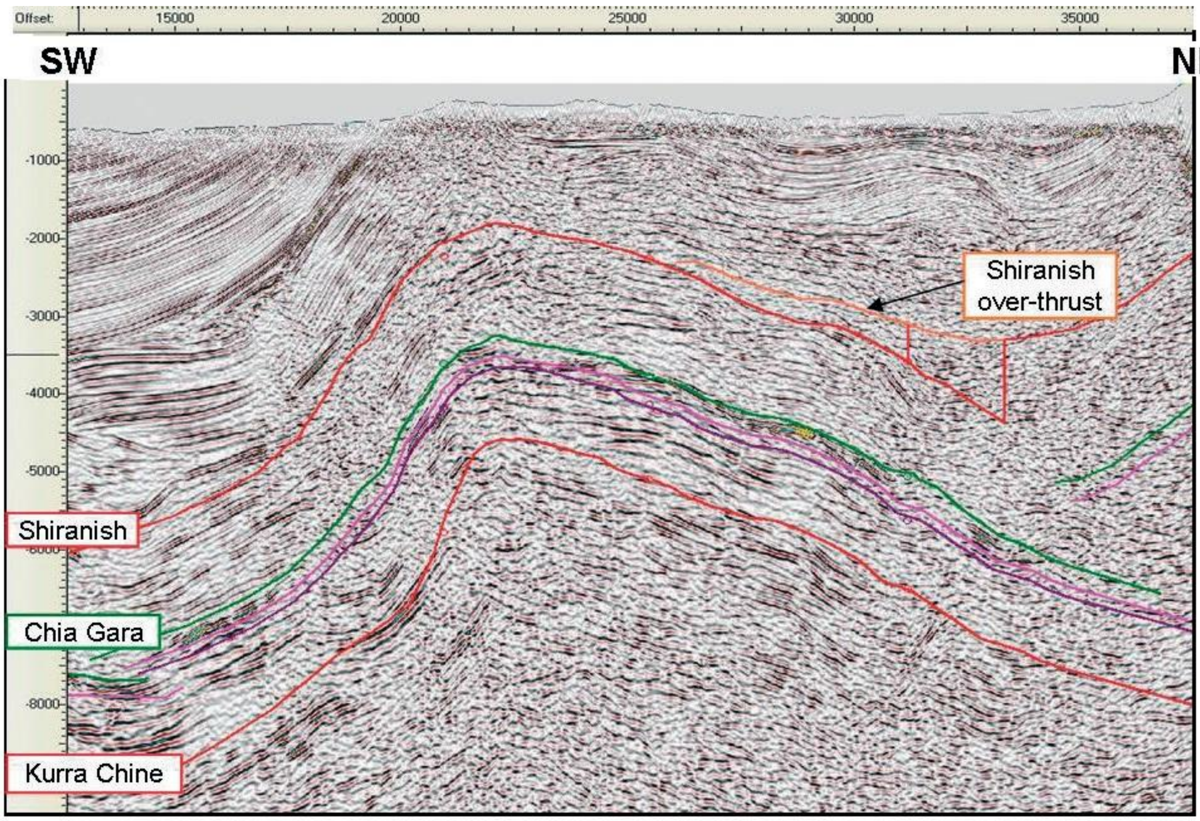


Figure 4: shows the characteristics of the thrust system based on the interpretation of 2D seismic profiles of the Chemchemal anticline [36]. Fig. 12 shows the precise position of this seismic profile.

The Qara Dagh Anticline runs in a NW-SE direction within the High Folded Zone. [23] regarded the southwestern boundary of the High Folded Zone as running along the southwest flank of the Qara Dagh anticline. This boundary coincides with the deepest fault over 3000 m displacement [23]. [24] showed that the Zagros Mountain Front fault is a reverse slip system. The oldest exposed rocks belong to the Pila Spi Formation, which forms the bulk of the Qara Dagh Range. At the surface, its length is about 108.75 km. The anticline is asymmetrical, doubly plunging, and linear with a sub-rounded hinge. The southeastern plunge occurs southwest of Derbendikhan town, whereas the northwestern plunge lies west of Agh Jalar village.

Pulkhana is a thruster and longitudinal structure. The axis is covered as a result of the northeastern limb thrusting over the southwestern limb and dipping a few degrees to 53°. The axis and the push are parallel. Three typical faults terminate the thrust. The thrust has a horizontal displacement of 3–8 kilometers. There is around a 2-kilometer vertical displacement. With a northeastern downthrown block, the Pulkhana Structure's biggest normal fault stretches for 15 km. One kilometer is the horizontal displacement. There is a 300-meter vertical displacement.

