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Geometric Analysis of the Khwelen Anticline from the Western Zagros Fold Thrust Belt in Kurdistan Region, NE Iraq

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ABSTRACT

Khwelen Anticline is one of three en echelon anticlines (Ashdagh, Qarawais, and Khwelen) within the low Folded-Thrust Zone, part of the NW segment of the Zagros Fold-Thrust Belt in the Garmian district of the Iraqi Kurdistan Region. The anticline is close to the high-folded thrust zone - low-folded thrust zone boundary. It is on the same trend as the Chamchamal anticline. The exposed rocks unit in the anticline range in age from the early Oligocene to the late Miocene, represented by five geological formations. The Kirkuk group and Jeribe Formation cropped out (in deep valleys) at the eroded core of the anticline. The Fatha Formation, as a carapace, forms the main geometric body shape of the anticline. While the Injana Formation is located at the two neighbouring synclines. The field observation along the three traverses perpendicular to the structure with the aid of remote sensing data, in addition to the geometrical analysis of the anticline, shows that the Khwelen anticline is asymmetrical, and single-plunged, ~10 km long and 5 km wide, an open box fold with NW-SE trend. Its SW limb is steeper and more deformed than the NE limb. An oblique strike-slip fault (transverse fault) cuts the anticline at its maximum wavelength. This fault separates the Khwelen anticline from the Qarawais anticline to the southeast. This study reveals that the anticline is a fault propagation fold developed above the thrust fault, starting from the detachment level at the base of the Jurassic series or in the Triassic.

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التحليل الهندسي لطية خويلين الواقعة ضمن الجزء الغربي لنطاق طي وزحف زاكروس في اقليم كوردستان، شمال شرقي العراق

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الملخص

طية خويلين هي واحدة من ثلاث طيات متداخلة في الامتداد وهي (أشداغ، قره ويس، وخويلين) والتي تقع في نطاق الطيات الواطئة والذي هو جزء من القسم الشمالي الغربي لحزام طيات زاكروس في منطقة كرميان في إقليم كردستان العراق. تقع الطية بالقرب من الحدود بين نطاقي الطيات العالية والواطئة وتمتد على نفس اتجاه طية جمجمال. يمتد عمر الصخور المكشوفة في هذه الطية من أوائل الأوليكوسين إلى أواخر المايوسين، متمثلة بخمس تكوينات جيولوجية وهي مجموعة كركوك وتكوين جريبي اللذان ينكشفان في لب الطية المتعري. يغطي هذه التكاوين تكوين فتحة والذي يشكل الدرع الاساس للشكل الهندسي للطية. أما تكوين إنجانة وهو أحدث التكاوين فينكشف في الطيتين المقعرتين المجاورتين لطية خويلين المحدبة. تُظهر الملاحظات الميدانية من خلال المقاطع الثلاثة العمودية على امتداد الطية وبيانات الاستشعار عن بعد بالإضافة إلى التحليل الهندسي للطية، أن طية خويلين هي طية صندوقية مفتوحة غير متماثلة ذات غاطس واحد، يبلغ طولها حوالي 10 كم وعرضها 5 كم، وامتدادها من الشمال الغربي إلى الجنوب الشرقي وطرفها الجنوبي الغربي أكثر ميلاً وتشوهًا من الطرف الشمالي الشرقي. يقطع الطية فالق مضربي بشكل عرضي عند أقصى طول موجي لها ويفصل هذا الفالق طية خويلين المحدبة عن طية قره ويس المحدبة الواقعة في الجنوب الشرقي من طية خويلين. تظهر هذه الدراسة أن هذه الطية هي من طيات تقدم الفالق الذي ربما تقدم من مستوى انفصال في تكاوين العصر الجوراسي او الترياسي.

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Introduction

The Western Zagros Fold-Thrust belt (ZFTB) represents a transitional segment between the Zagros and Taurus Fold-Thrust Belts, which extends for about 2000 km from the Bitis suture zone in the northwest (Turkey) to the Makran Trench, east of the Strait of Hormuz, in the southeast, cutting across the Kurdistan Region (NE Iraq) (Zainy et al., 2017). They were formed due to the collision between the Arabian and Eurasian plates. It started in the Late Cretaceous and hosted one of the world's largest petroleum provinces, containing about 7% of all reserves globally (Cooper, 2007). The belt exhibits variable width, with two main salients (bulges towards the foreland) in the Lorestan and Fars domains, and two major embayment (between the bulges) at Kirkuk and Dezful. The Kirkuk embayment lacks an effective basal Hormuz salt detachment. The Belt in the Iraq and Kurdistan region is around 350 kilometers in length and exhibits variable width, consisting of four significant tectonic blocks. (Fig. 1a) 1. Zagros Suture Zone 2. Imbricate Zone, 3. High Folded Thrust Zone (HFTZ) and 4. Low Folded Thrust Zone (LFTZ) (Lawa, 2018; Lawa et al., 2023; Omar et al., 2015). The last two domains also have different names, like Low Folded zone (Foothill zone) and High Folded zone (Fouad et al., 2015). During the last 30 years, the NW segment of the ZFTB has become an interesting new frontier for hydrocarbon exploration in the Middle East, with notable discoveries of oil and gas reserves. (Mackertich and Samarrai, 2015). This study deals with one of the structures within the low-fold thrust zone, which has not been studied from a geometrical point of view.

Investigating fold structures observed in the field or through remote sensing data provides a framework for understanding and measuring fold-related deformation (Nabavi and Fossen, 2021). The comprehension of folds and folding is based on meticulous geometrical examination. Their geometric properties and frequency of occurrence provide valuable data for economic exploration, seismic risk mitigation, kinematics, and rheology.

Several methods are used to study the fold-thrust belts, including: (a) balanced and restored cross-sections (Dahlstrom 1969; Mitra and Namson, 1989), (b) constructing geological cross-sections using methods like depth to detachment estimations (Chamberlin 1910; Mitra & Namson, 1989) and the Busk and dip domain methods (Busk, 1939; Suppe 1985), and (c) progress in understanding the quantitative relationships between thrusts and their related folds and the rules that help to limit the structural geometries (Suppe, 1983; Jamison, 1987; Mitra, 1990; Suppe and Medwedeff, 1990).

