Tectonic Boundaries and Depth Estimate of Some Gravity Sources in Diyala Area, East Central Iraq

Ahmed S. AL-Banna, Alaa N. Daham

Department of Geology, College of Science, University of Baghdad, Baghdad, Iraq

Abstract

   The Bouguer gravity and magnetic RTP anomalies data were used to detect the main tectonic boundaries of middle and south of Diyala Province, east Iraq. Window method was used to separate the residual anomalies using different space windows for the Bouguer and Magnetic RTP maps. The residual anomaly processed in order to reduce noise and give a more comprehensive vision about subsurface lineaments structures. Results for descriptive interpretation presented as contour maps in order to locate directions and extensions of lineaments feature which may interpret as faults. The gradient technique is used for depth estimation of some gravity source which shows that the sources depth range between (13.65 - 5.36) km. Some gravity sources confirms the depth of basement rocks, while other shallow sources related to sedimentary cover, on an assumption of body source approximated to a horizontal cylindrical. The Total Horizontal Derivative (THD) technique is used to identify the faults trends in the sedimentary cover and basement rocks depending upon gravity and magnetic data. The identified faults in the study area show (NW-SE),(NE-SW) and(N-S)trends. Most faults extending from the basement to the upper most layer of the sedimentary cover rocks. Depending on the detected faults, the main tectonic boundaries of the region were obtained.

Keywords: Bouguer anomaly, Magnetic RTP, Window method, THD, Tectonic boundary, Diyala-Iraq.

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الأنطقة التكتونية و تخمين أعماق بعض المصادر الجذبية في محافظة ديالى شرق وسط العراق

احمد شهاب البناء ، علاء نزار دحام*

قسم علم الارض، كلية العلوم، جامعة بغداد، بغداد، العراق

الخلاصة

أستخدمت بيانات شواذ بوجير الجذبية والمغناطيسية لدراسة الصدوع وتحديد الوضع التكتوني لوسط وجنوب محافظة ديالى, شرق العراق. استخدمت طريقة (النافذة) لفصل واستحصال خرائط الشواذ المحلية الجذبية والمغناطيسية. تمت معالجة الشواذ المتبقي لكلا الخرائط بهدف توضيح صورة عن التراكيب الخطية تحت السطحية. تم عرض النتائج لغرض التفسير الوصفي بشكل خرائط كنتورية من اجل تحديد الموقع الدقيق للصدوع الرئيسية. أستخدمت تقنية الانحدار لتخمين عمق بعض مصادر الشواذ الجذبي, العمق المستحصل للشواذ تراوح بين(13.65−5.36) كم. بعض الشواذ تكون ذات مصادر عميقة تتواجد ضمن صخور القاعدة بينما المصادر الضحلة تكون بالغطاء الرسوبي, على فرض مصادر الأجسام أسطوانية أفقية. تم استخدام تقنية المشتقة الافقية الكلية لتحديد اتجاهات الصدوع في الصخور الرسوبية وصخور القاعدة في منطقة الدراسة حيث

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*Email: qwerpp03@gmail.com

تبين ان اتجاهات الصدوع هي(NW–SE) و(NE–SW) و(S–N). أغلب تلك الصدوع تمتد من صخور
القاعدة إلى الطبقة العليا من الصخور الرسوبية. من خلال تحديد الصدوع امكن تحديد وضع الأنظمة التكتونية
ضمن منطقة الدراسة.

Introduction

The gravity anomalies reflect the variation in the density of subsurface source[1], [2]. At the same time the aeromagnetic anomalies reflected to a source of intrabasement or supra -basement phenomena[3].The gravity and magnetic used for investigation large, medium and local structure [4]. Gravity data were used to determine the location of boundaries of anomalies within the basement and sedimentary cover. The magnetic data related to changes in magnetic susceptibilities were used to determine the locations and the depths of the magnetic bodies. Different techniques including the total horizontal derivative (THD) were developed by many authors to enhance the magnetic and gravity fields. These techniques used to determine the tectonic boundaries and faults from residual gravity and magnetic anomalies [5].The purpose of this study is to interpret the available gravity and magnetic data, in order to our knowledge about the tectonic situation of the study area. Also the study attempt to find the relation between the oil field traps of the gravity and magnetic anomalies.

Location of the study area

The study area is situated in the middle part of the eastern side of Iraq in Diyala province. This area is located at the west of the Zagros Fold-Thrust Belt. In fact it lies partly in the low folded and partly in the Mesopotamian Foredeep which extended from the southern Hemrin lake to the south of the province Figure-1. The area is bounded by: latitudes (33º 54′ 08″- 34º 00′ 04″ North) longitudes (44º 15′ 36″- 46º 10′ 83″ East).
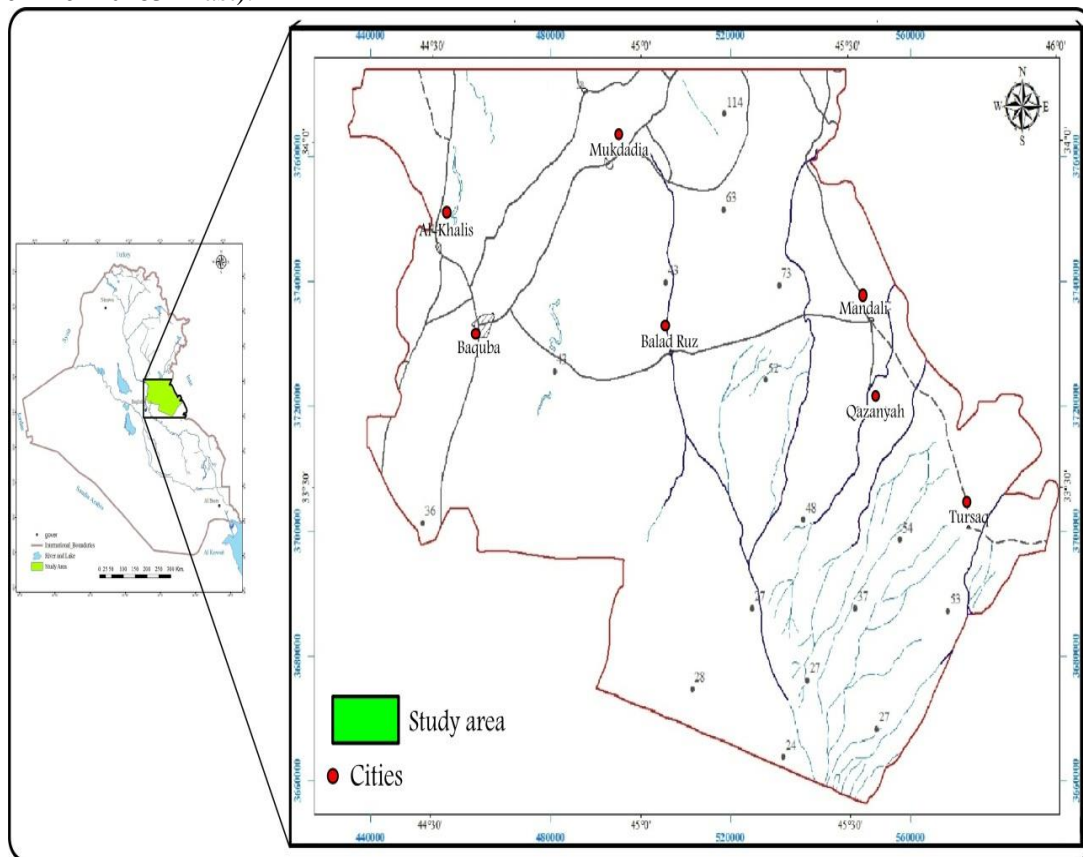

Figure 1-hows the location of the study area.

