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Delineation and Detection for a Number of Expected Oil Structures Northern Iraq by Gravity Investigations

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ABSTRACT

The surveyed area covers about 3000 km2 in the northern part of Iraq, with elevations ranging between 300 to 1910m above sea level. The study area is located within the foothills and high folded zones, including several important anticlines (Maqlob, Kand, Ain Sifni, Shaykhan, Chia Gara, and Maten anticlines). The geophysical survey is based on 232 gravity points. The gravity data had been corrected, and the Bouguer anomaly was calculated along each point. The optimum upward continuation level produced was arranged from 5 to 6 km, that applied to obtain the residual and regional anomaly profiles of the study area. The 2D modeling technique was used for the quantitative interpretation. Four gravity profiles were modeled. The results of this study show that the top depth of the basement rocks of the studied area is around 6km, and several faults are indicated in the sedimentary sections by potential methods. In addition, several grabens, half grabens, and horsts surrounded by normal and reverse faults are displayed in the sedimentary sections by gravity "lows" and "highs".

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تحديد وكشف التراكيب النفطية المحتملة في شمال العراق اعتمادًا على المسوحات الجاذبية

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الملخص

تغطي منطقة الدراسة مساحة تُقدَّر بحوالي 3000 كم² في الجزء الشمالي من العراق، ويتراوح الارتفاع فيها بين 300 و1910 م فوق مستوى سطح البحر. تقع منطقة الدراسة ضمن نطاقي الطيات الواطئة والطيات العالية، وتضم عددًا من الطيات المحدبة المهمة مثل طيات مقلوب، قند، عين سفني، الشيخان، جيا كاره، ومتين. اعتمدت الدراسة الجيوفيزيائية على 232 نقطة قياس جاذبية، حيث تم تصحيح بيانات الجاذبية وحساب شذوذ بوكير عند كل نقطة قياس. تم اختيار مستوى الاستمرارية الصاعدة الأمثل بحدود 5 إلى 6 كم، والذي استُخدم لاستخلاص الشذوذات الإقليمية والمتبقية لمنطقة الدراسة. استُخدمت تقنية النمذجة ثنائية الأبعاد في التفسير الكمي، وتمت نمذجة أربعة مقاطع جاذبية. أظهرت نتائج الدراسة أن عمق قمة صخور القاعدة في منطقة الدراسة يبلغ حوالي 6 كم، كما أشارت طرائق الجهد إلى وجود عدة فوالق ضمن التتابعات الرسوبية. بالإضافة إلى ذلك، تم تمييز عدد من الخسفات (Grabens) وأنصاف الخسفات (Half Grabens) المرتفعات (Horsts) المحاطة بفوالق اعتيادية ومعكوسة، والتي انعكست على شكل شذوذات جاذبية سالبة وموجبة ضمن المقاطع الرسوبية.

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Introduction

Measurements of gravity provide information about the densities of rocks underground. There is a wide range in density among rock types, and therefore, geologists can make inferences about the distribution of strata. Anomalies in the Earth's gravitational field result from lateral variations in the density of subsurface materials and the distance to these bodies from the measuring equipment. For reliable interpretation of the gravity anomaly, it is advisable to consult other geophysical data such as magnetic and seismic (Mariita, 2007).

As previously and, due to the fact that the potential method is one of the best ways to find out the subsurface structures and knowledge of variations in the thickness of sedimentary cover so it has been used in this study. This study involves the analysis of gravity data to delineate structures and faults and to locate any major structures in the study area.

The area of study covers about 3000 m2 in the north of Iraq, including the area eastern Duhok city, bounded by longitudes (43^{o} 28` E - 43$^{o}$ 60` E) and latitudes (36^{o} 39` N - 37$^{o}$ 23` N). Jassim and Goff (2006) divided Iraq into three tectonically different areas, the Stable

Shelf with major buried arches and anti-forms but no surface anticlines; the Unstable Shelf with surface anticlines, and Zagros Suture which comprises thrust sheets of radiolarian chert, igneous and metamorphic rock (Fig. 1). The study area is a part of the Foreland folds of the Alpine Orogen in northern Iraq, and they are located on the Mosul block that trend in a Taurus E-W direction (Numan, 1984).

