

GRAVITY AND GROUND MAGNETIC FOLLOW-UP OF AEROMAGNETIC ANOMALY WEST AI-GHAR'RAF RIVER, SOUTH IRAQ

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ABSTRACT

A more detailed gravity and ground magnetic surveys have been executed in a mostly agricultural area, which covers (28 × 40) Km and lies between Al-Nasiriya and Al-Kut Governorates, close to Al-Gharraf River and towards west. The surveys aim to determine deep structures within the sedimentary cover, by following-up a deep source anomaly, which appears in aeromagnetic and Unified Bouguer gravity maps. A net of polygons, including 868 gravity and magnetic stations with spacing interval of 0.5 Km, has been measured. Bouguer anomaly and total magnetic intensity (TMI) maps are constructed. Filters for enhancing shallow and deep source anomalies and high gradient areas were applied to Bouguer anomaly and TMI maps. The Bouguer anomaly map shows a prominent gravity high in ENE – WSW direction. In addition, residual anomalies that may reflect antiforms and synforms or faults are pointed out on this map. Gravity profiles across the gravity high and some residual positive anomalies are plotted. On the other hand, the TMI map shows a magnetic high, which has the same direction, extension, length and location of the gravity high. The magnetic high is, essentially, related to a basement intrusion, and it may be a causative source for the gravity high. Two magnetic profiles across and along this high are displayed. The study of depth maps of four seismic reflectors showed no anomalous structures down to the Permian surface (~ 6000 m deep), while it shows considerable paleostructures on this surface. Moreover, the magnetic high (the intrusion) is older than the Permian, which is (6000 – 9000) m deep. However, local magnetic anomalies (LMA) related to Quaternary gray sand sediments, can easily be recognized throughout the area. The LMA tend to disturb the earth's magnetic field. However, upward continuation filter is applied to remove the effect of these anomalies.

المتابعة الجاذبية والمغناطيسية الأرضية لشاذة المسح المغناطيسي الجوي في منطقة غرب نهر الغراف، جنوب العراق

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المستخلص

يتضمن البحث الحالي إجراء مسح مغناطيسي – جاذبي، أكثر تفصيلاً من المسوحات السابقة، في منطقة ذات طبيعة زراعية تبلغ أبعادها (40 × 18) كم وتقع بين محافظتي واسط وذي قار، إلى الغرب من نهر الغراف وذلك لغرض متابعة شاذة للمسح المغناطيسي الجوي الظاهرة في هذه المنطقة، والمحددة مسبقاً وفقاً لدراسة الخرائط الإقليمية المغناطيسية والجاذبية المتوفرة. إن مصدر هذه الشاذة عادة هو انبثاق صهيري (intrusion) قاعدي أو متوسط يقع بالقرب من القاعدة البلورية والذي من الممكن أن يكون مصدراً مسبباً لتراكيب تحت سطحية مفيدة في الاستكشافات النفطية وهي أحد أهداف هذه الدراسة. شمل المسح قياس 868 محطة (جاذبية ومغناطيسية)، وبمسافة فاصلة مقدارها 500 م، موزعة على شبكة من المضلعات غطت منطقة العمل. أعدت خارطتي شواذ بوجير وشدة المجال المغناطيسي

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الأرضي الكلي للمنطقة وطبقت مرشحات متعددة على الخارطتين لإبراز شواذ معينة أو مناطق الانحدارات العالية، إضافة إلى تحسين الصورة المغناطيسية والجاذبية. بينت خريطة بوجير وجود مرتفع جاذبي إقليمي بارز يمتد لمسافة 17 كم تقريباً ضمن المنطقة وباتجاه شرق شمال شرق، إضافة إلى تأشير عدد من المعالم الجاذبية المتبقية الموجبة والتي من الممكن أن تعود مصادرها إلى مرتفعات تراكيبية ضمن الغطاء الرسوبي. كما رسم مقطع جاذبي عمودي على المرتفع الجاذبي وآخر على الشواذ الجاذبية المتبقية الموجبة للدراسة الوصفية. من ناحية أخرى، أظهرت خريطة تساوي الشدة المغناطيسية الكلية وجود مرتفع مغناطيسي له خواص مقاربة للمرتفع الجاذبي من ناحية الموقع، الامتداد، الاتجاه والعمق، ومن الممكن يكون مصدر هذين المرتفعين (الجاذبي والمغناطيسي) هو واحد يقع قريباً من صخور القاعدة. تمت دراسة هذا المرتفع من خلال إعداد مقطعين مغناطيسيين، أحدهما عمودي والآخر يمر بمحاذاة محوره. ظهرت وبشكل واضح تأثيرات لشواذ محلية تعود إلى ترسبات رملية رصاصية اللون ذات العمر الرباعي، وفي عدة أماكن من الخريطة، أدت إلى تشويهات محلية لصورة المجال المغناطيسي الإقليمي وقد أزيلت بصورة تامة من الخريطة باستخدام مرشح الاستمرار الصاعد للمجال ولا ارتفاع مقداره 1000 م، كما أشرت التغيرات في نمط مناسيب المجال على شكل فائق أو مناطق ضعف ضمن مصدر المرتفع المغناطيسي. بينت دراسة الخرائط العميقة لثلاثة عواكس زلزالية عدم وجود تأثيرات تركيبية واضحة ناتجة عن الاندفاع الصهيري المدروس لغاية عمق 6000 م (سطح البيرمي)، فيما بينت وجود مرتفعات تراكيبية قد تكون نواتج مباشرة لتأثيرات هذا الاندفاع على السطح المذكور. إضافة لذلك، فمن المعتقد إن يكون عمر هذا الانثاق أقدم من العصر البيرمي وعمقه أكثر من 6000 م.

