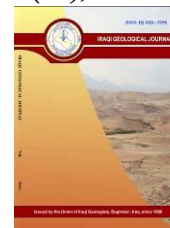




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Origin of a Negative Gravity Anomaly over an Anticlinal Structure: A Case Study from the Rumaila Oil Field, Southern Part of Iraq

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Abstract

The area of the southern part of Iraq, Basra Governorate is well-known as an area of giant oil fields (such as West Qurna 2, Rumaila, Tuba, Zubair, and Nahr Umr) associated with negative gravitational anomalies. The negative gravity anomaly over the Nahr Umr structure was interpreted from seismic sections as a piercement salt dome like Jebel Sanam (a hill located 80 km to the south). But, no evidence for salt existence is found beneath West Qurna 2, Rumaila, and Tuba structures in the seismic sections. The main problem facing the interpretation stage is the ambiguity in the source of this negative anomaly. In the South Rumaila oil field, the negative anomaly still appears despite the disappearance of salt; this case produces confusion in understanding the geological situation. The present study discussed the case and gave an interpretation for the presence of the negative gravity anomaly over these structures. A residual gravity map was prepared, synthetic case examples are given, and sedimentary successions from well data are studied and compared with the seismic section to define the thickness of formations, their density contrast, and structural geometry conditions. Considering the geometry, the results showed that an arch-shaped anticline consists of less dense rocks (Gotnia Formation) compared to denser adjacent formations (limestone). In this case, the density contrast can lead to a negative density contrast and a negative gravity anomaly. The density contrast values extracted from well data: 1- Nahr Umr (2.32 g/cm^3) and Maaddud (2.5 g/cm^3) formations. 2- Gotnia (2.36 g/cm^3) and Sulay (2.7 g/cm^3) formations imported as constraints in 2D forward gravity modelling. All the results of residual gravity, seismic section, and 2D modelling suggest that the reason for the negative anomaly above the South Rumaila oil field is due to the low-density layer of the Gotnia Formation.

Keywords: Negative gravity anomaly; Rumaila oil field; Gotnia Formation, South of Iraq

1. Introduction

A negative gravity anomaly over an anticlinal structure occurs when the subsurface rocks within the anticline exhibits lower density compared to the surrounding rocks. This density contrast reduces the gravitational pull, leading to a measurable decrease in gravity. Key reasons for this phenomenon include: 1. Salt Domes or Salt Cores, 2. Hydrocarbon Reservoirs, 3. Low-Density Sedimentary Layer, and 4. Structural Uplift of Shallow, Less-Dense Rocks. Important considerations should be noted related to this type of negative anomaly, which are the geometry vs density: While anticlines are structurally elevated rocks, the density of the uplifted rocks determines the gravity signal. Denser uplifted rocks would cause a positive anomaly, but low-density rocks dominate in negative anomalies. For exploration

significance: negative anomalies over anticlines are often exploration targets for hydrocarbons or salt-related mineral resources (Nyaberi, 2023).

Basra Governorate in the southern part of Iraq is well renowned for its enormous oil reserves, including West Qurna 2, Rumaila, Tuba, Zubair, and Nahr Umr, which are linked to negative gravitational anomalies (Dengyi et al., 2024). It was believed that the negative gravity anomaly in the Nahr Umr oil field was a piercement salt dome similar to Jebel Sanam, a hill located 80 km to the south of Basra Governorate (Aqrabi et al., 2010). This structural situation is supported by a seismic section across the Nahr Umr structure (Al-Kaabi et al., 2023). However, the seismic sections beneath the West Qurna 2, Rumaila, and Tuba structures show no signs of salt presence (Fig. 1).

