Interpretation of Gravity and Magnetic Data in the Erbil Plain (Iraqi Kurdistan Region)

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Doi: 10.23918/eajse.v7i1p284

Abstract: Gravity and magnetic anomalies create because of the lateral change in density and susceptibility of rocks underneath a certain datum. Gravity data in the form of Bouguer anomaly map of Erbil plain is subjected to quantitative interpretation by means of 2-D modeling by the assistance of some magnetic data in the form of profiles. Magnetic anomalies were interpreted qualitatively because of lack of magnetic properties of rocks. Seven gravity profiles in different directions from the Bouguer map were chosen to construct geological models which satisfy the situation. The residual anomaly of each profile was obtained by hand smoothing technique. It is shown that the main gravity low is attributed to thick Neogene sediments which are thrown against the Paleogene sediments by two major NW-SE faults which give rise to a density contrast of 0.3 gm/cm^3, while local anomalies were interpreted as reflections of local and shallow structures and depressions within the upper part of the Neogene sediments. The shallower anomalous bodies are less than two kilometers in depth while the main anomalous body of Erbil so-called trough reaches four kilometers in depth. Magnetic anomalies indicate both suprabasment and intrabasement anomalies. It is revealed that at least a part of the Pirmam anticline (NW of the Gomspan NE-SW trending fault) is underlain by basic igneous rocks in the basement.

Keywords: Erbil Gravity and Magnetic-IKR

1. Introduction

Geographically the area of the study covers about 2000 km^2 around the city of Erbil in the Iraqi Kurdistan region (northeastern Iraq). It is bounded by longitudes (43° 49` 54`` E – 44° 22` 3`` E) and latitudes (36° N – 36° 22` N) (Fig. 1). Topographically the area is characterized by a simple relatively wide plain bounded by two mountains. The first is the Pirmam, some 205km to the northeast of Erbil City, while the second is Qarachuq, some 30km to the southwest of the City at southwestern corner of the map in Figure 1.

Gravity and Magnetic geophysical methods are used to determine the spatial variations of the subsurface rock density and magnetic susceptibility which cause small variations in the earth's gravitational and magnetic fields respectively. Gravity and magnetic surveys are often the initial reconnaissance surveys prior to other types of survey such as seismic shooting (Ghaib, 2001; Aydogan et al., 2013). Magnetic readings were not interpreted quantitatively, because no adequate information about the magnetic properties of surface and subsurface rocks is present. Hence they were interpreted

Received: March 14, 2021
Accepted: June 12, 2021
Ghaib, F.A. (2021). Interpretation of Gravity and Magnetic Data in the Erbil Plain (Iraqi Kurdistan Region). *Eurasian Journal of Science & Engineering*, 7(1), 284-296.

qualitatively to assist the gravity interpretations. In quantitative interpretation, the aim is to determine a geophysical model for a subsurface geological body (with a chosen shape, attitude, depth and density contrast) which can give rise to the observed anomaly distribution. The residual gravity anomaly is often taken as the observed for a certain anomaly. Two problems are faced in such interpretation, the first is the method used in separating the residual anomaly from the regional background. Any of the techniques used for separation remains relative unless a lot of geological and/or geophysical information is available. The second problem is the precise definition of the source which must be consistent with the general geologic situation of the interpreted site.

2. Tectonic and Geological Setting

The area of study is a part of the Foreland folds of the Alpine Orogen in northern and northeastern Iraq. The folds of this belt become tighter and higher towards the north and northeast. The Erbil area is located on the Kirkuk basement block. The fold structures on this block (e.g. the Pirmam and Qerachuq anticlines) trend in the Zagros NW-SE direction (Numan, 1984).

Surficial expectedly thick Quaternary accumulation glacis and alluvial deposits that overlie the Upper Bakhtiari Formation of Late Pliocene age characterize most parts of the Erbil area. The stratigraphy underneath the Erbil plain is inferred from the outcrops of the above mentioned anticlinal structures that bound the plain (Fig. 1). The following is a brief resume of the lithostratigraphic descriptions (Buday, Jassim, 1987):

- PilaSpi Formation (M. & U. Eocene); consists of crystalline dolomitic, clayey or chalky limestone.
- Lower Fars Formation (M. Miocene); consists of limestone, marl and gypsum.
- Upper Fars Formation (U. Miocene); consists of loosely packed claystone, sandstone with lateral variations between these two types of sediments.
- Upper and Lower Bakhtiari Formation; (U. & L. Pliocene); the Lower Bakhtiari is composed of sandstone, claystone and siltstone. The Upper Bakhtiari Formation is composed of massive conglomerates, siltstones and claystone.

Upper Bakhtiari Formation is covered by a considerable thickness of Quaternary sediments around the Erbil City. Average density of the present rocks are calculated by Ghaib (2001) and given in Table 1.