Geology of the Study Area

The near surface or exposed rocks is covered mainly by Quaternary and Pre-Quaternary sediments [6] Figure-2. The Pre-Quaternary sediments Include: The Middle Miocene Sequence comprises a carbonate and marls of the Fatha (Lower Fars) Formation. Late Miocene -Pliocene includes a fluvial system of Fatha, Injana, Mukdadiya and Bai Hassan Formations [7]. Quaternary sediments of the Mesopotamian zone were deposited by the interacting Tigris and Diyala rivers. The alluvial fans

emanating from the surrounding elevated areas. Flood plain deposits include channel deposits and flood plain depression, sabkha and deltaic deposits [8].
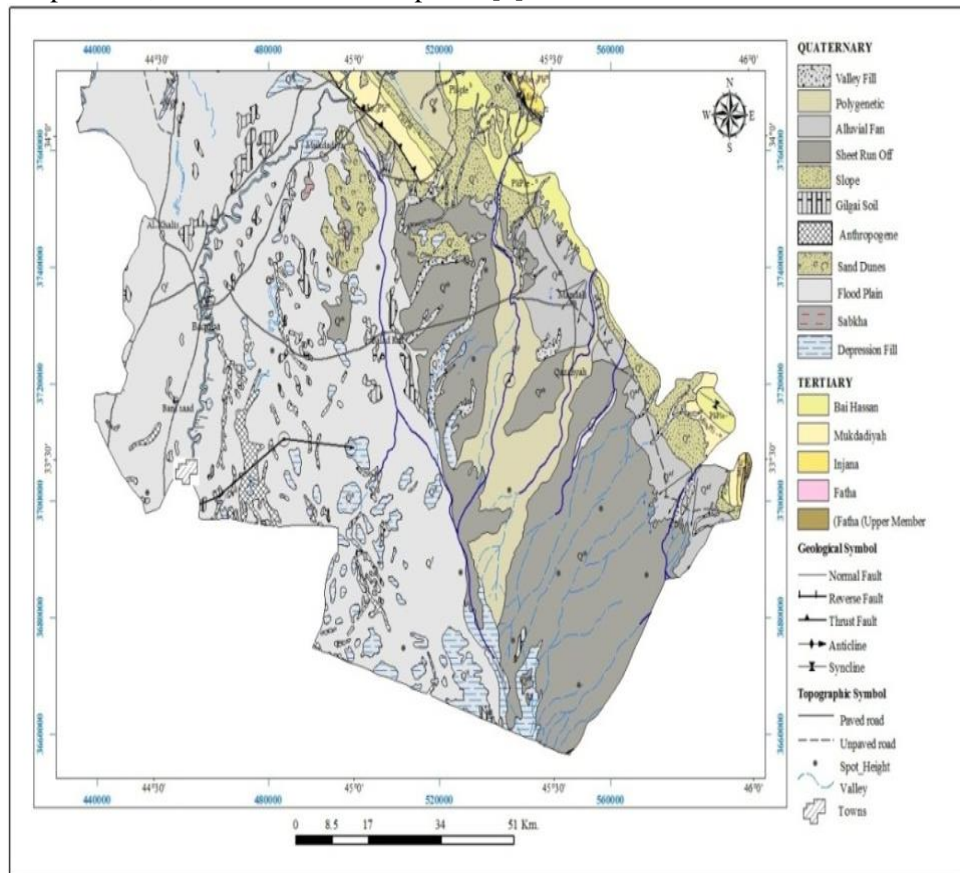

Figure 2-Geological map of the study area [6]

Tectonic Setting

The studied area is located within the low folded zone and Mesopotamian Foredeep. Tectonically the study area is part of the unstable shelf, most of this area represented by Tikrit - Amara subzone and northeastern is belong to Hemrin subzone [9] Figure-3, which is affected by the late regional intensive tectonic movements of the Alpine orogeny [10]. This tectonic movement caused the uplifting of Hemrin structure, in the Low Folded Zone and the development of asymmetrical sinking basin in the Mesopotamian Foredeep. In the Late Pliocene , the influence of this movement is extended to deform the sediments of the Mesopotamian Foredeep. The evidence of this deformation is the uneven paleo-surface of the pre-Quaternary rocks, which is now covered by thick Quaternary Sediments [11].
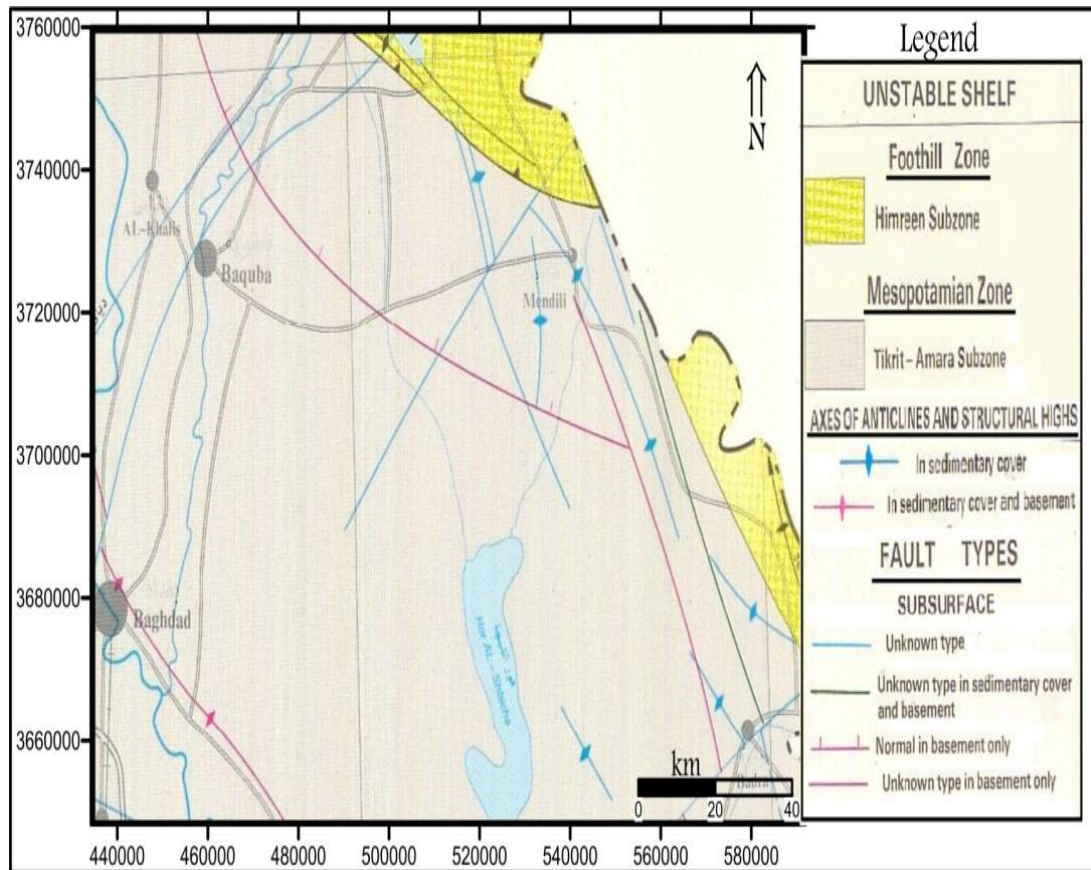
Figure 3- Tectonic map of study area [9].