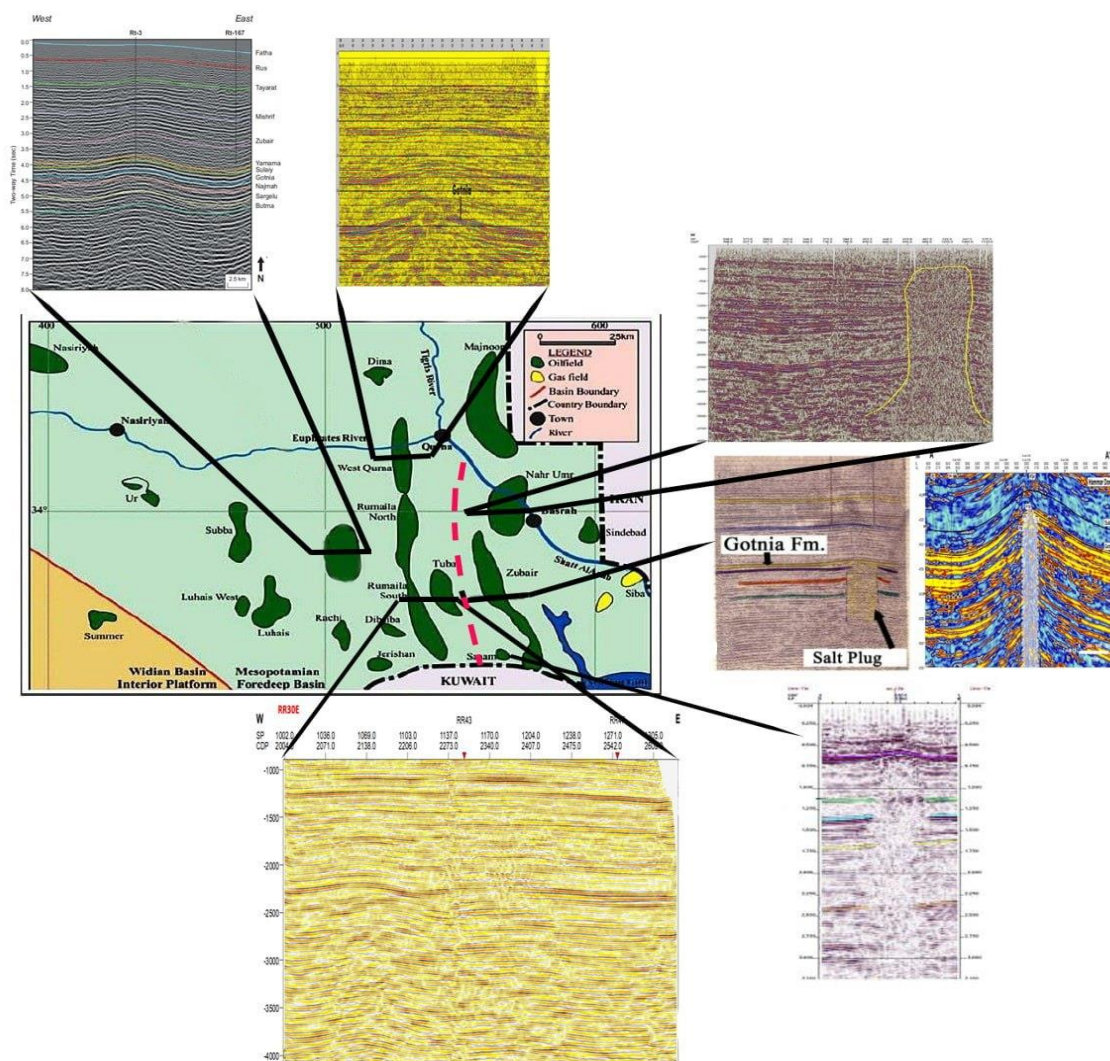


Fig. 1. The southern part of Iraq, in the Basrah Governorate. The area is very famous for the presence of giant oil fields such as West Qurna 2, Rumaila North and South, Tuba, Zubair, and Nahr Umr. For each oil field, the seismic section is presented. A dashed red line is drawn to separate the study region into two parts: the eastern part, which clearly shows the salt effects on these structures, while to the west of this dashed red line, no evidence for the salt presence is found in the seismic sections (Aqrabi et al., 2010; Al-Rahim, 2017)

Numerous negative gravity anomalies with amplitudes of a few milligals arise as diapiric folds with salt cores in the Basra region (Al-Sayyab and Valek, 1968). On a dominant regional contour, these

anomalies are shown as curvatures. The thickness gradient was 64 m/mGal, and the density contrast between the basement and sedimentary rock was estimated to be 0.37 gm/cc.

