A Gravity Survey and Data Interpretation of Tawke Structure (Iraqi Kurdistan Region)

Abdulwahab N. Al-dawoody
Department of Geology, College of Science, Salahaddin University
Email: abd2_n@yahoo.com
Received date: 20/1/2012 Accepted date: 3/6/2012

Abstract

In this study 780 gravity measurements were conducted in the Tawke area along the paved and accessible unpaved roads. The obtained gravity data was subjected to the necessary corrections and analyses qualitatively and quantitatively. For that purpose the Bouguer anomaly map was transformed analytically to regional and residual fields. Moreover two profiles trending NS were limited to a 2-D gravity models. The main structural features of the studied area as are recognized utilizing two main lines of evidence, namely, geological map and geophysical interpretations have one distinctive trend; it is the E-W Taurus trend. The Bouguer map of the Tawke area shows gravity high in the central part. It trends E-W. It is indicative of the main anticline. Two gravity lows indicating the two synclines bounding the structure from north and south are clearly shown. Six faults are inferred from gravity data. When inferred faults and gravity lows and highs are plotted on the geological map they show good agreement.

A considerable density contrast of 0.36 gm/cm^3 was observed between the Jeribe, Ana, Pila Spi, and Avana formation group against Lower Bakhtiari, Upper Fars and Lower Fars formation group and used in the modeling of two profiles. One main positive and two negative features characterize these profiles. The positive anomaly represents Tawke Anticline, the south negative anomaly represents Khabore syncline and the other Zakho syncline.

Geological model for profiles show that the Tawke Anticline is an asymmetrical Anticline producing a structural trap by tilting of the Miocene formations comprising sealing rocks (Fatha Formation) and reservoir rock represented by the Jeribe carbonates. Two small faults on the northern limb of Tawke Anticline have indications on the surface as seepages of oil.

Keywords: Geophysic, Gravity, Interpretation, Survey

مسح جذبي وتفسير المعطيات لتركيب طاوكي(أقليم كوردستان العراق)

عبدالوهاب نوشاد الداوودي
قسم علوم الارض، كلية العلوم . جامعة صلاح الدين
تاريخ استلام البحث:20 /2012/1 تاريخ قبول البحث:2012/6/3

الخلاصة

في هذه الراسة تم قياس (780) محطة جذبية في منطقة طاوكي على طول الطرق المعبدة وغير المعبدة. وأجريت التصحيحات الضرورية والتحليلات النوعية والكمية على المعطيات الجذبية. ولهذا الغرض تم فصل المجال الجذبي الأقليمي والمحلي لخرطة شذوذ بوجير بطريقة تحليلية. وتم رسم موديلات جذبية ذات بعدين لمقطعين بإتجاه شمال جنوب. تتميز الظواهر التركيبية الرئيسية لمنطقة الدراسة أن لها إمتداد سلسلة جبال طوروس شرق غرب كما هو ملاحظ من الخرائط الجيولوجية والجيوفيزيائية. حيث يظهر إرتفاع جذبي في الجزء المركزي من خرطة بوجير لمنطقة طاوكي، له إمتداد شرق غرب ويمثل الطية الحدبة الرئيسية. وكذلك يظهر بشكل واضح إنخفاضان جذبيان يمثلان طيتين مقعرتين يحددان التركيب من الشمال ومن الجنوب. أمكن إستنباط ستة فوالق من المعطيات الجذبية. ويمكن ملاحظة توافق جيد عند إسقاط هذه الفوالق والإرتفاعات والإنخفاضات الجذبية على الخريطة الجيولوجية. لبناء الموديلات للمقطعين تم إستخدام التباين في الكثافة بمقدار 0.36 غ/سم3 الملاحظ بين مجموعة التكاوين جريب، وعانة، وبيلاسبي، وآفانا من جهة، والتكاوين بختياري الأسفل، والفارس الأعلى والأسفل من جهة أخرى. هذان المقطعان يمتازان بوجود شذوذ موجب رئيسي وشذوذان سالبان. الشذوذ الموجب يمثل طية طاوكي المحدبة، والشذوذ السالب الجنوبي يمثل طية خابور المقعرة، والشذوذ السالب الشمالي فيمثل طية زاخو المقعرة. الموديل الجيولوجي للمقطعين يظهر أن طية طاوكي المحدبة هي طية غير متناظرة، تكوّن مصيدة تركيبية للنفط بواسطة وجود تكاوين المايوسين الصماء (الفارس الأسفل) الواقعة فوق صخور ضخور مصدرية متمثلة بتكوين جريب الكاربوني. هناك فالقان صغيران على الجناح الشمالي لطية طاوكي لهما دلائل على السطح على شكل نضوحات نفطية.

الكلمات الدالة: جيوفيزياء، جاذبية، تفسير، مسح.

Introduction

Tawke Anticlinal structure is located in the northern part of Iraqi Kurdistan Region, near Tawke village, about 7 km east of Zakho Town. It is close to Iraqi–Turkish border (Figure 1). It belongs to the Taurus range of Iraqi anticlines.

Oil traps in Northern Iraq are mainly of fold type (Anticline traps). All of the petroleum to date, in this region, is found in such structures [1] as is the case in Tawke structure. Seepages of oil in Tawke area are normally seen on the surface [2]; most of them are related to the beneath seated oil-storing formations.

Before the exploration activities of Norwegian Oil Company (DNO) in this region, the present first detailed gravity survey for Tawke Anticline was established in corporation with Directorate of oils and minerals in Erbil.

Bouguer anomaly map for any area is an important step towards understanding the subsurface structural pattern in this part of the High-Folded Zone of Iraq and precedes the expensive seismic survey. The later on drilled wells by the mentioned company as well as the cropping out rock types were good tools for the interpretational activities in this study.

