Study of Subsurface Structural Image and Model Using 2D Seismic Reflection Method of Injana Field Area, Northeastern Iraq

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Abstract
The Injana field area is located to the north of Baquba city within Diyala, which was studied and interpreted by using 2D seismic data from the Oil Exploration Company. The study was concerned with the Jeribe Formation which is located within the Injana field area and belongs to the Tertiary Age. Two reflectors were detected based on synthetic seismograms and well logs of the Khashim Al-Ahmer-2 well. The structural maps were derived from seismic reflection interpretations to determine the location and direction of the basin. The depth maps were conducted depending upon the structural interpretation of the picked reflectors to show several structural features. Structurally, seismic sections show that the Injana area is affected by two types of reverse fault systems trending in a NW-SE direction, the first represents thrust faults affected on the lower Fars (Red Beds & Seepage) and the layers above it, the salt bed within Lower Fars Formation being as a detachment surface of this fault, the second represents two reverse faults affected on the bottom part of the Lower Fars (Transition beds) and the layers beneath. In addition, the reverse faults become dense in the north part. The structural maps reveal an elongated asymmetrical narrow anticline affected by one major thrust fault at Lower Fars Formation, and an elongated asymmetrical narrow anticline surrounded by two major reverse faults and consisting of three domes separated, Injana, Khashim Al-Ahmer and Khashab domes at the Jeribe Formation.

Keywords: Injana Field; Fault system; Asymmetrical narrow anticline; Seismic section; Synthetic seismogram; 3D structural model

1. Introduction
Seismic methods are the most commonly used, especially when the seismic reflection method is applied to explore and investigate subsurface deposits of hydrocarbon accumulation (Hart, 2004). Seismic reflection provides more depth information with high detail and precision, through seismic section layers of subsurface rock sequences (Al-Sinawi, 1981). Seismic interpretation is the last step after the processing field data. The seismic data provides good visualization of the different properties and densities of subsurface rocks, through the determination of the acoustic impedance of the rock layers (Brown, 2011). In seismic reflection studies, the identification of accurate subsurface geological structures like folds, faults, and structural attributes of subsurface conditions, representation of data, representation in the seismic selection, velocity, time could be used to determine structural traps,
stratigraphy traps, depositional environmental, facies and direct hydrocarbon indicator (DHI), (Al-Sadi, 2017). Synthetic seismogram modeling gives a detailed diagram of the geological relationship with depth in order to determine the hydrocarbon content (Milsom, 2003) and (Arsenikos et al., 2015).

The aim of the current study is to use the seismic reflection data of the Lower Fars and the Jeribe Formations of the Injana field to determine the types of fault systems that affected the study area, and the trend of these faults, and create 2D Structural maps and 3D Structural model at the Lower Fars and the Jeribe formations of the Injana field respectively.

2. Location

The Injana field is located east of Iraq within Diyala, 66Km to the North of Baquba city and about 100 km NE of Baghdad (Fig. 1). According to the tectonic map of Iraq (Al-Kadhim, and Al-Attar, 1981), (Sissakian et al., 2016), the field is part of the Hamrin south range which is located central faulting zone and situated on the axial trend from the NW to the SE and includes (Injana-Khashim Al-Ahmer-Minsuryia), it’s located within for deep faulted area. The structure is an extended NW-SE trending anticline with a rock structure on the northeast and southwest sides created by reversing faults (O.E.C., 1980) and (El-Makhr and Abd, 2011).

![Fig. 1. Location map of the Injana field area, modified after (O.E.C., 1989)](image)

2.1. Geological Framework

Injana area is covered by surface deposits of the Quaternary polygenetic syncline fill also partially by the Jeribe and the Lower Fars (sediments), upper Fars (sand, silt, and clay) cover the study area. In general, the elevation of the area is about 100 (m.) above sea level, Topographically, the area is characterized as a complex region where the elevation of the land is about 200 m in the middle part and decrease towards the southwest and northeast parts where the elevation becomes 100 m above sea level.

3. Materials and Methods

3.1. Synthetic Seismogram Generations and Reflectors Definition

Synthetic seismogram of KA-2 well was generated using synthetic program within the IESX interpretation software of the interactive workstation (Geoframe) because the five wells were drilled in the Injana field area indicated by In-1, 2, 3, 4, and 5, the first four wells didn’t achieve their final target,
as the drilling stopped in them due to technical problems. Only the Injana-5 well, drilling was completed with a total depth (3523.5) meters penetrating Balambo Formation (O.E.C., 2014) (Khorshid and Khadm, 2015), and (Shyaa and Al-Rahim, 2021). But unfortunately, the well data represented by (Well Tops, Check-shot, and Sonic logs) of In-5 well are missing. That is why the data of KA-2 well locates to the southeast of the Injana field were adopted as inputs to construct the synthetic seismogram in the time domain for identifying the reflectors of seismic data.