The Basrah Block and the Mesopotamia Basin in the southern part of Iraq are investigated by Al-Rahim (1997). The study demonstrates that in all the analyzed forms of analysis and enhancing analytical techniques, the shallower formations in the southeast (Basrah Block) continue to exist as negative gravity anomalies, trending N-S. These structures are next to and accompanied by deep faults. This indicates that the presence of the Hormuz Salt has a significant impact on structures, which have N-S direction. As the overburden load mounted, it continued to structure due to its growth and the movement caused by the presence of salt (halokinesis). At this location in the research region, a comparable salt migration may have taken place in the Jurassic salt basin (Gotnia) (Jassim and Goff, 2006). The present study examined the situation and provided an explanation for why the negative gravity anomaly is present over these structures, especially the Rumaila oil field.

According to Jassim and Goff (2006), the sub surface structures in south of Iraq are divided into two types, one is folds formed by tectonic setting, and the other is salt dome related to the movement of the Hormuz Salt to the surface by density variation effect on the sedimentary layers and forming oil fields (Al-Muturya and Al-Asadi, 2008; Karim et al., 2010; Aljazeera, 2020). The structural geology of the Jurassic succession in the Zubair oil field and concluded that the oil field contained four folds, three of which are associated with the movements of the Hormuz Salt. Al-Kaabi et al. (2023) studied the oilfields classification in the Zubair Subzone by structural contour lines and described the South Rumaila oil field as a fold originated from horizontal stress.

Because the study area is located in the Mesopotamian Basin, there are many studies which focused on the petroleum system and petrophysical properties of rocks, so there is a lack of studies which dealt with the structural origin and tectonic history of fields. However, generally, there are a few studies about the Mesopotamian Zone, for example: Al-Mutury and Al-Asadi (2008); Aqrawi et al. (2010). Al-Kaabi et al. (2023) studied the oilfields' classification in the Zubair Subzone by structural contour lines and described the South Rumaila oil field as a fold originated from horizontal stress. Jaffar and Abdalnaby (2018) studied the stress regime of the Rumaila oilfield and concluded that the structure is divided into two parts, North and South Rumaila, by the Hammar strike-slip fault (Fig. 2).

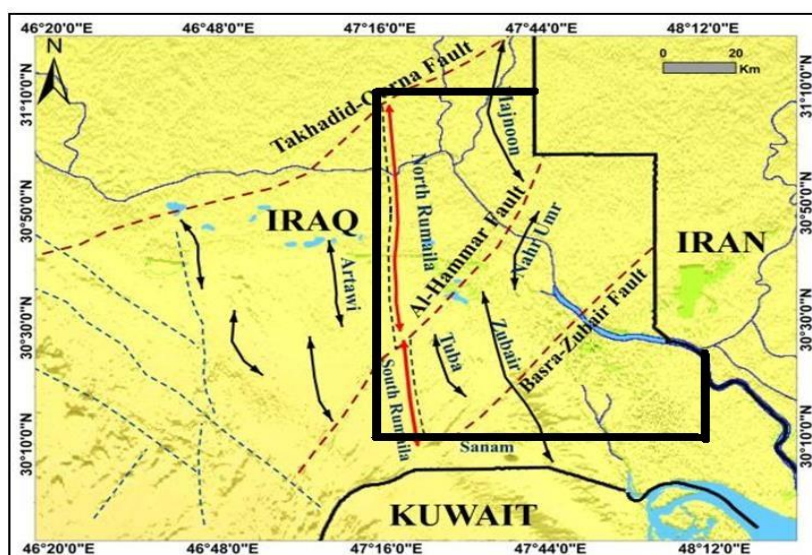


Fig. 2. Geological setting of the study area (Jaffar, 2018)

This study focused on the reasons for the presence of a negative gravity anomaly in the residual map of the South Rumaila oil field by explaining whether the cause of the anomaly is salt diapirs of the Hormuz Salt or horizontal tectonic movements of the Arabian Plate. The importance of negative

anomaly of gravity data in hydrocarbon exploration is considered the key to delineation of the Salt dome oil trap. And these salt diapirs play a role in the development of many anticlines by bending the overlying layers.