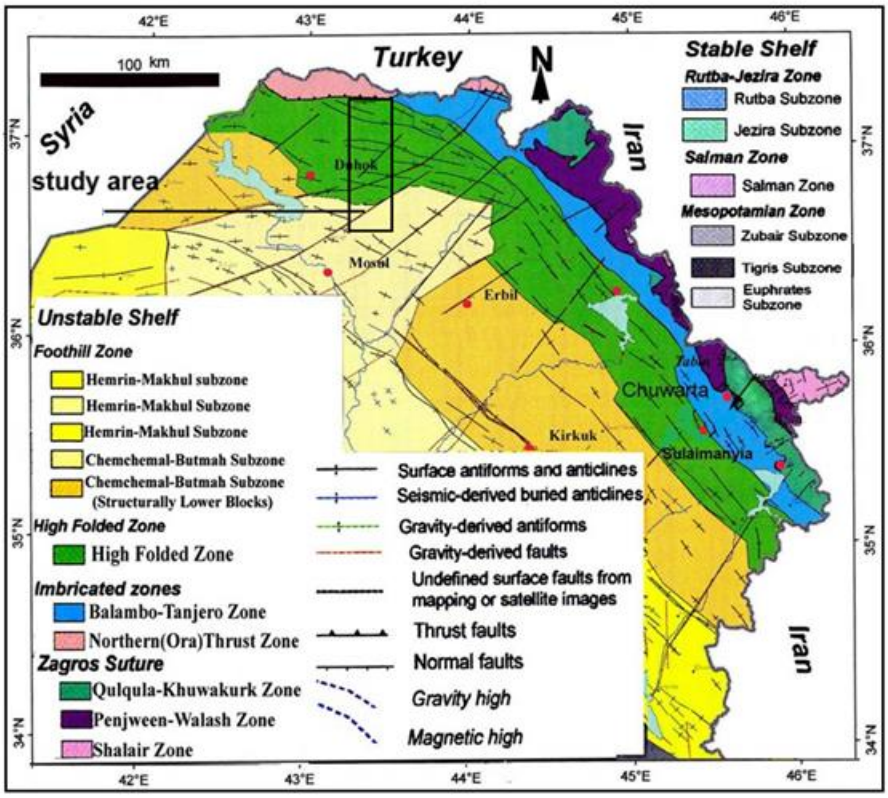

Fig. 1. Tectonic zones and structural elements of unstable shelf (After Jassim and Goff, 2006) with locations of the study area.

There are several common geomorphological features in the studied area, like agricultural plains, drainage patterns formed dendritically, valleys, foothills, low mountains, and high mountains. These geomorphological features of the area are cut up by fluvial erosion. The elevation of this area ranges between 250m to 1910m (Fig. 2).

Geophysical data are few for the northern parts of Iraq, except for some local surveys around the Duhok area. The Bouguer anomaly map of Iraq, published by Sayab & Valek (1968), did not cover the northern parts. Ghaib et al. (1998) carried out a local reconnaissance gravity survey covering about 600 km2 in the Sulaivany plain north-east of Dohuk city. Mutib and Al-Shaikh (2005) used shallow geoelectric investigations in the Mosul Area and discovered new subsurface folds with hydrocarbon probabilities. In a gravity survey, the variations in the Earth's gravitational field were caused by differences in the density of subsurface rocks. Most of the authors have used the value (0.17) gm/cm^3 as a density contrast between sedimentary cover and basement rocks, as reviewed by Al-Sinawi et al (1987). Nevertheless, Hamid (1995) used the value (0.18) gm/cm3 in a regional traverse along and around the present study areas. This value is advocated by Al-Shaikh and Mohammed (1997), who recommended its use in the Unstable Shelf of Iraq. The mean density of the sedimentary cover was given by Ditmar et al. (1971) to be (2.6) gm/cm3, considering an average density of (2.77) gm/cm^3 for the basement rocks (Ditmar et al., 1971). Al-Brifkani (2008) developed a schedule of the formations in his study area (near this study area) showing their thicknesses, ages, and lithology (Tab.1)

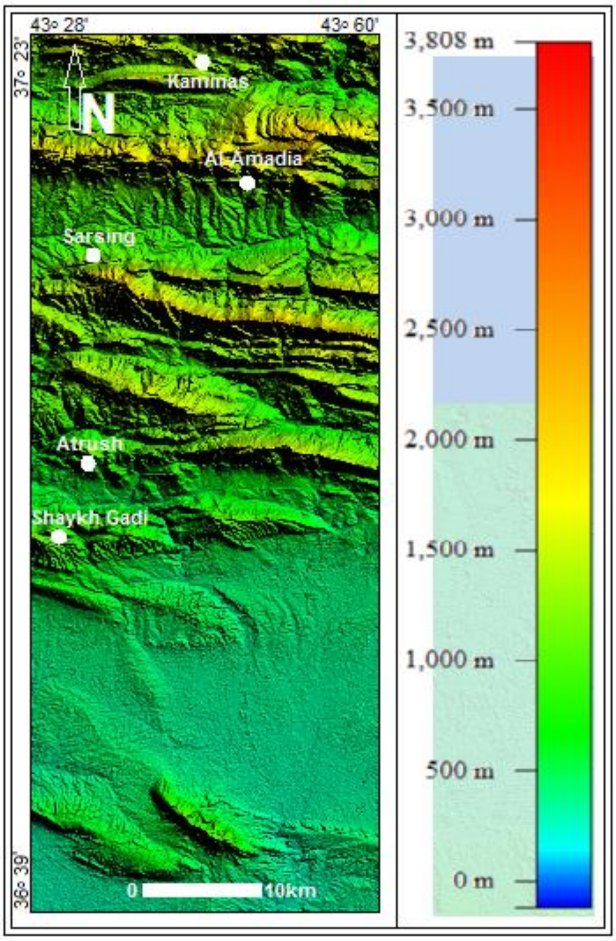

Fig. 2. The location of the study area on the Digital Elevation Model (DEM) showing geomorphological features.

MATERIALS AND METHODS

In a gravity survey, we measure variations in the Earth's gravitational field caused by differences in the density of subsurface rocks. 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 (Dobrin and Savit, 1988). The LaCoste and Romberge Gravimeter model G was used in this study. It has a range of more than 700 milligals, reading accuracy of ± 0.01 mgl, and a drift of less than 1 mgl/month. When this gravimeter was calibrated before the field work, the calibration factor did not change perceptibly with time. This eliminated the need for frequent checks of calibration during the work. The instrument did not show any trouble during the period of work.