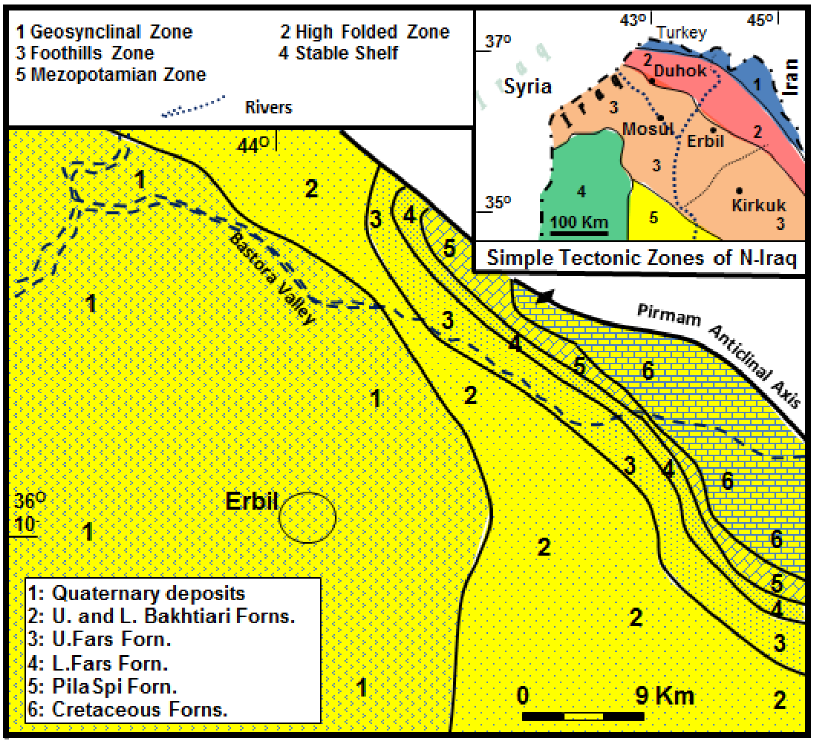

Figure 1: Location and geological map of Erbil area

Table 1: Average rock densities in the studied area

Rock unit	Mean Density (gm/cm^3)
Surface soil	1.7
U. Bakhtiari Formation	2.41
L. Bakhtiari Formation	2.19
U. Fars Formation	2.23
L. Fars Formation	2.33
Pilaspi Formation	2.46

3. The Bouguer Anomaly Map

442 gravity and 74 magnetic measurements were collected (Ghaib, 2001). The following short points were given by the qualitative inspection and analysis of the Bouguer anomalies (Fig. 2) and their derived Regional-, Residual-, Second derivative- and downward continuation maps as well as the magnetic profiles. The Bouguer anomaly map of the Erbil area shows a distribution of anomalies that is consistent with its geological position between the two NW-SE trending anticlines, Pirmam to the northeast and Qarachuq to the southwest. These anomalies fall geographically into three groups covering three provinces with distinctive behavior as follows (Numan & Ghaib, 2006):

1. The western province of the Erbil area is characterized by a main linear anomaly generally trending in NNW-SSE direction. This anomaly is disturbed by many other anomalies of second order with different magnitudes and directions.

2. The central province shows the main low gravity anomaly with a N-S to NW-SE directions is related to the central Erbil trough. It is truncated by many smaller but significant anomalies of NE-SW directions. These anomalies have their extension on sides of the central province.
3. The eastern province is characterized by anomalies that are mainly affected by the Pirmam anticlinal structure and its southwestern limb. The most prominent anomaly in this province is the so-called Bastora linear anomaly which trends NW-SE approximately parallel to the anticlinal axis. This anomaly is cut by at least two transversal NE-SW gravity anomalies. The resulting segments are clearly related to sets of faults in the mentioned directions.

The thickness of the sedimentary cover overlying the basement complex is calculated from the gravity and magnetic data to be 7- 9.5km. deepening towards northeast. The major faults in the Erbil area mainly the Bastora, the west Erbil and Gomspan faults are evident in both the gravity and magnetic data implying that most of these subsurface faults penetrate deep into the basement rocks. Faults inferred from the Bouguer anomalies and those interpreted from the Landsat images (i.e. lineaments) show conformable trends, which are in NE-SW, NW-SE, N-S, NNE and E-W directions.

Small undulations in the magnetic profiles indicate suprabasment anomalies which are crucial in the search of oil accumulations in suprataneous folds e.g. the east and northeast of Erbil gravity and magnetic anomalies, which is later on explored in details by one of the oil companies. Unfortunately, the results of their investigations are not for public use. (Figures 2, 3 and 4). The Gomspan magnetic anomaly has amplitude of 250 Gamma implying that it is an intrabasement magnetic anomaly (Figs. 2 and 5). This anomaly reveals that at least basic igneous rocks of the basement underlie a part of the Pirmam anticline (NW of the Gomspan NE-SW trending fault) (Ghaib, 2001; Numan & Ghaib, 2006).

4. Quantitative Interpretation

The technique that is commonly used for quantitative interpretation is to approximate the causative body to a simple shape of regular geometry. This geometrical shape which has its gravity effects on the surface can be estimated theoretically, comparing the gravity measurements in the field with the theoretical deductions of gravity values affected by the selected geophysical model. The theoretical values of gravity should be as near as possible to the gravity measurements in the field. This method of interpretation was developed by many researchers (i.e. Talwani et al., 1959; Talwani & Ewing, 1960; Morgan & Grant, 1963; Murthy & Roa, 1979) to make the theoretical calculations on irregular shapes of the subsurface interpreted bodies.