2. Materials and Methods

For a two-layer model with changeable density contrast, a synthetic model has been developed (Fig. 3) to help in clarifying the study concept and explaining why a negative gravity anomaly can exist above the folded structures. Because there is no lateral density variation, when the sedimentary layers are entirely horizontal, Gravity anomalies are not generated (Fig. 3, case a). Additionally, even with the presence of a fold structure, gravity has no effect if the two layers have the same density (Fig. 3, case b). However, if the structure is an anticline and the bottom layer's density is lower than the top layer's, then a negative anomaly is produced (Fig. 3, case c). In the anticlinal scenario, a positive anomaly can be produced when the bottom layer's density is higher than the upper layer's (Fig. 3, case d). The Rumaila oil field's case of negative anomalies, which is demonstrated to exist, is comparable to the case c in Fig. 3.

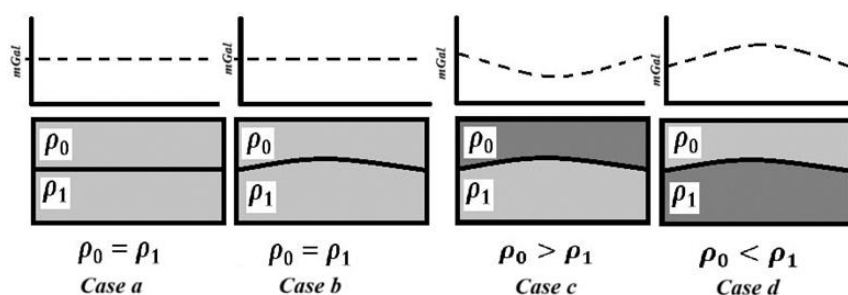


Fig. 3. Two layers model demonstrates different densities and structural forms. Case a) both layers have the same density and are horizontal. Case b) both layers have the same density but with an anticline shape. Case c) the density of the lower layer is larger than that of the upper layer with an anticline shape. Case d) the density of the lower layer is greater than that of the upper layer with an anticline shape. In case c a negative gravity anomaly could be produced.

Fig. 4 illustrates the prepared gravity data in the study area. It is clear that the Rumaila's structure coincides with a negative residual gravity anomaly. To address the idea of the methodology, the velocity and density data from well Rumaila 14 (Fig. 5a) and the structural depth section across the seismic line RR-34 (Fig. 5b) are prepared to define the difference in the density contrast in the sequence of the sedimentary succession. It is found that the boundary between: 1- Nahr Umr (2.32 g/cm³) and Mauddud (2.5 g/cm³) formations. 2- Gotnia (2.36 g/cm³) and Sulay (2.7 g/cm³) formations gave a negative density contrast (comparable to case c in Fig. 3), and the density contrast between the remaining formations gave a positive contrast value. Fig. 4b can help to design the 2D forward modelling for the same section and constrain the density, depth, and arc shape of the anticlinal structure.

3. 2D Forward Modelling Results

Using the Geomodel program for 2D forward modelling and according to the depth section (Fig. 4b), five bodies with assumed densities 0.150, 0.320, 0.150, 0.0350, 0.300 g/cm³ are created as bodies, which have a density contrast between the formations. Three bodies have positive density contrasts, whereas the other two have negative. Two scenarios are dependent on the modelling, the first without salt layer intrusion with a density of 0.300 (Fig. 6 a and b) and the second is with salt intrusion (Fig. 6 c and d). It was found that adding salt intrusion body will make the cumulative sum of the calculated gravity very large with a wide anomaly, which is not the case in the residual map and seismic section

for Rumaila oil field (Fig. 6 c and d). For these reasons, the second scenario is neglected. It was also found that the first scenario is more accurate and coincides with the actual case of Rumaila oil field (Fig. 6 a and b).

To resolve the ambiguity problem in the interpretation of gravity data, 2D model was made above the negative anomaly of the Rumaila South oil field. This model was created by Oasis montage (Geosoft) program (Fig. 7). The goal of the 2D model is to produce the best match between the calculated and observed anomaly curves to reduce the error. This process was achieved by importing the constraints data, which are densities of rocks from well data and structure from seismic section.