In this work, all gravity stations were surveyed for relative easting, northing, and elevation using a Garmin (72) Global Positioning System (GPS). The elevation of the reading station, relative to sea level, shows an accuracy of 4m when it is used continuously in the field. A Garmin (72) GPS has not exceeded a few meters for horizontal coordinate accuracy. The primary base station is known as an absolute gravity and elevation station; it is located at

Mosul University to Al-Shaikh et al (1975). This station has an absolute value of 979789.46 mGal, which is used as a reference point for the other stations in the studied area. The absolute value of the gravity could be found for those stations from the absolute value of the primary base station. In addition, eight secondary base stations were established in the studied area and tied to the primary base station. Transportation of the gravimeter from the base station to other stations and from one station to another was the most time-consuming aspect. The form of the field work means the way of the stations array, which is commonly by these ways: traverses, grid, and random. In this study, the random way is used for arraying the stations due to the major difficulties (mountains &valleys) in the study area. To facilitate the survey, it is a common practice to establish 232 gravity stations near and along highways, roads, and their branches, depending upon the feasibility of access and the spacing pattern necessary to detail the features. (Fig. 3).

Table 1: The outcropped formations in the study area from their typical locations (After Al-brifkany, 2008)

ERA	PERIOD	EPOCH	FORMATION	THICKNESS	DESCRIPTION
Cenozoic	Pliocene		Bakhtiari		Claystone, silty pebbly conglomerate, conglomerate.
	Miocene	M-U	Fars Group		Marl, Claystone, Sandstone
	Eocene	M-U	Pilaspi Limestone	85 m	White chalky limestone, partly dolomitic, recrystallized karstic in places, porous
	Eocene	M	Gercus	838 m	Moderately compact claystone -partly fissile silty with thin beds of green marl, plastic and thin horizon of conglomerate, massive, brecciated sandy and white slightly hard gypsum layers and nodules
	Paleocene-Eocene	UP-LE	Kolosh	777 m	Highly deformed silty claystone is mainly green
Mesozoic	Cretaceous	U	Hadiena	755 m	Conglomeratic, fragmental, and brecciated Limestones alternating with fragmental shelly limestone with frequent Hematite breccias and calcareous marls, ferruginous.
	Cretaceous	U	Bechma Limestone	315 m	Well-bedded massive white -buff, fractured limestone
	Cretaceous	L	Qamchuqa Limestone	799 m	Massive dolomitic limestone at the top, recrystallized, fossiliferous, and karstified.
	Jurassic-Cretaceous	UJ-LC	Chia Gara	232 m	Thin beds of Limestone and yellowish marly limestone with shale at the top
	Triassic	U	Kurra China	835 m	Dark brown black limestone alternated with dolomite, pyritic and fissile shale with slump structurewith gypsum beds at the bottom outcropping at the Turkey border
	Triassic	M	Geli Khana	875 m	Dolomite, ferroginous with black chert, dolomitic limestone, and shale
	Triassic	L	Beduh Shale	64 m	Shale, reddish brown, fissile with marl and limestone
	Triassic	L	Mirga Mir	200 m	Marly limestone, grey, oolitic silty at the bottom
Paleozoic	Permian	U	Chia Zairi	811 m	Dark blue Limestone, thin-bedded detrital with silicified limestone, hard, massive with chert nodules
	Carboniferous	L	Harur Limestone	62 m	Black organic Limestone, thin-bedded, detrital, intercalated with micaceous shale
	Carboniferous	L	Ora Shale	215 m	Black Mica and calcareous shale with olive green marl and thin detrital limestone
	Devonian	U	Kaista	30 m	Dark blue argillaceous Limestone, silty shale, and a streak of sandstone
	Ordovician		Chalki Volcanics	16 m	Dull greenish grey, red,white-olive Basalt, and soft red silt
	Ordovician		Pirispiki Red Beds	80 m	White massive cross-bedded Quartzite, slightly reddish marl and sandstone, conglomerate lenticels, and red shale.
	Ordovician		Khabour Quartzite	800 m	Alternation of thin-bedded fine-grained Sandstone,

	Shale	Quartzite, and silty micaceous shale, olive green-brown slightly metamorphosed

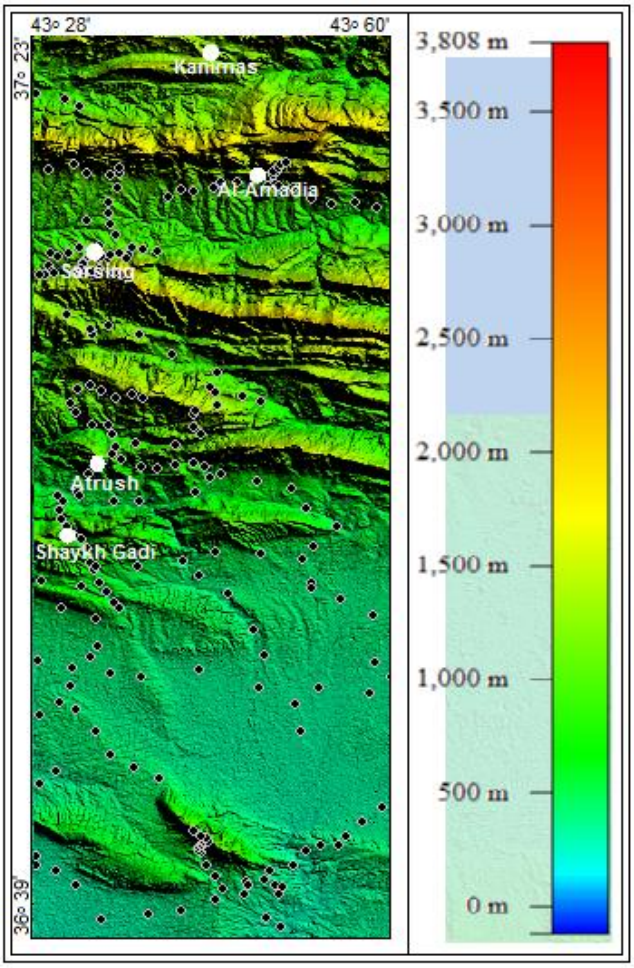

Fig. 3. The DEM of the study area displaying the locations of gravity stations (Black Dots).