In the Kurdistan region (NE Iraq), several previous studies have been conducted on the structural geology and tectonostratigraphy of Zagros fold-thrust belts among them (Ameen, 1991; Lawa et al., 2013; Ali et al., 2014; Al-Kubaisi and Barno, 2015; Omar et al., 2015; Burberry, 2015; Koshnaw et al., 2017; Koshnaw et al., 2020; Al-Khatony et al., 2019; Al-Hakari et al.,2020; Othman and Jadda, 2020; Syan and Omar, 2023; Zebari et al., 2020; Doski and McClay, 2022).

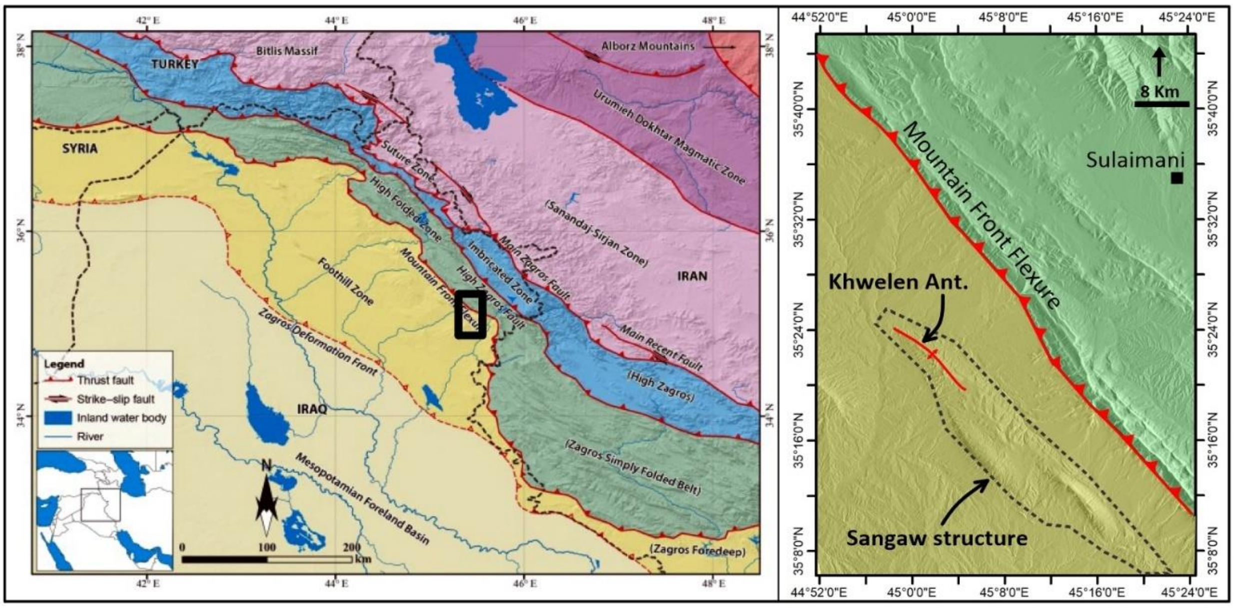


Fig. 1. Left: Tectonic subdivision of the NW segment of the ZFTB (Zebari et al., 2020).

Right: Sangaw structure shown in relation to the MFF.

This study focuses on the geometry and evolution of the Khwelen structure in the LFTZ, as well as the causes of fault-related fold generation. It can be considered a preliminary and pioneering study on this fold. The studied anticline is separated by a narrow syncline from the (HFTZ) by a main thrust fold (Darbandi -Bazian- Sagerma - Qardagh Mountain series), which marks this boundary and is well known as the Zagros Mountain Flexural Front (ZMFF) (Fig.1right). The survived and mapped area is about 121 Km2, which is bounded by the longitudes 44° 56′ 00″ and 45° 06′ 00″ E and latitudes 35° 24′ 00″ and 35° 20′ 00″ N. (Fig. 1).

Many researchers use structural studies and understanding of the causes of folds in thrust-and-fold belts worldwide to model tectonic evolution in orogenic and foreland areas (McClay, 2011). The challenges remain, despite greatly developed techniques, particularly in the understanding of the spatial and temporal evolution of the fold-thrust belt and its controlling factors, especially in an area like Sangaw. This study focuses on the tectonic style and evolution, using the geometrical analysis of a single-fold structure within the low Folded-Thrust Zone, part of the NW segment of the Zagros Fold-Thrust Belt in the Garmian district of the Iraqi Kurdistan Region, through extensive fieldwork and measurements superimposed by the construction of several structural cross-sections for the area under consideration.

Lithostratigraphy

Various Cenozoic lithostratigraphic units can be observed in the study structure, extending from Oligocene to the Pliocene (Fig. 2). The oldest exposed rocks are represented by thick reefal carbonates of the Kirkuk Group, which extends in age from Oligocene to Early Miocene (Aquitanian) (Bellen et al., 1959; Stevanovic and Markovic, 2003; Ghafour, 2012; Ameen and Ghafour, 2015; Ameen et al., 2020; Lawa et al., 2020). Bajawan Formation (Chattian), about 17 meters thick, is exposed within the deep valleys of the SW limb of the anticline, and it consists of very thick beds of milky porous, highly fractured, cavernous limestone. Anah Formation (Aquitnaian) is about 8 meters thick and composed of a fossiliferous, coral-rich, massive bed of limestone, recrystallised and occasionally brecciated of splintery grey color and tough, which changes to a thick bed, white, fractured coralline limestone. They are unconformably overlain by the Jeribe formation (Aquitnaian –Burdigalian) with remarkable conglomeritic horizons.

The (Aquitnaian –Burdigalian) succession is represented by carbonates of the Jeribe Formation and mixed carbonate-evaporates and clastics of the Fatha Formation (So-called Lower Fars Formation) (Ameen et al., 2020; Lawa et al., 2020). The latter represents the last marine facies in the Cenozoic column of Iraq and Kurdistan region (Lawa 1986; Al-Juboury and McCann, 2008; Khoshnaw 2017), and acts as a decollement surface and or cap rock (Aqrawi et al., 2010; Koyi, 2021).