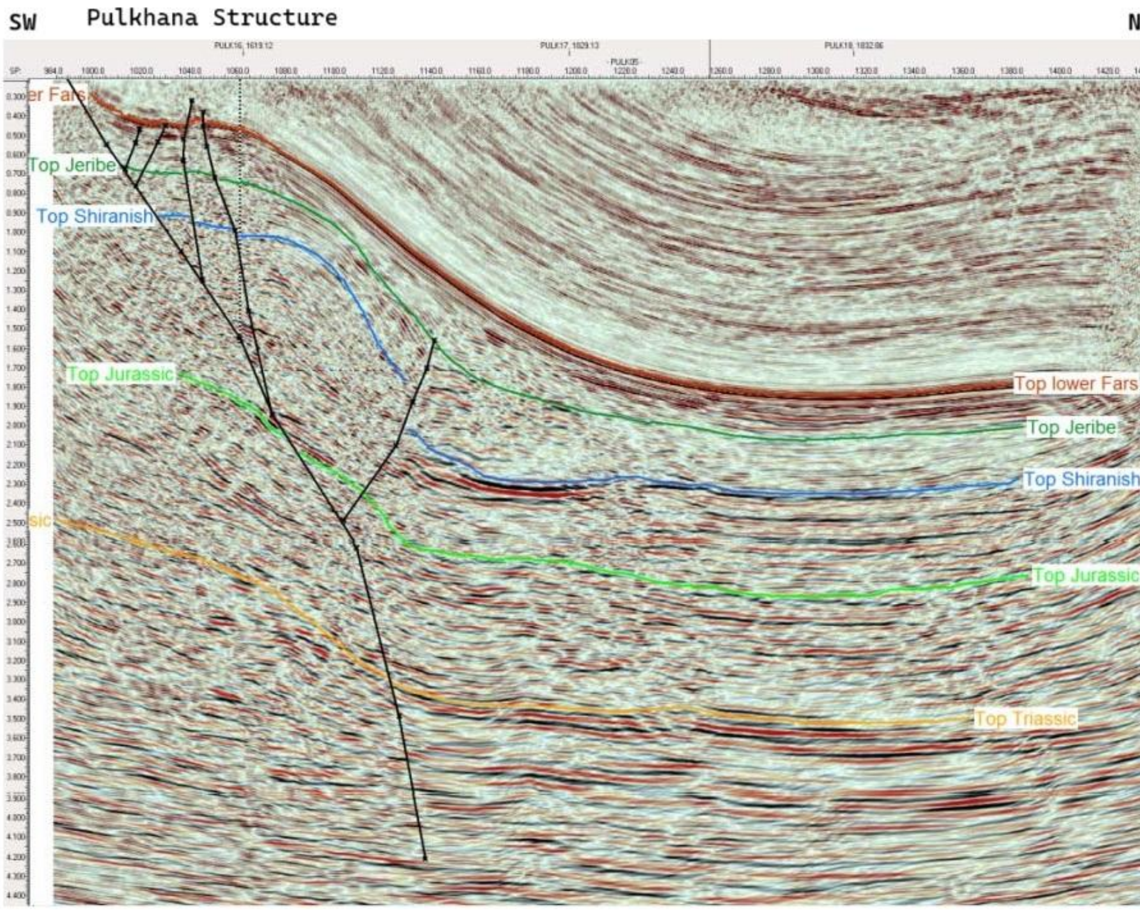


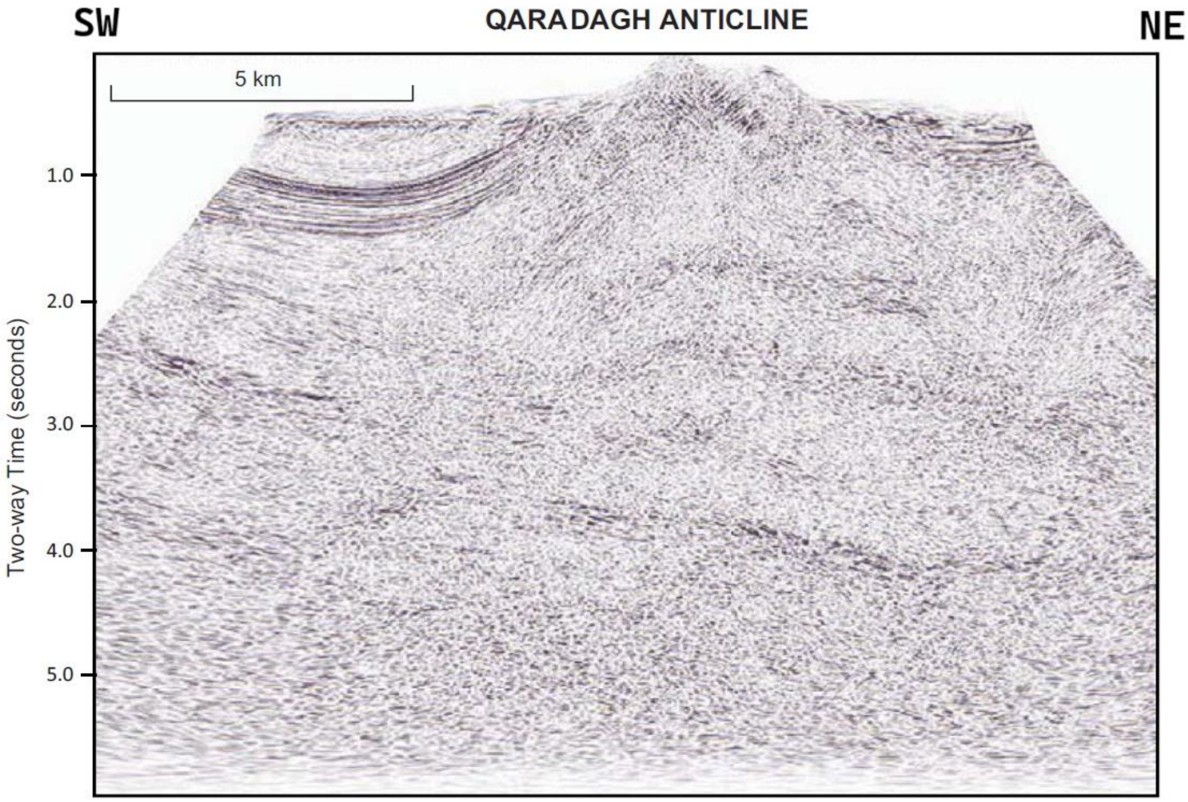
Figure 5: shows the characteristics of the thrust system based on the interpretation of 2D seismic profiles of the Pulkhana structure [36]. Fig. 12 shows the precise position of this seismic profile.

The Qaradagh anticline is a significant anticline that runs along the border of the High and Low Folded Zones for approximately 95 kilometers [37]. [38] classed or illustrated this anticline as a fault propagation fold, and [37] assumed the same mechanism for folding as well and drew a cross section to illustrate it. [29] utilized the same figure to calculate shortening of the Zagros Mountain Front Fault (ZMFF), which is thought to coincide (or emerge) close to the lower portion of the southwestern limb of the Qaradagh anticline north of Sangaw, and is responsible for its formation, according to the latter two studies. According to [35], the Qara Dagh anticline is a double plunging, NW-SE trending anticline with several water and wind gaps that split it into six segments. The northwestern plunge of the anticline has the lowest height point, 421 m (a.s.l.), while the southeast plunge has an elevation of 505 m (a.s.l.), and the highest peak, Sagerma Mountain, is 1834 m (a.s.l.). Hanjira (Qara Darbandi), Ba Sara, Sagerma, Zarda, Spei, and Golan are the six main segments of the Qara Dagh Range. In our research, we have recognized them as segments of the main Qara Dagh anticline, which runs from northwest to southeast.

info@journalofbabylon.com | jub@itnet.uobabylon.edu.iq | www.journalofbabylon.com ISSN: 2312-8135 | Print ISSN: 1992-0652

[39] just posted a low-resolution seismic profile of the Qaradagh anticline online, which has been structurally interpreted. An anticline and a primary reverse fault that exhibits a fault propagation fold are shown on this profile (Figure 6). Multiple interpretations of the profile are possible; the current study's interpretation is shown by light green lines that exhibit parasitic folding and do not depict the reverse fault.

Figure 6: 2-D seismic section showing areas of poor seismic imaging and structural complexity



in the anticlines' cores and crestal portions [40].

The Chia Surkh anticline (Qula structure) is a major anticline trending in the NW-SE strike direction coinciding with the ZFTB trend and three longitudinal systematic reverse faults situated on the SW side of the Chia Surkh anticline. The structures developed during Alpine Orogeny movements during the Early Miocene age. It is a double-plunging anticline. The Injana Formation is exposed in the core. The axis crosses the Diyala River. A reverse fault cuts the southern limb of the anticline causing steepening and local overturning of the beds.

