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Comprehension of Residual Gravity Anomalies Across S-N Profiles in the Northwestern Part of Iraq

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ABSTRACT

The studied region is located in northwest Iraq and spans approximately 1673 km², with elevations ranging from 300 to 1350 meters above sea level. The study area is of oil importance due to its proximity to the Tawki oil field with suitable conditions for migration and storage. This area contains several significant anticlines and is situated in the foothill and high folded zones. (Dahkan, Bekher, Tawki, and others). There are 60 gravity points on which the geophysical survey is based. After making corrections to the gravity data, the Bouguer anomaly was computed at each location. For the quantitative interpretation, the Geosoft Oasis Montaj program's 2D modeling technique was used. A total of four gravity profiles were created. The study's findings demonstrate that the top depth of the basement rocks in the investigated region is approximately 7 km, and gravity profiles in the sedimentary layers indicate the presence of several faults. The modeled profiles' results show that the sedimentary sections' "lows" and "highs" in gravity correspond to various grabens, half-grabens, and horsts that are encircled by normal and reverse faults.

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تفسير شذوذات الجاذبية المتبقية عبر مقاطع (شمال- جنوب) في الجزء الشمالي الغربي من العراق

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الملخص

تغطي منطقة الدراسة حوالي 1673 كم2 من شمال غرب العراق بارتفاعات تتراوح بين 300 إلى 1350 متراً فوق مستوى سطح البحر. تتميز منطقة الدراسة بأهمية نفطية كبيرة لقربها من حقل طاوكي النفطي الذي تتوفر فيه الظروف الملائمة للهجرة والتخزين. تقع هذه المنطقة ضمن مناطق سفوح الجبال والطيات المرتفعة التي تضم عدداً من الطيات المحدبة المهمة (دهكان، بيخير، طاوكي، وغيرها). تم إجراء المسح الجيوفيزيائي الجذبي لـ 60 نقطة، ومن ثم تم تصحيح البيانات وحساب شذوذ بوجير لكل نقطة. تم تطبيق تقنية النمذجة ثنائية البعد للتفسير الكمي باستخدام برنامج Geosoft Oasis Montaj، حيث تم نمذجة أربعة مقاطع جذبية. بينت نتائج هذه الدراسة أن العمق العلوي لصخور القاعدة في المنطقة المدروسة يبلغ حوالي 7 كم كما ميزت هذه الدراسة العديد من الفوالق في المقاطع الرسوبية. أظهرت نتائج المقاطع المدروسة أن هناك العديد من البروزات والهبوطات المحيطة بالفوالق الطبيعية والمعكوسة التي تظهر في المقاطع الرسوبية من خلال "الانخفاضات" و"الارتفاعات" الجذبية.

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Introduction

Anomalies in the gravitational field have resulted from lateral variations in the density of subsurface materials and the distance to these bodies from the measuring equipment (Mariita, 2007). The gravity method has been utilized in this study since it is among the best ways to determine subsurface structures and knowledge of variations in the thickness of sedimentary layers. Gravity data analysis is used in this work to identify important structures in the study region and to identify faults and structures. The research area, which is bordered by longitudes (42o 55` E - 42o 87` E) and latitudes (36o 68` N - 37o 19` N), is approximately 1673 km2, including the area in and surrounding the city of Zakho.

Iraq was divided into three tectonically distinct areas by Jassim and Goff (2006): the unstable shelf, which has surface anticlines; the stable shelf, which has major buried arches and antiforms; and the Zagros Suture, which consists of thrust sheets of igneous, metamorphic, and radiolarian rocks (Fig 1). The research region is situated on the Mosul block, which trends in a Taurus E-W direction. It is a portion of the Foreland folds of the Alpine Orogen in northern Iraq (Numan, 1984).

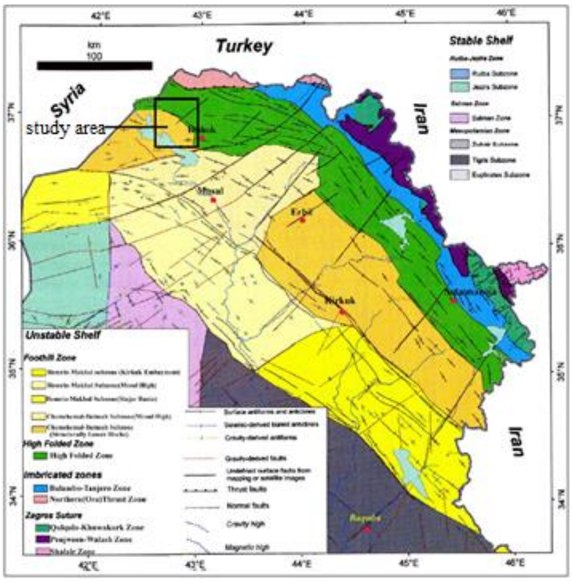

Fig. 1. Tectonic zones and unstable shelf structural features (after Jassim and Goff, 2006) together with research area locations.