Jeribe Formation (Aquitanian) is a unit about 8 m thick and represented by grey dolostone and by arenaceous, dolomitized limestone and dolostone; it shows well to thick beddings, occasionally pelletal and oolitic, showing enrichments of pelecypods and gastropods fragments, which are alternated with a friable marly, sandy, bituminous limestone.

The Fatha Formation (middle Miocene) has a thickness of 320m. It is composed of more than 40 shallowing-upward cycles (calcareous mudstone, carbonate, evaporate, and red claystone, from base to top). The lower part is characterized by the predominance of thick Carbonates and evaporates, showing alternations with pale grey-greenish gray marl, while the upper parts consist of red claystone, green marl, fossiliferous limestone, and thick nodular/banded gypsum that decrease in thickness upwards, until it disappears at the upper boundary with the overlying Injana Formation.

(Injana Formation) is composed of pinkish red to greenish grey thick to massive cross-bedded, coarse and medium-grained sandstone alternating with brownish red siltstone and mudstones, without evaporates and carbonates. Barzani et al. (2024) mentioned that they represent the first non-marine facies overlain by the Fatha Formation and exposed in both limbs of the anticline. Overlain by rhythmic clastic cycles of sandstone and claystone, they are lenticular as a mode of deposition, with many lateral changes to each other (Mukdadayah Formation). Its thickness on the SW limb exceeds that on the NE limb.

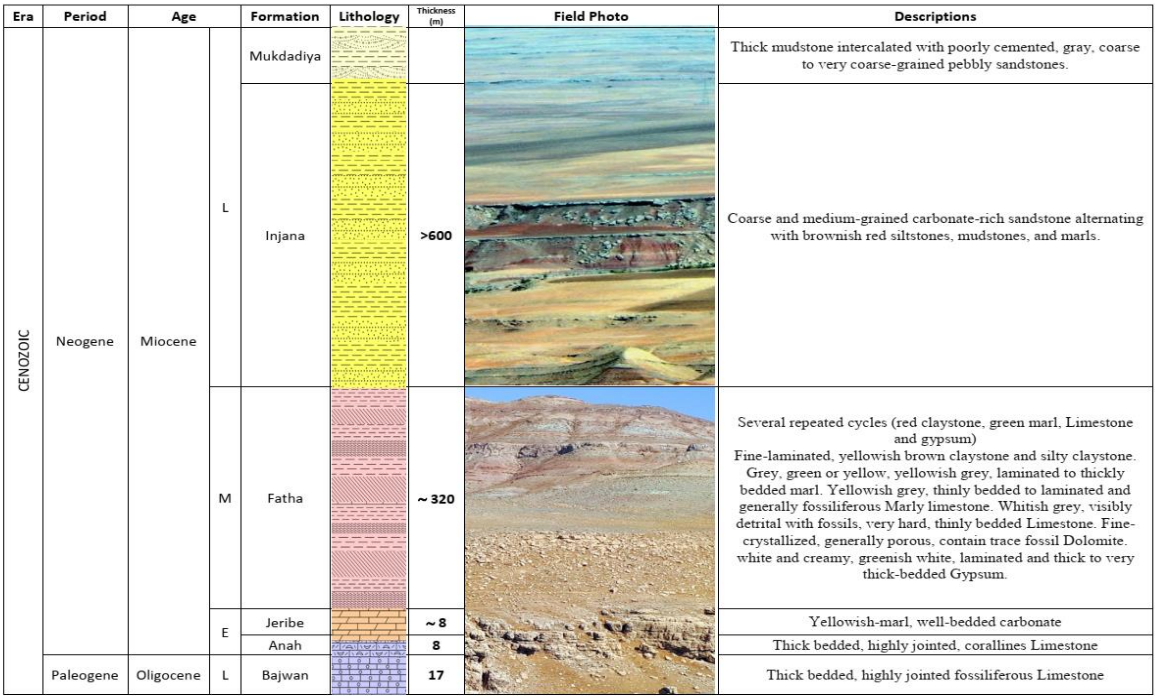


Fig. 2. Lithostratigraphic column of the Khwelen anticline

Results

Map view Description of Khwelen Anticline

The Khwelen anticline is one of three en-échelon anticlines (Ashdagh, Qarawais, and Khwelen) and is collectively called the Sangaw structure (Mackertich and Samarrai, 2015). The anticline is smaller in size relative to the other two anticlines (Fig. 3). It has a V-shape in the satellite image. The anticline is about 10 km long, of NW-SE trend, and its width decreases from 5.5 km to 1.1 km at the NW plunge. The Basara stream turned around the NW plunge of the anticline (Fig. 4a). In contrast, the anticline is terminated by a vertical transcurrent fault at the southeast, which separates the Khwelen anticline from the larger Qarawais anticline (Fig. 4b). No evidence indicates that the Khwelen anticline extends beyond the faulted area. The fault was recorded by Qadir et al. (2023) as a major transversal fault in Iraqi territory.