This program can extract the relationship between both the time and depth functions in a well location. The main steps for synthetic seismogram generation are:

- The sonic log was converted from depth to time domain using the provided check-shot. This relationship is essential in determining the reflection on the time lines of the seismic section & synthetic trace against the required bed in the well.
- The convolution process between reflection coefficients values and selected wavelet (zero-phase wavelet) from seismic data is made to make a synthetic seismogram from computed reflectivity series by convolved with an extracted wavelet to match the dominant frequency of processed seismic data.
- After that, Coloration between the signal of the seismic section and synthetic must be done to get the best match between them.

Reflectors identified on seismic line (PIK-18) that passing through the KA-2 well in order to pick and track the interest reflectors on all seismic lines within the Injana field area. Fig. 2 shows synthetic layout of the KA-2 well, and Fig. 3 represents a composite seismic section passing through well locations together with the synthetic traces constructed at those wells. The match between seismic traces and synthetic traces is good.

![Fig. 2. A good tie with seismic data of KA-2 synthetic seismogram](image-url)
3.2. Faults Recognition and Horizons picking

Seismic sections provide simultaneous clarification of subsurface structures such as faults and folds. The definition of the forms, various kinds, and geographical variances of these structures are critical because they play a significant role in the accumulation of petroleum. The high quality of the seismic section has enabled the characterization of some of the structure properties on the seismic section, like fault types and displacements of the fault. Consequently, two horizons representing Tertiary time were selected to be picked and mapped (Fig. 4). Picked horizons and their characteristics are shown in Table 1.

Table 1. Characteristics of picked horizons

<table>
<thead>
<tr>
<th>No.</th>
<th>Seismic Horizon</th>
<th>Event Picked</th>
</tr>
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<tbody>
<tr>
<td>1</td>
<td>Top Lower Fars Fn.</td>
<td>Peak</td>
</tr>
<tr>
<td>2</td>
<td>Top Jeribe Fn.</td>
<td>Peak</td>
</tr>
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Fault interpretation and picking were conducted using instantaneous phase sections. Instantaneous phase sections were generated from the original 2D reflectivity data. This type of attribute is derived from the estimation of local variation in the signal and highlights the discontinuities in the horizontal continuity of amplitude. During the interpretation, this display of attributes was extensively used to pick faults on seismic section and mapping. Fig. 4 illustrates the presence of major faults that were observed first at the shallow levels. Faults interpretation shows that Injana area has been affected by reverse and thrust faults system, therefore the patch horizons interpretation technique was adopted in this study, this technique was very important to draw maps for areas which affected by reverse faults systems.

Major faults were apparent at the picked horizon. The seismic section shows that the Injana area is affected by two types of reverse faults due to the high deformation of compression forces, these types are:
• One main thrust fault trending in NW-SE orientation which affected on the top of Lower Fars (Red Beds & Seepage) and the Formations above it with large displacements, the salt bed within Lower Fars Formation being the detachment surface of these faults.
• Two main reverse faults affected on Jeribe and Formations below it with high displacements within Injana area.
• In addition, two main reverse faults have been affected at north of Injana field.

All these events and effects in previous points 1, 2, and 3 which act at the Injana field area were shown in Fig. 4.

![Fig. 4. Instantaneous phase seismic section of PIK-24 Illustrates Injana structural dome affected by thrust and reverse faults of study area](image)

4. Results and Discussion

4.1. Two Way Travel time (TWT) Maps

A structure contour map is one of the most important tools for structural interpretation because it represents the full two-dimensional form of a map horizon, and subsurface configurations must be understood in detail to effectively delineate the structures that are favorable for hydrocarbon accumulation. This is because hydrocarbons are found in geological traps, and these traps may be structural or stratigraphic (Coffen, 1984) and (Arsenikos et al., 2015).