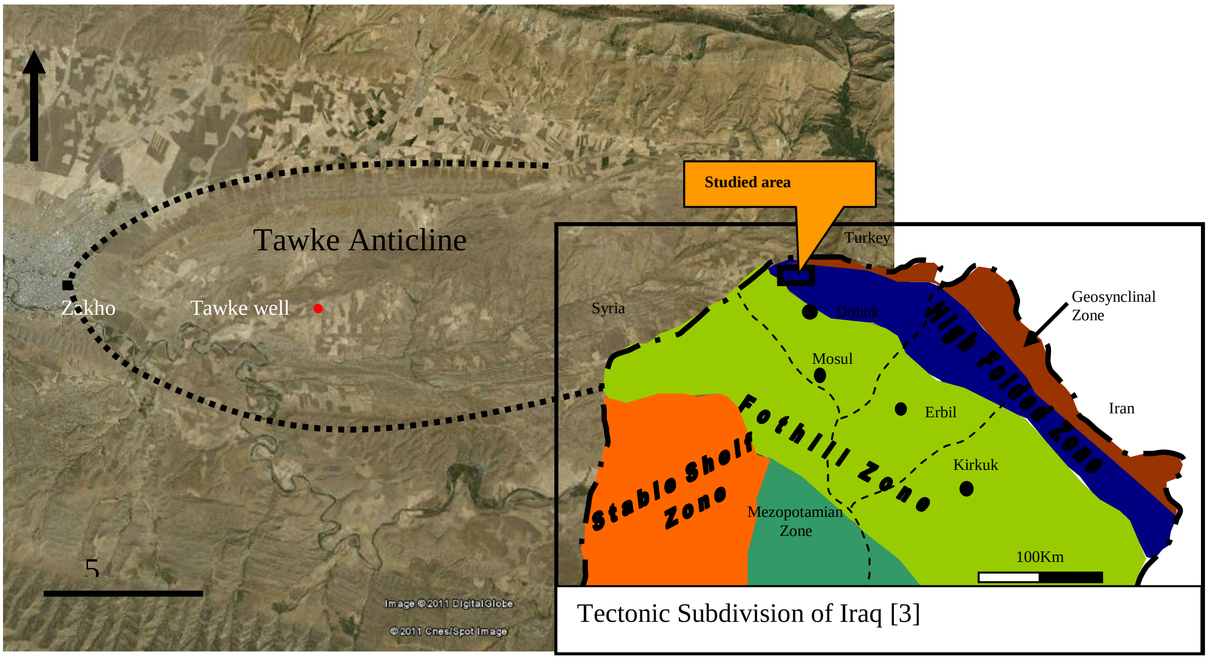

Figure (1): Satellite Image of studied area and Tectonic Subdivision of Iraq

General tectonic and geology of the study area

The tectonic setting of Tawke Anticline can be described in view of the regional tectonic setting of Iraq.[3] divided Iraqi territories into three main subdivisions. According to this subdivision, the study area is located in the high folded zone which is in turn the northern strip of the folded zone. The structures of this zone are originally strongly uplifted and their units are very complex. The High Folded zone is characterized by folds that possess high amplitudes. Successive anticlines in this zone have intervening synclines of similar widths to the anticlines. The main structural features are relatively long high Anticlines mostly asymmetrical with southern limb being steeper.

The two dimensional structures of the high folded zone in the northwestern parts are in E-W direction parallel to the Taurus fold thrust trend. The Tawke Anticline is a small structure relative to Bekher Anticline to the south. It has a length of 27 km and a width of about 8 km. Tawke Anticline is bounded from the north by Zakho Syncline while it is bounded by Khabore Syncline from the south (Fig.2).

A fault striking the eastern plunge of Tawke Anticline was first defined in an internal report of the Iraqi Oil Exploration Company (OEC) and was later confirmed by the seismic survey which was executed by DNO Company during (2006-2007).

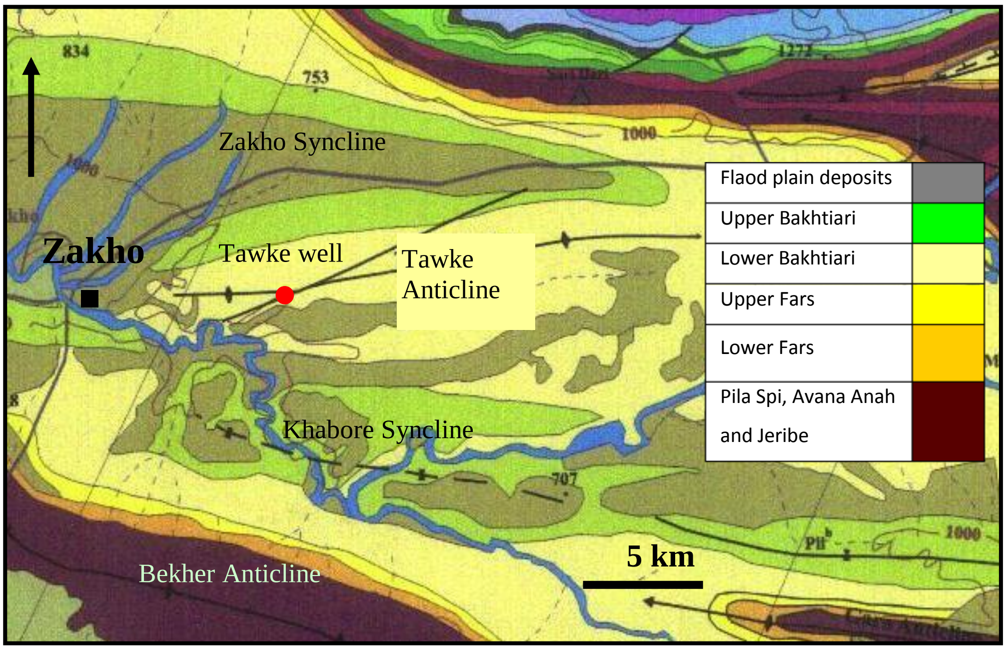

Figure (2): Geological map of the studied area (after the State establishment of geological survey and mining, personal communication).