Single-base method (the gravity base station) was adopted to correct the gravity readings in every station for the effect of temperature and pressure. The location and the elevation are entered in the corrections of the field measurements. Besides, the spacing between the stations is related directly to the feature types that are to be studied; it determines the length of the profiles and affects the stations' locations. The spacing between stations ranged between 500 and 5000 m. The habit for the field results is that the differences (Δg) for the gravity are determined. The observed gravity measurements as obtained in the field usually include various effects that must be removed to leave the effect of the sub-datum density irregularities only. The Bouguer anomaly of the gravity at a point is the difference between the observed value (gobs.) adjusted by the algebraic sum of all the necessary corrections (corr.) and that at the base station (gbase):

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

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

Where h is the elevation above sea level, gabs. is the absolute gravity value in the measurement point. This implies a known absolute value at the base station and the geo. is the theoretical gravity value at the geographic station latitude (ϕ) at sea level.

The theoretical gravity value, which is usually denoted by ($g\phi$), varies over the surface of the Earth because of its ellipsoidal shape. The International Association of Geodesy (IAG) in 1971 proposed a formula to calculate *g* at any latitude:

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

This formula gives the actual gravity value at sea level to within 0.1 mgl precision (Parasnis, 1997). This formula is applied in the present work. It is important to mention here that the Iraqi gravity surveys (the IPC – Bouguer map and later surveys) had applied the 1930s formula, which differs by about 12.5 milligals from the 1971 formula (Ghaib, 2001).

$$g_{\phi} = 9.78049(1 + 0.0052884\sin^2\phi - 0.0000059\sin^2 2\phi) m/s^2$$ ---------1930 formula

In an environment of irregular topography, the undulations above and below the elevation level of gravity observations are referred to as terrain correction. Terrain correction is necessary when the gravity effect due to topography between any station and the base station level is over the accuracy of the gravimeter. Computing these corrections by hand using topographic maps is a labor-intensive task. As noted by Leaman (1998), Hammer's method is manual, tedious, and prone to estimation error. Efficient and effective use of these corrections requires comprehensive (DEM) and computational power that is only now becoming generally available (Hinze et al., 2005; Nabigian et al, 2005, and Hwa Chen, 2009).

For each elevation point within the 30-meter DEM image compared to the elevation of the gravity station is compared. A rectangular prism with uniform density (2.175) is used to calculate the vertical component of the gravitational attraction between the gravity station and the prism. The Geosoft Oasis Montaj program set (GOM, 2008) and Terrain Correction Software (TCS) extension provide a complete system for processing and reducing gravity data from conventional ground surveys. The data obtained after application of the reduction on the raw data may be affected by several errors, the first is produced by the instrument itself, and the second by the field and reduction procedures. Instrumental errors come from the inaccurate reading of the data. Repeated readings in 61 stations showed an error in the observation of (± 0.04) mGal in (Δgo). The second type of error affects the gravity values more seriously. The errors encountered in this study are listed in Table 2.

Table (2): Source and magnitudinal effects of errors.

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

The total error in the Bouguer anomaly can be calculated using this formula:

$$E_{total} = \sqrt{E^2{}_{go} + E^2{}_{F_a} + E^2{}_{Bc} + E^2{}_{lat.} + E^2{}_{Tc}}$$ **= ± 1.297 mgl**

Results

The first step in the quantity interpretation is the visual inspection of the DEM image to choose the profile across the anomaly of interest. The second is to estimate approximately the horizontal extension, depth, shape, and thickness of the target using a geological background (Well logging, seismic sections, previous studies). The third step is to construct a geometric model which satisfies the abovementioned estimations and is consistent with the geologic situation by using recent computer programming (GOM, 2008). The methods used to calculate the gravity model response are based on the methods of Talwani et al. (1959) and Talwani & Heirtzler (1964), and make use of the algorithms described in Won & Bevis (1987). The GM-SYS inversion routine utilizes an inversion algorithm to linearize and invert the calculations. GM-SYS uses an implementation of that algorithm for gravity developed by the USGS and used in their computer program (Webring, 1985). GM-SYS uses a two-dimensional, flat-earth model for the gravity calculations; that is, each structural unit or block extends to plus and minus infinity in the direction perpendicular to the profile. The earth is assumed to have topography but no curvature. The model also extends plus and minus 30,000 kilometers along the profile to eliminate edge effects.

Because the modeling software, according to (GOM, 2008), requires straight line profiles, a kriging grid line was calculated for each survey line using all gravity station locations. All stations were projected perpendicularly onto this line, and station distances were calculated from the first station on each line (always the southernmost station). 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 anomalies. Table 3 describes the modeled units. The geometrical models designed in the present study are controlled with local seismic study (Bashiqa- Kand section (BK)) and exploratory wells such as Kand (KD), and Tawki (TK). Furthermore, all previous lithostratigraphic and structural studies were also taken into account in those models.