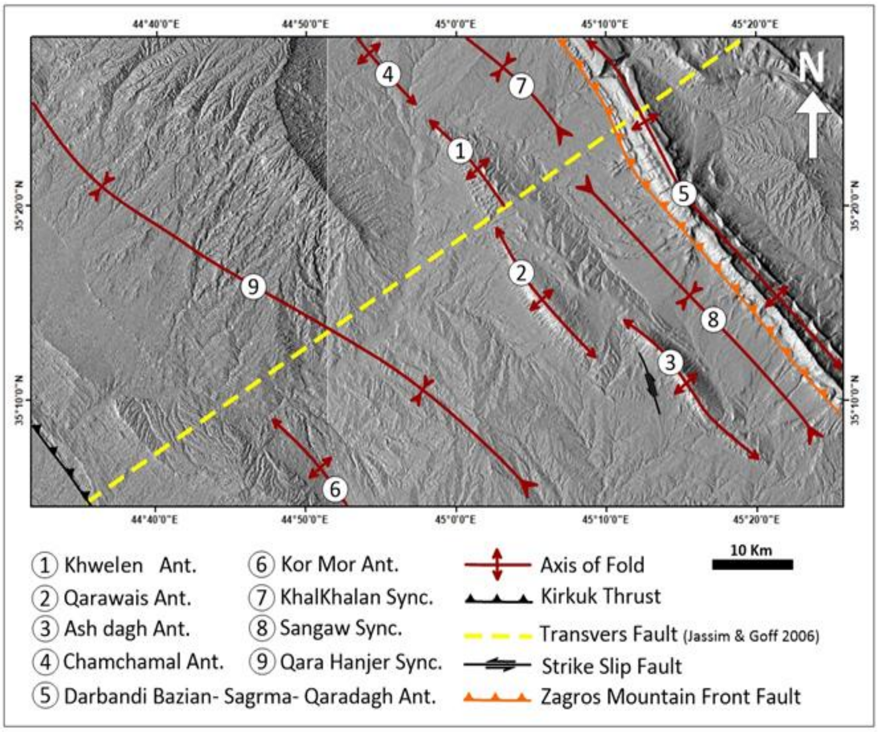


Fig. 3. DEM map showing the Khwelen Anticline and the surrounding

To the northeast, the anticline has a linear linkage with the Chamchamal anticline (Bretis, et. al., 2011), and an en-echelon linkage with the southeastern continuation towards Qarawais anticline. The plunge of the Qarawais anticline starts to rise from the southeastern truncated segments of the Khwelen anticline. The Sangaw syncline from the northeast separates it from the Darbandi Bazian-Sagrma-Qaradagh anticlinal series. At the same time, a wide syncline (Qara Hanjer syncline) is located between the Khwelen anticline and the Kirkuk structure to the southwest (Sissakian and Fouad, 2015).

The northeastern limb of the anticline turned 17° west toward the NW plunge. The highest point within the anticline is about 926 m (a.s.l.), with more than 300 m contrast with the surrounding area. The core of the anticline is flanked by structural slopes that were subjected to significant erosion by fluvial action, causing the formation of ridges referred to as cuesta on the northeast side and hogback on the southwest side (Fig. 4a). Mamlaha and Khwelen springs (high concentrations of H_2S and sulfide acid in the water) discharge close to the lower limit of the Fatha Formation strata (Fig. 4d). The uppermost beds of the Fatha Formation determine the outer circumstances of the anticline. In contrast, the beds of the lower unit of the Fatha Formation, which cover the crest part of the anticline, underwent a high rate of complex erosion that resulted in the formation of a number of deep and wide valleys and karst features. In addition, many Ponors (undeveloped sinkholes) are present at the crest part of the Khwelen anticline, formed due to dissolution or collapse (Fig. 4c). Generally, the SW limb of the anticline was eroded more than the NE limb.

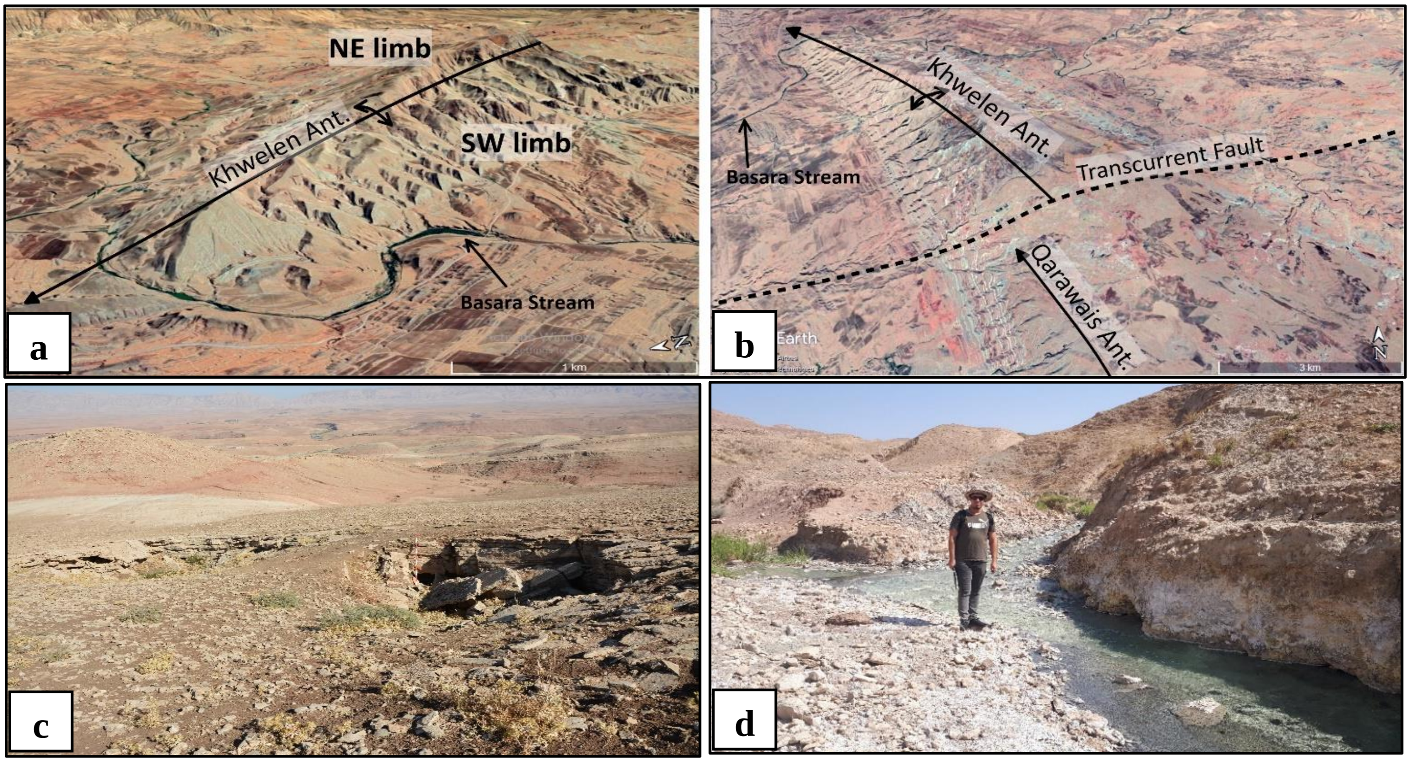


Fig. 4. a: NW plunge of Khwelen anticline. (Google earth). b: Transvers fault between Khwelen and Qarawais anticline (Google earth). c: Sinkhole, d: High sulphate Mamlaha springs.