The lithologic units which are cropping out in and around the study area are briefly described in table (1).

Table 1: A brief description of the lithologic units in the area [4, 5, 6, 7].

Formation	Age		Brief Description	Thickness
Lower and Upper Bakhtiari	Early and Late Pliocene	Tertiary	cyclic deposits (clayey, sandy and gravely materials)	1000-2000
Upper Fars	late Miocene – Pliocene		cyclic deposits (claystone and sandstone)	178
Lower Fars	Middle Miocene		cyclic deposits (claystone limestone and Gypsum)	Thin
Jeribe	Middle Miocene		Recrystallized and dolomitized limestone	87
Anah	Oligocene		brecctiated and recrystalline limestone	35
Pila Spi	Late Eocene		crystalline dolomitic and clayey or chalky limestone	245-320
Avana	Middle Paleocene		partial recrystalline limestone	30-50

An important note which should be kept in mind is that the Lower Fars Formation is overlying Jeribe Formation which is underlain by Dhiban Formation. The total thickness of Jeribe Formation at well TW-2 is about 87m while the depth of the contact between Lower Fars and Jeribe Formations is about 371m [7].

Data Collection and Reductions

The standard formula for the calculation of simple gravity anomalies assumes a flat earth surface at the observation point. Gravity stations should be sited on a flat area with at least 200m clearance from sharp changes in ground elevation. Moreover, surveys designated to solve geological problems should contain profiles of variable station spacing [8]. These two concepts were taken in mind when 780 gravity measurements, spaced between 300 and 500 m, were conducted in the Tawke area along the paved and accessible unpaved roads (Fig. 3).

Locations and elevations were determined using a Global Positioning System (GPS) Model Garmin since a differential GPS unit was not present at the time of surveying and spirit level techniques were so expensive. Gravity data were collected using LaCoste and Romberg gravity meter model G (Fig. 3). Latitude, Bouguer and Free air corrections were carried out relative to the locally established Base Station. A density of 2.2 g/cm^3 is used for Bouguer correction.

The total uncertainty in the final Bouguer value based on uncertainties in observed gravity, horizontal position, elevation and terrain correction was estimated to be about 0.35 mGal. The reduced gravity data was plotted as Bouguer anomaly map (Fig. 3).

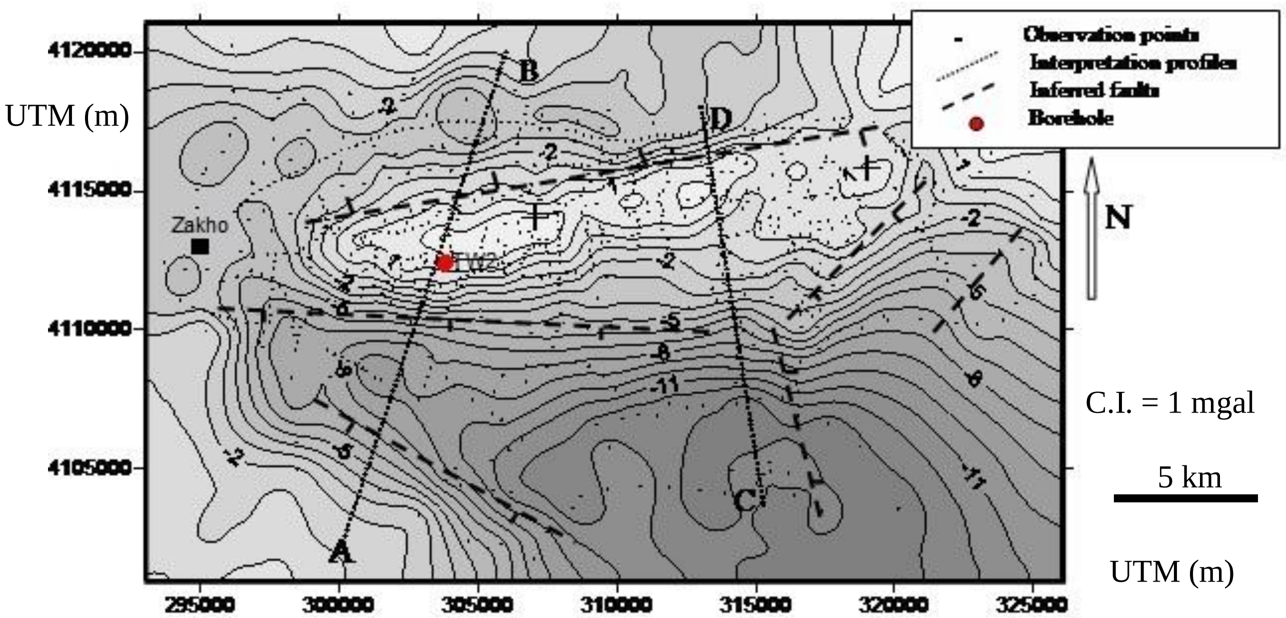

Figure (3): Bouguer Anomaly map of Tawke area showing the observation points and the two interpreted profiles.

Interpretation of gravity maps

Interpretation of gravity data is never unique, but always subjected to a wide range of possible solutions. This “ambiguity” in gravity interpretation could be overcome only when a great amount of additional information, particularly on the geology and structure of the prospected area is available. Fortunately two controls are present in the area of study, boreholes and clear outcrops. The Tawke Anticline was identified in detail, based on two steps of interpretation; the first is the qualitative analysis of Bouguer- , regional and residual anomaly maps while the second is the quantitative interpretation limited to a 2-D gravity model for two almost NS profiles.