The first step in such interpretation is the visual inspection of the Bouguer map to choose the profile across the anomaly of interest. The second is to estimate approximately the horizontal extension, depth, shape and thickness of target using one or more of the rapid methods of calculation such as those described by (Bott & Smith, 1958; Skeels, 1963; Grant & West, 1965). The third step is to construct a geometric n-sided polygon which satisfies the above mentioned estimations and is consistent with the geologic situation.

For both the preliminary estimations and the final calculations, the density of different rock units of the causative bodies and the surroundings should be known as precisely as possible in order to calculate the density contrast which is the cause of the gravity anomaly.

Litinsky (1989) showed that the gravity anomaly observed over a layered sedimentary basin is close to that calculated over a basin with the same configuration and depth but filled by homogenous (unlayered) sediments with a density that is equal to the real layered basin. Accordingly, it is not necessary to composite the effects of the layers separately. In relatively thick successions, the density contrast approaches minimal value with increasing depth (Litinsky, op.cit.).

For each of the versions of the geophysical models of an area experimentation of the gravity effect of an anomaly source is carried out with the density contrast kept constant. In this study, the densities which were calculated and are given in Table-1 above were utilized in modeling using traditional software based on Talwani et al. (1959) which is the most familiar method and of widespread use all over the world. The following are the description of the interpreted profiles whose residuals were separated using hand smoothing technique on the profile; their locations are shown in Figure 2.

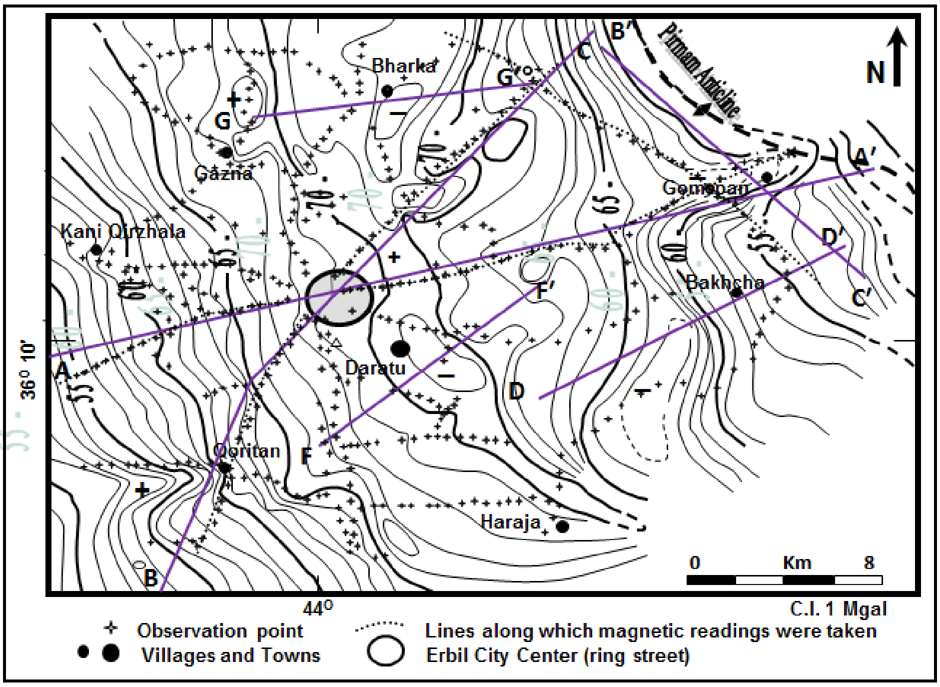

Figure 2: Bouguer anomaly map showing measurement points and interpreted profiles

5. Interpreted Profiles

Seven residual profiles were examined in the Erbil area for the purpose of modeling. Gravity modeling along profiles running through, or near the original stations give a better picture than those taken through the other parts of the Bouguer anomaly map. This is because contours in the Erbil area are extrapolated in the parts that lack good accessibility.

A. The Gomspan-Gwair Road Anomaly: Profile (AA`) in Figures (2 and 3) extends for about 45 km from Gomspan village area from the northeastern limb of the Pirmam anticline to Gwair highway in the WSW portion of the Erbil area. The profile shows gravity low with amplitude of about 18 mGal and a half-width of approximately 5 km. The anomaly has an asymmetrical shape, the northeastern side being little steeper. Wide negative anomalies in general (with some exceptions) reflect synclinal structures or troughs. Al-Shaikh et al. (1975) and Al-Shaikh & Mohammed (1997) used this relationship to interpret the subsurface structure underneath Harir plain which is also situated between two anticlines.

Based on (Ghaib, 2001) about the Erbil area and on the nature of the residual anomaly, it is suggested that Erbil area is underlain by a trough that is bounded by two NW-SE major faults (Fig. 2). The northeastern fault is probably a reverse fault according to the models given by Numan & Al-Azzawi (1993). The presence of this fault was also suggested by Al-Saigh et al. (1989). Another indication for the presence of this fault is the Landsat image lineaments (Ghaib, 2001). The southwestern fault was suggested by Hamid (1995). He proposed a normal fault of deep origin. This is in agreement with field gravity data and their interpretations were given by the present authors.