The examined area has several similar geomorphologic characteristics, including valleys, foothills, low mountains, high mountains, and dendritic drainage patterns. The area's geomorphologic characteristics are fragmented by river erosion. There is a main known fold in this area (the Bekheranticline). The Bekher anticline outcrops surrounding the research area plains provide insight into the strata beneath them (Fig. 2). This region has elevations ranging from 300 meters (north of the Mosul dam) to 1350 meters. (at the northern Summayl village close to the crest of the Bekher anticline).

The northern regions of Iraq have limited geophysical data, except for a few local studies conducted in the Duhok area. The regions of the north of Iraq were not included in Sayyab & Valek's 1968 Bouguer anomaly map. However, there have been a few local geophysical investigations conducted in the region. For example, Ghaib et al. (1998) conducted a small reconnaissance gravity survey in the northeastern Sulaivany plain near

Dohuk city, covering an area of around 600 km². Using shallow geoelectric studies, Mutib and Al-Shaikh (2005) found new subsurface folds with hydrocarbon probability in the Mosul Area.

According to a gravity survey, fluctuations in the density of underground rocks were responsible for changes in the earth's gravitational field. According to a review by Al-Sinawi et al. (1987), the density disparity between basement rocks and the sedimentary cover has been utilized by the majority of authors, and it is 0.17 gm/cm³. However, in a regional traverse along and around the current study locations, Hamid (1995) employed the value (0.18) gm/cm³. Al-Shaikh and Mohammed (1997) supported this value and suggested using it in Iraq's Unstable Shelf. Ditmar et al. (1971) calculated the average density of the sedimentary cover to be (2.6) gm/cm³, taking into account the average density of the foundation rocks, which was (2.77) gm/cm³.

Al-Brifkani (2008) created a diagram of the formations that illustrates their lithology, ages, and thicknesses in his study region, which is close to our study area.

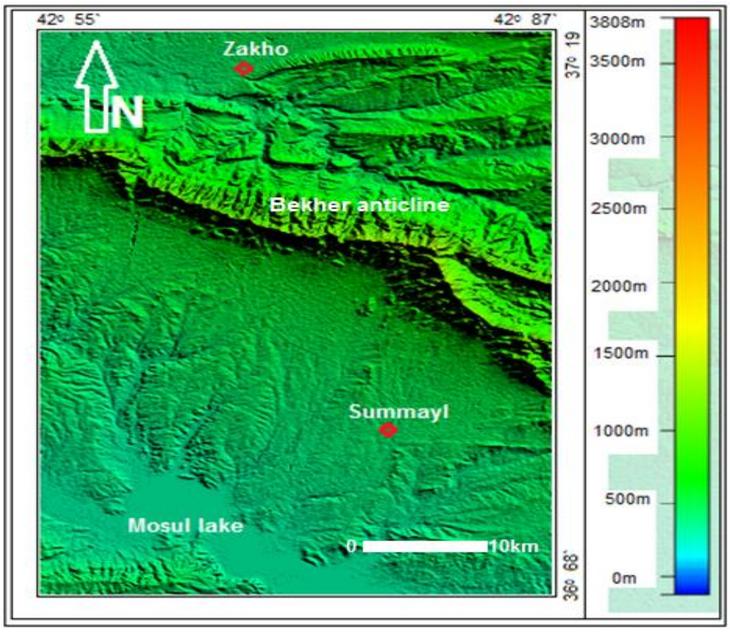

Fig. 2. The research area's location with respect to geomorphologic elements on the Digital Elevation Model (DEM).

MATERIALS AND METHODS

By measuring variations in the density of underground rocks, we can determine fluctuations in the earth's gravitational field through gravity surveying. These variations lead to the prediction of subsurface geologic structures. The observed values of gravity (g) contain the effect of all the masses of the earth’s body, as well as the effect due to the earth’s rotation and tides.

In this work, the LaCoste and Romberg Gravimeter Model G was employed. It features a reading accuracy of ± 0.01 mg, a drift of less than 1 mg/month, and a range of over seven hundred milligrams. The calibration factor of this gravimeter did not noticeably alter over time when it was calibrated prior to the field operations. As a result, there was no longer a requirement for regular calibration checks while working.

The instrument showed no problems at all during the working time. Using a Garmin (72) Global Positioning System (GPS), all gravity stations were surveyed for relative easting, northing, and elevation for this operation. When the reading station is utilized consistently in the field, its height concerning sea level displays an accuracy of ±4 meters. A Garmin 722 GPS's horizontal coordinate accuracy hasn't gone beyond a few meters. According to Al-Shaikh et al. (1975), the main base station is identified as the Absolute Gravity and Elevation Station, which is situated at the University of Mosul. With an absolute value of 979789.46 mGal, this station serves as a benchmark for the other stations within the examined region. From the absolute value of the primary base station, the absolute value of the gravity may be determined for those stations. Furthermore, eight secondary base stations were set up in the area under investigation and linked to the central base station. The most time-consuming part involved moving the gravimeter between sites and from the base station to additional stations.