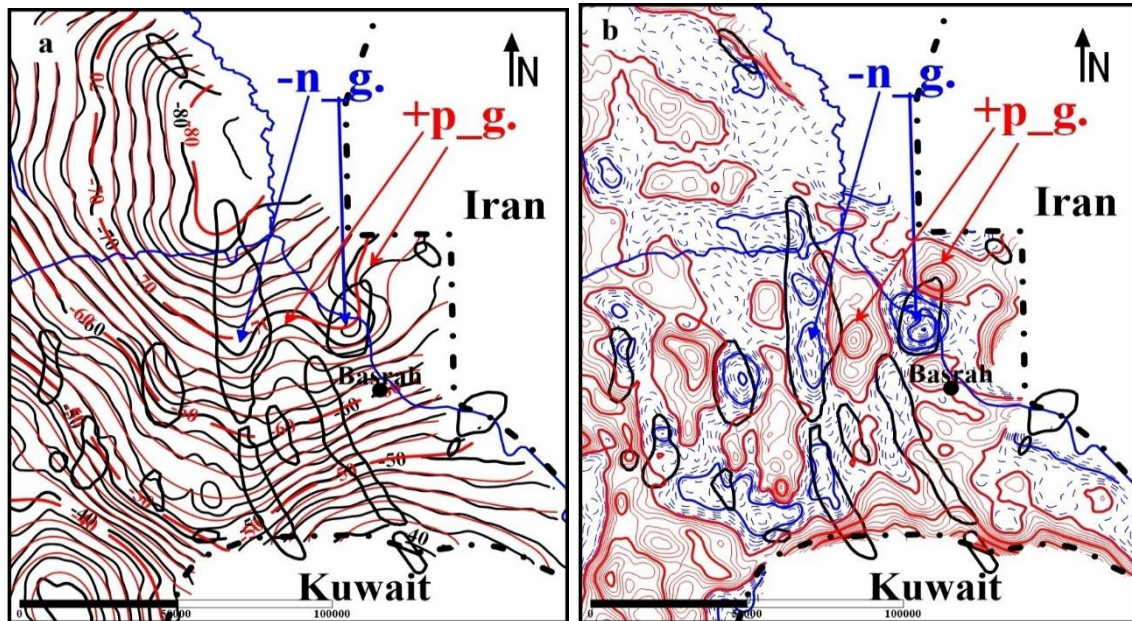


Fig. 4. a) Bouguer gravity map (black colour) (I.P.C, 1960) and regional average smooth (red colour). It is clear that when the contour curves are outside, away from the main low value of the gravity field in the study area, then the residual anomaly will be negative, and the opposite situation will produce a positive residual value. b) the residual map, which shows a negative coincidence with Rumaila, West Qurna 2, and Nahr Umr oil fields. The Zubair structure follows a negative and positive residual values

