Structural Study of the Late Oligocene-Early Miocene Sequence in Khabaz Oil Field, NE of Iraq

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Abstract

Khabaz Oil Field is located in Kirkuk, about 20 Km southwest of Kirkuk City between Jambour and Bai Hassan oil fields. Tectonically, it is located on the Unstable Shelf within the Low Folded Zone (Zagros Fold Belt). Six wells in Khabaz oil field with two seismic lines (Line K8 and KK54) are used to conduct the geometric analysis, which include the description of fold and fault systems for the purpose of understanding the structural setting of Jeribe (Early Miocene) and Azkand (Late Oligocene) formations in this field. Khabaz structure is a double plunging positively inverted subsurface asymmetrical anticline influence the whole pre-Holocene sedimentary sequence. The interlimb angle of this structure ranges between 137° to 151° which is classified as a gentle anticline. The dip values of the axial surface range between 82 – 84°, so it can be classified as an upright fold with a general trend NW-SE. The core of the anticline is bounded by two high angle dipping reverse faults splay dipping toward each other. These faults pushed the core of the anticline upward with respect to the limbs of the structure. The Southwestern limb is affected by several high angle inverted faults that were possibly bifurcated from one or two major faults. The Northeastern limb is also influenced by a series of high angle reverse, some are dipping toward the core of the structure and few others are dipping toward the limbs. Some of these faults especially those influenced the southwestern limb of the anticline were inherited from the original normal faults that bounding the graben structure developed during the deposition of the Shiranish Formation. During the Late Plio-Pliocene contraction phase, the sense of slip on these faults were inverted and the faults migrated upward into the Tertiary sequence resulting in the formation of the positively inverted structure.

Keywords: Geometric analysis; Inverted fault; Jeribe Formation; Azkand Formation; Thrust fault

1. Introduction

The present study deals with two intervals succession in Khabaz oil field which represent important hydrocarbon traps during the Tertiary period. Trap assessment is essential to the oil field of a prospect and is an integral part of every effective plan for exploration of hydrocarbons or evaluation of resource. The first seismic survey in the Khabaz area is started in 1971 and indicated the necessity the presence of the Khabaz prospect, the first discovery in well Kz-1 which was drilled in 1976. The development in this oil field was started 1987 by France Technip Geoproduction for the North Oil Company. the oil

DOI: 10.46717/igj.55.1F.6Ms-2022-06-21
field which described it an anticlinal structure located between Jambour and Bai Hassan oil field and sited parallel to the Kirkuk oil field trend. The Khabaz Oil Field is located in Kirkuk Governorate, about 20 Km southwest of Kirkuk City between Jambour and Bai Hassan oil fields. Tectonically, it is located in an Unstable Shelf within Low Folded Zone (Zagros Fold Belt) (Jassim and Goff, 2006)(Fig.1).

Fig.1. Base map for the study area showing studied boreholes and selected lines of seismic section (K-8 and KK-54) and tectonic map according to Al-Ameri and Zumberge (2012)

Six wells (Kz-3, Kz-4, Kz-6, Kz-7, Kz-10 and Kz-43) data with two seismic lines (Line K8 and KK54) for Jeribe and Azkand succession are used to conducting the geometric analysis which include the description of fold and fault systems for the purpose of understanding the structural setting of Khabaz oil field. There are many previous studies that dealt with structural and geometric analysis of many structural and subsurface geological features using seismic sections and oil wells information throughout Iraq such as Al – Kubaisi and Ahmed (2018) Kareem et al. (2021) and Naji et al. (2022).

The Jeribe Formation was deposited during late Lower Miocene which consisting generally of massive limestone, recrystallized, dolomitized and anhydrite. Bellen et al. (1959) they were suggested that the Jeribe Formation was deposited in lagoon and backreef to reef depositional environments. Backreef to reef facies associations are predominant (Jassim and Goff, 2006 and Aqrawi et al., 2010). While the Azkand Formation was deposited during Late Oligocene, and described at the first time by Bellen in 1956 in the Qara Chuqh structure within the Azkand cirque in which it is comprised of thick massive, dolomitic, and recrystallized, generally porous limestone with thickness about 100 m (Bellen et al., 1959). The Azkand succession was deposited in the fore reef depositional environment (Jassim and Goff, 2006).
2. Materials and Methods

The Khabaz oil field in this study is covered by two seismic lines (K-8 and KK-54) (Figs. 2 and 3) with sparse 2D data of different vintages and quality. Two reflectors were picked in present study, these are Jeribe and Azkand formations, in addition to younger reflector (Fatha Formation) and older reflectors (Shiranish and Kometan formations which appeared in studied seismic sections (Figs. 4 and 5). Six wells data (Kz-3, Kz-4, Kz-10 and Kz-43) were used to checking the tops and draw cross section for the studied formations. Software such as Petrel and Stereonet v.11 were used to plot and reconstruct the data for the current study.