Based on that, after finishing horizons picking overall 2D lines, fault boundaries maps of the Lower Fars & Jeribe horizons were drawn according to horizon contacts with fault sticks that picked on seismic sections. Subsequently, TWT values for each horizon were performed a gridding process and mapped in time domain using Petrel Software available on interpretation center of Oil Exploration Company. A 100 m above sea level reference datum was used together, and 100ms and 50m contour intervals in the preparation of time maps of Lower Fars and Jeribe respectively (Figs. 5 and 6).
Fig. 5. TWT map of Lower Fars reflector

Fig. 6. TWT map of Jeribe reflector
4.2. Structural Model

A 3D modeling is a display that allows properties to be created by using pre-defined system variables such as cell volume, seismic resampling, zone index, and so on. Each cell will be assigned a numerical value that corresponds to the system variable that has been chosen. Geometrical modeling extends beyond simple geometrical properties to more complex property distributions such as random normal distribution, zone segments, fault segments, seismic connected volumes, and well index region, (Schlumberger, 2013). Consequently, depending on the result of seismic structural interpretation (depth grids and fault boundaries of Lower Fars and Jeribe Fns), the Petrel program was used to create a 3D structural model in the depth domain to identify the structural framework of the Injana region. This model gives an initial strategy for the future of the field works such as drilling wells or preparing planning for a new 2D or 3D seismic surveys in study area.

Structurally, the Lower Fars 3D model shows one elongated Asymmetrical anticline extending to the northwest-southeast direction, the anticline has been affected by one major thrust fault along the anticline axis, and one can see the layer dip toward northeast and southwest directions of Injana area. The Jeribe 3D model shows the area is divided by two major reverse faults into three parts and the middle part represents an elongated Asymmetrical narrow anticline which consists of three domes separated by saddle areas, Injana dome in the middle part, Khashim Al-Ahmer dome in the southern part, and Khashab dome appears in the northern part. The layer dip is steep at domes area, and becomes gentle toward northeast and southwest directions beyond the reverse zones. Inj-5 and KA-2 wells have been drilled on middle and southern domes respectively. There is a high shift to the northwest in the structural axis of the Khashab dome, this reflects an increase in the forces of tectonic deformation in the northern part of the area, with the possibility of being affected by a strike-slip fault separating between Injana and Khashab domes (Figs. 7 and 8).

Fig. 7. A 3D view of structural model of Lower Fars Formation in depth domain
Fig. 8. A 3D view of structural model of the Jeribe Formation in depth domain

In addition, a cross-section passes in the center of Injana area towards the Northeast-Southwest was derived in the depth domain to reveal the structural shape and salt attitude in the area (Fig. 9).

Fig. 9. A cross-section derived from a seismic interpretation passes through the Injana area

The last stage of structure development is the uplift block on two conjugate faults (Fig.10), show’s evidence of the existence of uplifting.
Fig. 10. Simulation geological cross-section model illustrates the geometry of main structural features in Injana area

5. Conclusions

Based on seismic evidence and structural maps results, tectonic evolution of Tertiary basin, and basin analysis of the Lower Fars and Jeribe formations, the following major conclusions are achieved:

1- Tectonically, the Injana area is a part of a mobile shelf of the Mesopotamian basin and relatively, it was considered an active area due to being affected by the compressional phase which started at the end of the upper Cretaceous age.

2- Structurally, Injana field area considers as a complex area due to:

- The area has been affected by a reverse fault system, one major thrust fault with 500 m maximum displacement affected on Lower Fars and formations above it, and two major reverse faults with 300 m maximum displacement affected on the Jeribe and formations below it, and these faults become dense in the north part.
- The salt layer within the Lower Fars Formation is being the detachment surface of the thrust fault, and the salt intrusive through faulted zones led to the presence of salt bodies within the Lower Fars Formation.
- The structural maps reveal an elongated Asymmetrical narrow anticline affected by one major thrust fault at Lower Fars Formation, and an elongated Asymmetrical narrow anticline surrounded by two major reverse faults at Jeribe Formation, its consist of three separated domes, Injana dome in the middle part, Khashim AL-Ahmer dome in the southern part, and Khashab dome in the northern part.
- The northeast limb of lower Fars Fn. represents the shallower hanging wall, and the field dome (middle part) of Jeribe Fn. represents the shallower steep hanging wall surrounded by gentle deep and broad syncline areas from the southwest and northeast sides.
- There is shifting in the structural axis at the northern part, this reflects the area affected by strike-slip-fault separated between Injana and Khashab domes. Al-Adhaim river which passes through the north part of Injana area confirms the existence of this fault.

3- Consequently, due to the complexity of a structural image, the area has a good promising for hydrocarbon exploration at Tertiary Formations.
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