Khwelen Anticline from Different Cross-sectional View

An effective method for building the structural framework of a deformed region is to use a cross-section or a series of them. The correct understanding of the cross-sections, which are compatible within themselves, gives us a consistent picture of deformed beds (Groshong, 2006). Three cross-sections were created perpendicular to the overall orientation of folds in the region to analyze the geometry of the Khwelen anticline. Each cross-section has a length of approximately 10 kilometers. The cross-sections are created by utilizing information from geological maps created at a scale of 1/50,000 (as shown in Figure 5), digital elevation models with a resolution of 12.5 meters, and data collected in the field.

The dip data along and/or adjacent to the section lines are projected onto a topographic profile that has been scaled to the same dimensions in both vertical and horizontal directions to create the section. The stratigraphic contacts are also situated along each portion of the topographic profiles. The topographic profile, dip data, and outcrop data are utilized to manually create the structural sections employing the dip domain approach (Groshong, 2006) based on the idea that rock strata are flexed into planar segments separated by small bending zones. The axial surface divides the interlimb angle between neighboring dip domains in half for beds with consistent thickness.

When designing the cross-sections, it is challenging to maintain a constant Fatha Formation thickness while fitting the dip data's geometry. Additionally, when trying to reconstruct the geometry between the Khwelen anticline and the syncline to the northwest, various interpretations are suggested to achieve the optimal alignment between the available data and fold geometry.

The first cross-section (A-Ā) is selected to represent the geometry and nature of the NW plunge of the anticline. The (B-B̄) cross-section is selected to represent the maximum deformed part of the anticline caused by maximum stress, in which the oldest rock units are cropped out. The (C-C̄) cross sections represent the anticline's wide crystal segment box fold. (Fig. 6). All traverses' start and end points are located in both neighbor synclines.