مجلة جامعة بابل للعلوم الصرفة والتطبيقية مجلة جامعة بابل للعلوم الصرفة والتطبيقية مجلة جامعة بابل للعلوم الصرفة والتطبيقية

info@journalofbabylon.com | jub@itnet.uobabylon.edu.iq | www.journalofbabylon.com ISSN: 2312-8135 | Print ISSN: 1992-0652

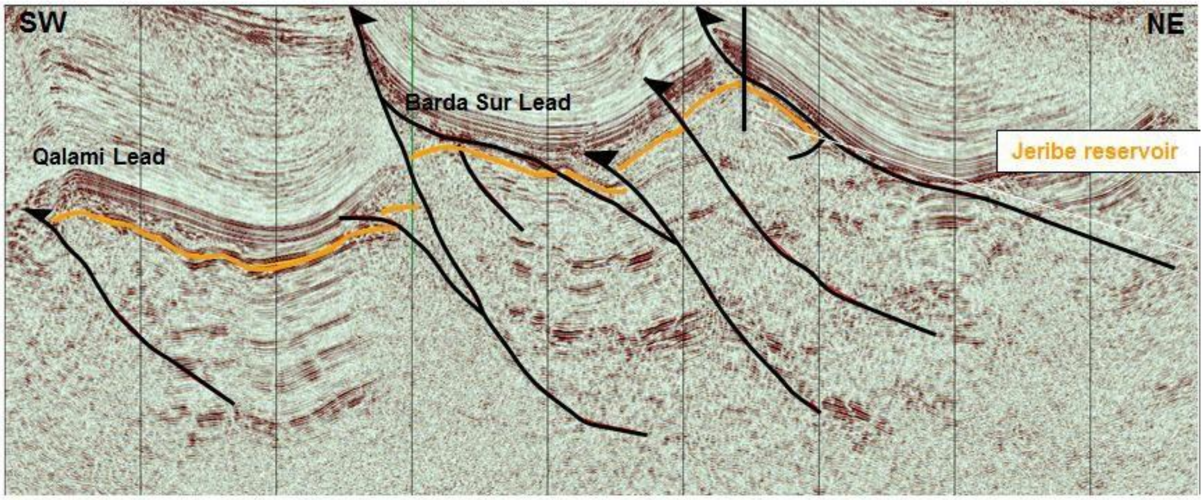


Figure 7: shows some characteristics of the thrust system based on the interpretation of 2D seismic profiles of the Chia Surkh structure [36] . Fig. 12 shows the precise position of this seismic profile.

The Bow and Arrow Rule is used to infer the direction of tectonic motion at the research location. This technique connects the two extremities (tip points) of a single thrust's outcrop trace with a straight line. This line's length represents an estimate of the displacement, and its perpendicular bisector provides an estimate of the slip direction (Figure 8) and table (1).

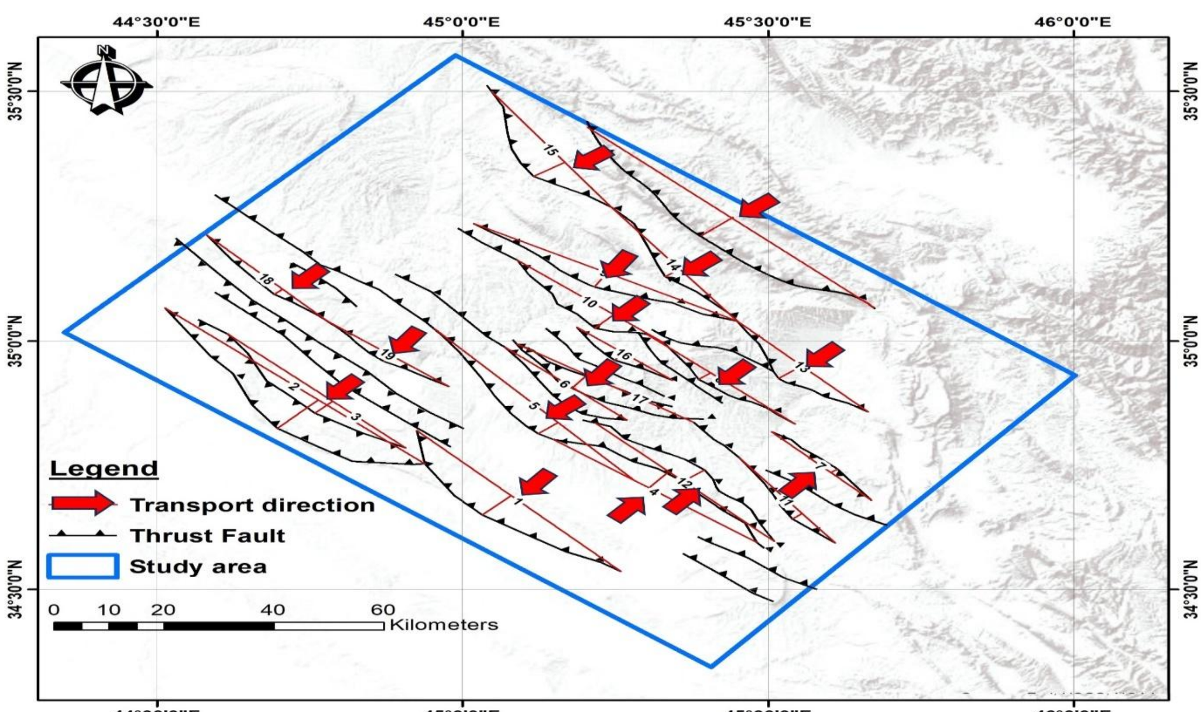


Figure 8: Transport direction in the research region as determined by the Bow and Arrow rule.

ISSN: 2312-8135 | Print ISSN: 1992-0652
info@journalofbabylon.com | jub@itnet.uobabylon.edu.iq | www.journalofbabylon.com

مجلة جامعة بابل للعلوم الصرفة والتطبيقية مجلة جامعة بابل للعلوم الصرفة والتطبيقية مجلة جامعة بابل للعلوم الصرفة والتطبيقية

مجلة جامعة بابل للعلوم الصرفة والتطبيقية مجلة جامعة بابل للعلوم الصرفة والتطبيقية مجلة جامعة بابل للعلوم الصرفة والتطبيقية

info@journalofbabylon.com | jub@itnet.uobabylon.edu.iq | www.journalofbabylon.com ISSN: 2312-8135 | Print ISSN: 1992-0652

Table 1: shows the primary thrust displacement estimates for the study Region according to the Bow and Arrow rule.