The array of the stations is what defines the form of the fieldwork, and it is commonly represented by traverses, grids, and random ways. Due to the main challenges (mountains and valleys) in the study area, the stations are randomly arrayed in this study. It is usual to place 60 gravity stations close to and along highways, roads, and their branches to assist the survey. The number of stations is determined by the accessibility of the location and the spacing pattern required to accurately define the characteristics. (Fig. 3). The gravity values in each station were adjusted for the effects of temperature and pressure using the single-base approach, or the gravity base station. (Fig. 4)

The location and elevation were added to the field measurement corrections. Additionally, the distances between the stations influence the positions of the stations and define the length of the profiles, all of which are directly related to the feature types that need to be researched. The distances between the stations varied from 500 to 5000 meters. It is customary to calculate the gravity differences (Δg) based on the field results.

The field-derived observed gravity readings typically incorporate several factors that need to be reduced to focus solely on the impact of the subdatum density abnormalities.

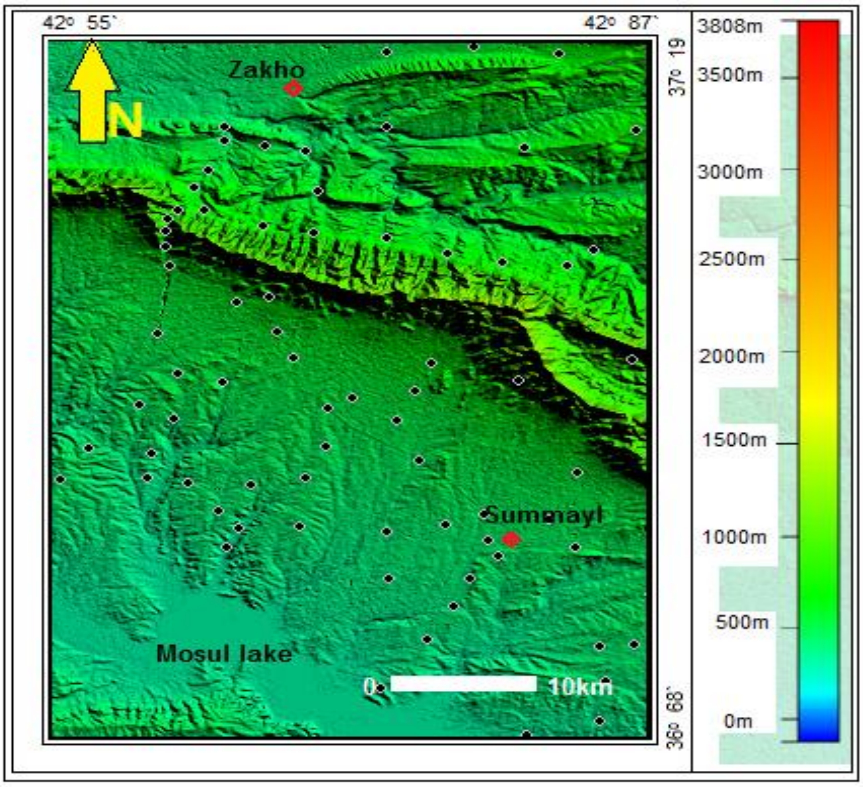

Fig. 3. The DEM of the study area displaying the locations of gravity stations (black dots)

The difference between the measured value (gobs.) at base station (gbase) and that corrected by the algebraic sum of all required adjustments is the Bouguer anomaly of the gravity at that point:

$$\Delta g_B = g_{obs} + \sum {}_{corr.} - g_{base}$$

$$\Delta g_B = (g_{abs.} - g_{theo.}) + (0.3086 - 0.04193\rho)h + \Delta g_{Ter.}$$

where gabs. is the absolute gravity value at the measurement place and h is the elevation above sea level. The theoretical gravity value at the geographic station latitude at sea level is represented by gtheo, and this suggests a known absolute value at the base station. The ellipsoidal form of the globe causes the theoretical gravity value, which is typically represented by (gϕ), to fluctuate throughout its surface. An equation for calculating gϕ at any latitude was proposed by the International Association of Geodesy (IAG) in 1971.

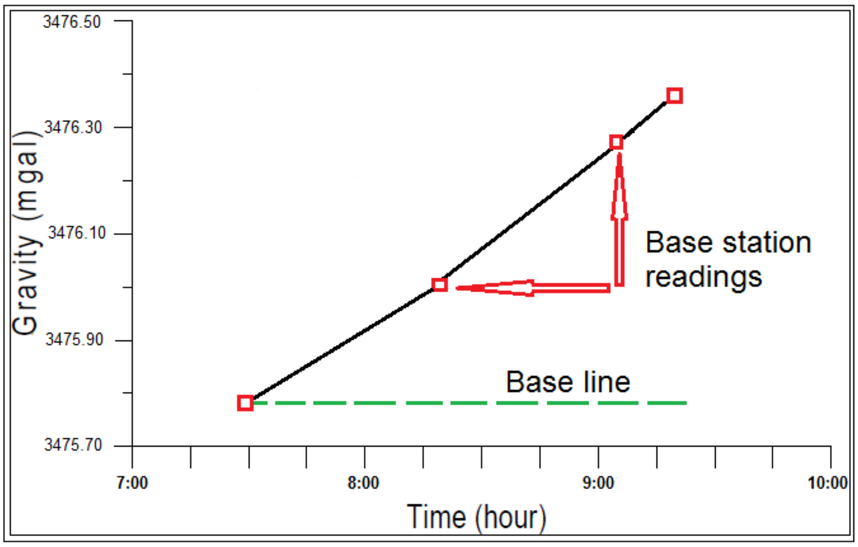

Fig. 4. Drift curve for one-day gravity work 07/08/2010

$$g_\phi = 9.780318(1 + 0.0053024\sin^2\phi - 0.0000059\sin^2 2\phi)m/s^2$$ -----------1971 formula