Qualitative Interpretation

The qualitative interpretation of Bouguer and transformed anomalies simply involves describing and explaining the anomaly geologically on the basis of geological and geophysical knowledge and particularly on the basis of experience as to what anomaly (shape and magnitude) does a certain object (anomalous body, density boundary, …etc) generate. In this way, the interpreter obtains an idea about the pattern of geological structures and tectonic lines as well as the places where rocks with a high or low density are concentrated. The magnitude and size of an anomaly are important because the size of an anomaly is proportional to the density contrast between the structure and its host rocks and not the absolute density of any of them.

By separating the gravity effects associated with shallow and local gravity sources from more regional and deeper effects, using regional-residual separation techniques, we can obtain an improved correlation between geology and gravity anomalies. We pursued a formal interpretation of the gravity data, focusing on the subsurface structure. As a first step, a regional-residual separation based on [9] was performed. Based on the residual anomalies, we inferred the main features of the near subsurface structure while the regional field reflected the deeper situation.

Bouguer anomaly map

The visual inspection of the Bouguer Anomaly map shows that it is characterized by the presence of major two-dimensional positive anomaly occupying the central part of the studied area surrounded by others which are smaller positive or negative anomalies. Most of these anomalies are trending in E-W direction, which is the main trend of the structures in this area. Main local gravity gradients are towards north and south across the main trend of the Taurus Fold-Thrust Belt (Fig. 3)**.**

The maximum gradient value is observed on the southern limb of the Tawke anticlinal positive anomaly and reaches about 3.5 mGal/km while it is about 2 mGal/km in the northern side. The crestal area of the Tawke Anticline is almost coinciding with this anomaly. The anomaly has a maximum value of 2 mGal with amplitude of 9 mCal. The southern part of the studied area is occupied by a main negative anomaly with a minimum value of -13mGal. The presence of several irregularities within this anomaly exhibited by contour patterns, particularly in the form of local noses give impressions that the gravity field in the speculated synclinal area has been influenced by relatively shallow anomalous masses within the trough. Moreover many linear anomalies are also present on both sides of the major central anomaly following the main structural strike of the area as well as other directions (Fig. 3). These anomalies are usually interpreted qualitatively as faults.

Faults are usually reflected on the gravity maps or profiles since they lead to a considerable lateral density variation. The extension of the faults, their orientation and the position of the downthrown side is determined by their effects on the gravity contour lines. A resume' of the delineation of faults on gravity maps is given in [10, 11]. The Bouguer anomaly values reflect the summation of the gravitational attraction of all subsurface sources (i.e. shallow and deep) [12], hence the inferred faults, in this study, are those related to both deep and shallow sources. In the Tawke studied area, six faults were detected from the Bouguer anomalies (Fig. 3). The main trends of faults in this area are NW-SE, NE-SW and E-W.

When the inferred faults and gravity highs and lows were plotted on the geological map, a good consistent was observed. The major high is almost coinciding with the Tawke anticlinal axis while the major lows (1 and 2) in the northern and southern parts are defining the axes of both zakho and Bekher synclins (Fig. 4). It seems that the Tawke anticline is bounded by two strike slip faults on both limbs (faults 1 and 2 in figure 4), while its eastern plunge is stroked by more than one fault trending in the NE-SW direction (faults 3 and 4). It can be also observed that these faults are to an accepted extent have some indications on the geological map like the sudden curvature of the river beside fault 5 and along the river in fault 2, 4 and 6.

It is generally accepted that the basement rocks comprise blocks of various dimensions. These blocks are separated by faults of different trends depending upon the geologic history in a particular area of study. The basement faults have their effect on the sedimentary cover during the tectonic history.

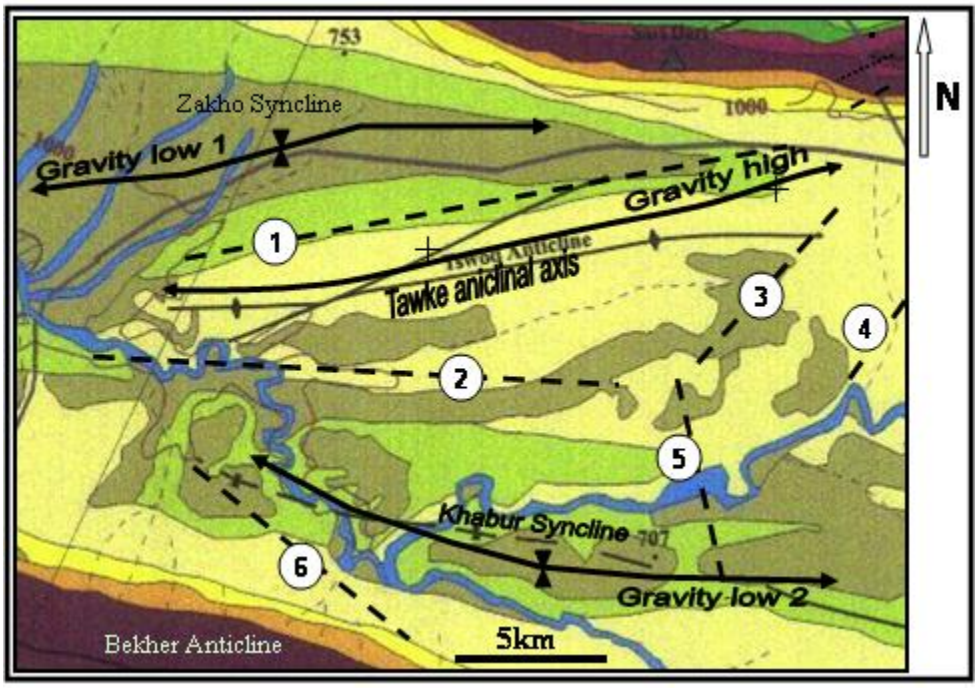

Figure 4: Inferred faults and gravity highs and lows superimposed on the geological map

Transformed anomaly maps

The transformed or derived gravity anomalies are usually obtained, either graphically or analytically from the anomaly values given in square grid. Trials with different grid spacing were made to compute and construct analytically regional and residual maps. Among many, the radius $3s\sqrt{5}$ was found to be most reliable (where s is the grid space and equal to 500m). [9] methods were applied to calculate the transformed gravity values.