Fault No.	Displacement (Km)	Accumulated displacement (Km)	Direction
0	4.56	4.56	SW
1	7.8	12.36	SW
2	5.8	18.16	SW
3	5.09	23.25	SW
4	4.6	27.85	NE
5	4.6	32.45	SW
6	4.63	37.08	SW
7	1.93	39.01	NE
8	3.1	42.11	SW
9	4.58	46.69	SW
10	5.1	51.79	SW
11	2.6	54.39	SW
13	5.9	60.29	SW
14	3.47	63.76	SW
15	6.9	70.66	SW
16	2.78	73.44	SW
19	3.2	76.64	SW
24	4.7	81.34	SW

Faults and structural patterns were portrayed to show the tectonic elements that define the region as a result of the geologic integration and the interpretation of seismic data. The tectonic feature that is most prevalent is the NW-SE thrust faults, which run subparallel to the fold axis extension with a typical NE dip (Figure 9). Numerous significant decollement faults, including lower Paleogene, lower Miocene, and lower Mesozoic decollements, are also present in the region (Figure 10).

In addition, the area's structural pattern identifies two major units that define it, and the Paleogene and Mesozoic structural elements that major Decollment Fault separates on one another, where the faults flow from northwest to southeast, are implicated in the area's structural structure (Figure 10).

مجلة جامعة بابل للعلوم الصرفة والتطبيقية مجلة جامعة بابل للعلوم الصرفة والتطبيقية مجلة جامعة بابل للعلوم الصرفة والتطبيقية

info@journalofbabylon.com | jub@itnet.uobabylon.edu.iq | www.journalofbabylon.com ISSN: 2312-8135 | Print ISSN: 1992-0652

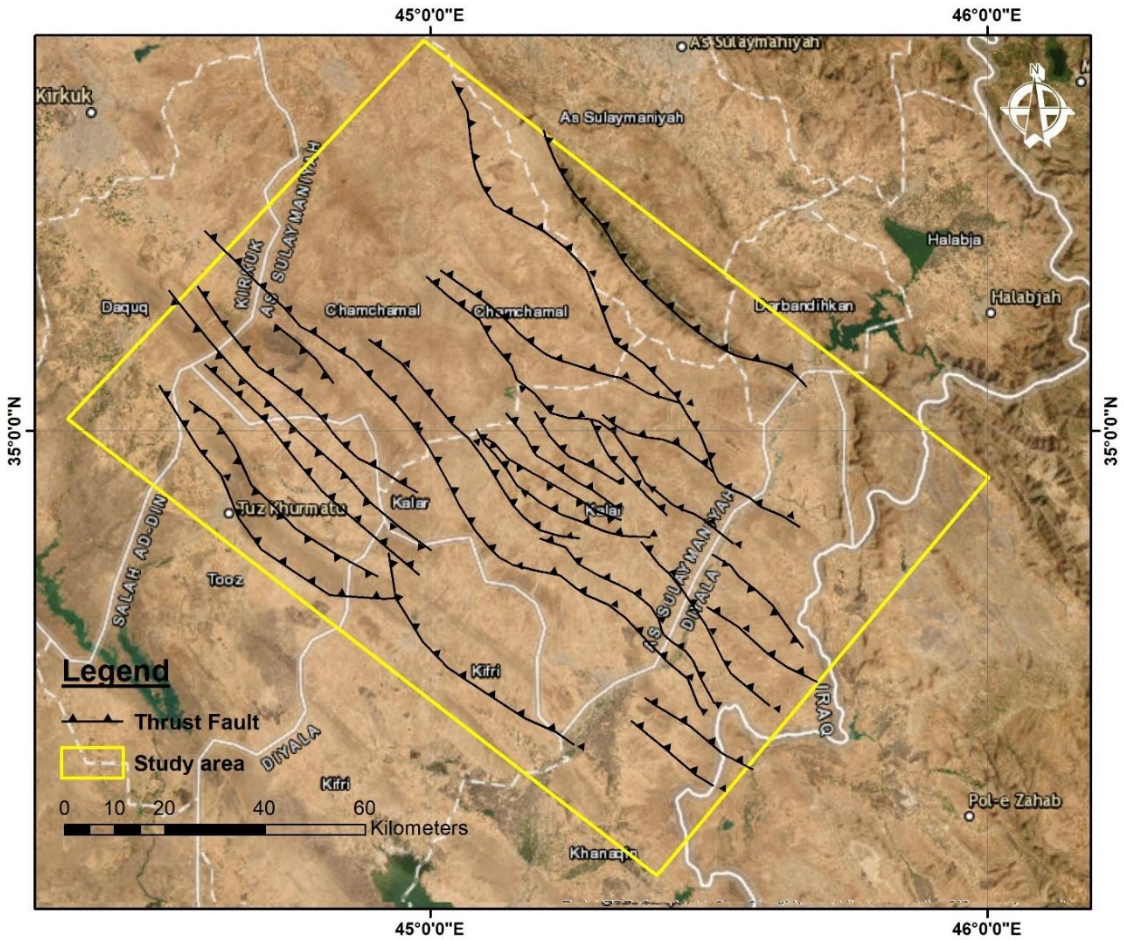


Figure 9: shows faults in the research region depicted on the seismic data and satellite image.

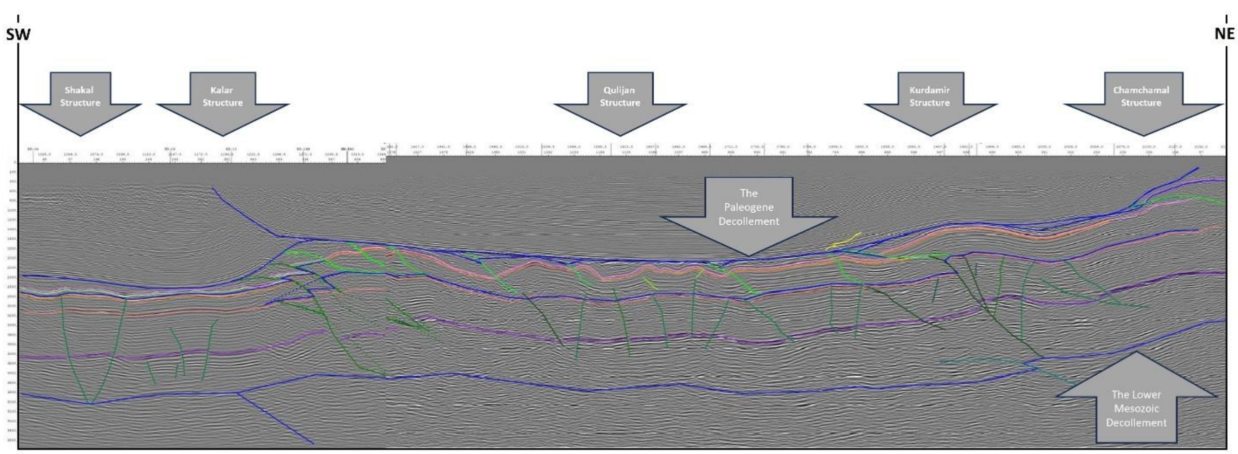


Figure 10: shows the studied area's fault system and deformation styles.