With a precision of 0.1 mgl, this formula provides the real gravity value at sea level (Parasnis, 1997). In this study, this formula is utilized. It is significant to note that the 1930s formula, which deviates from the 1971 formula by roughly 12.5 milligals, was used in the gravity measurements conducted in Iraq (the IPC-Bouguer map and subsequent surveys) (Ghaib, 2001).

$$g_\phi = 9.78049(1 + 0.0052884\sin^2\phi - 0.0000059\sin^2 2\phi)m/s^2$$

Terrain correction refers to the variations above and below the elevation level of gravity readings in a setting with variable topography. When the topographic gravity effect between any station and the base station level exceeds the gravimeter's accuracy, terrain correction is required. It takes a lot of work to calculate these corrections by hand using topographic maps. Leaman (1998) pointed out that Hammer's method is laborious, manual, and prone to estimating mistakes.

Comprehensive (DEM) and computational capacity, which are only now widely available, are necessary for the efficient and effective deployment of these adjustments (Hinze et al., 2005; Nabigian et al., 2005 and Hwa Chen, 2009).

The difference between each elevation point in the 30-meter DEM image and the gravity station's elevation is computed. We compute the vertical component of the gravitational pull between the prism and the gravity station using a rectangular prism of uniform density (2.175 g/cm³). The Terrain Correction Software (TCS) extension and Geosoft Oasis Montaj program suite (GOM, 2008) offer a comprehensive method for reducing and processing gravity data from traditional ground surveys.

Many errors, the first caused by the instrument itself and the second by the field and reduction methods, may have an impact on the data that is acquired after applying the reduction on the raw data. The incorrect interpretation of the data results in instrumental errors. The observation of (± 0.04) mGal in (go) was shown to include an error based on repeated observations in 61 stations. The gravity readings are more severely impacted by the second kind of inaccuracies. Table (1) is a list of the errors that were made during this study.

Table 1: Source and magnitudinal effects of errors.

Source	Magnitudinal Effect (mGl)
Measurement error (go)	**0.04**
Elevation (Free air) error (Fa)	**1.23**
Elevation (Bouguer) error (Bc) including density	**0.38**
Latitude error (lat)	**0.02**
Terrain elevation error(Tc) + Density error	**0.0006 + 0.15**

RESULTS

The visual examination of the DEM image to select the profile across the anomaly of interest is the first stage in the quantity interpretation process. The second method involves utilizing a geological background to roughly predict the target's horizontal extension, depth, form, and thickness (well logging, seismic sections, past research). The third phase involves using modern computer programming to create a geometric model that satisfies the estimations stated above and is consistent with the geologic situation (GOM, 2008).

The gravity model response is computed using algorithms outlined in Won & Bevis (1987) and is based on the techniques of Talwani et al. (1959) and Talwani & Heirtzler (1964). The calculations are linearized and inverted by the GM-SYS inversion procedure using an inversion algorithm. The USGS produced an implementation of the gravity method, which is utilized by GM-SYS in their computer software (Webring, 1985). When calculating gravity, GM-SYS employs a two-dimensional, flat-earth model in which each structural unit or block has a length that varies from plus and minus infinity in a direction perpendicular to the profile. It is presumed that the earth has a flat surface without any curvature. To remove edge effects, the model also extends plus or minus 30,000 kilometres along the profile.

Using all of the locations of the gravity stations, a kriging grid line was created for every survey line because the modeling software, according to GOM (2008), required straight-line profiles. Station distances were measured from the initial station on each line, which is invariably the southernmost station, and other stations were projected perpendicularly onto this line.

The density of the various rock units of the causative entities and the surrounding area should be determined as exactly as possible for both the preliminary estimations and the final calculations. This is necessary in order to compute the density contrast that causes the gravity anomalies. The modeled units utilized in each of the study's modeled profiles are listed in Table (2).

Table 2: Describes the modeled units and their densities

Geologic period	Density (g/cc)	Reference
Quaternary and Neogen	2.175	(Sayyab & Valek, 1968) and (Abbas & Masin, 1975)
Paleogen	2.33	Calculated form (Mutib,1980) & (Ghaib ,2001)
Cretaceous	2.57	(Ghaib ,2001)
Jorassic and Triasic	2.71	(Al-Mashhadani, 2000)
Paleozoic	2.65	(Al-Mashhadani, 2000)
Basement	2.78	(Ditmar, et al, 1971)

As illustrated in Fisg. (5), the geometrical models developed in this work are regulated using exploratory wells like Kand (KD) and Tawki (TK) and local seismic study (Bashiqa-Kand section (BK)). Additionally, such models incorporated all prior structural and lithostratigraphic research.