Fig. 2. Seismic section of the Khabaz Structure, Line K8

Fig. 3. Seismic section of the Khabaz Structure, Line KK54.
Fig. 4. Structure contour map (depth map) of Jeribe Formation in Khabaz oil field (modified after OEC, 2017)

Fig. 5. Structure contour map (depth map) of Azkand Formation in Khabaz oil field (modified after OEC, 2017)
3. Classification of the Khabaz Structure

The values of dip and dip direction were calculated from two depth maps for the two studied formations of the Khabaz Structure which are shown in Figs. 2 and 3, all depths are taken from sea level. Table 1 showing the dip direction and dip value which calculated for the studied formations (Jeribe and Azkand) within two limbs of the Khabaz structure, along two traverses (A and B) marked on the structural map for the top of Jeribe and top of Azkand (Figs. 4 and 5).

Table 1. Calculation of the dip and dip direction from the structure contour maps of the Khabaz structure

<table>
<thead>
<tr>
<th>Section</th>
<th>Formation Name</th>
<th>Dip Direction &amp; Dip amount</th>
<th>NE Limb</th>
<th>SW Limb</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>Jeribe</td>
<td>043°/10°</td>
<td>190°/20°</td>
<td></td>
</tr>
<tr>
<td>B</td>
<td>Azkand</td>
<td>006°/20°</td>
<td>240°/35°</td>
<td></td>
</tr>
<tr>
<td>A</td>
<td>Jeribe</td>
<td>043°/20°</td>
<td>190°/24°</td>
<td></td>
</tr>
<tr>
<td>B</td>
<td>Azkand</td>
<td>006°/17°</td>
<td>240°/32°</td>
<td></td>
</tr>
</tbody>
</table>

The dip of the axial surface of the fold and the interlimb angle are obtained from stereo-net projection software by using dip and dip directions of the depth contour maps for two formations (Jeribe and Azkand) (Figs. 6 and 7) and Table 2.

Table 2. Attitude of the axial Surface dip and the interlimb angle of the Jeribe and Azkand tops by the Stereonet Software

<table>
<thead>
<tr>
<th>Formation</th>
<th>Bearing &amp; Dip amount of the Axial Surface</th>
<th>The Interlimb Angle</th>
<th>Plunge of the Hinge Line</th>
</tr>
</thead>
<tbody>
<tr>
<td>Jeribe</td>
<td>042° / 82°</td>
<td>138°</td>
<td>51/12°</td>
</tr>
<tr>
<td>Azkand</td>
<td>025° / 85°</td>
<td>137°</td>
<td>33/11°</td>
</tr>
</tbody>
</table>

Fig. 6. Stereographic projection of Khabaz structure on the Jeribe Formation near A. NW plunge B. SE plunge.
Fig. 7. Stereographic projection of Khabaz structure on the Azkand Formation near A. NW plunge B. SE plunge.

According to fold classification of Fluety (1964) and based on the values of the interlimb angle, the Khabaz Anticline is representing a gentle anticline along A and B sections. The axial surface is representing a surface which formed from the consecutive folded surfaces and contains the hinge lines. According to the dip values of axial surface (Pluijm and Marshak, 2004), Khabaz anticline which ranging from 82-84º, so it can be classified as upright fold. Based on the plunge of hinge line (Pluijm and Marshak, 2004), Khabaz anticline which characterized by shallow fold in the NW plunge side and horizontal to the SE plunging side, therefor the Khabaz anticline is classified as a double plunge anticline (Figs. 8 and 9). Barnes and Lisle (2004) explained the symmetry and its relationship with the length of limbs, the folds which have unequal limbs and dip angle are called Asymmetrical. The values of dip angles in the Khabaz structure ranging from 10-20º in the NE limb and 20-35º in the SW limb (Table 2) confirmed that Khabaz Structure is asymmetrical anticline.