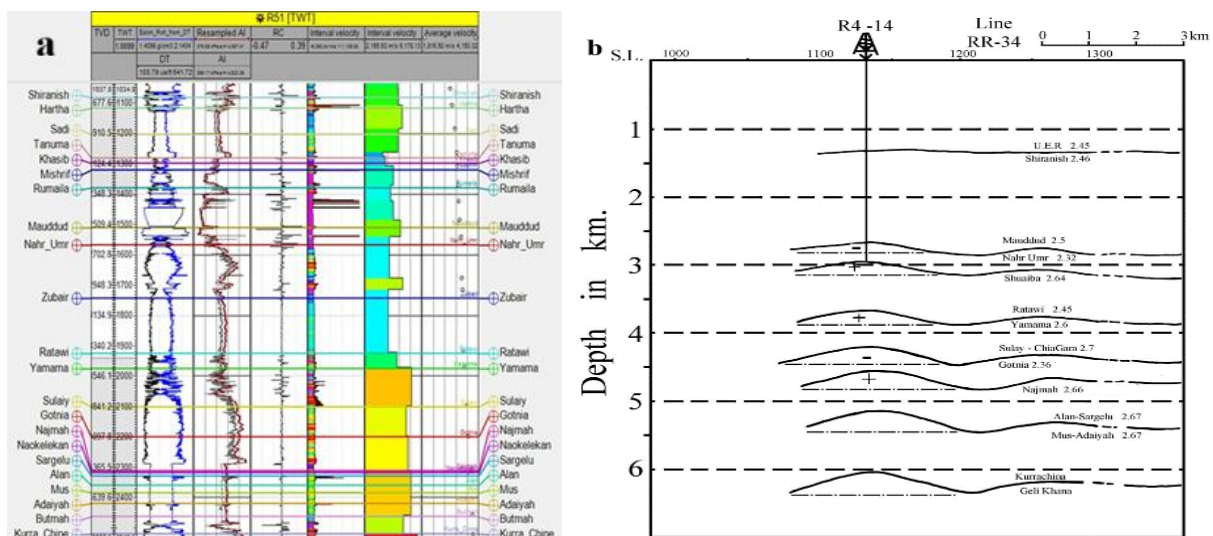


Fig. 5. a) R14 well data, which includes interval velocity (Zaidan et al., 2024), and b) Structural depth section across seismic line RR34 as shown in Fig. 1 for Rumaila South oil field (Jamal et al., 1984)

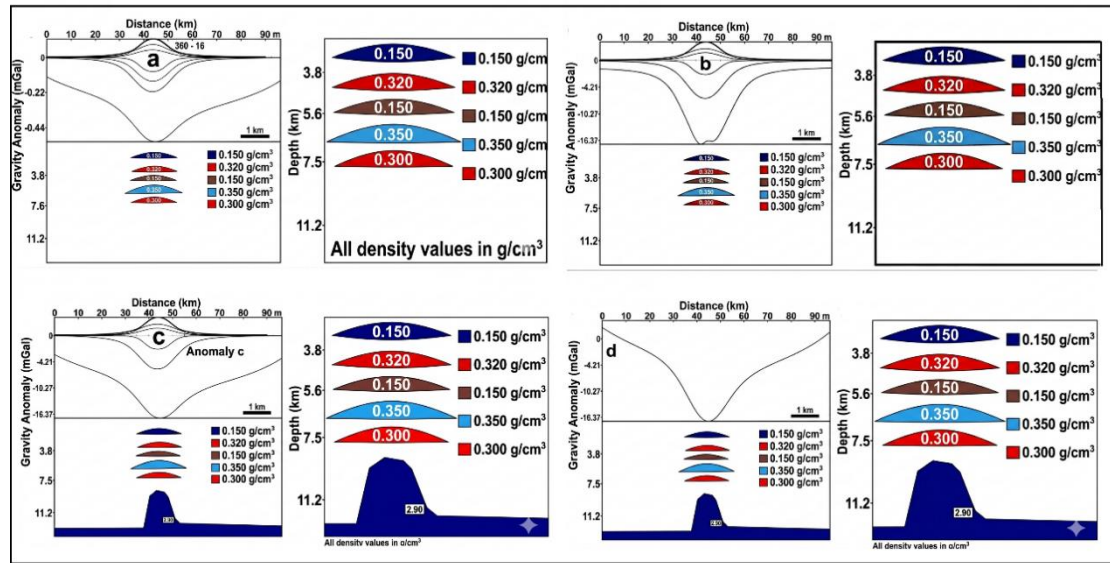


Fig. 6. a and b) for the scenario with no salt intrusion. In a, five anomalies are detected. Three with positive values and two with negative values, in b, the cumulative sum, c and d) is the scenario with salt intrusion, in c, the effect for each body is shown, and d represents the cumulative sum. The anomaly created with salt intrusion is large in value and wide in distance, which is not the case in the Rumaila South oil field.