INTRODUCTION

Although, the aeromagnetic maps of CGG (1974) and the unified Bouguer gravity (UBG) maps by Al-Kadhimi and Fattah (1984) have regional nature, these maps are usually used in primary stages of delineating the deep geological structures that have special importance in hydrocarbon explorations. However, many gravity surveys of relatively small scales, which carried out in the Western Desert (e.g. Al-Bdaiwi, 2004), show mismatching with UBG. The main reason of this mismatching is attributed to relatively large spacing interval between grid lines used in UBG; 5 Km in the Mesopotamian Plain and 10 Km in the Western Desert, with spacing interval of 1 Km between stations. For the purpose of determining deep sedimentary structures, an important anomaly has been suggested for further detailed land magnetic and gravity surveys (Al-Bdaiwi, 2010a). The anomaly covers an agricultural area of about (40×28) Km and located south of Al-Kut City. In the aeromagnetic map, the anomaly has amplitude of 20 nT and 18 Km wave length, trending ENE – WSW. The CGG (1974) interpreted this anomaly as an intrusion of 7.5 Km deep (Fig.1). On the other hand, Bouguer gravity map expresses a gravity high and relatively broad gravity saddle. It appears to have a relationship with the magnetic anomaly (Fig.2). This magnetic – gravity anomaly may be related to supra basement magnetic body that could eventuate anomalous structure within the deeper part of sedimentary column (Al-Bdaiwi, 2010a). The present study focuses on the gravity and ground magnetic surveys, carried out to follow-up this anomaly, and their results.

The agricultural nature of the studied area, which is covered by very complicated irrigation and drainage channels, made the accessibility to the measuring points difficult. Therefore, the field work was executed along polygons rather than regular grid. A Google Earth image and topographic maps at scale of 1: 100 000 were used as a base map to delineate the polygons along available tracks and paved roads with a measuring step of 500 m, for the area under investigation. The total number of the measured stations is 868.

■ Location

The studied area is located between Nasiriya and Wasit Governorates, at a distance of about 65 Km; south of Al-Kut city, it occupies Al-Fajir town. Al-Ghar'raf River passes through the eastern side of the studied area, which is bounded by the following coordinates (Fig.3):

Longitude	45° 42'	45° 55'	45° 51'	46° 03'
Latitude	32° 02'	32° 08'	31° 46'	31° 50'