Fig. 8. Three-dimensional structural model of the Jeribe Formation in Khabaz oil field
Fig. 9. Longitudinal sections NW-SE direction of the Khabaz structure showing the plunging anticline structure, A) Jeribe Formation, B) Azkand Formation
4. Fault Systems in the Khabaz Structure

Marouf and Al-Kubaisi (2005) mentioned that the major folds of the Foothill (the un-elevated folded) Zone were developed as positively inverted structures. They showed that the area of the foothills was affected by intensive NE-SW extension during the late Campanian-Maastrichtian time resulted into formation of NW Trending grabens and half grabens. NE-SW compressional stresses resulted into positive inversion of those pre-existing grabens and half grabens and the formation of positively inverted structures. Khabaz structure is one of them.

Fig. 10 is a structure (time converted into depth) cross section across Khabaz anticline with vertical scale approximately four times the horizontal scale. Four horizons were recognized basing on data from wells Kh-7, Kh-10, and Kh-6, these horizons are; the tops of Lower Fars, Jeribe, Shiranish and Kometan. The seismic cross section clarifies that Khabaz structure is a positively inverted anticline. The core of the anticline is bounded by two high angle dipping normal faults splay dipping toward each other's.

These faults pushed the core of the anticline upward with respect to the limbs of the structure. The South western limb is affected by several high angle inverted faults that we possibly bifurcated from one or two major faults. The North Eastern limb is also influenced by a series of high angle reverse, some are dipping toward the core of the structure and few others are dipping toward the limb. Some of these faults especially those influenced the southwestern limb of the anticline were inherited from the original normal faults that bounding the graben structure developed during the deposition of Shiranish Formation. During the later Plio-Plistocene contraction phase, the sense of slip on these faults were inverted and the faults migrated upward into the Tertiary sequence resulted into formation of the positively inverted structure.

From structural contour maps, and seismic sections there are three major faults with others minor fault (No information was available about minor faults from the Oil Exploration Company, but it was seen from the available seismic section) effected upon the studied succession, these major faults are F1, F2 and F3 (Figs. 11 and 12) and their attitudes in Table 3. The dip direction and amount of the Khabaz structure faults was calculated from the structural map and seismic cross section (Table 3) and classify
according to Earle (2015). These calculations and measurements were appeared the F1 is revers fault (dip of fault plain for F1 > 45) while F2 and F3 are normal faults (Figs. 11 and 12). The block between F2 and F3 was relatively moved down-side to forming a graben area at the northwest plunging.

Table 3. Attitudes and fault types in Khabaz oil field

<table>
<thead>
<tr>
<th>Section</th>
<th>Formation</th>
<th>Fault 1 Dip direction and amount</th>
<th>Fault 2 Dip direction and amount</th>
<th>Fault 3 Dip direction and amount</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>Jeribe</td>
<td>025/53(^\circ)</td>
<td>032/75(^\circ)</td>
<td>210/75(^\circ)</td>
</tr>
<tr>
<td>B</td>
<td>Jeribe</td>
<td>025/53(^\circ)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>A</td>
<td>Azkand</td>
<td>025/53(^\circ)</td>
<td>032/75(^\circ)</td>
<td>210/75(^\circ)</td>
</tr>
<tr>
<td>B</td>
<td>Azkand</td>
<td>025/53(^\circ)</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Fault type

- Reverse
- Normal

Fig.11. Cross sections of the Jeribe Formation in Khabaz structure provide an anticline structure, a. Section A, b. Section B (Structural map modified after OEC, 2017)
Fig. 12. Cross sections of the Azkand Formation in Khabaz structure showing the faults systems, a. section A, b. section B (structural map modified after OEC, 2017).

5. Conclusions

The Khabaz structure is a double plunging positively inverted subsurface asymmetrical anticline influence the whole pre-Holocene sedimentary sequence. This structure is characterized by values of the interlimb angle ranging from 137 to 151º which is classified as a gentle anticline. And the dip values of axial surface were ranging from 82 to 84º, so it can be classified as an upright fold with a general trend NW-SE. Three major faults pushed the core of the anticline upward with respect to the limbs of
the structure. The southwestern limb is affected by several high angle inverted faults that we possibly bifurcated from one or two major faults. The North Eastern limb is also influenced by a series of high angle reverse, some are dipping toward the core of the structure and few others are dipping toward the limb. Some of these faults especially those influenced the southwestern limb of the anticline were inherited from the original normal faults that bounding the graben structure developed during the deposition of Shiranish Formation. During the later Plio-Plistocene contraction phase, the sense of slip on these faults were inverted and the faults migrated upward into the Tertiary sequence resulted into formation of the positively inverted structure.

Acknowledgments

The authors are very grateful to the reviewers, Editor in Chief Prof. Dr. Salih M. Awadh, the Secretary of Journal Mr. Samir R. Hijab, and the Technical Editors for their great efforts and valuable comments.

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