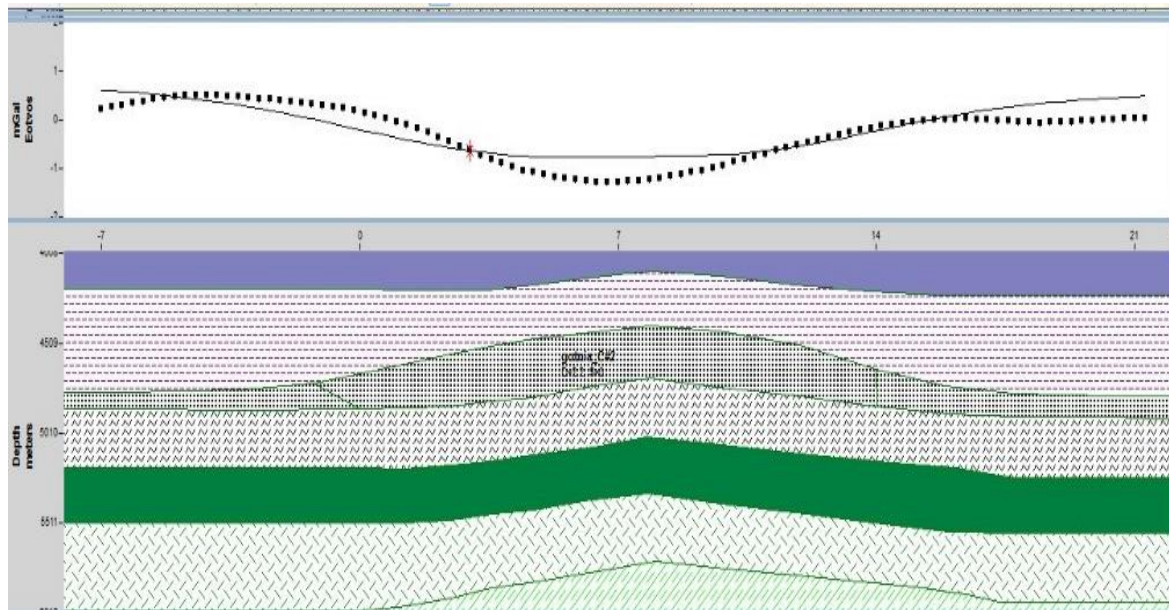


Fig. 7. Final 2D forward model for Rumaila South Oil Field. The low-density values of the Gotnia Formation are the main reason for the negative anomaly over the structure

4. Results and Discussion

The current study used a residual anomaly map to delineate the structure of the Rumaila South, and a two-dimensional geological model was developed over the South Rumaila Oil Field to explain the reasons for the negative gravity anomaly yielded from the anticlinal structure (Rumaila South). According to the concepts of the gravity method, the antiform structures produce positive anomaly

structures, because the lateral density contrast increases towards the centre of the structures. Whereas a negative anomaly is produced from a syncline when the density contrast in the core of the structure becomes less than that of the surrounding rocks. But in the present case, the Rumaila South structure is an anticline with a negative anomaly, which will confuse the interpretation of the geophysical model.

In this study area, the structures were classified according to their origin. Al-Kaabi et al. (2023) studied the antiforms in the southern part of Iraq and divided them into two groups, one originating from tectonic movements and the other from salt structures affected by the Hormuz Salt. And they classified the Rumaila South structure as an anticline formed by tectonic movements. Jaafar and Abdalnaby (2018) claimed that the Rumaila South structure is a longitudinal anticline and separated from the Rumaila North by the Hammar strike-slip fault. The difference between the Hormuz Salt and the Gotnia Formation is the depth and horizontal extension. The Hormuz Salt is deeper, and geographically has a huge extension that will effected in on overlying layers and produced salt diapiric antiforms. While the Gotina Formation is relatively thinner and has a local impact.

The results of the 2D model, as explained in Fig. 7 shows that the reason for the negative anomaly is due to a relatively low-density layer that has negative density contrast. From well data and geological information, the Gotnia Formation consists of evaporate rocks, so these type of rocks has lower density than other sedimentary rocks. That means the reason of negative anomaly is due to the Gotnia Formation, which is proved by the absence of the deep Hormuz Salt in the seismic section and the tectonic origin of the structure.

From this point, the model's result is more accurate, yields the best match between the observed and calculated data, and reduces the error to 0.05. The model simulates the real geological situation, which shows that the origin of Rumaila South is due to tectonic movements.

5. Conclusions

The obtained results explain that the interpretation of a negative anomaly should be accomplished by using many geological constraints. In the Rumaila South oil field structure, a negative anomaly exists due to the presence of the Gotina Formation. The Gotina Formation consists of thick evaporates, which tend to be of lower density than the overlying and underlying Formations. This density contrast is the Key to constructing the model to simulate the geological situation. The origin of the structure is related to horizontal tectonic movements, and this tectonic origin was proved by many authors, excluding the effect of the deep Hormuz Salt. Ultimately, the study suggests that prioritizing negative gravity and magnetic anomalies is crucial, as they may be associated with economically viable structures beyond simple synclines during the interpretation stage.

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