The gravitationally effective block, bounded by these two faults, if approximated to a slab, should be downthrown to a depth of about 3 km. It would thus accommodate the Neogen formations and the U. Paleogene (Pilaspi Formation) collectively against the Paleogene and U. Cretaceous formations. These two groups of rocks give rise to a density contrast of (-0.3) gm/cm3 based on the assumption of Litinsky (1989).

The model proposed here has the Erbil plain as the site of accumulation of very thick Neogene sediments about two kilometers that become even thicker just to the east of the Erbil city. This deduction is consistent with the thickness given by many authors for sediments underneath the Erbil plain. For example, Haddad et al. (1975) estimated a thickness of 2000-3000 m for both the U. and L. Bakhtiari Formations, while Hassan (1981) insinuated the U. Bakhtiari succession that is about 1800 m thick beneath Erbil plain.

On the magnetic profile (Fig. 3), the northeastern fault (i.e. parallel to the southwestern limb of the Pirmam anticline) is indicated clearly. This suggests a basement uplift beneath Pirmam anticline. The southwestern fault on the other hand, is also indicated but with a lower amplitude in the magnetic profile. The high amplitude of the northeastern part of the magnetic anomaly probably implies a change in basement lithology. However, the effects that these two faults have on the magnetic profile purport that they strike the basement complex. Quantitative interpretation of magnetic anomalies using models is an arduous undertaking especially where no knowledge of susceptibility and polarization is available. The problem is compounded where the substratum is structurally and compositionally complex. Nettelton (1976) described the different constraints in this respect and in view of his results; quantitative interpretation of magnetic data is believed to be useless in our case.

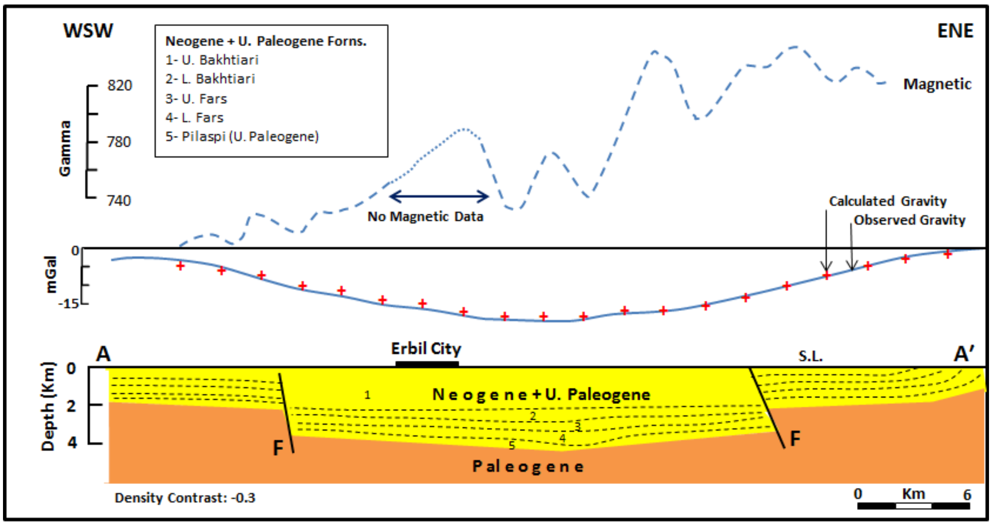

Figure 3: Profile AA`

B. Bastoora-Pirdawood Anomaly: Profile (BB`) (Figs. 2 & 4) extends for about 45 km from the southwestern limb of Pirmam anticline to the village of Pirdawood in the extreme southwestern portion of the Erbil area. The negative anomaly is conspicuous showing maximum amplitude of about 15 mGal. Its northeastern side is again steeper than the southwestern one. The same considerations in profile AA` were used to interpret this anomaly. Two main faults northeastern and southwestern are indicated and are effective structures which throw the Neogene and U.Paleogene (Pilaspi) Formations collectively against the Paleogene and U. Cretaceous formations giving rise to density contrast of (0.3) gm/cm3. The anomalous block has almost the same parameters as in AA`.

An interesting hydrogeological phenomenon in the Bastoora strike valley is thought to be a consequence of the proposed northeastern fault. Eastwards from the trace of this fault, the water wells have a low yield of bad quality water (Khairy, 2000; Pers.com.), whereas westwards from the trace of the fault, the water wells have a good productivity of good quality water. Exaggerated box in Figure 4 shows the envisaged detailed cross-section of the northeastern fault. To the east of the fault, water from the U. and L. Bakhtiari Formations (catchment area) as well as from the L. Fars and the U. Fars Formations percolates down the fault plain and is lost to great depths.