Data Acquisition and Processing

Bouguer anomaly map of the studied area (Figure-4 (A) is a part of the Bouguer anomaly map of Iraq. It is constructed by Iraqi GEOSURV and reprocessed in (2010_s) by a Getech group (British Institution)[12], and it was compiled at a scale1:1000,000 and contour interval of(2) mgal. The Bouguer anomaly values within the studied area range from (- 48) mGal in the southwestern parts of it, to (-86) mGal in the northeastern parts of the map. The regional gravity of the studied area decreases toward the northeast Figure-4 (B).

The aeromagnetic map of the study area is part of the aeromagnetic(total magnetic intensity) map of Iraq. It is constructed by Iraqi GEOSURV and reprocessed in (2010_s) by a Getech group (British Institution)[12]. The scale and contour interval of the aeromagnetic map is 1:1,000,000 and 10 nT. The Total Magnetic Intensity (TMI) data was processed to obtain the Reduction To Pole (RTP)map Figure-4 (C)in order to symmetrically position the anomalies above the causative bodies. This process is achieved by GET GRID program. The grid lines of the survey were done with space interval of (1) km in Iraq. The magnetic values of the Reduction To Pole(RTP)within the studied area range from 5010nT in the NW and SW parts of the study area, to 4830 in the northeastern parts of the map. The general trend of the regional magnetic gradient (Figure-4(D) across the studied area is the northeastern and the magnetic value decrease towards the northeast.

The gravity and magnetic values decreasing toward the north east coincide with increasing of the basement depth.
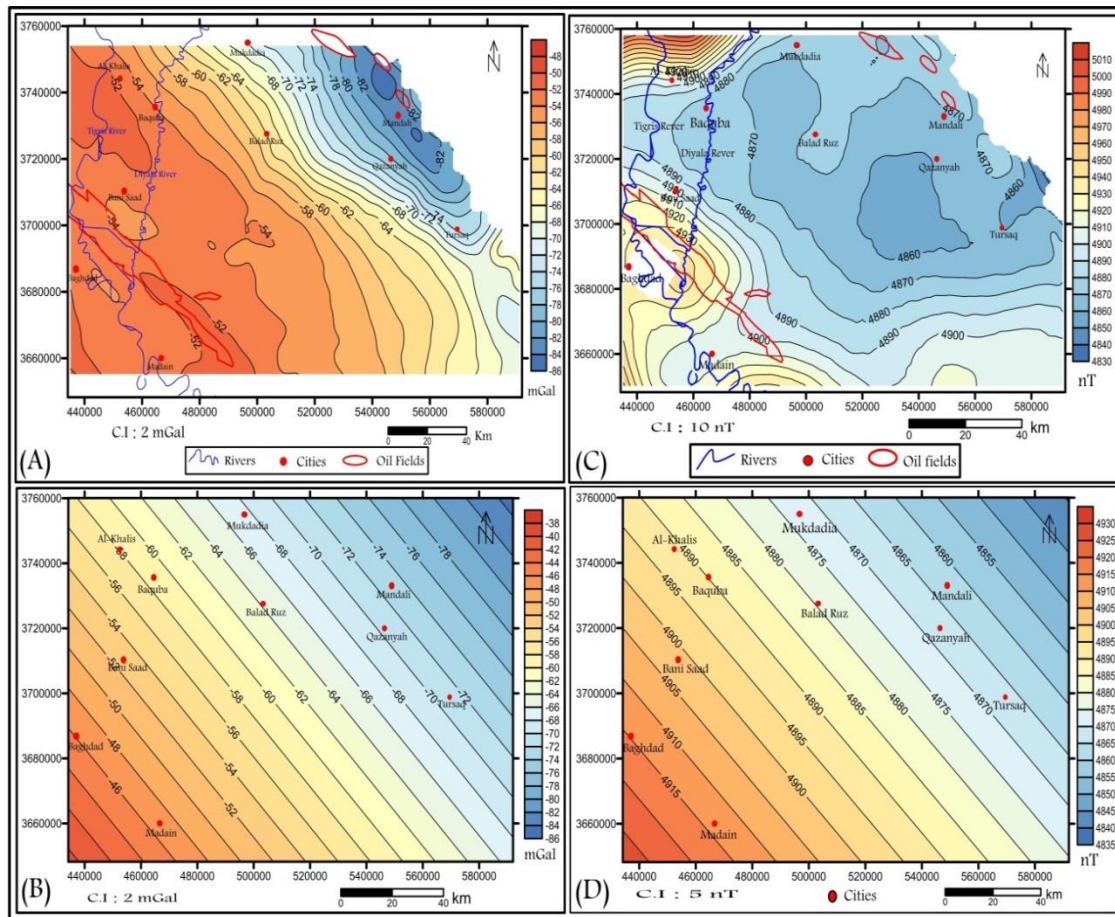
Figure 4-(A): Bouguer Gravity anomaly map (B): Regional Gravity anomaly map (C):Magnetic RTP anomaly map (D): Regional Magnetic RTP anomaly map.