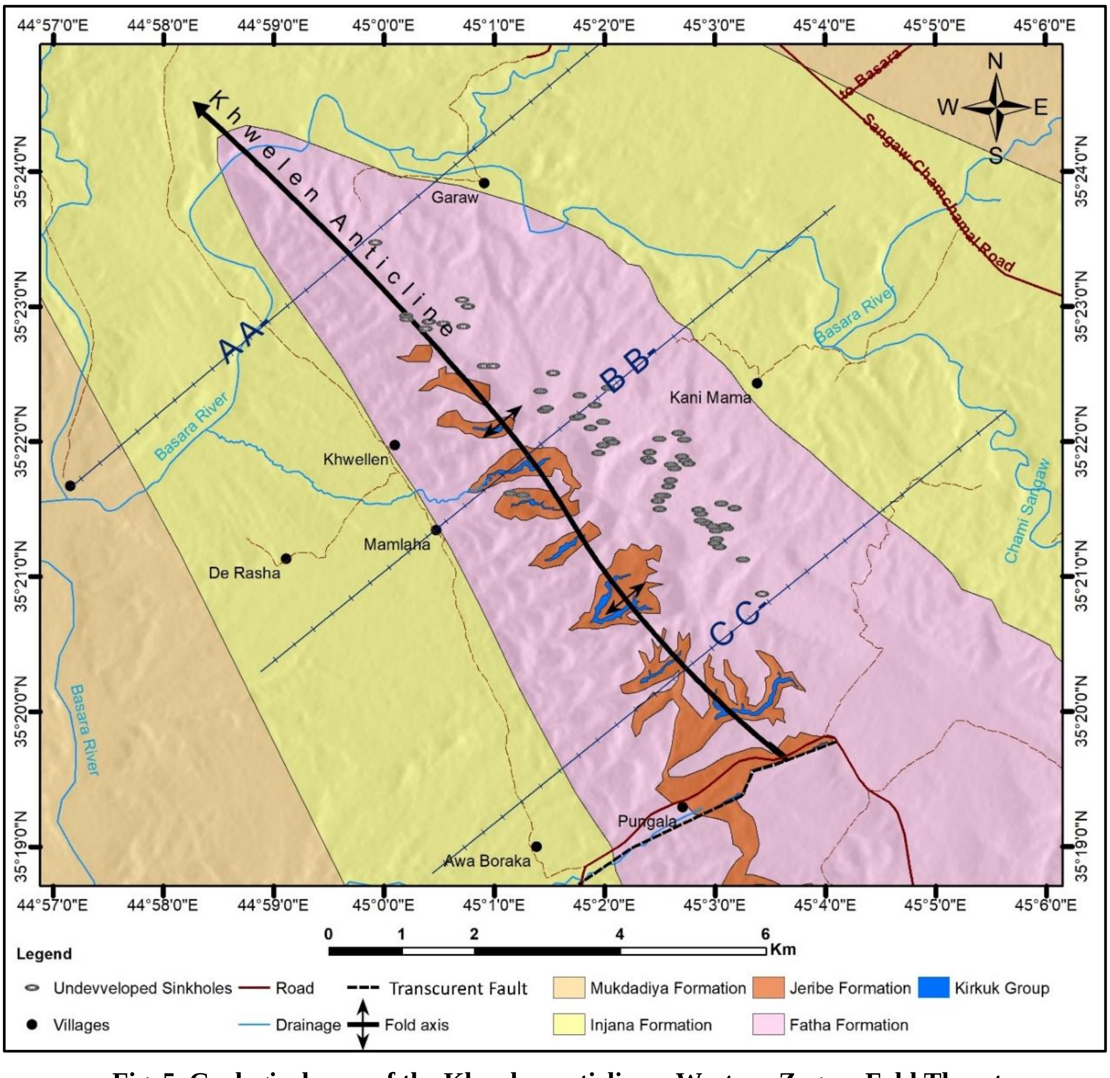


Fig. 5. Geological map of the Khwelen anticline – Western Zagros Fold Thrust

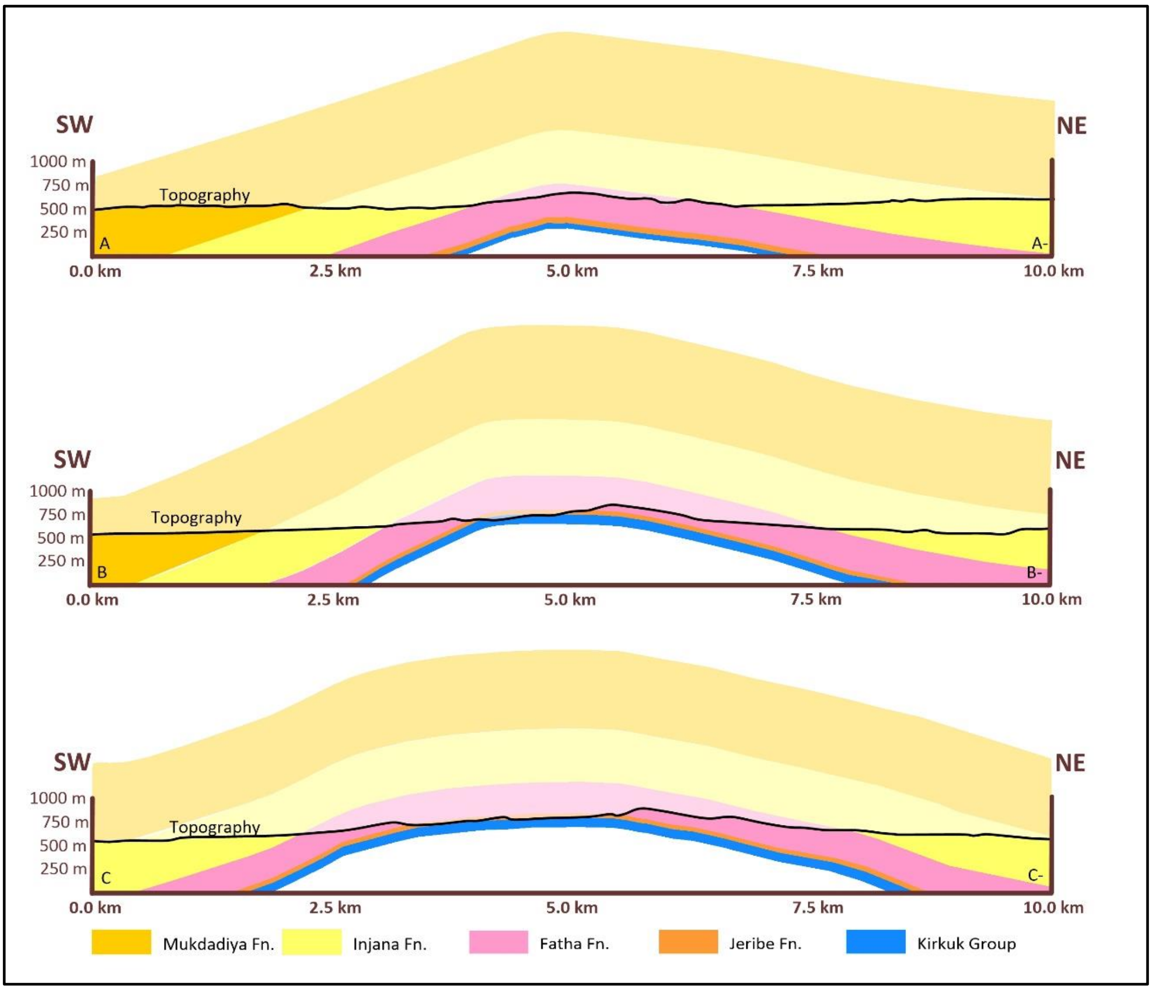


Fig. 6. Geological Cross-sections of the Khwelen anticline

The anticline length in section (A-Ā) is about 2.45 km, started to appear by the slightly inclined beds of the upper unit of the Fatha Formation, which forms the body of the Khwelen anticline as an NE limb. The attitude of the beds suddenly changed at the crest of the anticline to form the SW limb of the anticline. Resistant beds of the Fatha Formation at the SW limb show the flat iron topography (Fig. 4a).

In the (B-B̄) section, the anticline width is about 4.8km. The strata of the Injana Formation exhibit a semi-horizontal, eventually transitioning to a tilt towards the northeast. The boundary between the Injana Formation and the Fatha Formation is identifiable along the section. The Fatha Formation's upper succession is gently dipping beds forming the body of the anticline. The strata represent the northeastern limb of the anticline. The anticline's crest segment comprises horizontally arranged strata from the Fatha Formation (Lower succession). Erosion creates a broad (upstream) and a deep (downstream) valley, precisely amid the anticline towards the southwest. The Fatha, Jeribe, Anah, and Bajwan Formations are cropped out horizontally (Fig.7 b, c, and d). The valley's (downstream part) intersects the inclined (>30) strata of the Fata Formation, representing the anticline's southwestern limb. The body of the anticline terminates in the last carbonate rock bed of the Fatha Formation within the Mamlaha village (Fig. 7e). Then, the rock strata of the Injana Formation appear with the same amount of dip angle until the village of Derasha (Fig. 7a), and then the dip amount decreases towards the axis of the Qarahanjir syncline.

The anticline at the (C-C̄) section is wider than the two previous sections; it widens more than 6 km. The section crosses the highest topographic point over the anticline, higher than 920

m. The NE limb of the anticline consists of the gently dipping beds of the Fatha Formation, which changes to semi-horizontal (Fig. 7g) and horizontal beds to form the wide crest segment of the anticline in this section. The southwestern limb of the anticline was eroded, and a wide valley formed.