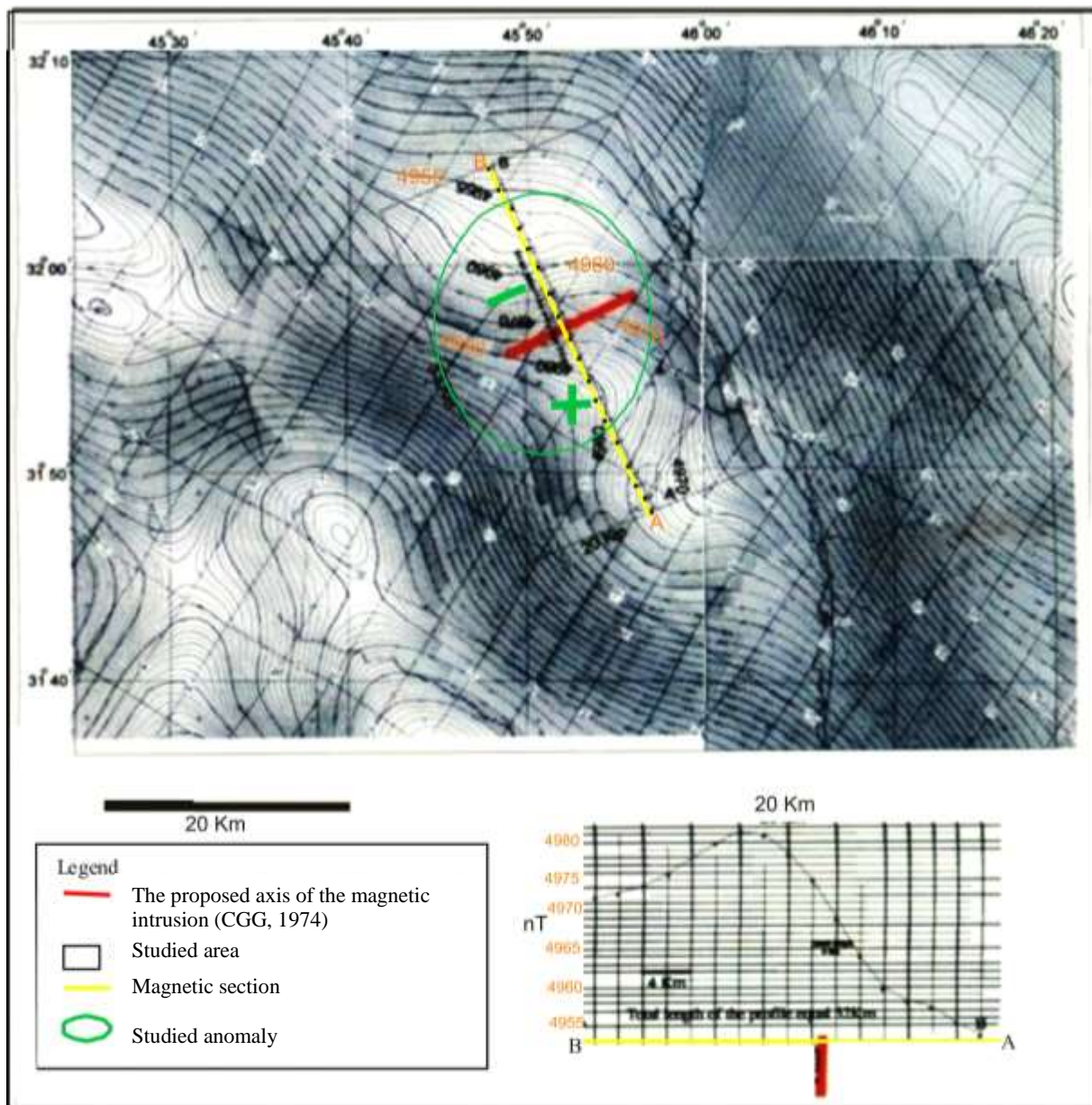


Fig.1: Aeromagnetic map of CGG (1974) exhibits the studied anomaly and its relation with the surroundings. The lower part shows magnetic cross section along the axis of this anomaly