مجلة جامعة بابل للعلوم الصرفة والتطبيقية مجلة جامعة بابل للعلوم الصرفة والتطبيقية مجلة جامعة بابل للعلوم الصرفة والتطبيقية

info@journalofbabylon.com | jub@itnet.uobabylon.edu.iq | www.journalofbabylon.com ISSN: 2312-8135 | Print ISSN: 1992-0652

Figures 11–13 display the Neogene section's structural arrangement. As can be observed from the geoseismic sections, the Neogene structures of the research region are somewhat more complicated than Mesozoic units and are linked to numerous strong thrusting faults at various stratigraphic levels. The Neogene period is where the majority of the Mesozoic faults died (Figure 10).
The structural pattern of the study area is affected by two major tectonic phases: the Neogene phase and the Mesozoic phase. The Neogene structures are not associated with Mesozoic structures.

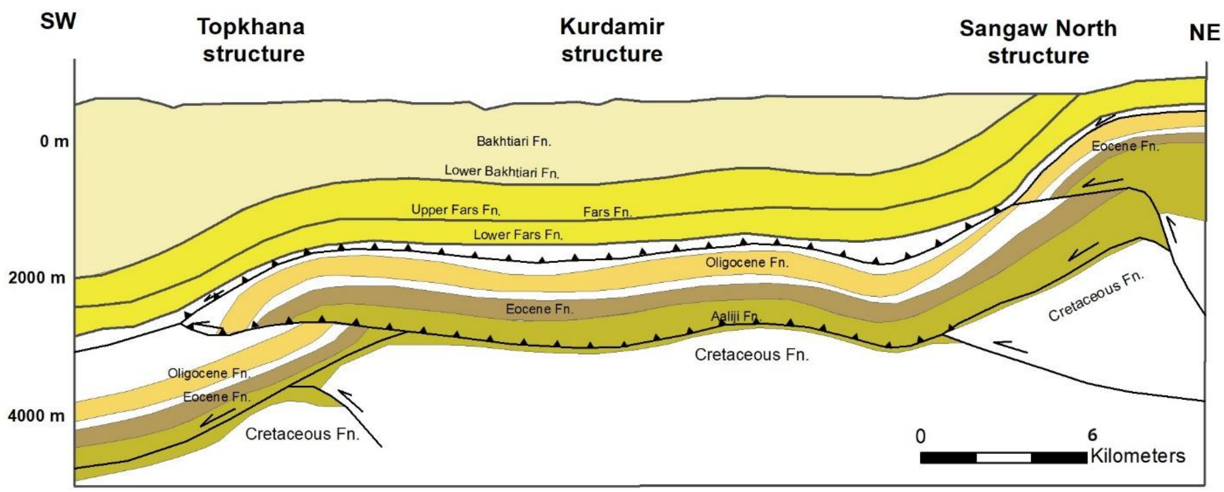


Figure 11: Geological cross-section in the study area showing Topkhana, Kurdamir, and Chemchemal structures.

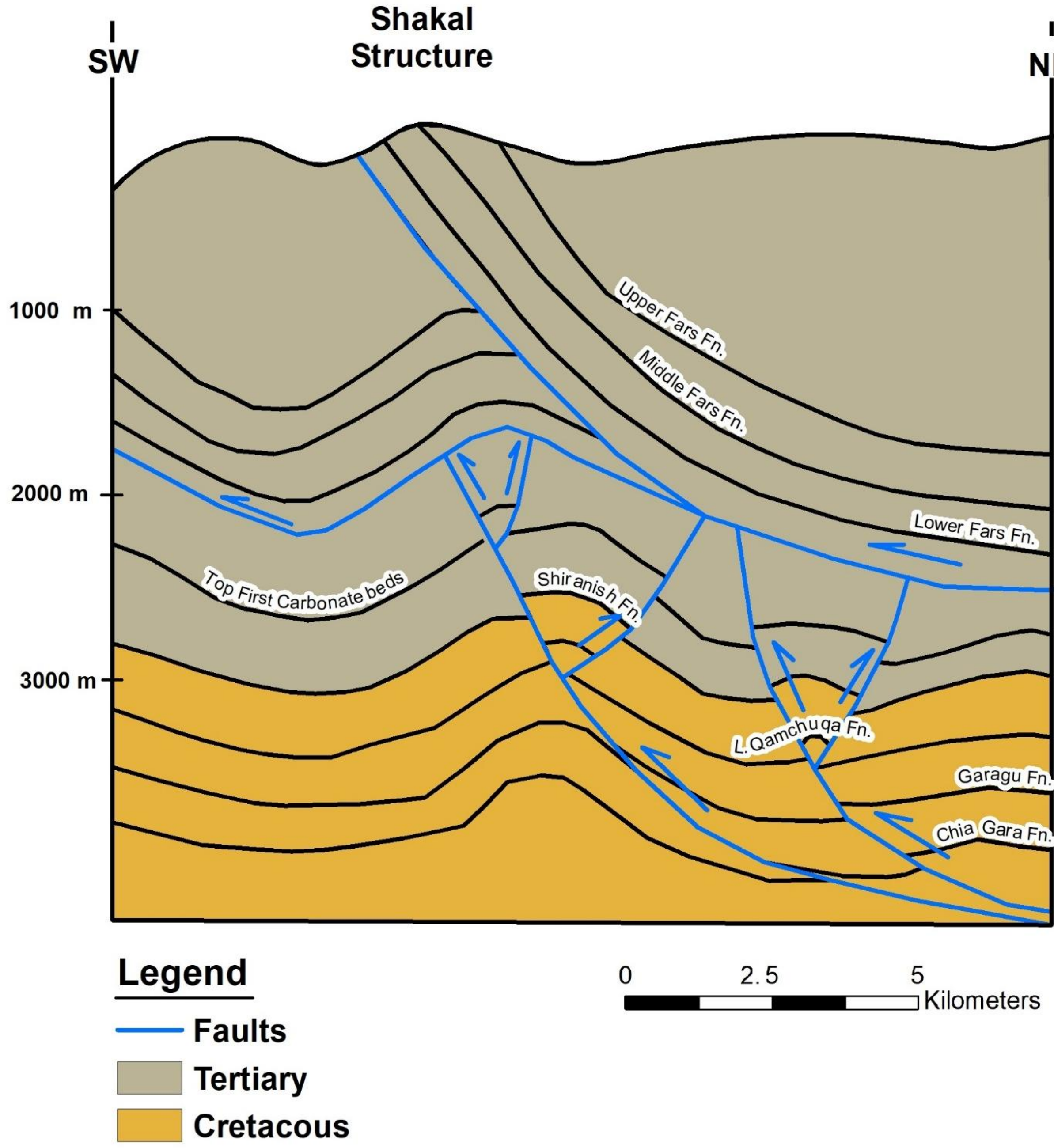


Figure 12: Geological cross-section showing the structural configuration of the Shakal structure.