Regional map

It is rare to find a Bouguer anomaly map that has not been influenced by regional gravity fields. Gravity anomalies due to regional structures as well as density variations within the basement complex may mask anomalies of more local significance.

The general view of the regional anomaly map (Fig. 5) shows quite regular contour lines in the E-W direction reflecting the main structural units of the area. An average gradient of about 1 mGal/km was observed towards north. The anticlinal axis and other structural feature detected above in the Bouguer anomaly map can hardly be followed. The author believes that a suitable ring is used for separating the regional in such a way that most of those features are gone to be showed on the residual anomaly map. This gradient reflects the increase of density towards the north because the older formations are raised upwards near thrust zone.

Taking into consideration the geotectonic aspects of stretching of the Arabian plate and separation and movement of the Turkish plate towards the north and the Iranian plate towards the northeast and east in the beginning of the Mesozoic Era in this region, an overall north and northeasterly dip of the basement-cover interface should indeed be the logical result.

The local deviation from the general dip, in the studied area, may need further geophysical studies such as seismic reflection, in order to give accurate interpretation.

As far as the author knows, seismic survey in the area is carried out after the gravity survey. Unfortunately the data is not for public use.

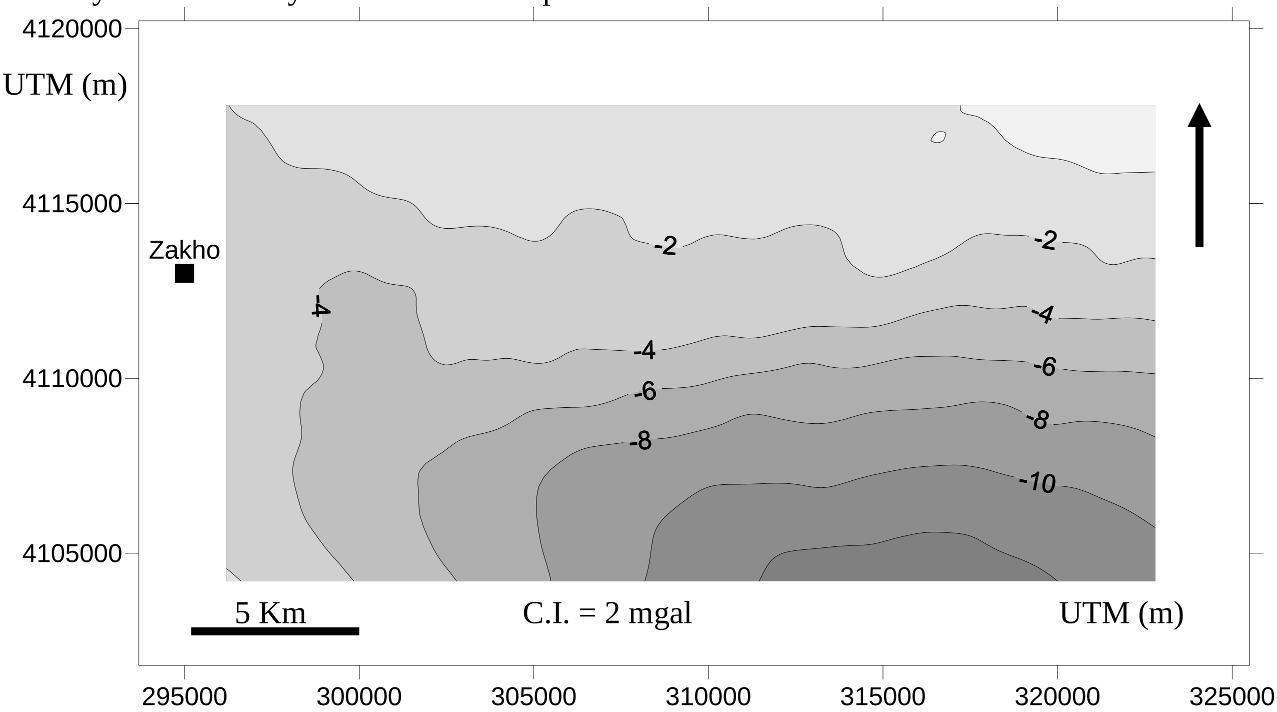

Figure (5): Regional anomaly map

Residual map

The residual anomaly map (Fig. 6) is of special interest since it reflects the size and shape of the relatively shallow subsurface anomalous masses. The main positive anomaly is trending in E-W direction with its eastern end wider than the western. The axis of this positive anomaly is consistent with the Tawke anticlinal axis. The maximum value of this positive anomaly is greater than 4 mGal at the western end. The maximum gradient value is observed on the southern limb reaching about 2 mGal/km. The main negative anomaly located farther to south is the reflection of the Khabor syncline with a minimum value of -3 mGal.