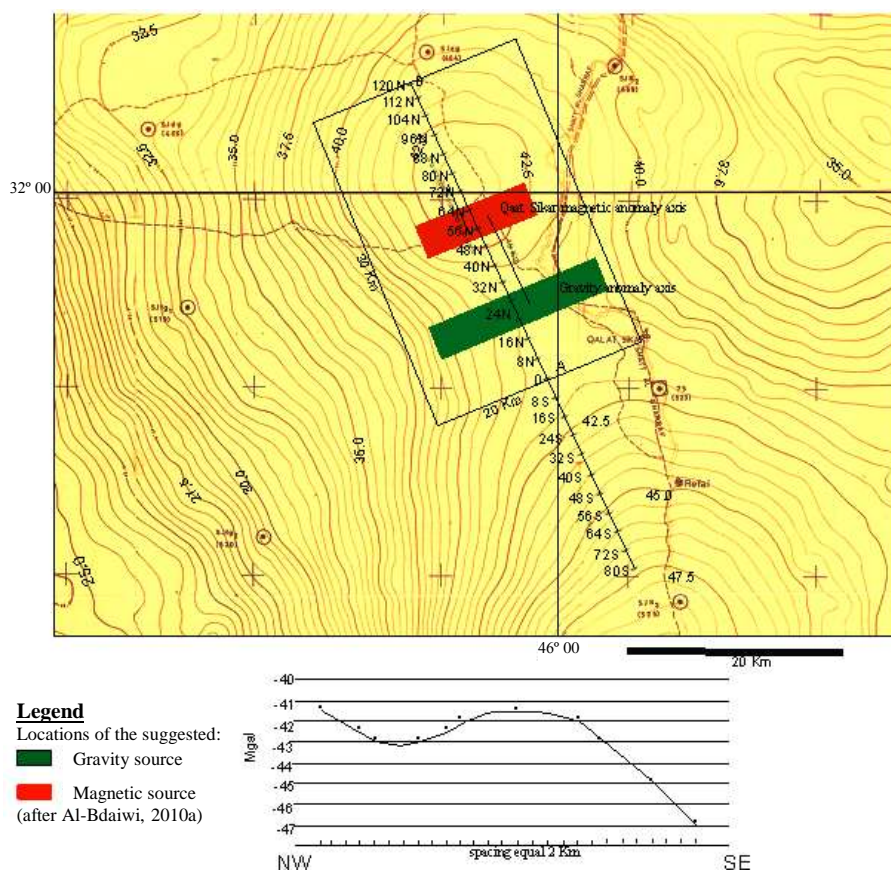


Fig.2: Bouguer gravity map of the studied area (after Al-Kadhimi and Fattah, 1984)

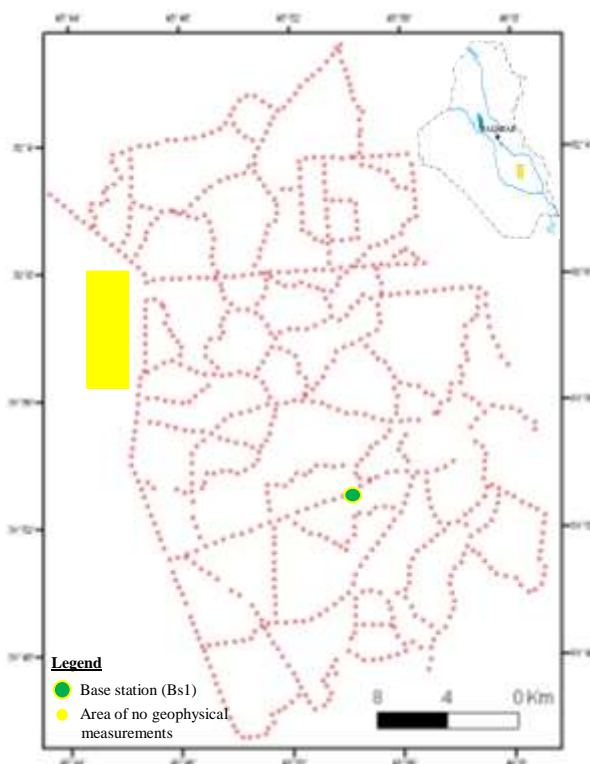


Fig.3: Location map of the studied area and the distribution of 868 measuring stations

▪ Aim

The present work aims to execute detailed gravity and ground magnetic surveys to determine deep sedimentary structures that may be resulted from the source of the magnetic anomaly. It also aims to verify the nature (depth, direction, dip and extension) of the causative source of the concerned aeromagnetic and gravity anomalies.

GEOLOGY OF THE AREA

The studied area is completely covered by Quaternary sediments of Mesopotamian Plain. The sediments are different in type; including flood plain sediments (sand, silt and clay), sand dunes, sand sheet sediments, marsh sediments (mud with organic materials) and shallow depression sediments (clay and silt clay) (Barwary and Yacoub, 1992 and Deikran and Mahdi, 1993).

Geomorphologically, the studied area has almost flat terrain and the average height of the ground surface is 11 m (a.s.l.). Al-Gharraf River, which has the main net of irrigation channels, passes through the eastern side of the area. Active sand dunes of Barchan type cover the northwestern part of the area (Deikran and Mahdi, 1993); therefore, performing geophysical measurements in this part was not possible (Fig.3).

Tectonically, the area is related to Mesopotamian Foredeep of the Outer Platform (Fouad, 2012). Jassim and Goff (2006) mentioned that "the studied area is located in the Euphrates Subzone (the western part of the Mesopotamian Zone, which in turn forms the extreme eastern unit of the Stable Shelf). The Euphrates Subzone is a monocline dipping to the NE with short anticlines (< 10 Km) and structural noses and it is the shallowest unit in the Mesopotamian Zone. The basement is generally (7 – 9) Km deep, but the Subzone has thick Quaternary sediments compared with the Tigris Subzone. Mesopotamian Zone contains buried faulted structures below the Quaternary cover, separated by broad synclines. A major N – S trending gravity and magnetic high is located along the Gharraf River, between the Tigris and Euphrates rivers, which may indicate a buried Hercynian structure". They also mentioned that the Quaternary sediments alone are up to 300 m thick in the Mesopotamian Zone. Anticlines and horsts lie beneath undeformed or gently deformed Neogene cover, and are frequently related to long-lived paleostructures (Aqrabi *et al.*, 2010).