Table 3: Describes the modeled units and their densities

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

The residual and regional gravity for four profiles in the study area were produced using an upward continuation filter by applying the empirical method of Zeng et al. (2007). The method consists of calculating the correlation factor (r) between upward continued fields at two successive heights. The correlation factor is plotted as a function of increasing continuation height. The height that gives the maximum deflection is the optimum height (Fig. 4). The produced upward continuation heights were applied to obtain the residual anomaly profiles in the study area, are range from 5 to 6 km.

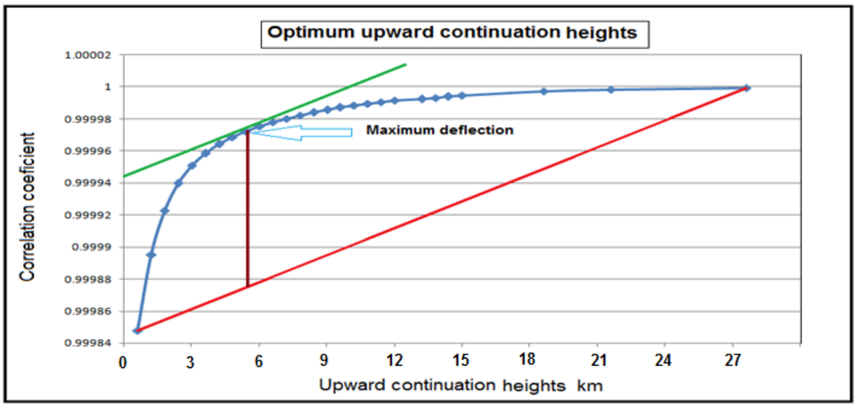

Fig. (4) Cross-correlations between continuations to two successive upward heights versus the upward heights.

The designed models include the sedimentary sequence and the basement complex with the structure situation, and the thickness of depositional formations is deduced from the study of Al-Brifkani (2008). Fig. 5 shows the locations of produced profiles in the study area.

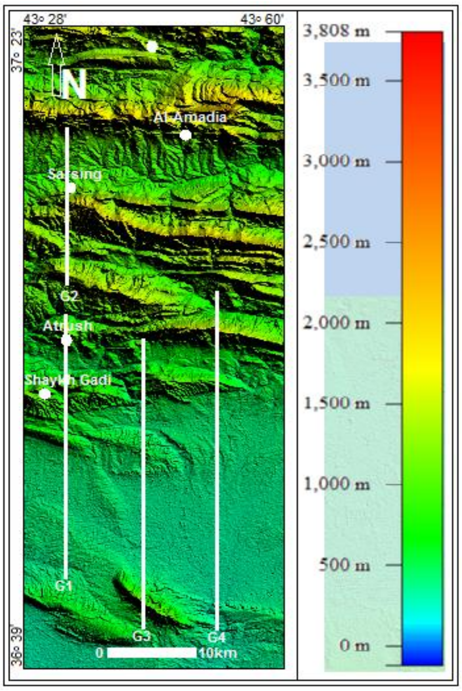

Fig. (5) The DEM image with the locations of profiles in the study area

Profile G1

This profile extends for about 53 km from Bashiqa village to Atrush village (Fig. 6). This profile displays three gravity "highs", the first one is located over Khursabad anticline according to Mutib and Al-Shaikh (2005) with an amplitude of about 2 mGal and a half-width of approximately 2 km, the second one appears above the extension of Maqlob anticline with an amplitude of about 2.5 mGal and a half-width of approximately 3 km. The third one is displayed over the Ayn Sifni anticline with an amplitude of about 2 mGal and a half-width of approximately 3 km. This anomaly may be formed by a reverse E-W fault. Fourth gravity "high" is indicated over the Shaikhan anticline with amplitude of about 15 mGal and a half-width of approximately 7 km, it can be explained as horst bounded by two E-W reverse faults according to Gulf Keystone (2010) (Fig.7). In addition, there are three gravity lows pointed out in this profile representing the synclines between each two anticlines.

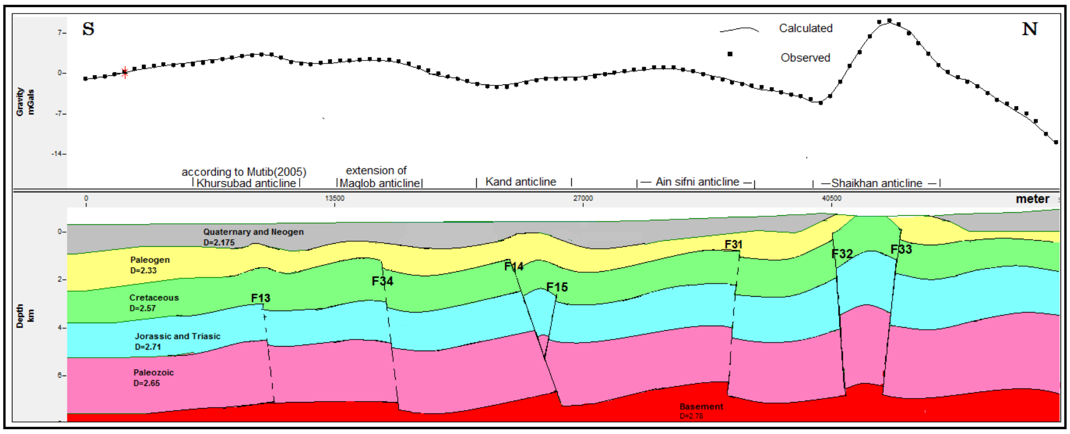

Fig. 6. Cross-section and gravity data along profile G1. The upper panel shows the gravity profile along the cross-section- the dots represent the observed gravity values and the line shows the calculated gravity for the model below. The lower panel shows the modeled geologic cross-section- depths are positive downward.