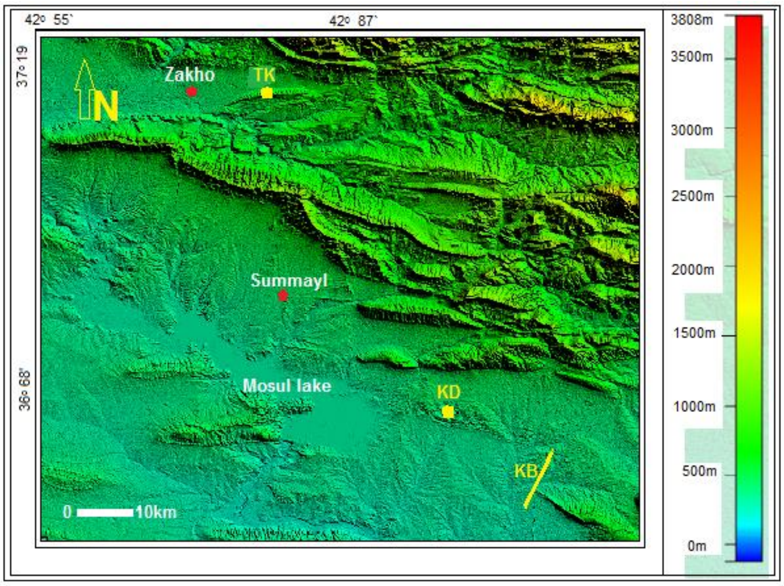

Fig. 5. The DEM image with the locations of exploratory wells (TK, KD) and a seismic section (KB) around the study area.

The residual and regional gravity for three profiles in the study area were produced using an upward continuation filter by applying the empirical method of Zeng et al. (2007). The process involves figuring out the correlation coefficient (r) between upward-continuing fields at two consecutive elevations. Plotting the correlation factor against increasing continuation height is done. The ideal height is the one that results in the greatest deflection (Fig. 6). The residual anomaly profiles in the research area were obtained by applying the upward continuation height that was produced. (Table 3).

The basement complex with its structural configuration and the sedimentary sequence are included in the developed models, and Al-Brifkani's (2008) analysis is used to infer the thickness of the depositional formations. The locations of generated profiles within the research region are displayed in Fig. (7).

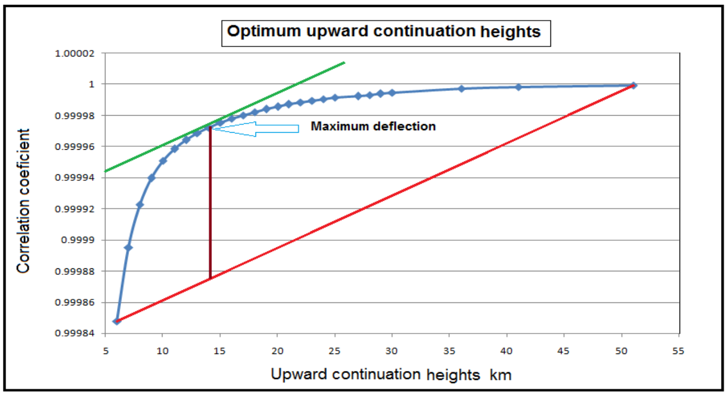

Fig. 6. Crosscorrelations between continuations to two successive upward heights versus the upward heights.

Table 3: The heights of the optimum upward continuation for three gravity profiles.

Prof. name	Optimum upward height in km
G1	6
G2	6
G3	7
G4	7

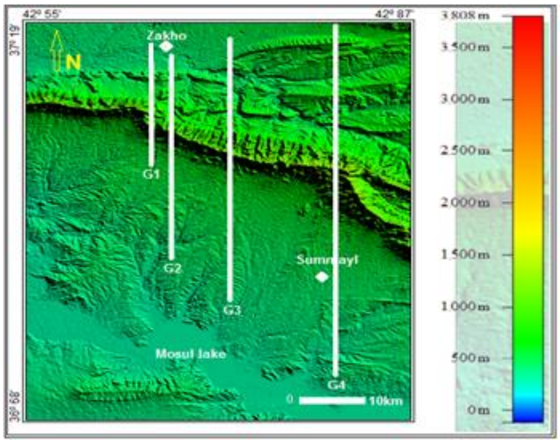

Fig. 7. The DEM picture containing the research area's profile positions

Residual Gravity Profile

Profile G1

This profile, as shown in Fig. (8), runs through the original stations and extends for about 26 km from the northern part of Mosul Lake to Zakho City in the western portion of the Zakho region. The profile shows gravity low near the Gulley Zakho area with an amplitude of about 16 mGal and a half-width of approximately 6 km. The anomaly has an asymmetrical shape, the southern side being a little steeper. Wide negative anomalies in general, with some exceptions, reflect synclinal structures or troughs according to Al-Shaikh & Mohammed (1997). In this profile, the negative anomaly reflects the anticline structure of Bekher Mountain. It is thought that the Bekher anticline in this profile is underlain by a graben bounded with two E-W normal faults (F1, F2). This model shows that there are changes in the thickness of sedimentary formations beneath the Bekher anticline. This can be explained—to a great extent—by the presence of deep-seated and major faults (F1) affecting the basement complex and sedimentary section.