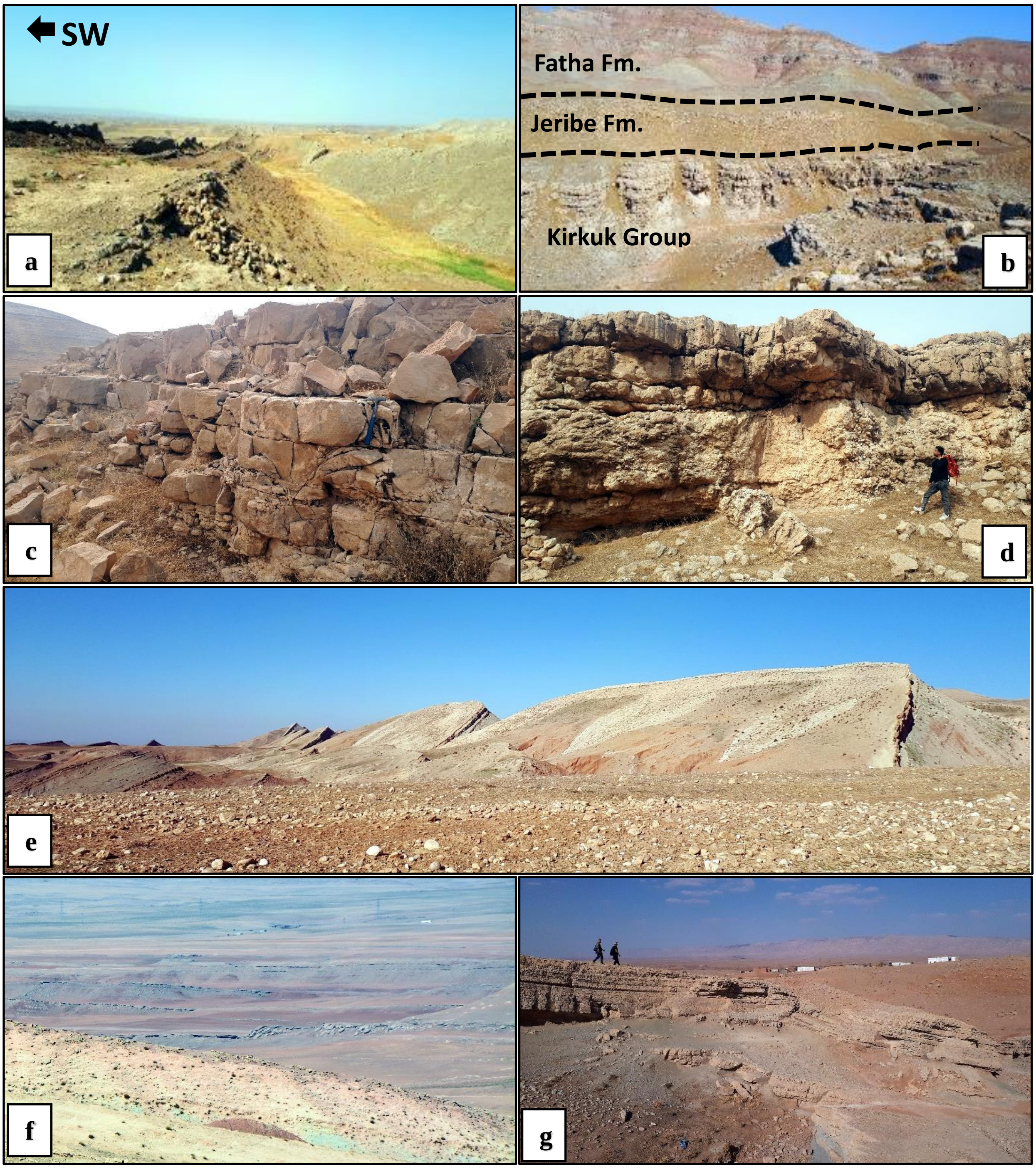


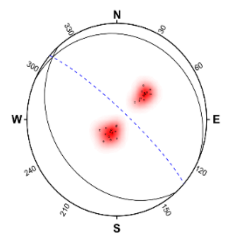
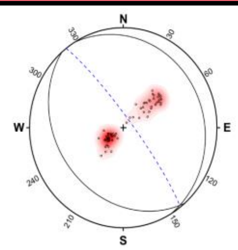
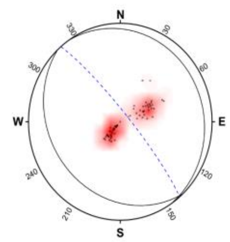
Fig .7. a: Inclined sandstone beds of Injana Fn. (SW limb) of the anticline, b: eroded core of the Khwelen anticline, c: horizontal beds of Jeribe Fn., d: horizontal beds of Kirkuk group in the core of the anticline, e: the last carbonate beds of Fatha Fn. (SW limb) of the anticline, f: gently inclined beds of Injana Fn. (NE limb) of the anticline, g: Kink style fold in (NE limb) of the anticline.

Geometric analysis

This research involves 200 field measurements (dip angle and dip direction of the bedding planes) dispersed along three traverses perpendicular to the hinge line used to describe the fold style of the Khwelen anticline. Then, their average is used to construct the sections (Fig. 6). Poles to planes and calculated average attitude of each limb are plotted on the equal area (Schmidt) net using the Stereonet 11 program, and Pi diagrams have determined the axial surface and fold axes orientations.

The stereographic representation of the 62 bedding plane measurements through section (A Ā) shows that the mean attitude is 025°/13° for the NE limb and 229°/30° for the SW limb of the Khwelen anticline. This reveals an asymmetrical style. The hinge line trend is 312° and plunges at 04°, while the axial surface is dipping 81° toward 042°. The Interlimb angle is 138°. Consequently, the structure belongs to the gentle and upright folds depending on the Fleuty Classification (1964). While the synoptical stereographic projection of strata (67 measurements) through section (B-B̄) shows that the average attitude of the NE and SW limbs is 059°/16° and 229°/31°, respectively, which implies an asymmetric anticline with a lesser dip angle at the back limb. The orientation of the hinge line and axial surface is 142°/02° and 053°/82°, respectively. Consequently, the Khwelen structure has foreland-ward vergence and is classified as an upright fold. The interlimb angle is 133°. The lower hemisphere stereogram of the exposed beds (71 measurements) via section (C-C̄) in the Khwelen structure shows that the average attitude of the back and forelimbs is 056°/11° and 227°/26°, respectively, which is simply an asymmetry. The dip of the axial surface is 82° toward 050°; the fold axis is 139°/01°, and the interlimb angle is 143°. Thus, the anticline's vergency is toward the foreland (Fig. 6). The SW flank of the anticline through sections (B-B̄) and (C-C̄) reveals two separate pole clusters, but section (A Ā) shows only a pole cluster (Table 1).