The structural features which were obtained from the Boguer anomaly map were superimposed on the residual anomaly map. It is obvious that there is a good consistent between them and the residual anomalies. A fault striking the eastern plunge of Tawke Anticline was first defined in an internal report of the Iraqi Oil Exploration Company (OEC) and was later confirmed by the seismic survey which was executed by DNO Company during (2006-2007). It is believe from this study that two faults are present, not one as shown in Figure 6.

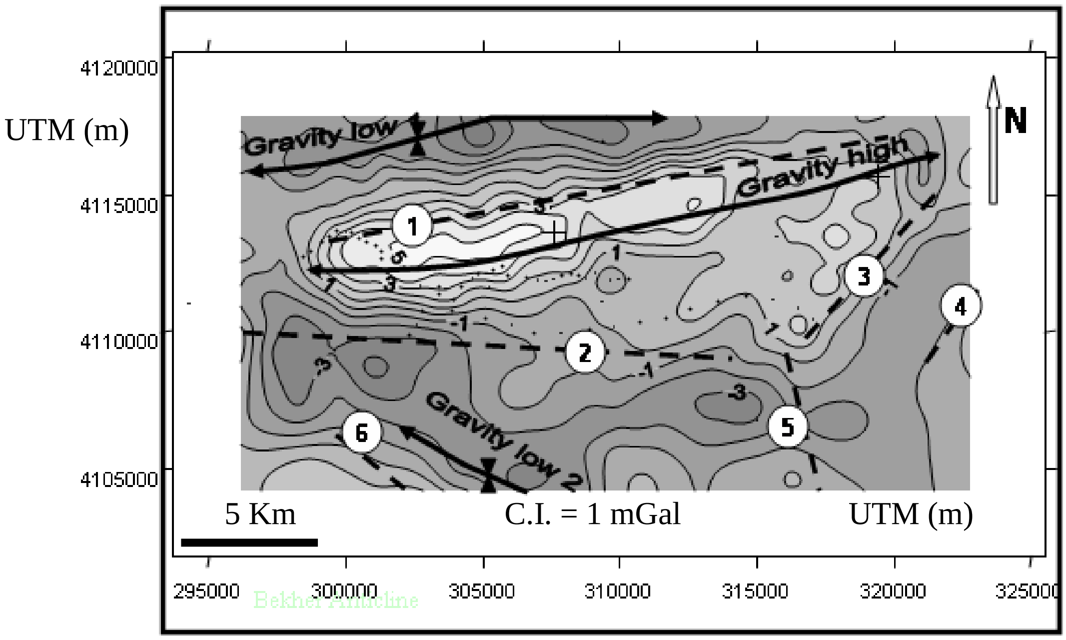

Figure (6): Residual anomaly map

Quantitative Interpretations by Modeling

Two aspects make the quantitative interpretation of the data difficult. The first is that the gravity value at a certain point is the summation of the gravitational attraction of all subsurface sources detected by the instrument. The second is the lack of a unique solution for a certain gravity anomaly [12, 13].

The 2D modeling procedure using the formula of [14] is widely used in simulating structures. It involves the use of suitable residual gravity anomaly and model parameters (density contrast, depth and shape). 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.

A considerable density contrast of 0.36 gm/cm^3 was observed between the Jeribe, Ana, Pila Spi, and Avana formation group against Lower Bakhtiari, Upper Fars and Lower Fars formation group (Table 2). In our geophysical approach we have assumed that there is no lateral variation of the lithologies in these two groups of formations and hence the densities used are generally applicable throughout the area.

Table 1: Shows the calculation of the density contrast.[15,16].

Formation	Thickness	Density	T*d	Group density
L.B.	1000-2000	2.19	2190	2.21
U.F.	178	2.32	413	
L.F.	Thin	2.34		
Jeribe	87	2.71	236	2.57
Anah	35		1016	
Pila Spi	245-320	2.54		
Avana	30-50			

The well information and surface outcrops from geological map (Fig. 2) and geological section (fig. 7) were of great importance for constructing the model shape and depth for profiles AB and CD (Fig. 3). Along profiles AB and CD residuals and regionals were obtained for the purpose of modeling (Figs. 3, 8 and 9). The regional for both profiles are taken by hand smoothing as a line dipping towards the south depending on the regional map

(Fig. 5). Their residuals show the same features; one major positive and two negative anomalies, but the positive anomaly in the profile CD is wider.

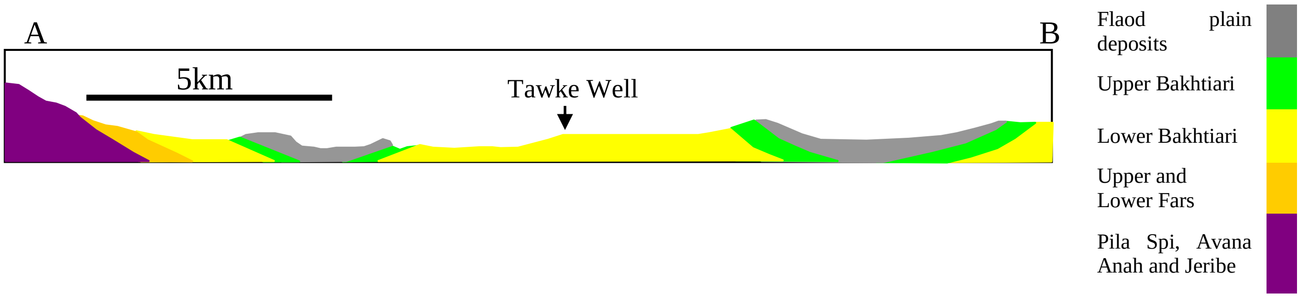

Figure (7): Geological section along gravity profile AB [5].