It is worth mentioning that the sedimentary column in Iraq is practically not-magnetic; i.e. the sedimentary formations of this column did not contain appreciable magnetic minerals to create discernible anomalies even if these formations were displaced vertically with considerable throw (Al-Bdaiwi, 2010b). However, some Quaternary sediments, derived from igneous and/or metamorphic rocks, contain very small quantities of magnetite and hematite minerals may disturb the magnetic field forming local magnetic anomalies.

PREVIOUS GEOPHYSICAL STUDIES

Except the gravity and aeromagnetic surveys, which covered most of the Iraqi territory and have regional nature, no particular geophysical study was performed in the studied area. These surveys are:

- Regional aeromagnetic and aerospectrometric survey of Iraq carried out by CGG (1974). The total magnetic intensity map shows many residual magnetic anomalies that may be related to intrasedimentary igneous intrusions. A magnetic anomaly appears in aeromagnetic map have been chosen to be followed up by ground magnetic survey (the present work).

- Regional gravity surveys; unified in a Bouguer gravity map of Iraq by Al-Kadhimi and Fattah (1984). The studied area expresses a relatively broad gravity saddle, which has the same trend as that of the magnetic anomaly.
- Interpretation of seismic survey in the area east of Al-Diwaniya (including the studied area) by OEC (1991) determined four reflectors. Depth maps of these reflectors show increasing depths from the southwest to the northeast (as shown below), i.e. dipping beds towards the north east as follows:
 - Top of Hartha Formation (1800 – 2150) m
 - Top of Shu'aiba Formation (2900 – 3300) m
 - Top of Triassic (4500 – 5100) m
 - Top of Permian (5700 – 6300) m

Paleostructures however, exist at the top of the Permian only (no structures appear shallower than 5100 m). Accordingly, it could be concluded that the sedimentary cover overlaying the Permian has not been strongly affected by the Alpine stresses. Furthermore, the dip of the strata within the studied area is also estimated to be (1.5 – 2) °.

It is worth mentioning that a similar study to the present work was reported by Amin *et al.* (2010), where gravity and geomagnetic surveys were executed in the southeastern part of Iraq between Amara and Qurna in an area covered by (70 × 120) Km to fill a gap of previously executed gravity and magnetic surveys. The surveys, which were carried out along polygons with stations of 1 Km apart, aimed to make regional geophysical mapping. Although, the magnetic survey displayed the regional picture, but the Bouguer gravity map showed two impressive anomalies that probably reflect associated hydrocarbon structures. The accuracy of the gravity measurements was (0.022) mGal.

GEOPHYSICAL AND TOPOGRAPHIC WORKS

The present geophysical work includes gravity and ground magnetic works. Both gravity and magnetic measurements were acquired at the same station and time. There are however, few exceptions, especially, when the station has high noise level in gravity; the magnetic reading has been acquired only, and vice versa. For the sake of accuracy and quality control, 15% of the total measurements were repeated at the same day; as repeated points and 10% of them were repeated at the different days; as control points. The location, readings and time are recorded at each station as well as any relevant topographic or geologic information and details of any visible or suspected source of noise.

The topographic works included stabilizing basic gravity station and stations of measurements that required positions and elevations. GPS of Garmin Version 12XL type with accuracy of ± 2 m is used for adjusting the positions, while Digital Total Station devices, type Topcon, version 721 and type Lica, version 405 was used for calculation of elevations. The accuracy of elevations is ± 3.7 cm/Km.

It is important to mention two factors that affecting the geophysical surveys. The first one is the agricultural nature of the area, which has prevented the performance of a regular grid; therefore, polygons are chosen along the available tracks and paved roads. The second is the microseismicity related to earthquakes, happened in Oct. 24th (southeast of Turkey), Nov. 29th and Dec. 24th 2011, have strongly affected on gravimeter and gravity measurements, where the field work has been completely stopped.