ISSN: 2312-8135 | Print ISSN: 1992-0652
info@journalofbabylon.com | jub@itnet.uobabylon.edu.iq | www.journalofbabylon.com

مجلة جامعة بابل للعلوم الصرفة والتطبيقية مجلة جامعة بابل للعلوم الصرفة والتطبيقية مجلة جامعة بابل للعلوم الصرفة والتطبيقية

ARTICLE
JOURNAL OF UNIVERSITY OF BABYLON
For Pure and Applied Sciences (JUBPAS)
Vol.33; No.4.| 2025

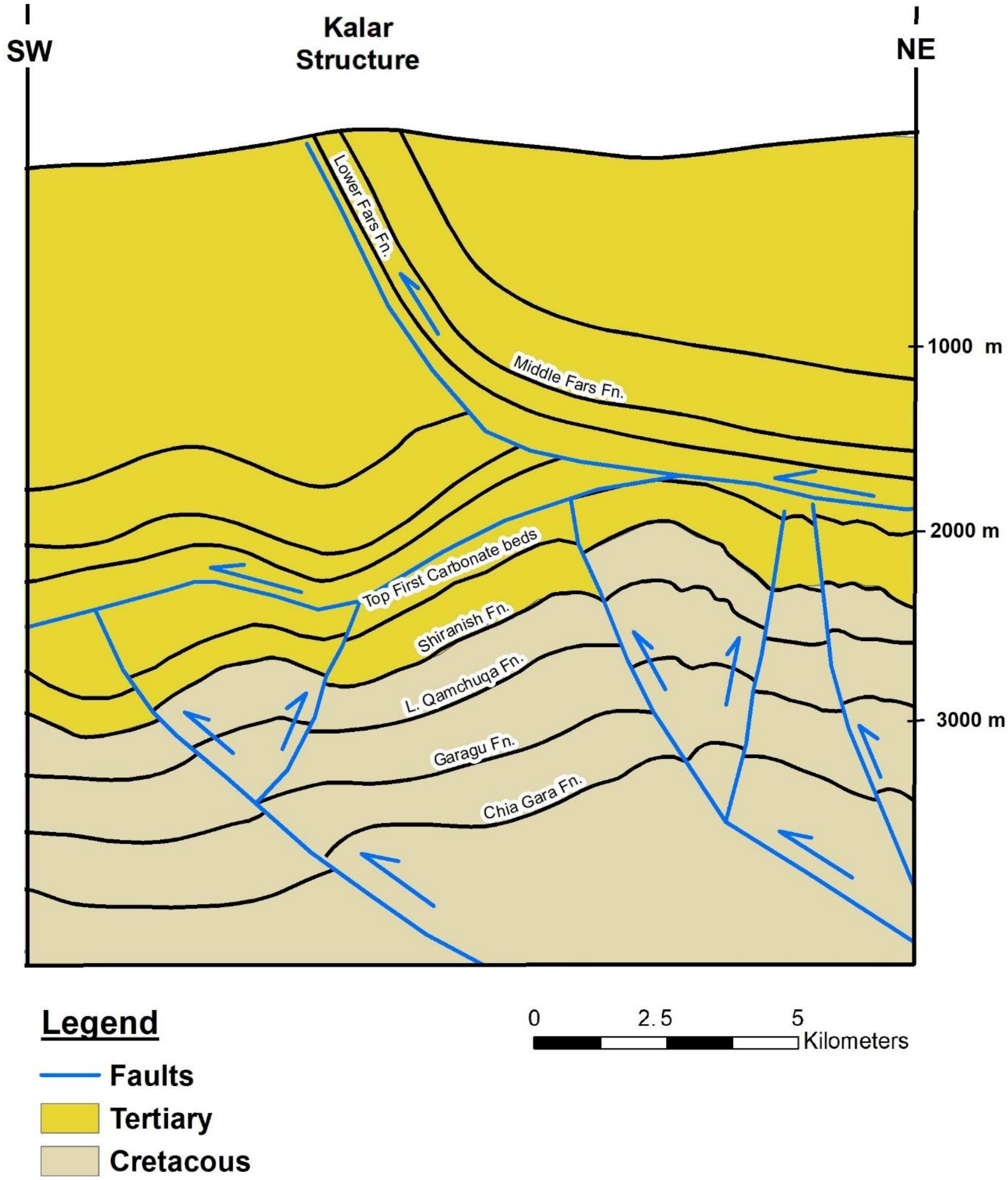


Figure 13: shows a geological cross-section of the Kalar structure.

Numerous theories have been proposed by various researchers to explain the thrust region's folded structural characteristics. [41] and [42] have thoroughly examined the intricate geometric ramifications of the interactions between the folding and faulting. As a virtually bed-parallel collection of structures along the inadequate beds, the aforementioned results show that a series of straightforward differential slip thrusts had been formed. Steeping, overturning, and breaking through the other limbs are the effects of persistent differential movement (movement on the top beds is greater than on the lower beds) on the gentle limbs.

ISSN: 2312-8135 | Print ISSN: 1992-0652
info@journalofbabylon.com | jub@itnet.uobabylon.edu.iq | www.journalofbabylon.com

مجلة جامعة بابل للعلوم الصرفة والتطبيقية مجلة جامعة بابل للعلوم الصرفة والتطبيقية مجلة جامعة بابل للعلوم الصرفة والتطبيقية

info@journalofbabylon.com | jub@itnet.uobabylon.edu.iq | www.journalofbabylon.com ISSN: 2312-8135 | Print ISSN: 1992-0652

5 CONCLUSION

The current study focuses on interpreting and assessing the seismic data of the area under investigation in terms of the tectonic patterns and underlying geologic features that define the region. The area's structural style is determined by combining the geology and seismic reflection data.

The deformation mechanics within the Zagros Simple Fold Zone reflect a combination of fragile and ductile behavior resulting from the compression forces exercised during the current orogenic processes. The well-developed folds, ranging from narrow to isoclinical geometries, indicate a significant horizontal shortening, with factors such as pre-existing weak layers that play a fundamental role in welcoming strain. The structural styles and inherent complexities of folds found in the simple folding zone of Zagros emphasize the importance of detailed mapping and geological analysis.