Residual Anomaly Separation

The separation process are intended to isolate small anomaly that resulting from shallow geological structures from large anomaly caused by deep geological structures. The Window methods have been used in the process of separating residual field from the regional field. This method is a similar to Griffin method [13] in separation anomaly, which involves the averaging of gravity values along the periphery of a circle with its center at the point for which the residual is computed. The residual value is the observed value at the center minus this average. In present study the different spacing Windows method applied on the potential data using Surfer program, this method is not of the Surfer program applications, but the use of the potential of the graphic to reach the desired result. The spacing Window(24, 36)km using to study the residual gravity and magnetic anomalies .The residual gravity and magnetic maps together observed that the dominant trend of gravity anomalies is NW- SE, rather than magnetic anomalies that shows the dominant trend to the NW- SE and NE- SW Figure-5.

The line that separates between the positive and negative anomaly is called the Zero crossing line, this line shows the main trending of the anomalies. Most anomalies axis in gravity maps shows NW-SE trend. According to the values of anomalies and the most trends separated to three major zones. The first one includes I, II and III. The second includes anomaly IV, and the third includes A,B ,C and D anomalies Table1 which represents the corresponding between gravity and magnetic anomalies in the same location.

Table 1-Gravity and Magnetic anomalies derived from Window maps in the study area.

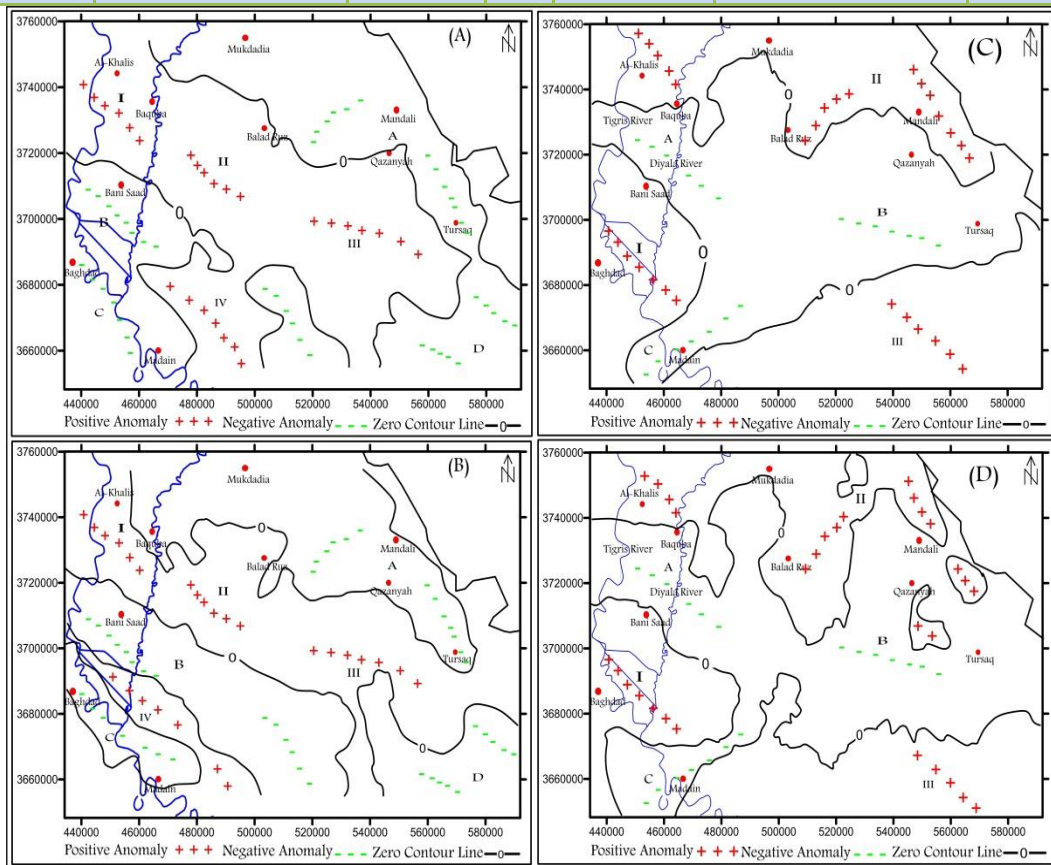| Gravity anomaly	Positive/Negative	Trend	↔	Magnetic anomaly	Positive/Negative	Trend
I	Positive	NW-SE		A	Negative	NW-SE
II	Positive	NW-SE		B	Negative	NW-SE & E-W
III	Positive	NW-SE		B	Negative	NW-SE & E-W
IV	Positive	NW-SE		I	Positive	NW-SE
A	Negative	NW-SE		II	Positive	NW-SE& NE-SW
B & C	Negative	NW-SE		I	Positive	NW-SE
D	Negative	NW-SE		III	Positive	NW-SE & E-W

Figure 5-Showing the residual gravity anomaly axes maps of window (A): 36 km (B):24 km and and residual magnetic anomaly maps of window(C):36 km (D):24 km

Depth Estimation by Gravity Source

The horizontal and vertical gradients of every gravity anomaly profile are intersecting in three points. The nearest intersection point to the center of the gravity anomaly is the only one that has a distance(x) from the center, in spite of using various interval of determination of horizontal gradient[14]. Many elongated geological structures such as anticline, syncline, elongated basins, can be approximated to two-dimensional models as a horizontal cylinder. The horizontal and vertical gradient of the horizontal cylinder body gives in the equation below [15]:

D = 2.37 Distance (x) + 0.029

D= depth of the source

X= The distance between the center of the gravity anomaly and the nearest intersection point of horizontal and vertical gradient

The present method has been used to estimate the depth of source of two gravity anomalies in the study area. These gravity anomalies are observed on the unified residual gravity anomaly map of spacing window 24 km. These anomalies are:-

1- The anomaly(III) is a large positive gravity anomaly, which is nearly horizontal cylinder in shape and length of the profile about 27 km. This anomaly is situated south of Balad Ruz city, middle of the study area. A gravity profile crossing the structure perpendicularly is considered to determine the depth of the source Figure-6. The horizontal gradient is determined using spacing interval of 0.5 kilometers Figure-7. Depth of the gravity source center is found to be equal to 13.65kilometers, which means that the source center is within the basement rocks.

Depth = 2.37 x5.75 + 0.029

2- The anomaly (IV): positive gravity anomaly, the gravity source approximated to a horizontal cylindrical body, length of the profile about 13 km. This anomaly is situated East of Baghdad city and east of Tigris river SW of study area. The NE-SW gravity profile was considered to apply the present method and estimate the depth of the gravity source Figure-6.The horizontal and vertical gradient of this profile is determined with spacing interval1 kilometers Figure-7.The obtained depth of the source using the suggested method is equal to 5.36 km. The gravity source considered to be within the sedimentary cover.