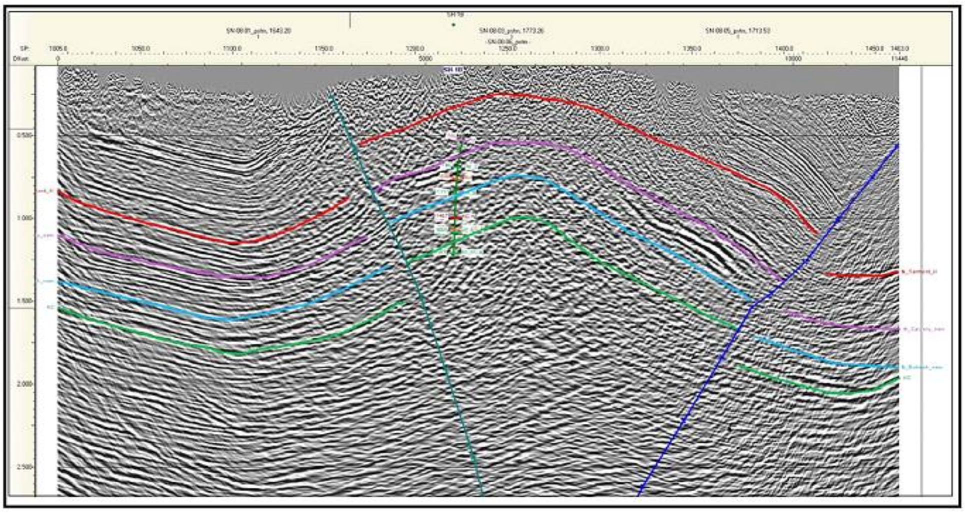

Fig.7 A north-to-south view of the Shaykhan structure and interpreted horizons on seismic line SN-08-06. The well is 1.25 km along this line and projected into the section. The Shaykhan structure lies between the two major east-west faults (Gulf Keystone, 2010).

Profile G2

This profile extends for about 36 km from Atrush village to the north of Bamirni village (Fig.8). This profile shows two gravity "highs", the first one is shown over Chia Gara anticline with an amplitude of about 30 mGal and a half-width of approximately 8 km. This anomaly can be explained as a big horst bounded by two E-W reverse faults with different directions, in addition to one E-W normal fault within the structure. The second one appears over the Matin anticline with an amplitude of about 16 mGal and a half-width of approximately 6 km. There are no observed values over the crest of the Matin anticline; therefore, the amplitude of this anomaly is lower than the true. In addition, there is one negative anomaly in this profile located between Chia Gara and Matin anticlines corresponding to the great plane.

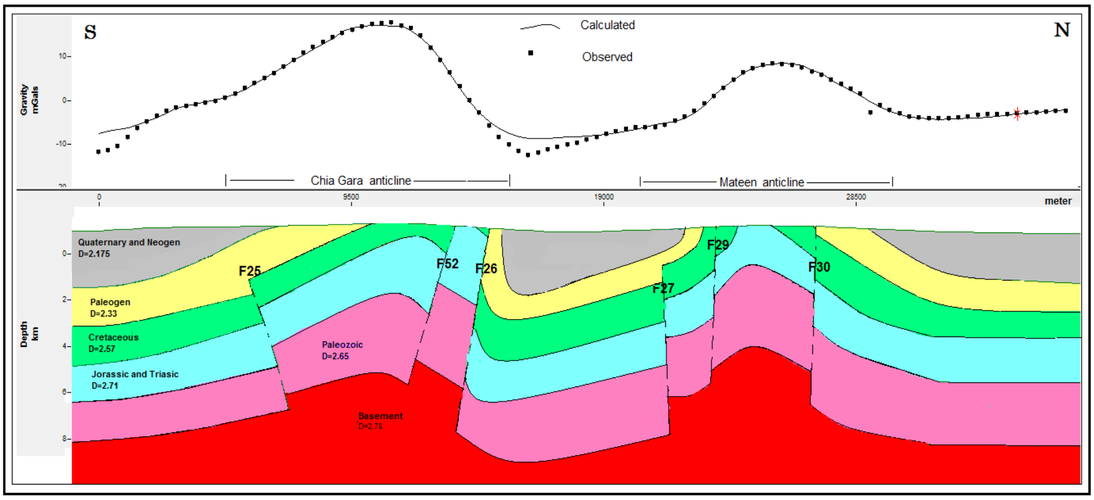

Fig.8 Cross-section and gravity data along profile G2. The upper panel shows the gravity profile along the cross-section- the dots represent the observed gravity values and the line shows the calculated gravity for the model below. The lower panel shows the modeled geologic cross-section- depths are positive downward.