▪ Gravity Survey

Two types of gravimeters have been used in this work; the first is the modern CG-5 (Sceintrex Autograv System) gravity meter, manufactured by Canadian Sceintrex Limited Company, with sensitivity of $\pm 1 \mu\text{Gal}$. Corrections provided in the system include Tide, Instrument Tilt, Temperature, advanced Noisy Reading Rejection, Seismic Noise Filter/ FIR Filter and Near Terrain Corrections. The second gravimeter is LaCost & Romberg model D gravity meter with sensitivity of $\pm 1 \mu\text{Gal}$. The latter instrument was used due to a fault that affected the first instrument, which had already completed some 20% of the survey. The two sets of measurements of both gravimeters have been tied and adjusted by adding more control points among the two sets. Auxiliary base station (Bs.1) (Fig.3) was established inside the studied area and tied with a reference base station (Bs.0) by the usual looping for interpolation of the absolute gravity value for each measuring station. The mean error (M) of gravity measurements is $\pm 0.033 \text{ mGal}$.

Processing of gravity raw data includes applying the necessary corrections and filtering, gridding and mapping. Data filtering, gridding and mapping have been accomplished with the aid of the well-known package of geophysical programs Oasis Montaj™ (Geosoft). All the required corrections including latitude, free air and Bouguer have been applied on the raw data, and then Bouguer anomaly value for each station has been calculated using the following formula:

$$g_b = g_{obs} + C_F - C_B - g_0$$

Where:

g_b ; Bouguer anomaly

g_{obs} ; the observed gravity value

g_0 ; the theoretical value of gravity

C_F ; free air correction

C_B ; Bouguer correction by using density value equal to 2.00 gm/cm^3

The corrected data have been gridded using minimum-curvature method, then mapped to produce Bouguer gravity map for the whole studied area (Fig.4). It is worth to mention that the corrected data represent local relative gravity survey where the values are not tied to the national anomaly map (UBG).

▪ Qualitative Interpretation

Bouguer anomaly map of the studied area (Fig.4) displays gravity lows and highs. These are described hereinafter:

— **The Gravity Lows:** Two gravity lows dominate the studied area; the first is the equidimensional low; situated at the northern part; pointed out as – Ve1, with its southward extension (marker G3) and the second is situated at the south; pointed out as – Ve2. The – Ve1 has a Bouguer value of -60.0 mGal and a diameter about 20 Km with maximum amplitude of about -2.0 mGal , while the – Ve2 is a part of a regional gravity low as appears when looking at the surroundings (Fig.2). Actually, the two gravity lows – Ve1 and – Ve2 are related to the same source i.e. the negative background that dominates the Mesopotamian Foredeep, as will be discussed later in the results and discussion paragraph.