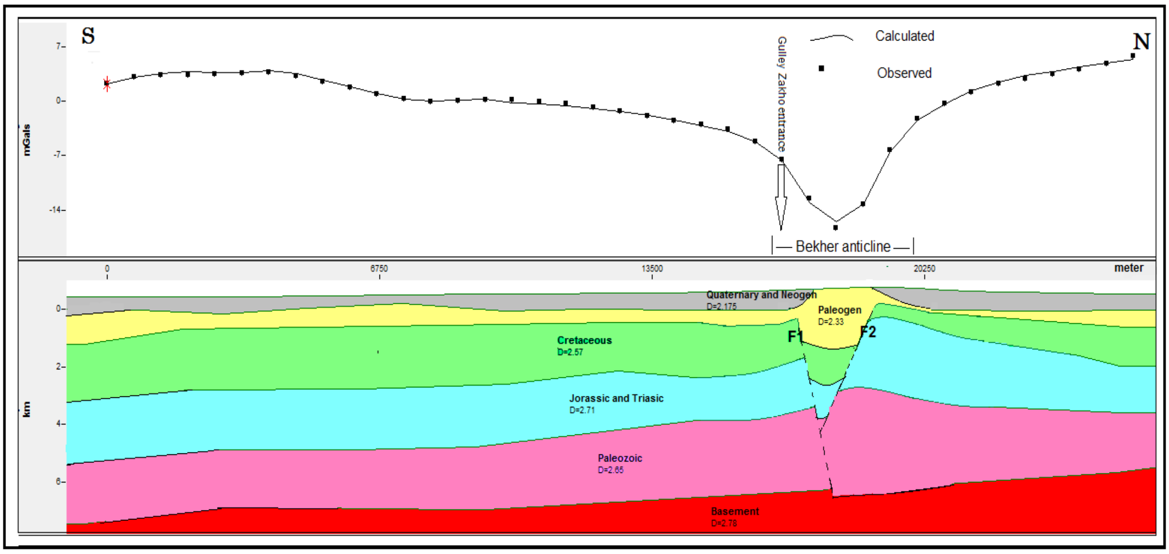

Fig. 8. Gravity data and cross section along profile G1.

The cross-sectional gravity profile is depicted in the upper panel; the line represents the calculated gravity for the model below, and the dots indicate the measured gravity values. The predicted geologic cross section with positive downward depths is displayed in the lower panel. “D” is the density in g/cc.

Profile G2

This profile runs roughly 42 km in the west of the Zakho region, from the northern Mosul Lake to Zakho City (Fig. 9). The profile shows two anomalies. First, a gravity "high" with an amplitude of roughly 3.5 mGal and a half-width of roughly 3 km appeared in the southern Bekher anticline over the Summayl anticline, according to the current study. It is believed to be caused by two E-W faults: the northern fault (F47) is reversed, and the southern fault (F43) is normal. The second is a gravity low in the Gulley Zakho region with an amplitude of roughly 14 mGal and a half-width of approximately 8 km. This anomaly has a vast extent and a similar shape to the prior anomaly in the Gulley Zakho profile because of the closeness between both profiles, although there are some variances in anomaly magnitudes.

Profile G3

This profile, as indicated in Fig. (10), extends for about 60 km from northeastern Mosul Lake to east of Zakho City in the Zakho region. Four anomalies are depicted in the profile. The first is positively identified beneath the Summayl anticline, with an amplitude of roughly 2 mGal and a half-width of roughly 3 km, based on the current investigation. The second one, called High, has an amplitude of roughly 1 mGal and a half-width of roughly 2 km. It is situated in the southern region of the Bekher anticline. A NW-SE reverse fault could have generated it (F8). The third is modest, roughly 8 km in half-width and 7 mGal in amplitude, and it is situated in the southeast of Zakho City. It is proposed that a graben confined by two E-W normal faults (F1, F2) underlies the Bekher anticline in this profile. The fourth anomaly is positive, situated in the eastern part of Zakho city across the Tawki anticline (oil field structure), and has an amplitude of roughly 6 mGal and a half-width of roughly 3.5 km. It is believed to be surrounded by two E-W faults, the northern one being reverse (F5) and the southern one being normal (F4). The supra-basement features in this profile define the limit of the basement rocks.