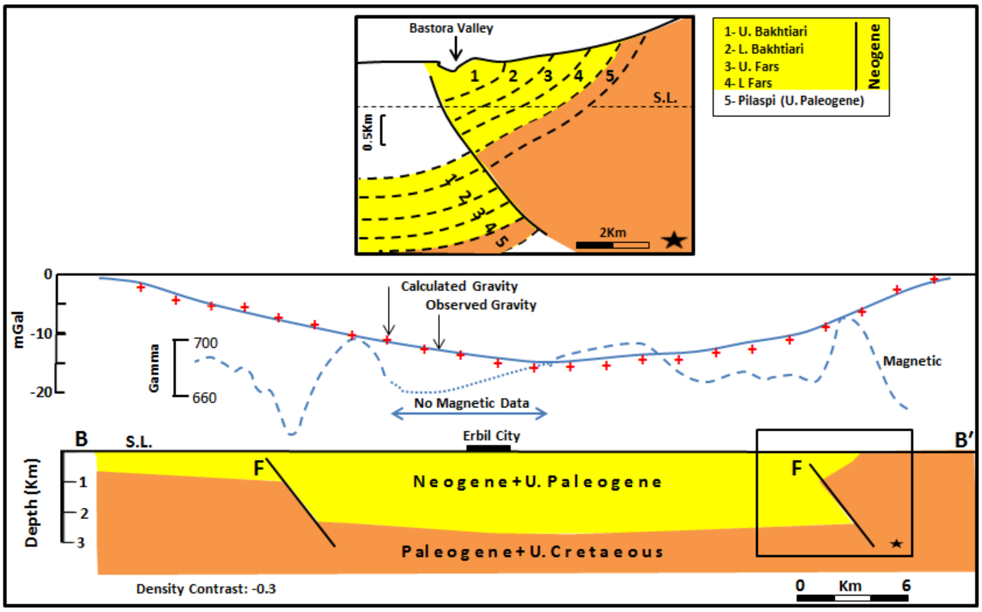

Figure 4: Profile BB`

L. Fars Formation retains some water which dissolves carbonates and sulphates to become poor quality water (Omar, 2000, Personal communication). To the west of the fault plane, however, water is retained in the U. and L. Bakhtiari Formations giving a profuse good quality water. The two faults are again well indicated on the magnetic profile as two anomalies of about (70) γ amplitude.

C. The Gomspan Cross-Roads Anomaly: Profile (CC`) (Figs. 2 & 5) runs almost parallel to the southwestern limb of Pirmam anticline approximately perpendicular to a fault which had been mentioned in (Numan and Ghaib, 2006). The fault was distinguished to strike Pirmam anticline in the NE-SW direction with the southern part being raised. The anomaly has a maximum gravity amplitude of 14 mGal.

A model is designated that throws the U. Fars, L. Fars and Pilaspi Formations collectively against L. Bakhtiari and U. Fars Formations (Fig. 5) with a density contrast of 0.1 gm/cm3, in the form of a local graben. The magnetic profile across the fault (Fig. 5) shows an anomaly of about 100γ. The profile shows that the whole area covered by this profile may have been elevated extending outside towards the northwest including the fault zone. The whole anomaly (comprising the fault zone) shows amplitude of about 250 γ which suggests an intrabasement magnetic anomaly with respect to the southeastern extension of the profile.

There is no published literature about the presence of this fault. However, it is plotted on the map of lineaments prepared by Numan, 2000, (in Ghaib, 2001). On the surface, the expected trace of the fault is following the Gomspan gorge which is locally named "Derbend Gomspan". Hassan et al. (1999) suggested that this gorge is a favorable site of a dam project. The establishment of the fault along this gorge as well as the Bastoora fault in the present interpretation makes this suggestion untenable, though a small dam is now under construction.