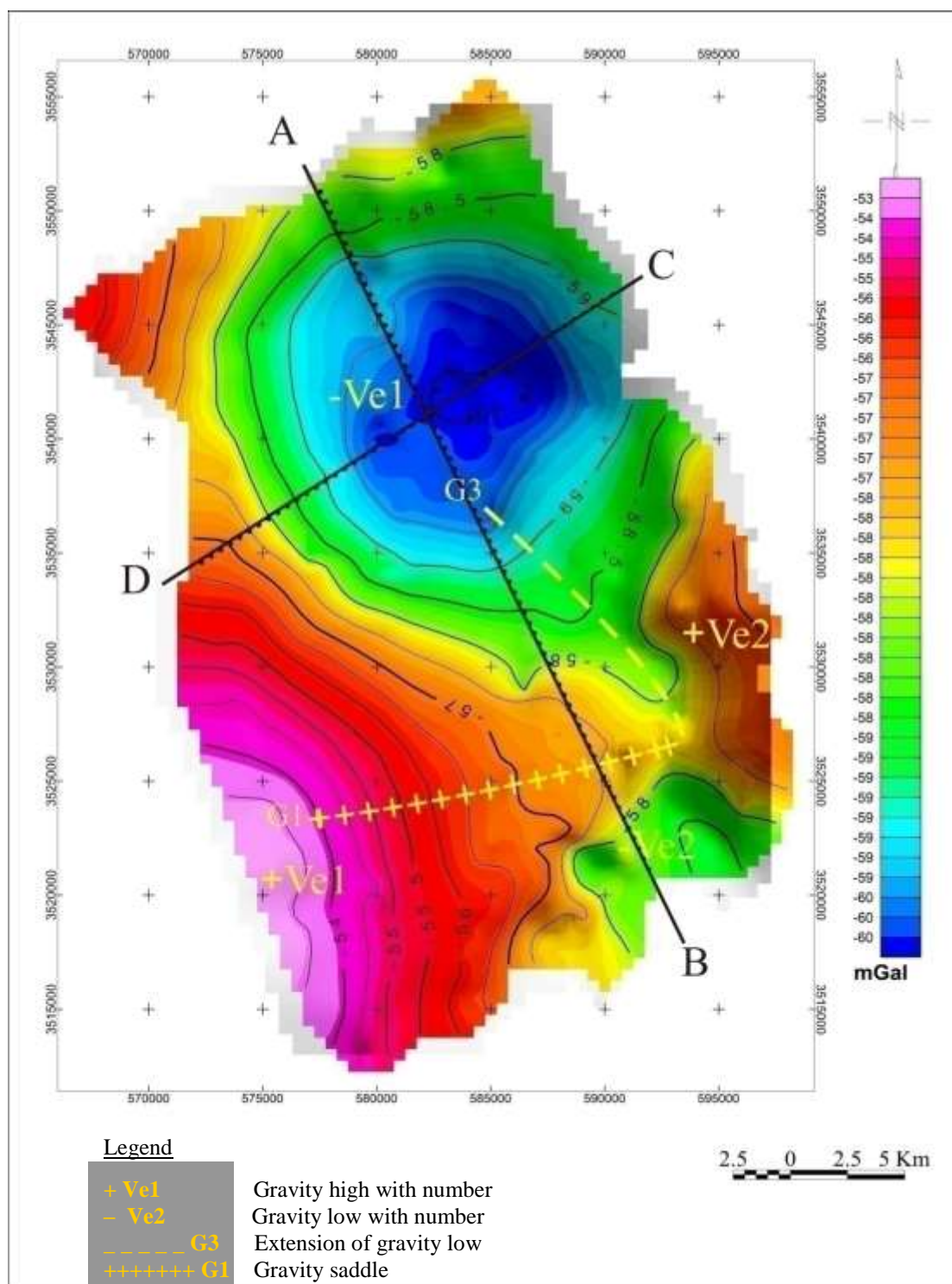


Fig.4: Bouguer gravity map of the studied area

— **The Gravity Highs:** Bouguer anomaly map seems to be composed of two gravity highs (+ Ve1 and + Ve2). The gravity high (+ Ve1), extends eastward; represented by a gravity saddle; pointed out as marker G1 and trending ENE – WSW. The marker has amplitude of about + 1.75 mGal, while the maximum values of the gravity highs; + Ve1 and + Ve2 are about + 5.0 mGal and 2.5 mGal, respectively. Whereas, the second gravity high (+ Ve2) is marked on Fig. (4).

Different types of filters have been applied to the Bouguer map to enhance shallow or deep anomalies (Geosoft, 2010). Low Pass filter (LP) has been applied to the Bouguer map to show the regional anomalies (Fig.5). The used wavelength cut off is 14 Km and the expected depth of these anomalies is 8.5 Km. However, vertical derivative filter has been applied to enhance the residual anomalies (Fig.6). Positive residuals appear superimposed on the main negative, i.e. markers G7 trending NNW – SSE, and the markers G8 and G2, trending N – S, which may be antiforms structures. Impressive positive residual markers are G5 and G6 trending ENE – WSW. These are superimposed on the main gravity high (the + Ve1, G1 and + Ve2). They may reflect the effect of the causative source within shallower part of the sedimentary cover. Total Horizontal Derivative (THD) filter; determines the high gradient areas, which have a direct relation with faults, edges and the boundary of the main effective structures (Fig.7). The red color delineates the high gradient areas or the boundary in which the density encounters high changes, whereas the blue color represents the areas of no changes in density. The high gradient delineates the boundary of the causative source of the gravity anomaly.

To explain the variation of the gravity field and also the shape and amplitude of the anomalies along the gravity high and the gravity low, two gravity profiles; AB in the direction N – S and CD in the direction E – W, have been constructed (Figs.8 and 9). Profile AB shows the variation of the gravity curve across the gravity high. A distance of about 20 Km displays the variation from the gravity low to the gravity high that reflects the boundary in which the density of the rocks encountered high variations. The imposed residual anomalies on the regional field are easily recognized in this profile, too. In Fig. (9), the residual positive anomalies imposed on the –Ve1 have been focused. These anomalies are exaggerated by using the first derivative filter, which is in turn smoothed by B-spline filter (the line of blue color). The positive residual is of interest when looking at antiforms structures.

▪ Magnetic Method

Two magnetometers of Proton type, which measure the total magnetic field known as Magnetic Measurement System (portable and base station) ENVI PRO with magnetic sensitivity of ± 0.1 nT, have been used in the survey. Generally, the area has low noise level and the readings are stable. However, some Quaternary sediments that contain sand (derived from igneous or metamorphic rocks) been affected the regional field value in some places. These sediments are able to disturb the local field and form Local Magnetic Anomalies (LMA) (Al-Bahadily and Yousif, 2012). The accuracy of the magnetic measurements is ± 0.9 nT. It has been calculated depending on 101 control points.