In the Neogene, the Zagros Mountain belt—also known as the 'Folded Zone'—was formed when the Eurasian plate docked with Iraq. As the Cenozoic era progressed, a sequence of surface anticlines trending northwest-southeast in the Sangaw North region formed, which, according to seismic data, in certain instances overlies folds and sub-thrust structures (Figure 6).

In the most recent 5 million years, much of the present-day structure was formed by large thrusts, according to the structural interpretation and seismic analysis. The present-day structures' flanks show evidence of smaller-scale faulting and back thrusts caused by earlier thrusting. This leads to intricate shapes. The current surface anticline is the product of a last episode of intense thrusting that began at an apparent unconformity at the top of Kolosh/base of Pila Spi and ended with the fast deposition of undeformed sediments.

The 2D seismic data are used for determination of the structural configurations and the tectonic features which are analyzed through the study of interpretation. Such data reflect that the Paleogene structure of the study area is an asymmetrical NW-SE trending anticlinal feature dissected by a set of NW-SE fault systems. Added, the pre-Paleogene structures of the studied area are very complex, where the area is of NE dip and affected by severe faulting through varying stratigraphic levels.

The nappe-duplex stack in the research region features a variety of fold-fault shapes and frequencies. South of the Kalar-Kirkuk thrust, there is less folding, decoupling, and pushing. With faults, the horizons gradually get shallower and steeper toward the northeast, with many folds and large displacement thrusts. Fault systems are very complex, comprised of Neogene faults, the Paleogene Decollement, Mesozoic reverse and/ or strike-slip faults, and the Lower Mesozoic Decollement. Numerous fault types, ages, and deformation styles are connected by a single fault system throughout the research region. Less decoupling occurs below L. Miocene than in the northern region, and horizons have gradually dropped towards the foreland with an abrupt elevation step and low-angle decoupling in Neogene strata.

The study area has a nappe-duplex stack, many decollements, Older, steeper faults may reactivate during younger deformation episodes, and faults may reactivate again during wedge internal restructuring. This might be a part of the Pliocene strike-slip that affects all levels. Stack of duplexes, each with its stress regime and fold-fault system; some significant faults cut more than one duplex, resulting in huge folds or fold systems; during wedge reconfiguration, folds are reshaped and faults are reactivated.

مجلة جامعة بابل للعلوم الصرفة والتطبيقية مجلة جامعة بابل للعلوم الصرفة والتطبيقية مجلة جامعة بابل للعلوم الصرفة والتطبيقية

info@journalofbabylon.com | jub@itnet.uobabylon.edu.iq | www.journalofbabylon.com ISSN: 2312-8135 | Print ISSN: 1992-0652

Conflict of interests.

There is no conflict of interest, according to the authors.

References

[1] H., Syan, Soran; and a., Omar, Abdulla., 2023. Structural Style of Taq Taq Anticline in the Zagros Fold-Thrust Belt in the Iraqi Kurdistan Region from the Integrated Surface and Subsurface Data. Iraqi Geological Journal. Vol. 56, 2C. 2C.DOI: https://doi.org/10.46717/igj.56.2C.18ms-2023-9-24.23:10

[2] F., Mouthereau; O., Lacombe; and J., Vergés., 2012. Building the Zagros collisional orogen: Timing, strain distribution and the dynamics of Arabia/Eurasia plate convergence.Tectonophysics.Volumes 532–535. DOI:https://doi.org/10.1016/j.tecto.2012.01.022.

[3] A., Sembroni; R., Reitano; C., Faccenna; and P., Callieri., 2024. The geologic configuration of the Zagros Fold and Thrust Belt: an overview. Med. Geosc. Rev. 6, 61 86.DOI:https://doi.org/10.1007/s42990-024-00118-6

[4] C. M., Burberry; J. W., COSGROVE; and J.-G., LIU., A study of fold characteristics and deformation style using the evolution of the land surface: Zagros Simply Folded Belt, Iran. Geological Society, London, Special Publications, Volume 330, Pages 139 – 154, https://doi.org/10.1144/SP330.8

[5] Jordi Carreras; and Elena Druguet., Complex fold patterns developed by progressive deformation, Journal of Structural Geology, Volume 125, 2019, Pages 195-201, https://doi.org/10.1016/j.jsg.2018.07.015.

[6] Paumard et al., 2019. Seismic imaging techniques for complex fold-and-thrust belts. Geophysical Journal International, 218(1), 98-112.

[7] Chima et al., 2019. Structural traps and fault dynamics in foreland basins: Insights from seismic analysis. Geoscience Frontiers, 10(2), 295-310.

[8] Rubaye et al., 2019. Subsurface geological structures and seismic stratigraphy in the Kurdistan region. Arabian Journal of Geosciences, 12(4), 106.

[9] Manzi et al., 2020. 3D seismic interpretation and reservoir modeling in foreland basins. Petroleum Geoscience, 26(3), 289-310.

[10] R., Mamdouh Gadallah; and Ray, Fisher., 2008, Integrated Geophysical and Geological Mapping of the Lithological and Geological Structures at a Proposed Generator site. Exploration Geophysics. Berlin: Springer Science & Business Media. Vol.7 No.12.DOI:https://doi.org/10.4236/gep.2019.712005

[11] Z.,Tao; and T. M., Alves., 2019. Impacts of data sampling on the interpretation of normal fault propagation and segment linkage. Tectonophysics, 762, 79-96.

[12] M. A. F.,Miraj; and M. Z., Idrees., 2021. Subsurface structural interpretation of Missa Keswal Area, Eastern Potwar, Pakistan. The Iraqi Geological Journal, 146-156.

[13] S., Sherkati; and J., Letouzey., (2004). Variation of Structural Style and Basin Evolution in the Central Zagros (Izeh Zone and Dezful Embayment), Iran. Marine and Petroleum Geology. 21, 535-554.DOI: http://dx.doi.org/10.1016/j.marpetgeo.2004.01.007.

[14] M. M., Abdeen; Y. A. H. A., EL-Kazzaz; G. M., Attia; M. A., Yehia; and S. M., Hassan., 2009. Mapping geological structures in Wadi Ghoweiba area, Northwest Gulf of Suez, Egypt, using ASTER-SPOT data fusion and ASTER DEM. Egypt. J. Remote Sensing & Space Sci., 12, 101-126.DOI

[15] M., Alavi., (2004). Regional stratigraphy of the Zagros fold-thrust belt of Iran and its proforeland evolution. American Journal of Science, 304(1), 1–20. https://doi.org/10.2475/ajs.304.1.1

[16] Beydoun et al., 1992. Petroleum in the Zagros Basin: A Late Tertiary foreland basin overprinted onto a hydrocarbon-rich passive margin. AAPG Memoir, 55, 309–339.