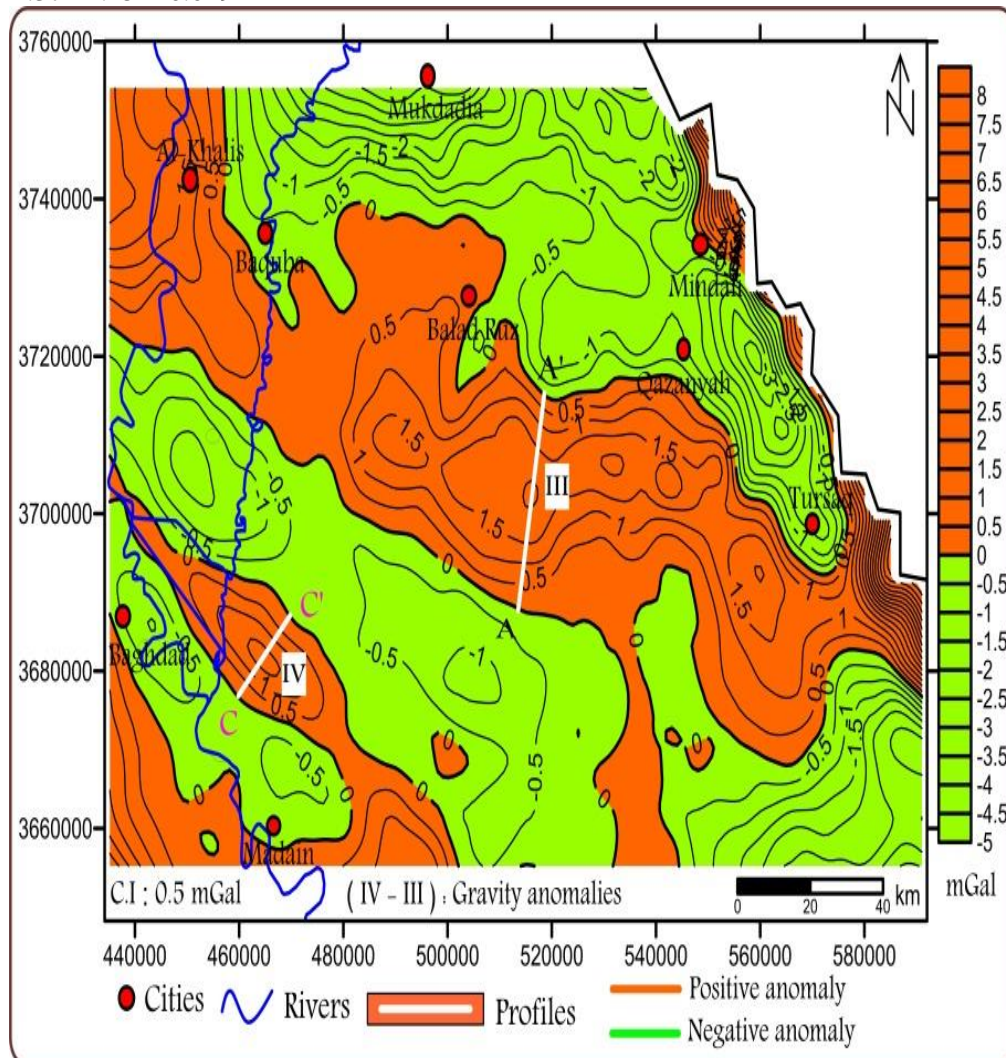Depth = 2.37 x2.25 + 0.029

Figure 6-Shows profiles (A-A') and (C-C') was detected on the residual gravity anomaly of spacing window (24)km
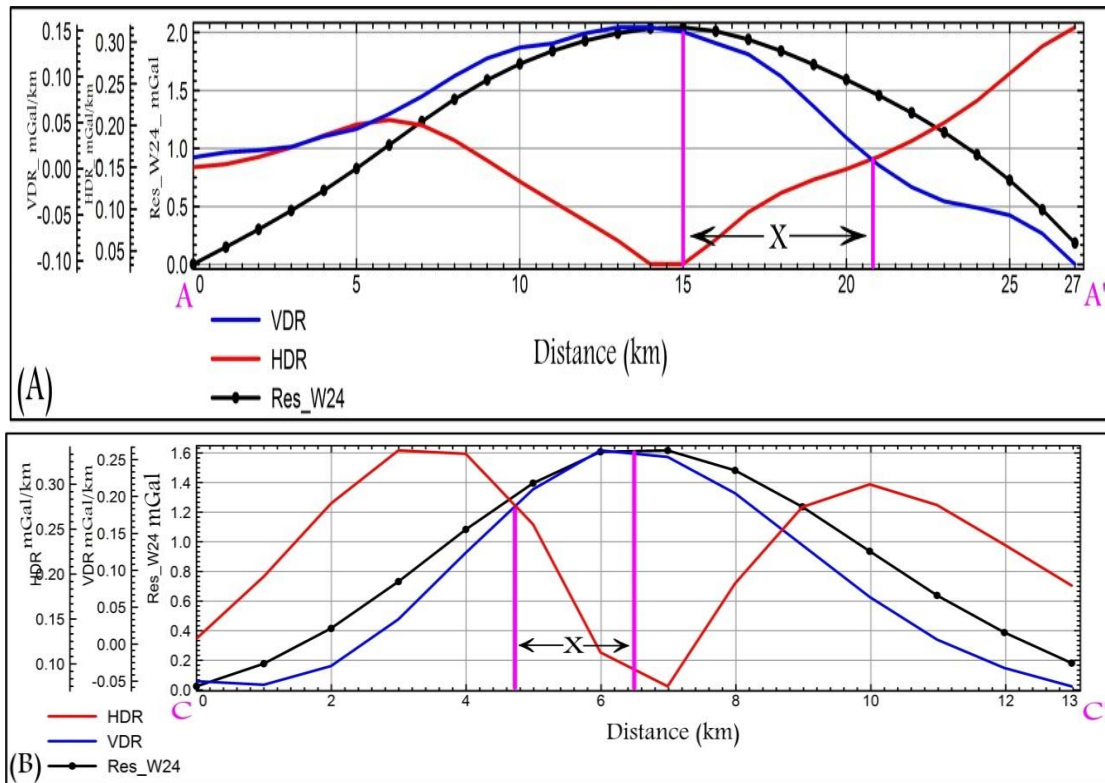
Figure 7-Showing the effect of horizontal interval distance variation (spacing between gravity values used for determined horizontal gradient),on horizontal and vertical gradient curves forms and on the intersection point of them relative to the central anomaly axis.
(A): The profile (A-A') is trending N-S a crossing (III) anomaly.
(B): The profile (C-C') is trending NE-SW a crossing (IV) anomaly.