The positive anomaly is taken to be the core area of the Tawke Anticline, while the southern and northern negative anomalies representing the Khabore and Zakho synclinal troughs respectively. The depth to the top of the model in profile AB is close to the depth of Jeribe Formation as estimated from the succession of the well No. 2 and the lateral extent is limited to the geological section (Fig. 7). On the other side the profile CD is tied with the rock exposures since the borehole is located too far. There is a good matching between the observed and the calculated anomalies, except in profile AB at which the calculated negative anomalies are somewhat greater than the observed, which is possibly related to the recent unconsolidated deposits having low density in Khabore syncline and Zakho syncline.

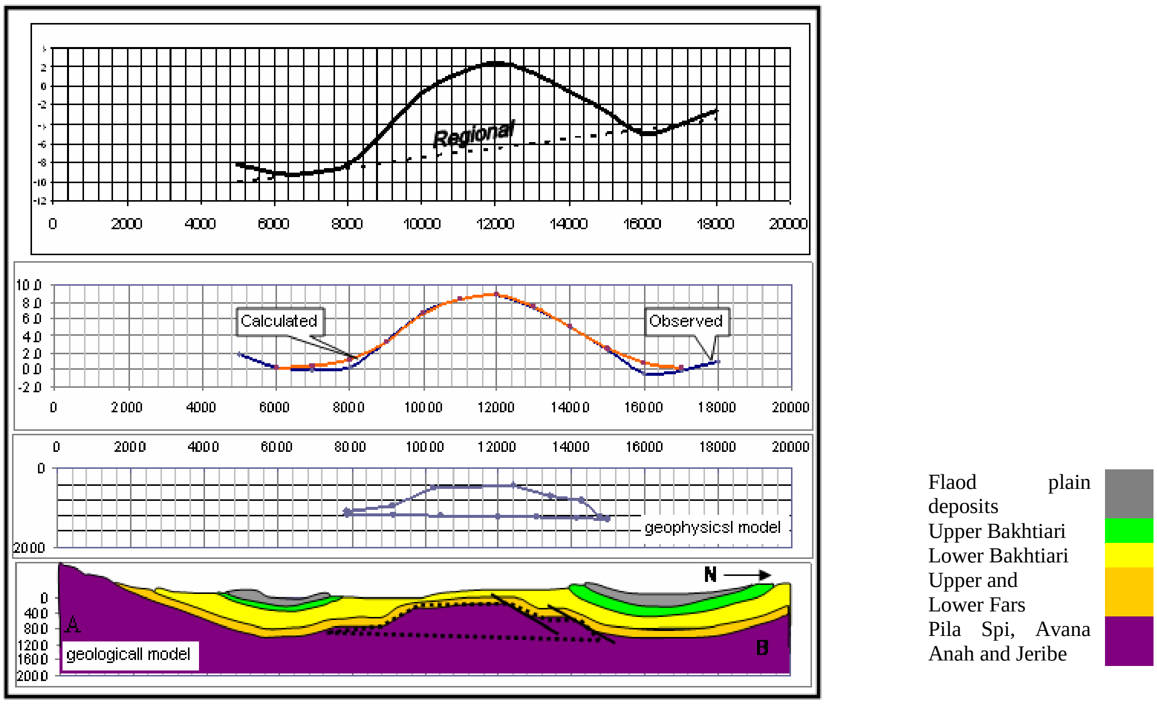

Figure (8): Bougure Anomaly, regional, residual, constructed geophysical model and geological model for profiles AB.