[17] P.R., Sharland; R., Archer; D.M., Casey; R.B., Davies; S.H., Hall; A.P., Heward; A.D.,Horbury; and M.D., Simmons., 2001.Arabian Plate Sequence Stratigraphy. GeoArabia, Special Publication,2, Bahrain, 371

[18] N., Mcquarrie., 2004.Crustal scale geometry of the Zagros fold–thrust belt, Iran. Journal of Structural Geology, 26,519–535.

[19] Alavi., 2007. Structures of the Zagros fold-thrust belt in Iran. American Journal of Science, 307(9), 1064-1095.

[20] W.N., Kent., 2010. Structures of the Kirkuk Embayment, northern Iraq: foreland structures or Zagros Fold Belt structures. GeoArabia, 15(4), pp.147-188.

[21] S., Homke; J., Vergés; P., Van DerBeek; M., Fernandez; E., Saura; L., Barbero; B., Badics; and E., Labrin., 2010.Insights in the exhumation history of the NW Zagros from bedrock and detrital apatite fission-track analysis: Evidence for a long-lived orogeny. Basin Research, 22,659–680.

[22] R.I., Koshnaw; B.K., Horton; D.F., Stockli; D.E., Barber; M.Y., Tamar-Agha; and J.J., Kendall., 2017.Neogene shortening and exhumation of the Zagros fold-thrust belt and foreland basin in the Kurdistan region of northern Iraq. Tectonophysics, 694,332–355.

[23] Goff., 2006. Tectonic setting and structural evolution of the Zagros Fold Belt. Geological Society of London Special Publications, 272, 127-150.

[24] Berberian., 1995. Tectonic evolution of the Zagros orogenic belt. Tectonophysics, 250(1-3), 1-36.

[25] T., Maher Zainy; Nadhir Al-Ansari; E., Tobias, Bauer; and Maria Ask.,2017. The Tectonic and Structural Classifications of the Western Part of the Zagros Fold and Thrust Belt, North Iraq, Review and Discussion. Journal of Earth Sciences and Geotechnical Engineering.vol.7, no. 2, 2017, 71-89.DOI:

[26] H.G.K., Balaki; and A.A., Omar., 2019. Structural assessment of the Bradost and Berat structures in Imbricate and High Folded zones—Iraqi Kurdistan Zagros belt. Arabian Journal of Geosciences, 12(4), p.106.

[27] M., PIROUZ; G., SIMPSON; A., BAHROUDI; and A., AZHDARI., Neogene sediments and modern depositional environments of the Zagros foreland basin system. Geological Magazine. 2011;148(5-6):838-853. doi:10.1017/S0016756811000392

[28] Mohseni et al., 2022. Depositional environments and trace fossil assemblages in the Pabdeh Formation, Zagros Basin. Geological Journal, 59(2), 278-295.

[29] A. A., Omar; F. A., Lawa; and S.H., Sulaiman., 2015. Tectonostratigraphic and structural imprints from balanced sections across the north-western Zagros fold-thrust belt, Kurdistan region, NE Iraq. Arabian Journal of Geosciences, 8, pp.8107-8129.

[30] K., Mukherjee; J.K., Ghosh; and R.C., Mittal., (2012). Dimensionality Reduction of Hyperspectral Data Using Spectral Fractal Energy Features.Geocarto International, January. Vol. 27, No. 6.http://dx.doi.org/10.1080/10106049.2011.642411

[31] H.G.K., Balaki; and A.A., Omar., 2018. Clues to inferred different thrust-related fold models and thin-thick skinned tectonics within a single folded structure in Iraqi Zagros, Kurdistan region. Arabian Journal of Geosciences, 11(12), p.293.

[32] M., Frehner; D., Reif; and B., Grasemann., 2012. Mechanical versus kinematical shortening reconstructions of the Zagros High Folded Zone (Kurdistan region of Iraq). Tectonics, 31(3).

[33] A. H., Jamal; and Doski, Ken McClay., 2022.Tectono-stratigraphic evolution, regional structure, and fracture patterns of the Zagros fold-thrust belt in the Duhok region, Kurdistan, northern Iraq. Tectonophysics. Volume 838, DOI: https://doi.org/10.1016/j.tecto.2022.229506.

[34] Barwary; and Slaiwa., (1993) geological map of Khanaqin quarangle, sheet NI-38-7 (scale 1\250,000) GEOSURV, Baghdad, Iraq. Biostratigraphy of oligocene succession in the High-Folded Zone, Sulaimani, Kurdistan region, Northeastern Iraq. Arab J Geosci. Vol. 7.

info@journalofbabylon.com | jub@itnet.uobabylon.edu.iq | www.journalofbabylon.com ISSN: 2312-8135 | Print ISSN: 1992-0652

[35] V. K., Sissakian., 1993. GEOMORPHOLOGY AND MORPHOMETRY OF THE GREATER ZAB RIVER BASIN, NORTH OF IRAQ Iraqi Bulletin of Geology and Mining. Vol.9, No.3.

[36] Afren., 2011. Structural analysis of the Zagros Simple Folded Zone based on 2D seismic profiles. Afren Oil Company Report.

[37] S.H.S., AL-Hakari., (2011). Geometric Analysis and Structural Evolution of NW Sulaimani Area, Kurdistan Region, Iraq (Unpublished doctoral dissertation) University of Sulaimani, Kurdistan region, Iraq.

[38] A.O., Ibrahim., (2009). Tectonic style and evolution of the NW segment of the Zagros Fold-Thrust Belt, Sulaimani Governorate, Kurdistan Region, and NE Iraq (Unpublished doctoral dissertation) University of Sulaimani, College of Science, 187p.

[39] Energy Pedia news., (2015). Iraq: Vast Exploration provides initial resource assessment for the Qara Dagh Block, Kurdistan. Retrieved from http://www.energy-pedia.com/news/iraq/vast-exploration-provides-initial-resource-assessment-for-the-qara-dagh-block--kurdistan

[40] Vast Exploration Inc., 2011. The Kurdistan Opportunity, Qara Dagh Block. Corporate presentation, November 2011.

[41] J., Suppe., 1983. Geometry and kinematics of fault-bend folding. American Journal of Science, v. 283, p. 684-721.

[42] S.E., Boyer; and D., Elliott., 1982. Thrust systems. AAPG Bulletin 66, 1196–1230. https://doi.org/10.1306/03B5A77D-16D1-11D7-8645000102C1865D

مجلة جامعة بابل للعلوم الصرفة والتطبيقية مجلة جامعة بابل للعلوم الصرفة والتطبيقية مجلة جامعة بابل للعلوم الصرفة والتطبيقية

info@journalofbabylon.com | jub@itnet.uobabylon.edu.iq | www.journalofbabylon.com ISSN: 2312-8135 | Print ISSN: 1992-0652