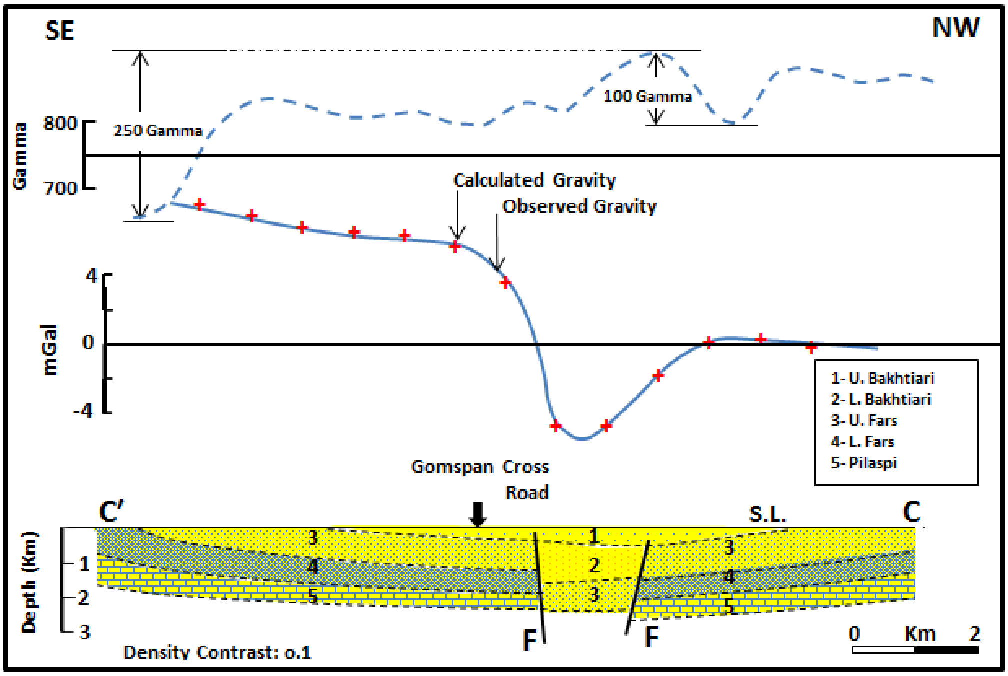

Figure 5: Profile CC`

Bakhcha Anomaly: Profile (DD`) (Figs. 2 & 6) is taken across the major NW-SE trending Bastoora fault. The anomaly has a maximum amplitude of (11) mGal. The designed model is a reverse fault which is consistent with the interpretation given for profiles AA` and BB`. The density contrast best fitting the observed anomaly is (0.18) gm/cm3. This exists between the Paleogene and U. Cretaceous formations together against the Neogene formations.

Synoptic consideration of the interpretation of profiles AA`, BB` and DD` draws a subsurface picture for the area under Erbil plain in that it is a huge site of considerably thick Neogene deposits. This makes the area (called a basin by hydrogeologists) a typical Foredeep site in the Iraqi Foreland Fold Belt. Furthermore, the huge thickness of the U. and L. Bakhtiari Formations as well as the thick Quaternary deposits on top make the area under the Erbil plain one of the most proliferous aquifers in Iraq.

E. Qoritan Anomaly: Profile (EE`) (Figs. 2 & 7) cuts the positive Qoritan anomaly along a NNW-SSE direction. The Qoritan anomaly results from an E-W trending positive nose of a structure that extends westwards to the outside of the area of study. On the map in figure 2, this anomaly coexists with the eastern plunge of the Demirdagh anticline which is locate few kilometers to the west out in the study area. There is however, a difference between the anomaly trend which is E-W and the trend of the Demirdagh anticlinal plunge which is NW-SE.

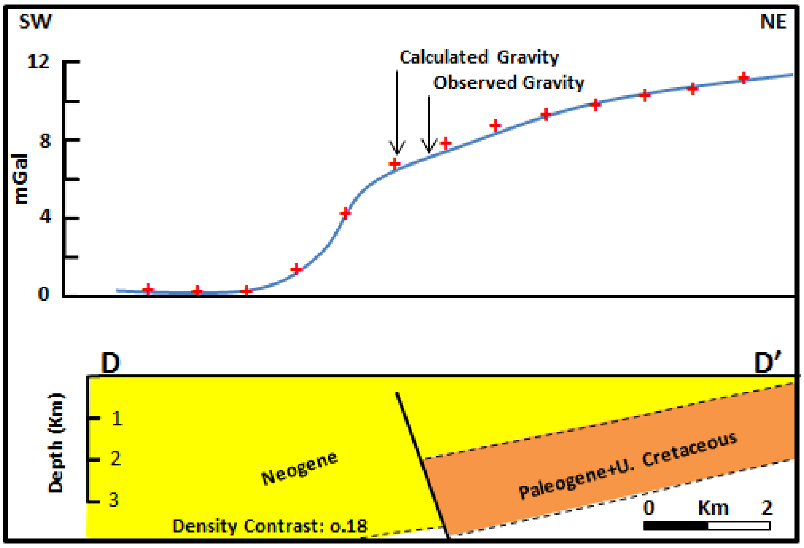

Figure 6: Profile DD`

Three alternative interpretations for the Qoritan anomaly may be suggested, they are:

A model (Fig. 7A) that involves a density contrast of (0.15) gm/cm3 between the L. Fars and the Pilaspi Formations together against the U. Fars Formation. Ahmad (1980) interpreted a similar positive anomaly few kilometers to the west of this area (Demirdagh well area). He suggested that the anomaly is due to the Demirdagh anticline with a similar configuration of formations giving rise to the anomaly. Hence, the present interpretation suggests that the anomaly is due to the eastern plunge of the Demirdagh anticline.

A model (Fig. 7B) that applies a horst-like struture which may extend northeastwards to the area of Gomspan fault (Fig. 2). The Paleogene formations are thought to be thrown against the Neogene formations giving rise to a density contrast of (0.14) gm/cm3.

Contrary to norms, the fluviatile U. Bakhtiari Formation has a greater density than that for the fluviatile L. Bakhtiari Formation. This peculiarity may be deciphered by a third model of the Qoritan anomaly (Fig. 7C). It may well be due to an ancient erosional channel or valley in the upper surface of the L. Bakhtiari Formation that was filled later by the U. Bakhtiari rocks. This model requires a density contrast of (0.2) gm/cm3 which is present between these formations. A similar interpretation was given by Al-Saigh et al. (1989) for one of the positive anomalies near Pirmam anticline.

This type of interpretation which has more than one solution for an anomaly is a typical case for the ambiguity faced in the gravity interpretation. As mentioned before, there are no surface structural features or relevant subsurface data to substantiate one of the above described three models. However, the area in and around Qoritan village is characterized by a relatively good yielding aquifers (Surdashi 2000, Personal Communication.) which may indicate the presence of a local buried trough in the L.