Profile G3

This profile extends for about 50 km from the southern Maqlob anticline to the east of Atrush village (Fig. 9). This profile shows three anomalies; the first is a gravity "low" indicated over the Maqlob anticline with an amplitude of about 40 mGal and a half-width of approximately 4 km. It can be explained as a graben bounded by two NW-SE normal faults according to the study of Kent (2010) (Fig. 10). The second is positive, located over the Mahd anticline with an amplitude of about 2.5 mGal and a half-width of approximately 2 km. It may be formed by an E-W normal fault. The third is a gravity "high" that appeared over the Shaikhan anticline with an amplitude of about 8 mGal and a half-width of approximately 6 km.

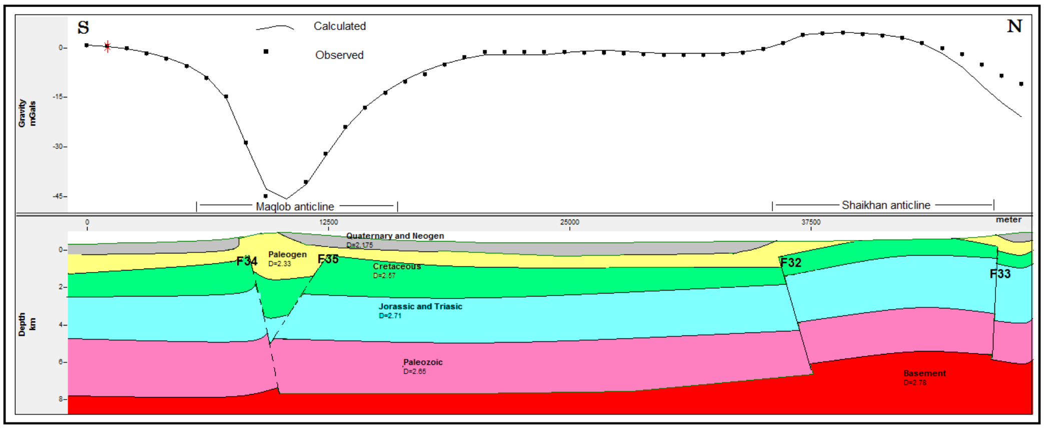

Fig. 9. Cross section and gravity data along profile G3. The upper panel shows the gravity profile along the cross section- the dots represent the observed gravity values and the line shows the calculated gravity for the model below. The lower panel shows the modeled geologic cross section- depths are positive downward.

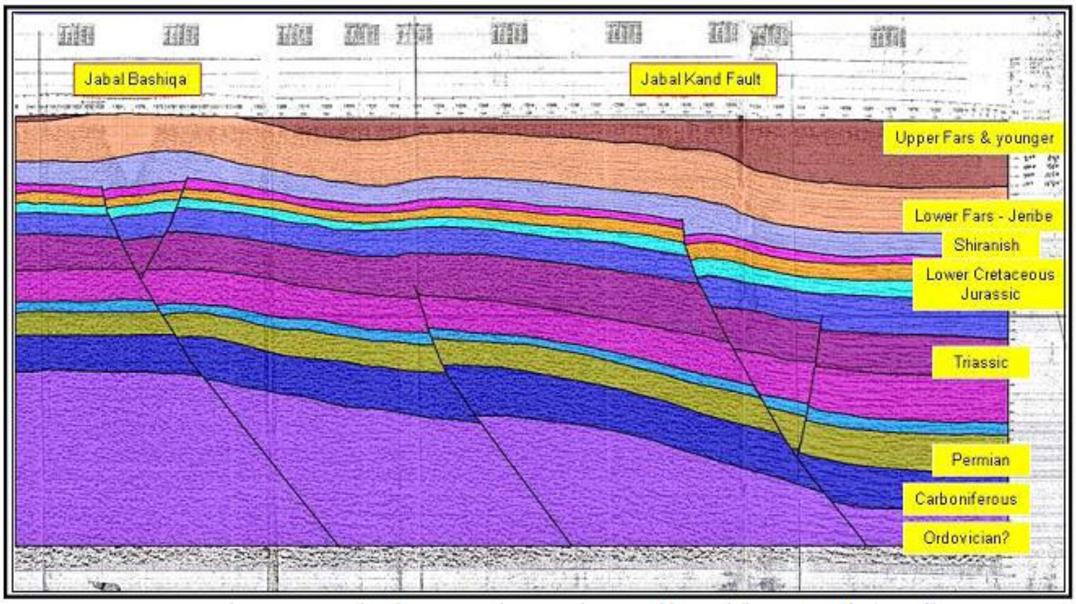

Fig. 10. The seismic line crosses the plunges and ends of Kand and Bashiqa anticlines (after Kent, 2010).

Profile G4

This profile was extended for about 55 km from the southern Maqlob anticline to the north of the Shaikhan anticline (Fig.11). This profile shows two anomalies, the first is a gravity "low" located over both the plunge of Maqlub anticline and the plunge of Mandan anticline with an amplitude of about 9 mGal and a half-width of approximately 5 km. It can be explained as a graben bounded by two NW-SE faults. The southern one is normal that corresponding with the plunge of the Maqlob anticline, and the northern one is reverse, which is indicated over the Mandan anticline. The small bulge between them is pointed out as a small anticline between two plunges according to the study of Al-Abaadie (2012). The second anomaly is positive, illustrated over the plunge of the Shaikhan anticline with an amplitude of about 8 mGal and a half-width of approximately 4 km.