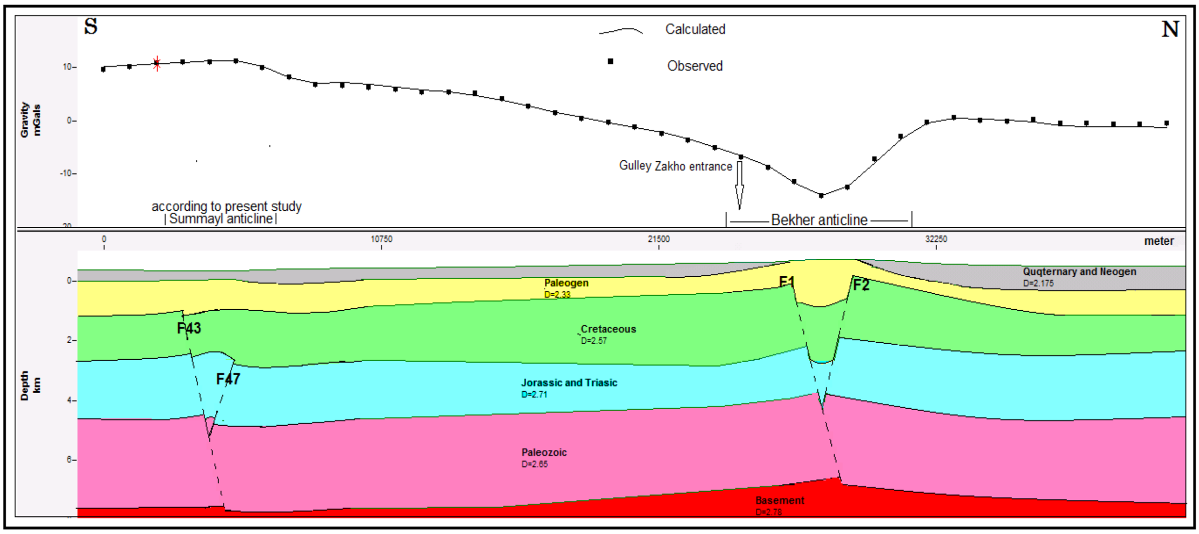

Fig. 9. Gravity data and cross section along profile G2.

The gravity profile along the cross section is displayed in the upper panel; the line represents the estimated gravity for the model below, and the dots indicate the measured gravity values. The predicted geologic cross section with positive downward depths is displayed in the lower panel. “D” is the density in g/cc.

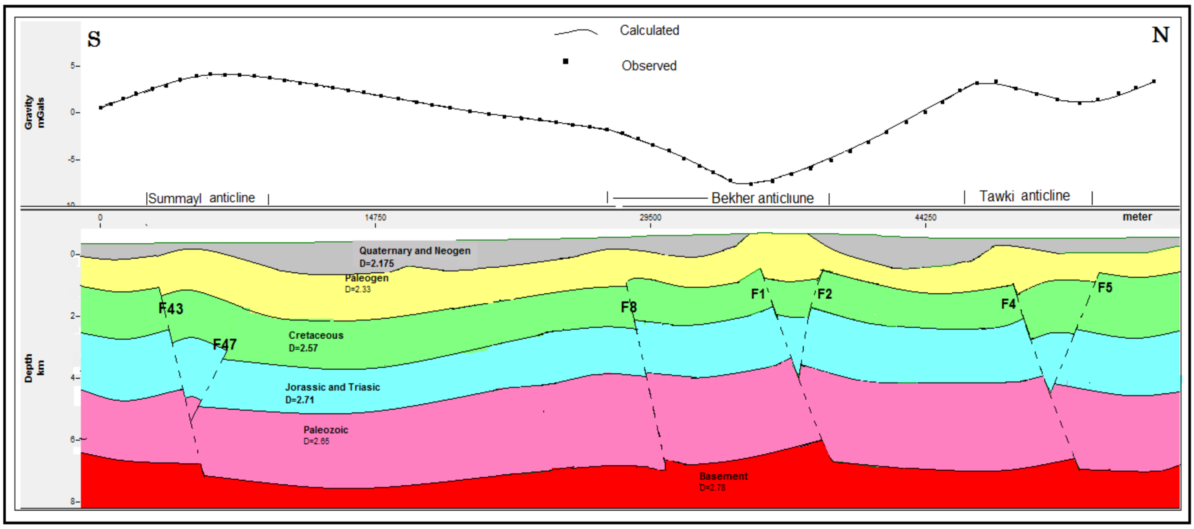

Fig. 10. Gravity data and cross section along profile G3.

The gravity profile along the cross section is displayed in the upper panel; the line represents the assumed gravity for the model below, and the dots indicate the observed gravity values. The predicted geologic cross section with positive downward depths is displayed in the lower panel. “D” is the density in g/cc.

Profile G4

This profile was extended for about 90 km from Wana village (southern Mosul Lake) to northeastern Zakho city. (Fig. 11). Five gravity "highs" and three "lows" features characterise this profile. The initial gravity "high" with a half-width of around 3.5 km and an amplitude of roughly 5 mGal is situated above the Masraj anticline. It is hypothesised that two E-W faults (F53, F56) produced it. The second gravity "high" has a half-width of around 2 km and an amplitude of roughly 2 mGal as it emerges above the Taira anticline. This anomaly is thought to be located over two E-W faults (F18, F19). The third one, which has an amplitude of around 7 mGal and a half-width of roughly 10 km, is visible above the extension of the Dahkan anticline close to Faida town. It may have been produced by two E-W stepped faults (F41, F42). The fourth gravity "high" with an amplitude of around 3 mGal and a half-width of roughly 4 km was seen over the southern portion of the Bekher anticline. Over the Tawki anticline plunge, with an amplitude of around 4 mGal and a half-width of roughly 3 km, the fifth gravity "high" was identified. The first and second gravity lows were represented with two synclines; the first was shown between the Masraj and Taira anticlines, and the second appeared between the Taira and Dahkan anticlines. Except for a slight increase in the amplitude and half-width, the third negative anomaly is similar to that in the GGz profile and is visible over the northern portion of the Bekher anticline. Its amplitude is roughly 17 mGal, and its half-width is roughly 8 km.