Bakhtiari Formation and thickening of the U. Bakhtiari Formation. The present authors thus prefer the third model.

Daratu Anomaly: Profile (FF`) (Figs. 2 & 8) is located to the southeast of Erbil city across a negative elongated NW-SE trending anomaly called here the Daratu anomaly. It extends transversely for about (17) km in the NE-SW direction with a maximum amplitude of (4) mGal. It is an asymmetrical anomaly with the northeastern side being steeper than the southwestern side. Again, the density variations between the Neogene and Paleogene formations and a thickness of about 2 km for the former deposits satisfy the field anomaly. The Daratu anomaly represents, with many other negative closed anomalies, the central area of the Erbil trough.

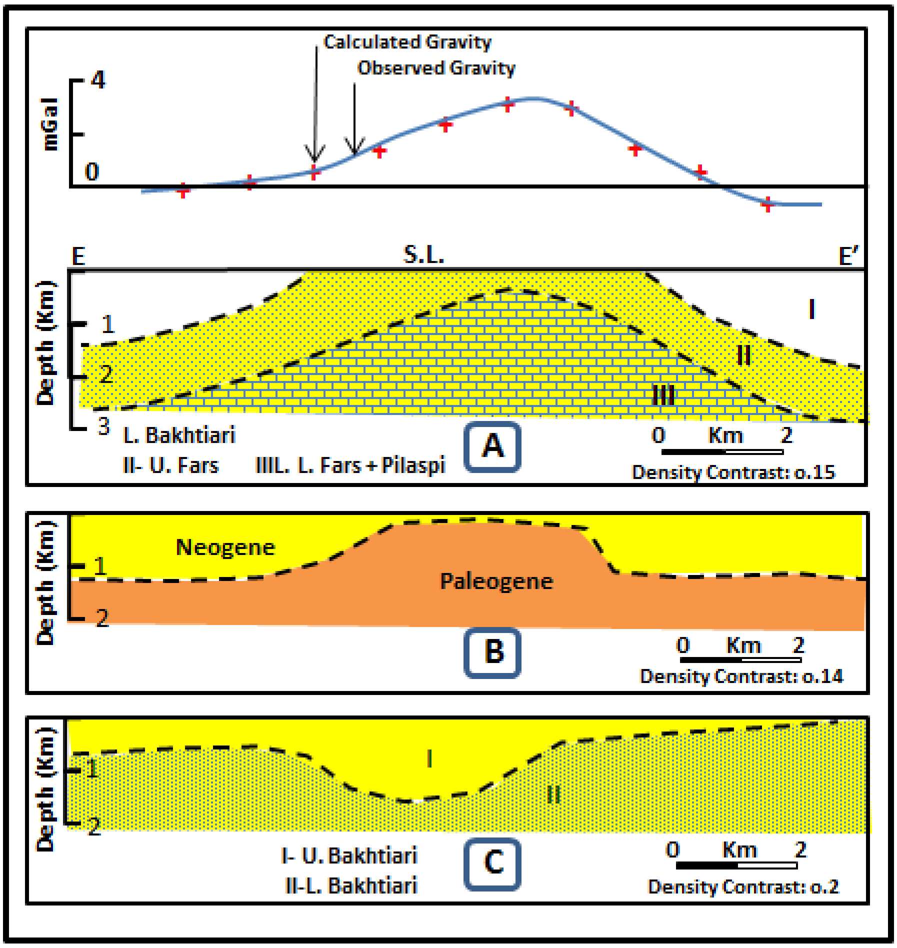

Figure 7: Profile EE`

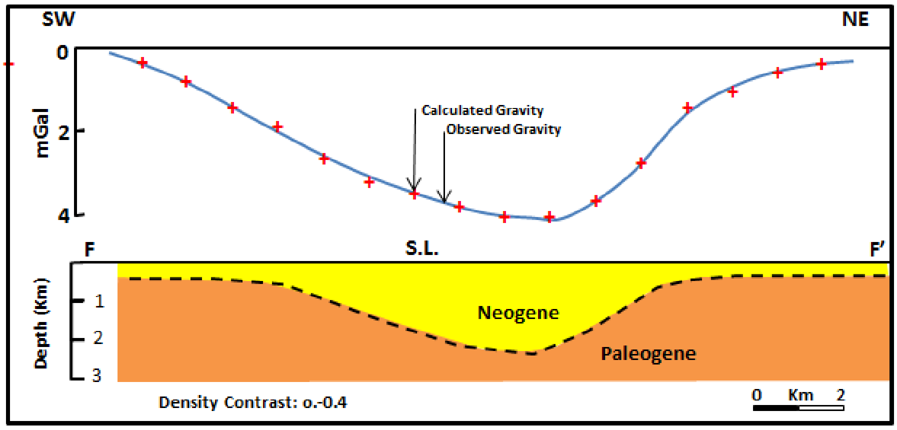

Figure 8: Profile FF`

Bharka Anomaly: Profile (GG`) (Figs 2 & 9) cuts the oval negative anomaly around the Bharka village to the north of Erbil city on the same line of negative anomalies with the Daratu anomaly. The profile extends for about (14) km in the ENE-WSW direction. The anomaly exhibits a maximum amplitude of about (4) mGal. A density contrast of (-0.14) gm/cm3 which exists between the L. Bakhtiari and the U. Fars Formations is adequate for the production of the observed anomaly. The geologic situation, which is interpreted as an ancient erosional channel in the U. Fars Formation's upper surface that was filled later on by fluviatile L. Bakhtiari deposits. This situation again makes the area around Bharka village rich in ground water.