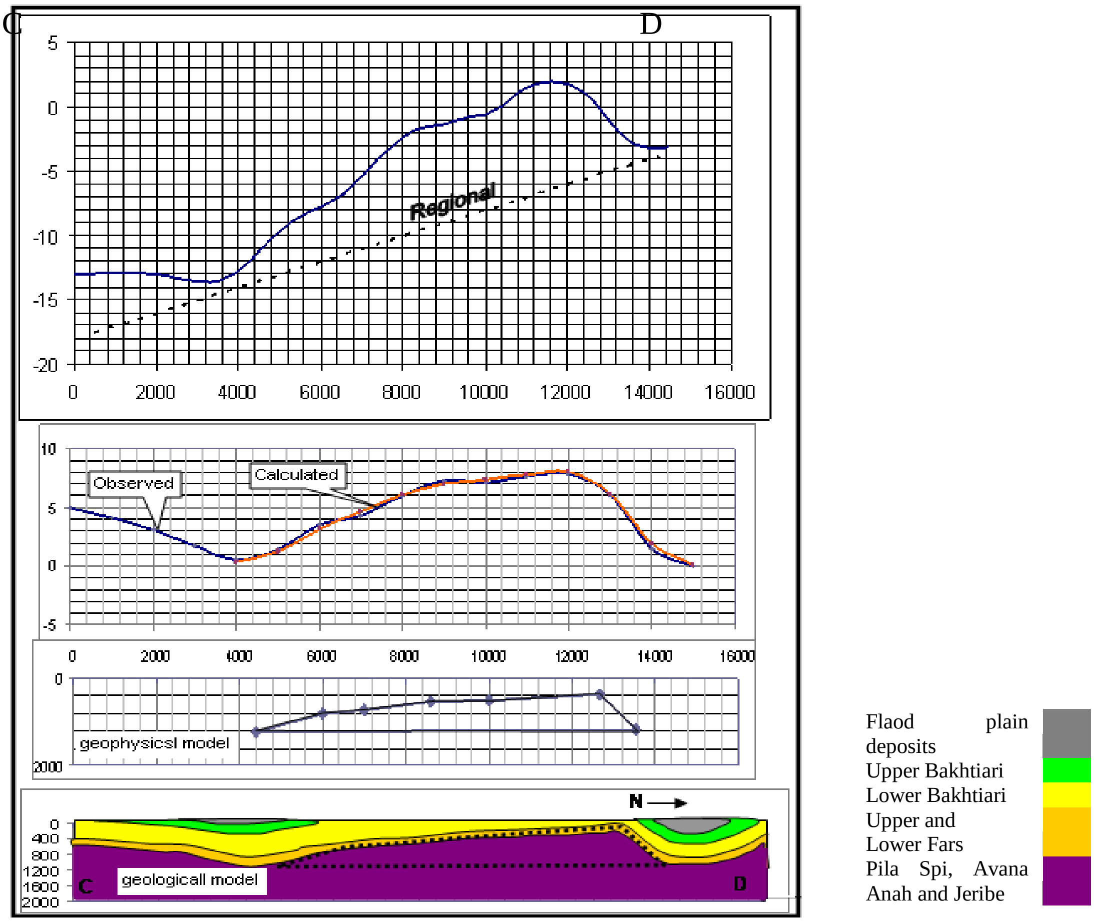

Figure (9): Bougure Anomaly, regional, residual, constructed geophysical model and geological model for profiles CD.

Conclusions

The main structural features of the studied area as are recognized utilizing two main lines of evidence, namely, geological map and geophysical interpretations. Fold structures in figure (2) have one distinctive trend; it is the E-W Taurus trend. The Bouguer map of the Tawke area (Fig. 3) shows gravity high in the central part. It trends E-W. It is indicative of the main anticline. Two gravity lows indicating the two synclines bounding the structure from north and south are clearly shown.

Six faults are inferred from gravity data (Fig. 3). Their trends, extensions and fault plane dip directions are estimated. Some of these faults have indications on the surface as shown by the geological map. The inferred faults show good agreement with geological map (Fig. 4).

A considerable density contrast of 0.36 gm/cm^3 was observed between the Jeribe, Ana, Pila Spi, and Avana formation group against Lower Bakhtiari, Upper Fars and Lower Fars formation group (Table 2). This density contrast is used for modeling of two profiles AB and CD. One main positive and two negative features characterize these profiles. The positive anomaly represents Tawke Anticline, the south negative anomaly represents Khabore syncline and the other Zakho syncline.

Geological model for profiles AB and CD show that the Tawke Anticline is an asymmetrical Anticline producing a structural trap by tilting of the Miocene formations comprising sealing rocks (Fatha Formation) and reservoir rock represented by the Jeribe carbonates (Fig8 and 9). The depth to the top of the model in profile AB is close to the depth of Juribe formation in the Tawke well and the lateral extends are limited to the geological section (Fig. 7), while the profile CD is tied with out crops only. Two small faults on the northern limb in the profile AB were suggested for the purpose of modeling, these faults have indications on the surface as seepages of oil.

References

[1] T. Buday, 1980, The Regional geology of Iraq. V. I., Stratigraphy and paleoecology, Kassab. I. I. M., and Jassim, S. Z. (eds.), S.O.M., Baghdad. 445p.

[2] G. H. Sherwani, 2002, Reconnaissance study of oil seepages in Tawke –Zakho. Internal Report, General directorate of petroleum and minerals, Ministry if Industry, KRG, 10p.

[3] T. Buday, and S.Z. Jassim, (1987): The regional geology of Iraq. Tectonism,Magmatism and Metamorphism. Vol.2 D.G. OF geologic survey and mineral investigation, Baghdad, Iraq. 352p.

[4] F.S. Al-omari and A. Sadek, (1975). Stratigraphy of Alveolina bearing strata from Duhok area Northern Iraq. N. Jb. Geol. Palaont. H. 10, pp. 577-585.

[5] A.S. Abdul – lateef and T. Hradeckey, (1977). The regional geological mapping of Al-Khabour area. No(838), Baghdad, S.O.M. Library (unpublished).

[6] S. Z. Jassim, S. A. Karim, M. A. Basi, M. A. Al-Mubarak, and J. Munir, 1984. Final Report on the regional geological survey of iraq. Vol.3, Stratigraphy, GEOSURV, Baghdad, Lib. Unpub. Rep., No.1447, 498p.

[7] D.M. Ibrahim, 2008. Sedimentology and Reservoir Characteristics of Jeribe Formation (Middle Miocene) in Tawke Oil Field - Zakho Kurdistan Region - Iraq. Unpublished Thesis, Salahaddin University.

[8] A.S. Murray and R.M.Tracey, 2003. Basic practice in gravity Surveying, Australian Geological Survey Organization (AGSO), (htpp://www.agso.gov.au/).

[9] W.R. Griffin, 1949. Residual gravity in theory and practice, Geophysics, 14: 39-56.

[10] R.E. Sheriff, (1978) a First Course in Geophysical Exploration and Interpretation. IHRDC, Boston.

[11] S. Mares, (1984), Introduction to Applied Geophysics. D. Reidel Pub. Co. Dordrecht-Boston- Lancaster, 581p.

[12] M.B. Dobrin, (1976): Introduction to geophysical prospecting, McGraw Hill book company, 630p.

[13] L.L. Nettelton, 1983. Elementary gravity and magnetics for geologists and seismologists, Soc. Expl. Geophysics, Monographs, Tusla, USA. 121p.

[14] M. Talwani, J.L. Worzel and K. Landsman,1959. Rapid gravity computation for two dimensional bodies with application to the Mendacino submarine fracture zone, Geoph. Research 64: 49-59.

[15] N.H. Alsaigh, F.A. Ghaib, and S.K. Abdul-Karim, (1989), A Reconnaissance gravity and Magnetic Investigation along Erbil – Shaqlawa Highway, NE-Iraq. Arabian gulf J. Sc. Res., Vol. 7, P. 7-19.

[16] A.A. AlSalihi, 2010. New Perspective of Simulation of Gravity Low across some Foot Hill Folds / North Iraq. Unpublished Thesis, University of Mosul