Table 1: Geometrical analysis of the Khwelen anticline (Dip direction /Dip angle)

AA-		
Avg. Forelimb bedding	229°/30°	
Avg. backlimb bedding	025°/13°	
Fold axis	312°/4°	
Axial surface	042°/81°	
Interlimb angle	138°	
Gentle and upright fold		
BB-		
Avg. Forelimb bedding	229°/31°	
Avg. backlimb bedding	059°/16°	
Fold axis	142°/02°	
Axial surface	053°/82°	
Interlimb angle	133°	
Upright fold		
CC-		
Avg. Forelimb bedding	227°/26°	
Avg. backlimb bedding	056°/11°	
Fold axis	139°/01°	
Axial surface	050°/82°	
Interlimb angle	143°	
Gentle and upright fold		

Discussion

Three fundamental systems of fault-related folds define the structural characteristics of fold-thrust belts: detachment folds, fault propagation folds (fault-tip folds), and fault-bend folds (Mitra, 2003). We compare and contrast these primary theories of fault-related folds with the results of the fold geometry analysis and cross sections of the Khwelen anticline to identify an acceptable model for structure. The detachment fold model (the disharmonic and lift-off) is symmetric. The flat-topped detachment folds with a large hinge area and a steeper angle than at the limbs (Mitra and Namson, 1989). The fault-propagation folding is formed when the thrust fault loses slip and ends up in sections by transferring shortening to a fold emerging at its tip. Fault-bend folds occur when beds move over bent faults (Suppe, 1983). Therefore, several characters are considered to determine that the folding model of the structure as a fault propagation fold. A wide hinge area and shorter, steeper forelimbs characterize the asymmetrical Khwelen anticline. The anticline does not show the shape of a bent fault, and there is no flat top. Furthermore, there are folded beds instead of horizontal beds at the SW limb of the central fold body, which indicates that the folding of the wrapped beds is preceded by the breaking of the strata by the fore-thrust ramp.

The angular relationship between the hinge and northeastern limb (Fig. 7g), in conjunction with the existing local kink-style fold, possibly reflects backthrust activity and suggests that the anticline is a fault-propagation fold. It is developed by the most recent tectonic event in a long history of the underlying faults that existed well before the Zagros Orogeny (Koshnaw et al., 2020). As previously interpreted by Kent (2010), faults with NW–SE strikes function as thrust faults, which generate all the fault-related folds of the Zagros fold-thrust belt, and always start from the same detachment level located at the base of the Jurassic series or in the Triassic.

Khwelen, Qarawais, and Ashdagh are the three en-echelon anticlines that are all inside the Sangaw structure (Figs. 1 and 3). The structure's wavelength is wider than 12 km across the Qarawais anticline. According to Koyi and Mansurbeg (2021), the structure initiated from a deeper décollement above which a thicker part of the stratigraphic column has been shortened. The detachments are larger-scale anticlines with a surface trace >10 km; marly carbonates and/or evaporates in the Sarmord, Barsarin (Gotnia), Naokelakan (Najmah), Sargelu, Alan, Adayah, and Kurra Chine formations are candidates for this deep décollement horizon, with a role for Late Campanian–Palaeocene marl and clastics (Omar et al., 2015).

The difference in geometry strike (Khwelen anticline vs. Qarawais anticline) may be indicative of the fold wavelength, amplitude, and displacement variation on individual thrusts. Alternatively, it might be attributed to the influence of a strike-slip fault (Transcurrent fault) (Figs. 3 and 4b) that aligns with subsurface lineaments (Burberry, 2015). It is expected that when the fault displacement grows, the fault's lateral length will increase at a higher rate than the displacement rate. (Keller et al., 1999). Current authors believe that the transcurrent fault explains why the southeastern plunge of the Khwelen anticline has not been developed.

The fact that the thickness of the Mukdadiya Formation varies and is greater on the southwest limb of the anticline in comparison to the northeast limb is evidence that the structure was active throughout the deposition processes (~5 Ma). This result aligns with previous research conducted by Lawa et al. (2013) and Koshnaw et al. (2020). (Koshnaw et al., 2017) deemed the Mukdadiya Formation's syn-tectonic growth strata to be indicative of syn-kinematic deposition along the Kirkuk frontal fault structure.

The geometrical analysis of the anticline (Table 1), in addition to the en-echelon linkage with the Qarawais anticline (Fig.3, 4b), reveals that the Khwelen anticline is not the extension of the Qarawais anticline, as mentioned (mapped) previously (Qadir et al., 2023; Stevanovic and Markovic, 2004).

Conclusions

The Khwelen anticline is a single plunge, asymmetric box fold, of NW-SE trend, V-shaped in map view, about 10km in length, and 5km wide. A southeast vergence transcurrent fault inhibited the development of the southeast plunge of the anticline from developing. The anticline is located within the Sangaw structure; the SE end of the anticline has en echelon linkage with the Qarawais anticline. The NW plunge has a linear link with the Chamchamal anticline. The anticline is a type of fault propagation fold developed above the front thrust fault, starting from the detachment level located at the base of the Jurassic - Triassic series. The existing local kink-style fold in the northeastern limb reflects the back thrust acting on the anticline. The Bajwan and Anah formations are exposed in the deep valleys at the core of the anticline. The early Miocene Euphrates and Jeribe formations are overlaid, with the Fatha Formation presenting the main structure of the anticline. The SW limb of the anticline is steeper and subjected to fluvial erosion than the NE limb.

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