Total Horizontal Derivative(THD)of Residual Gravity and Magnetic Anomalies

The spatial distribution of the anomalies axes or the straight lines of the maximum total horizontal derivative considered as a lineaments[16], [17] and [5].The Total horizontal derivative represents the resultant of two horizontal derivatives ,the 1st horizontal derivatives are:(dT/dx)and (dT/dy) where T is the anomaly, the 2nd horizontal derivative are:(d^2T/dx^2) and (d^2T/dy^2), (dT/dx) can be used in delineation magnetic and gravity contact. Total Horizontal Derivative (THD) gives in the equation below:

$$THD = \sqrt{(dT/dx)^2 + (dT/dy)^2}$$

The total horizontal derivatives were determined for the residual gravity and magnetic maps for the spacing window(36, 24, 12 and 6)km. The axes of the maximum total horizontal derivative were plotted on the obtained maps. The axes of the anomalies of the total horizontal derivative (THD)residual gravity and magnetic data of that considered spacing windows are shown in Figure-8.The lineaments, which represent the axes of the maximum horizontal gradient of gravity and magnetic anomalies for the study area in Figure-8. To study lineaments faults of gravity and magnetic maps was divided into three parts: the southwestern parts of the study area mainly faults characterized by NW-SE trend that extend along the Tigris river and be parallel to it and located east of Baghdad city.

The middle parts of the study area, the trend of the lineaments faults NW-SE, that extend   from south of Baquba and Balad Ruz cities to the south east of the study area. The eastern parts characterized by NW-SE trend and have high slope values, they reflect a highly dense variation of the subsurface structures produced, these faults lie near the Iraqi-Iranian border, also there is some faults have trend NE-SW located west Qazanyah city. The eastern south of maps show that the trend of faults is NW-SE and located west of Tursaq city. For study the lineaments faults of magnetic maps Figure-8 (a, b, c, d) by dividing the area into three parts :(western part – middle part and eastern part).

The western parts of the study area mainly lineaments faults lie near the Tigris and Diyala rivers and be parallel to them, the trend of lineaments is NW-SE. The middle part of the study area shows the trend of faults are (NW-SE) and (NE-SW) these lineaments faults located southern of the study area. There are mainly faults in the eastern parts of the study area, the trend of the lineaments are NW-SE and lie east of Mandili and Tursaq cities near the Iraqi-Iranian border .
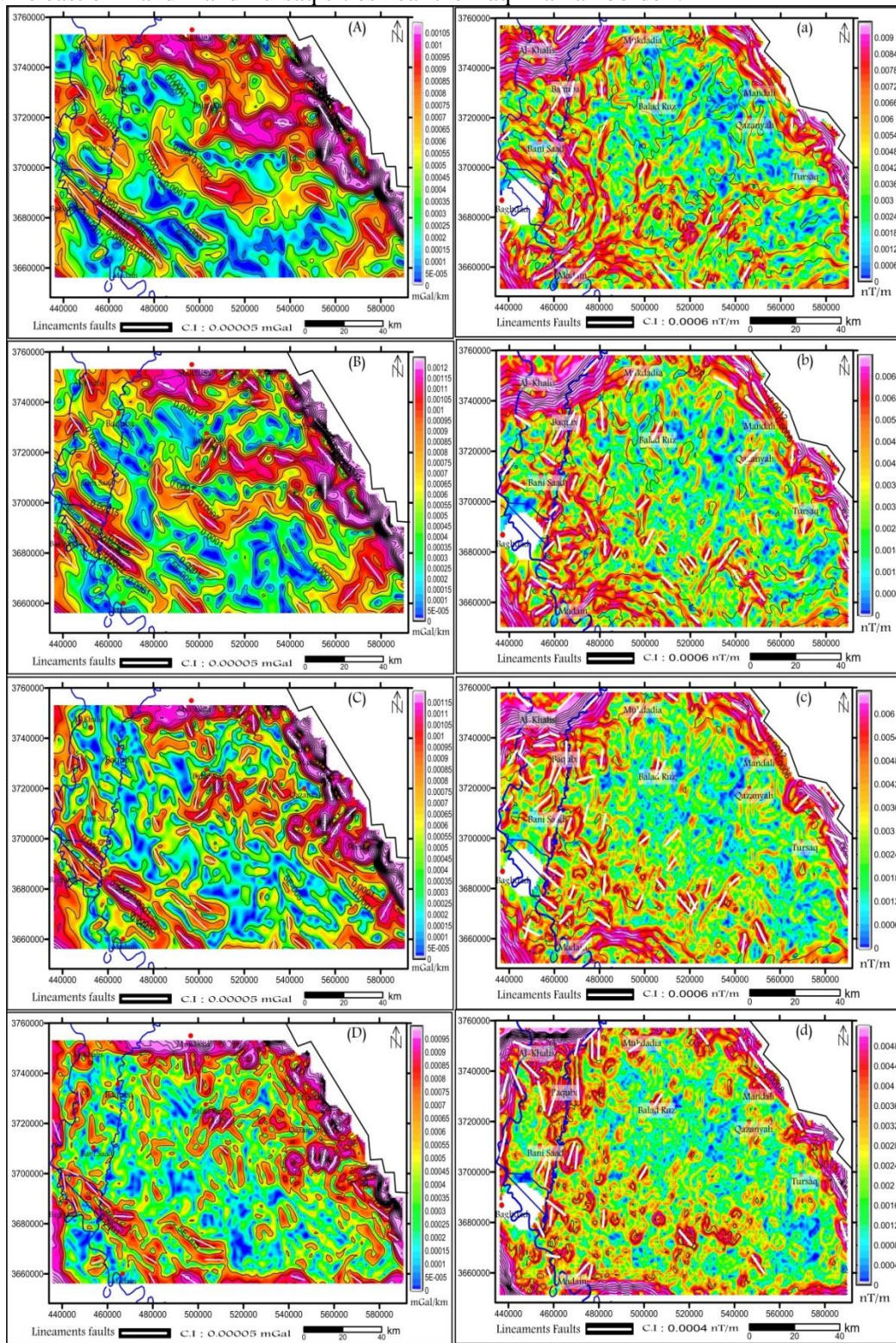

Figure 8-The total horizontal derivative(THD) and the axes of the maximum values of the residual gravity anomalies of spacing window: A: 36 km B: 24 km C:12 km D:6 km and magnetic anomalies of spacing Window: a: 36 km b: 24 km c: 12 km d: 6 km

Faults System Inferred From the Total Horizontal Derivative THD Gravity and Magnetic Anomalies of Different Depths and Tectonic Boundaries:

According to[7] the regional faults system in Iraq formed during late Precambrian Nabitah orogeny and were re-activated repeatedly during the Phanerozoic. To compare the gravity and magnetic lineaments with the structural and tectonic features of the study area, they are superimposed on its tectonic map Figure-9, it is observed that most of the faults inferred from gravity data showing NW-SE, while the faults inferred from magnetic data showing NW-SE and NE-SW, N-S trends. Generally, the orientation of gravity and magnetic lineaments is in coincidence with that of the structural elements in the study area.