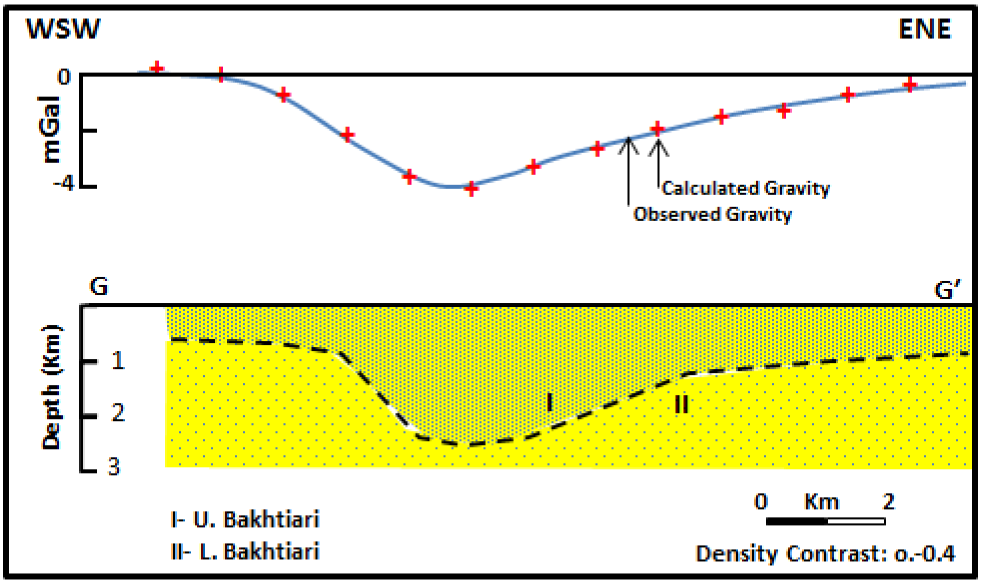

Figure 9: Profile GG`

6. Conclusions

The subsurface structure in Erbil area has been a matter of speculation since virtually no surface outcrops are present in this intervening area between two major anticlines. Several authors suggested gigantic synclines that are 45 km wide for the Erbil area, e.g. Parsons (1955), Al-Omeri & Sadik (1973) and Buday & Jassim (1987). Elsewhere in the world, there have been situations described where successive anticlines have horizontal strata in the intervening areas (Belousov, 1968).

According to these approaches, seven gravity profiles in the Erbil area were interpreted quantitatively by models. The main gravity low is attributed to thick Neogene sediments which are thrown against the Paleogene sediments by two major NW-SE faults which give rise to a density contrast of 0.3 gm/cm3. On the other hand, local anomalies were interpreted to be the reflection of local structures and depressions within the upper part of the Neogene sediments. The subsurface structure is devoid of any single gigantic synclinal structure of the type described by previous workers. Rather the strata are essentially horizontal with very mild open flexures (such as the Erbil trough) and are bounded near the major anticlines by major faults and complicated by many minor faults.

Regional and local profiles in the Erbil area show that two important density contrasts within the stratigraphic succession contribute to the gravity anomalies. The first is between the Neogene formations collectively (2.29 gm/cm3) against the Paelogene formations and the Upper Cretaceous Formations (2.48 gm/cm3). The second density contrast is within the upper most part of the succession i.e. the Quaternary deposits, U. Bakhtiari, L. Bakhitiari, U. Fars and L. Fars Formations. From the relatively high to low densities, this part of the succession is arranged in the following order: U. Bakhtiari, L. Fars, U. Fars and L. Bakhtiari.

The major faults in the Erbil area mainly the Bastoora, the west Erbil and Gomspan faults are evident in both the gravity and magnetic data implying that these subsurface faults penetrate deep into the basement rocks. Small undulations in the magnetic profiles indicate supra-basement anomalies which are crucial in the search of oil accumulations in suprataneous folds, e.g. the east Erbil gravity and magnetic anomalies. The Gomspan magnetic anomaly has amplitude of 250 Gamma implying that it is an intra-basement magnetic anomaly. This anomaly reveals that at least a part of the Pirmam anticline (NW of the Gomspan NE-SW trending fault) is underlain by basic igneous rocks of the basement.

The gravity anomalies of shallow sources are mainly caused by the density contrast between the U. Bakhtiari Formation of higher density and the Quaternary deposits of lower density. In this respect, the currently used aquifers in the Erbil area are situated in the Quaternary and recent deposits rather than the U. Bakhtiari Formation. On this basis, the underground water accumulation can be confidently outlined depending upon the negative residual anomalies which imply the presence of thick water yielding Quaternary deposits.

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