The gravity profile along the cross section is displayed in the upper panel; the line represents the expected gravity for the model below, and the dots indicate the obtained gravity values. The predicted geologic cross section with positive downward depths is displayed in the lower panel. “D” is the density in g/cc.

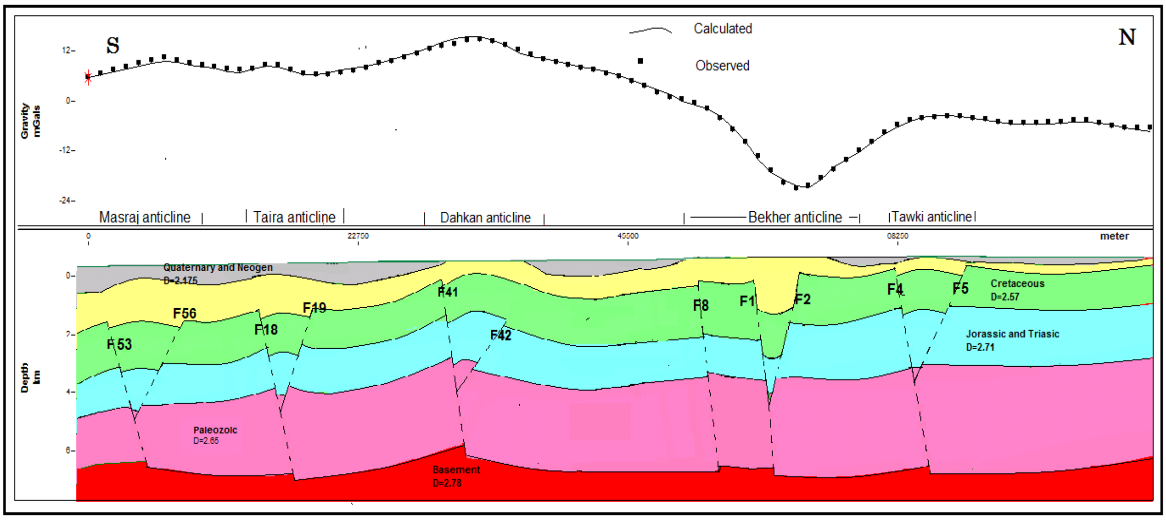

Fig. 11. Gravity data and cross section along profile G4.

DISCUSSION

The most heavily modelled anomalies in the earlier profiles are a result of anticline structures connected to tectonic faults that originate from horsts and grabens. A summary of the geophysical anomalies that were modelled in this work is provided below.

Bekher structure

It has a varied gravity anomaly extending from Zakho City (with an E-W trend) to Duhok City (with an NW-SE trend). It is apparent in the profiles (G1, G2, G3, G4) with values ranging from -16 to 3 mGals. The negativity of the anomaly is gradually increased towards the west plunge, reflecting a graben feature near Gulley Zakho. The negative anomaly above the Bekher anticline that appeared in these profiles may be the result of the Eocene rocks (Pila Spi Fm.) covering the crest of the anticline near the Zakho region, which is suggested as due to a graben feature filling with Gercus rocks.

Tawki anticline

It has a little positive anomaly with a maximum value of around 3.5 mGal and a lowest value of roughly 1 mGal that is situated in the eastern part of Zakho City. This anomaly may be formed by two E-W faults appearing as small stepped faults. It is noticed that the presence of a local gravity "high" is due to the folding of Mesozoic rocks as shown in profiles G3 and G4.

Subsurface Summayl anticline

It is reflected as a gravity "high" identified in the present study, which extends parallel to Bekher anticline with the same trend (NW-SE). It is thought to result from stepped tectonic faults (F43, F47) below the subsurface anticline.

Dahkan structutre

Dahkan anticline with an E-W trend has a maximum positive anomaly of about 7 mGal. This anomaly appears in profiles (G4) as stepped tectonics E-W faults; the southern one is normal (F41) and the northern one is reverse (F42).

Conclusion

Throughout this effort, the following findings were made:

1 .In this investigation, the novel empirical upward continuation method developed by Zeng et al. (2007) was the most often used approach for achieving the best separation between the regional and residual abnormalities.

2 .The ideal heights for upward continuation applied to the gravity profiles are between 6 and 7 km below sea level, which corresponds to the basement depth and is consistent with the 2D models.

3 .Negative anomalies are associated with the Bekher anticline near Zakho city. This irregularity was interpreted as a graben or partially graben during the Cretaceous period and then transformed into an anticlinal fold above the Cretaceous formations.

4. The Summayl anticline, a new subsurface anticline close to Summayl hamlet, has been identified by the current investigation.

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