Detection of major tectonic boundaries is very important for distinguish the main fault zones, The NW-SE trend system in the study area represented mainly by four regional faults, while the NE-SW transversal faults system trends represented by three regional faults and N-S trend system represent by one regional fault Figure-10 as the following:

• The Tikrit-Amara Fault(T-A F)the fault extended through sedimentary and basement rocks. This fault appears in gravity and magnetic data of trend NW-SE and located east of Baghdad city. The fault extended from Al-Jazira region in NW of Iraq through Tikrit and Balad into Baghdad and Nahrawan. It continues along the SE trending stretch of the Tigris river between Kut and Amara. Major buried anticlines are located along this fault zone (Nahrawan, E-Baghdad). Seismic and gravity data indicate that the zone is associated with a Late Cretaceous graben system[18].

• The North-Bani Saad Fault (N-B F) NW-SE trend was extended from NW to the SE of the study area and south-east Baquba city. The Mandili-Tursaq Fault (M-T F) NE-SW trend extends from Mukdadiya city to the south Tursaq city, extend from basement to the depth 7km from sedimentary rocks. This fault inferred from gravity maps. The Makhul-Hemrin Fault(M-K F)trending NW-SE and located NE of the study area, that extends from basement to the sedimentary rocks. The Makhul-Hemrin Fault Zone has a magnificent surface expression represented by one of the longest anticlinal chains in the Middle East. This fault zone may be the boundary between the Eastern Arabian and Zagros Precambrian terranes and also forms the Boundary between the Stable and Unstable Shelf. Late Cretaceous extension may have occurred along this fault zone. It was strongly reactivated during the Pliocene and forms the SW boundary of the area affected by Late Tertiary folding .

• The Sirwan Fault(S F)extends from north Baquba city along Diyala river to south-west of study area, NE-SW trend. The Sirwan fault zone runs along the Sirwan(Diyala)river in N of Iraq. It extends into central and SW of Iraq, the Sirwan fault forms the N boundary of the Mesopotamian Transversal block. The Mesopotamian block is the largest Transversal block with the deepest basement which dips uniformly to the NE. It contains low amplitude NW-SE and NE-SW trending swells and depressions. The South Bani Saad Faults (S-B F) NE-SW trend transversal fault crossing other faults (M-T F), it is trending NW-SE and extends to the SE of Balad Ruz to the south of Bani Saad cities. The South Qazanyah Fault (S-Q F)appears in the south of Qazanyah city NE-SW trend, this is very clear in magnetic maps and extend from basement to the sedimentary rocks, while this fault extend only in sedimentary rocks in gravity maps.

• The East-Baquba Fault(E-B F) N-S trend and located east of Baquba and Bani Saad cities and extend from basement to the sedimentary rocks.

The gravity and magnetic residual map of spacing windows (6) km and plotted with oil fields locations. Generally it was observed that the oil fields locations showing good coincidence with the positive gravity anomalies Figure-10, while the locations of fields have weak relation with residual magnetic anomalies. Most of the structure in the study area have their axis in the NW- SE, therefore the fields have the same trend as well as the laying on the positive anomaly or near the Zero contour line of residual gravity map. In residual magnetic map, the fields are weak coincidence with the positive magnetic anomalies and located on the zero contour line and distributed along the positive and negative gradient of RTP anomalies in same locations Figure-11.
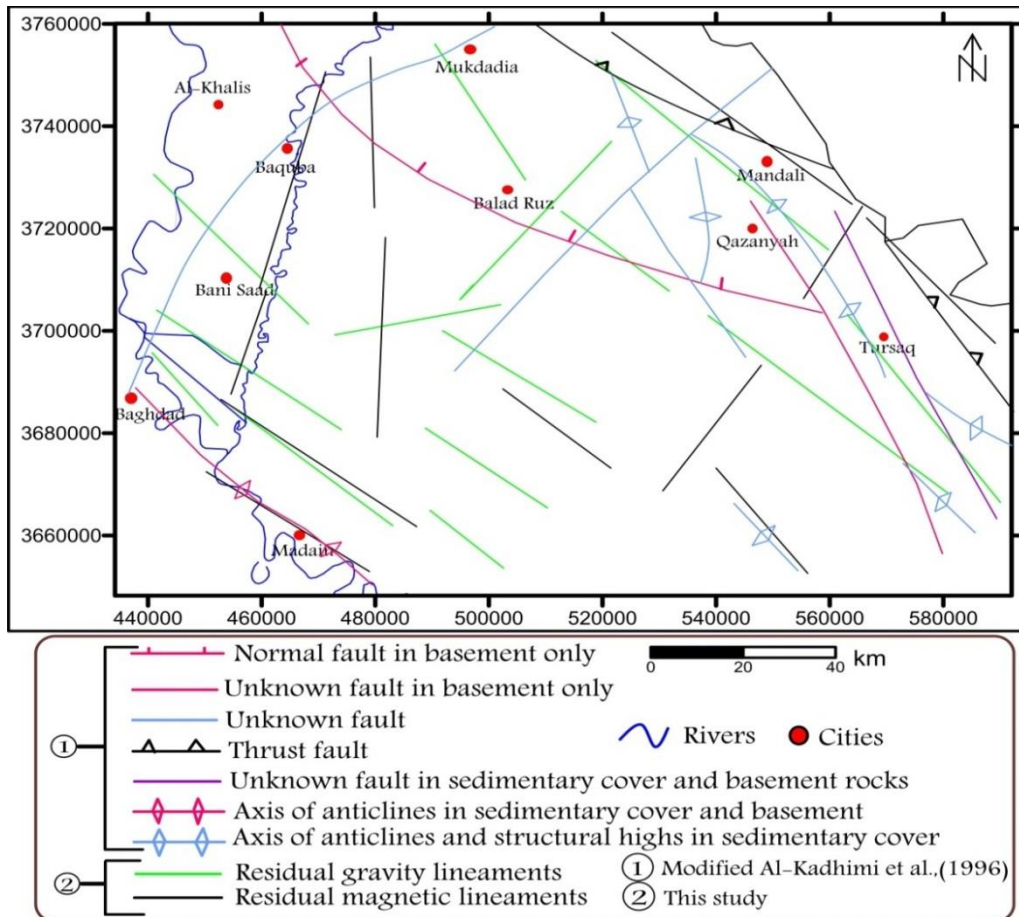
Figure 9-Gravity and magnetic lineaments superimposed on the tectonic map of the study area.
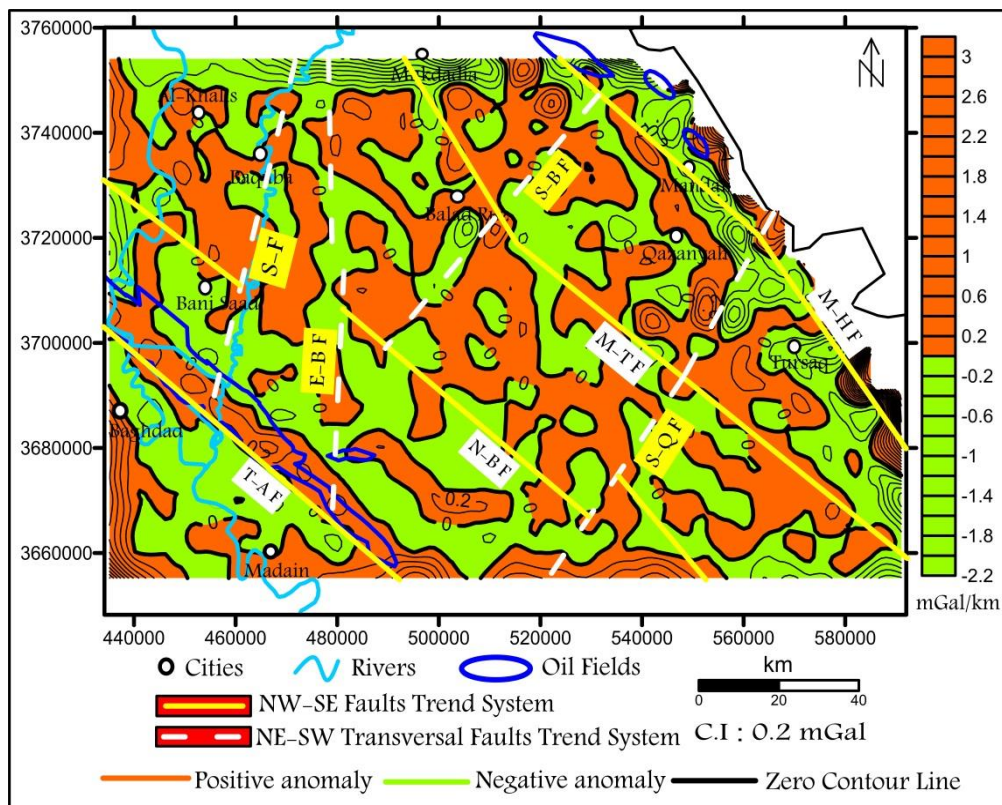