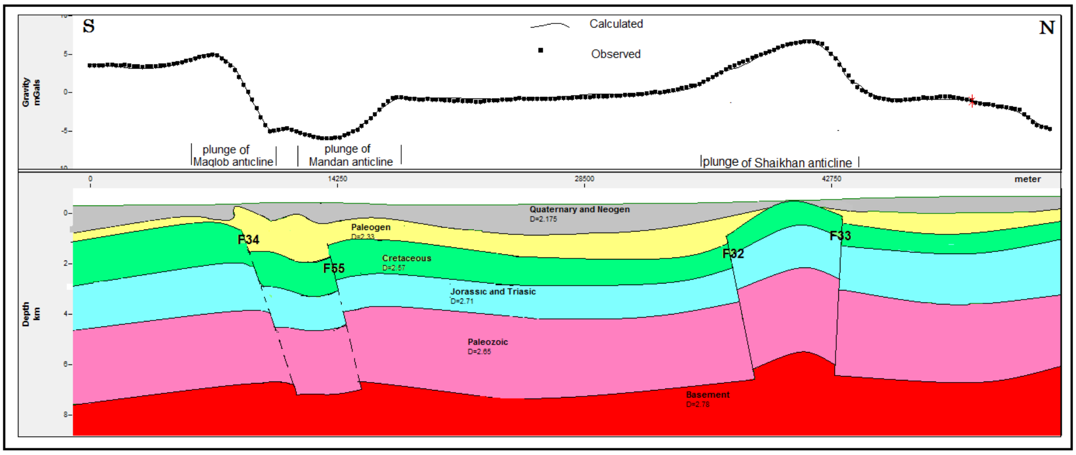

Fig.11 Cross-section and gravity data along profile G4. The upper panel shows the gravity profile along the cross-section- the dots represent the observed gravity values and the line shows the calculated gravity for the model below. The lower panel shows the modeled geologic cross-section- depths are positive downward.

Discussion

The most modeled anomalies in the previous profiles are caused by anticline structures associated with tectonic faults, which are formed from grabens and horsts. The gravity field anomalies in the studied areas reflect the combined effects of Paleozoic, Mesozoic, and Cenozoic tectonic development. The faults are matched well with the situation of surface structures described by some authors, and fit with the information concluded from some local geophysical studies (Ghaib, 2001; Kent, 2010; Gulf Keystone, 2010). The following is a discussion of those geophysical anomalies which modeled in the present study.

Kand anticline

It has a small "high" gravity within a bigger "low" gravity as indicated in the profile G1. This anomaly may be caused by a main normal fault (F14) increasing the negativity; in contrast, the secondary reverse fault (F15) is decreasing it. (Fig. 6).

Shaikhan structure

It is a gravity "high" located at the north of Shaikhan village with an E-W trend; it has values ranging from -12 to 9 mGal. This anomaly appeared clearly in the profiles (G1, G3, and G4). This anomaly is explained as a horst bounded by two E-W reverse faults (F32, F33) according to Gulf Keystone (2010).

Maqlob and Mandan structure

Maqlob anticline is a gravity "low" that extends near Bashiqa village with a maximum value of about 6 mGal and a minimum value of about -32 mGal. The negativity in this anomaly is caused by a graben bounded with two normal faults (F34, F35), the same as the Bashiqa anticline described by Kent (2010). The high negativity appeared in the Maqlob anomaly may be explained as a syncline within the graben that makes the best fit between observed and calculated gravity values. This anomaly appeared clearly in profile G3, while appearing in profile G4 as a wide negative anomaly due to the combination with the plunge of the Mandan anticline. The new combined anomaly may be explained as a big graben divided by a small horst(anticline) according to Al-Abaadi (2012).

Khursubad anticline

This structure has a small positive anomaly with a maximum value of about 3.5 mGal and a minimum value of about 1 mGal. This anomaly may represent the east end of the Filfyl anticline (Al-Majid,2013). It was formed by an NW-SE reverse fault (F13).

Chia Gara structure

It is the higher positive anomaly that appeared in the study area with a maximum value of about 17 mGal. The outcropping of Mesozoic rocks (Chia Gara Fm.) in the core of the anticline is due to the uplifted faulted block extending to the basement boundary underneath the structure. This anticline, with the Mateen anticline, represents the maximum uplift in the study area; this may explain the high positivity of this anomaly. This anomaly contains a set of E-W normal and reverse faults (F25, F26, F52) that contributed to this big uplift.

Mateen anticline

It is another high positive anomaly appeared in the study area close to Al-Amadia village. This anomaly can be explained as a wide horst bounded with two E-W reverse faults (F27, F30). It is divided into two parts by a graben bounded by two E-W normal faults (F28, F29).

Conclusions

The following conclusions were reached in the course of this work:

1. During this study, the best separation between the regional and residual anomalies was performed using the new empirical upward continuation method applied by Zeng et al. (2007).
2. The optimum upward continuation heights applied to the gravity profiles range between 5 and 6 km under sea level, reflecting the basement depth, which is matching with the 2D models.
3. Anticline structures of Kand and Maqlob are accompanied by negative anomalies. These anomalies were explained as grabens or half grabens under the Cretaceous period and converted to anticlinal folds above the Cretaceous Formations, similar to the Bashiqa anticlines.
4. The concentration of major normal faults, which are suggested in the study area are increases far away from the collision boundaries of the Arabian plate. By contrast, the existence of major reverse faults increases north and northeastwards. These may be explained as a differentiation in the compression energy.
5. The present study has concluded a subsurface anticline called Khursubad. In addition, unknown structural extensions are also identified.

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