Figure 10-Residual gravity map (spacing window 6km) showing major tectonic boundaries inferred from gravity and magnetic data and oil fields locations.
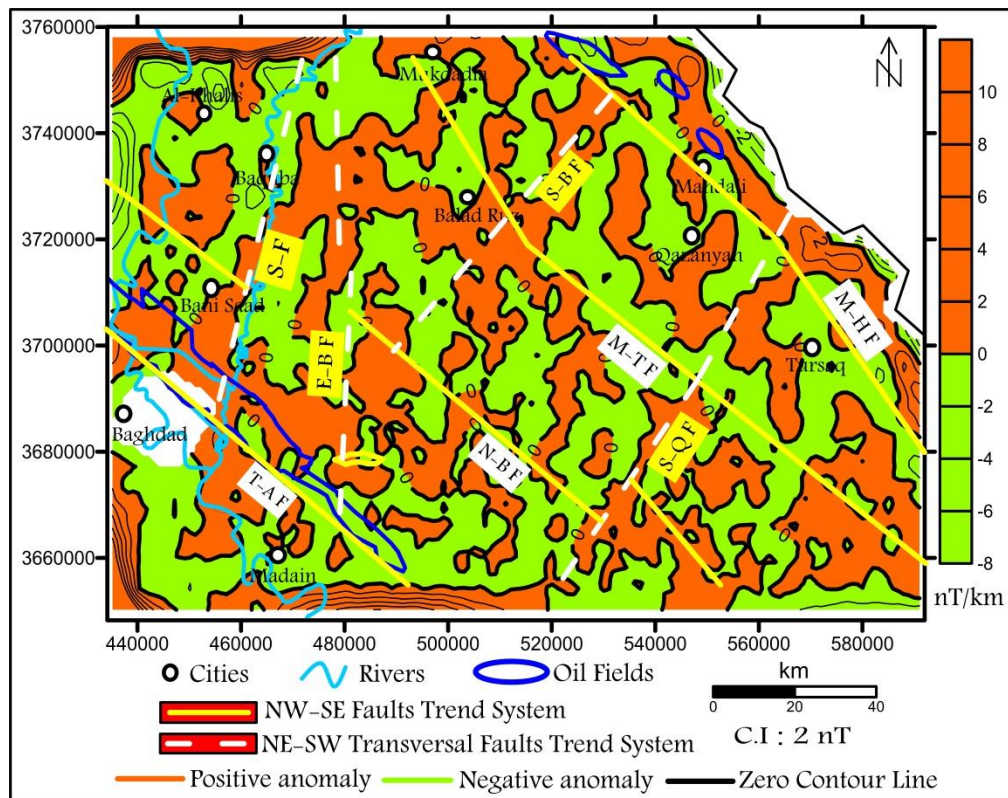
Figure 11-Residual magnetic map (spacing window 6km) showing major tectonic boundaries inferred from gravity and magnetic data and oil fields locations.

Conclusions

1- The trending of majority of the residual gravity lineaments towards NW-SE and magnetic lineaments toward NW-SE & NE-SW. In general, the orientation of gravity and magnetic lineaments is in coincidence with that of the structural elements in the study area.

2- Faults inferred from gravity data mostly trending NW-SE, which may be related to the Najd (longitudinal) faults system for the deep source and Alpine orogeny for the shallow source. The faults inferred from magnetic data characterized by many trends these are NW-SE and NE-SW and N-S, it is clear that the magnetic data indicate to the several system Nabitah, Najd and Transversal fault system.

3- The horizontal and vertical gradients of gravity anomaly are considered in the present study to estimate the depth to the gravity source. Two gravity anomalies from the residual gravity anomaly map of window 24 km are used for applying the present method for source depth estimation. It is found that the source of (IV) gravity anomaly is within the sedimentary rocks with depth equal to 5.36 km. While the depth of the source of the gravity anomaly(III) which equal to13.65 km may be within the basement rocks.

4- The oil fields locations show good coincidence with the positive gravity anomalies, while the locations of fields have weak relation with residual magnetic anomalies. Oil traps laying on the positive anomaly or near the Zero crossing line of residual gravity map. In residual magnetic map, the fields are weak coincidence with the positive magnetic anomalies and located on the zero contour line and distributed along the positive and negative gradient of magnetic anomalies in same locations.

5- Finally, tectonic boundaries map were constructed for the study area.

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