Processing of magnetic row data included applying diurnal correction, normal correction and filtering, gridding and mapping. Normal correction has been applied on the magnetic measurements by using the IGRF equations, which is included in Geosoft, updated in 2010. IGRF provides a reasonable representation of the actual regional field in the surveyed area (Milsom, 2003). The resulted data have been gridded using minimum curvature method, and then mapped to produce Total Magnetic Intensity Map (TMI).

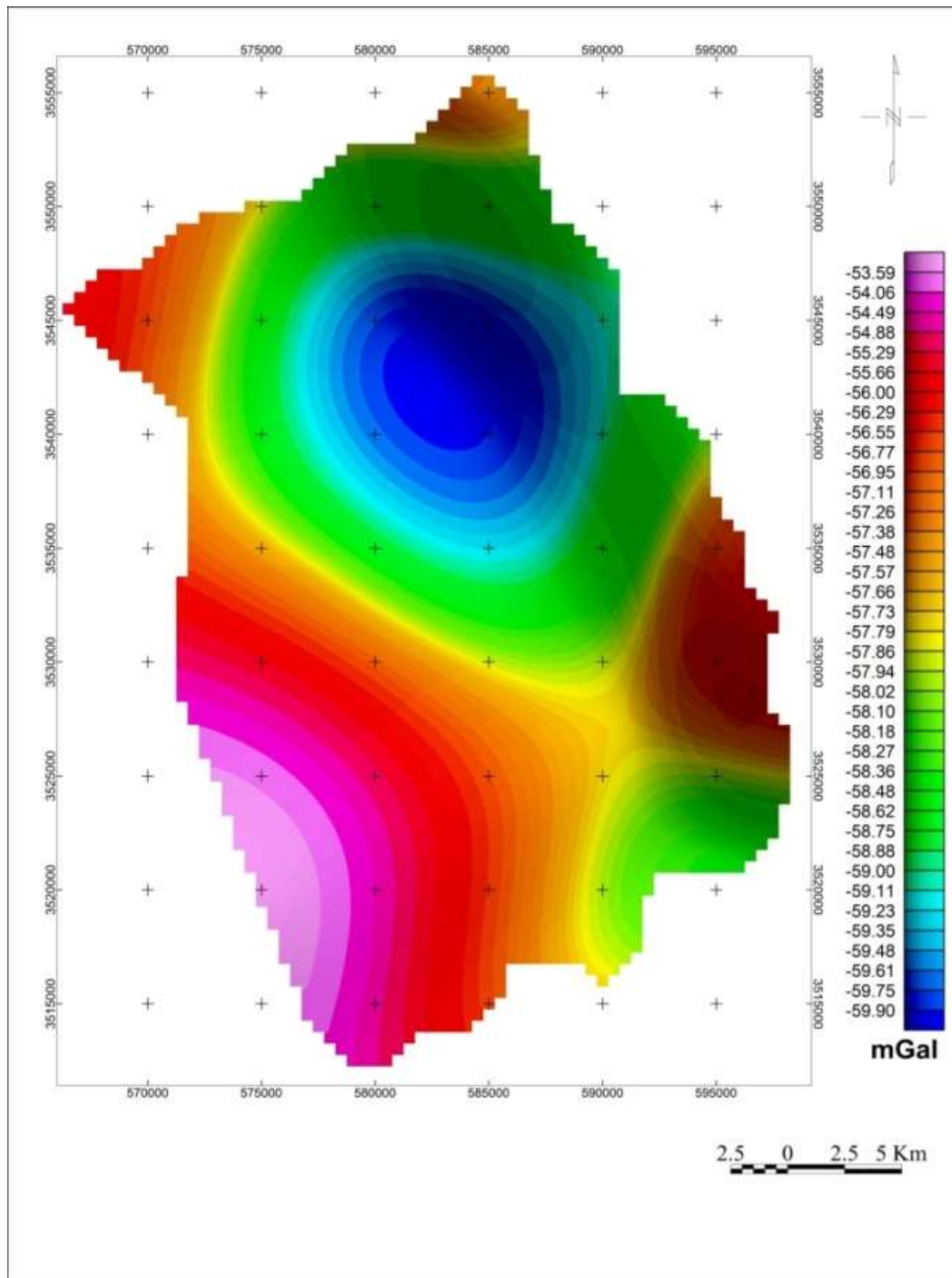


Fig.5: Low pass filter applied to the Bouguer gravity map

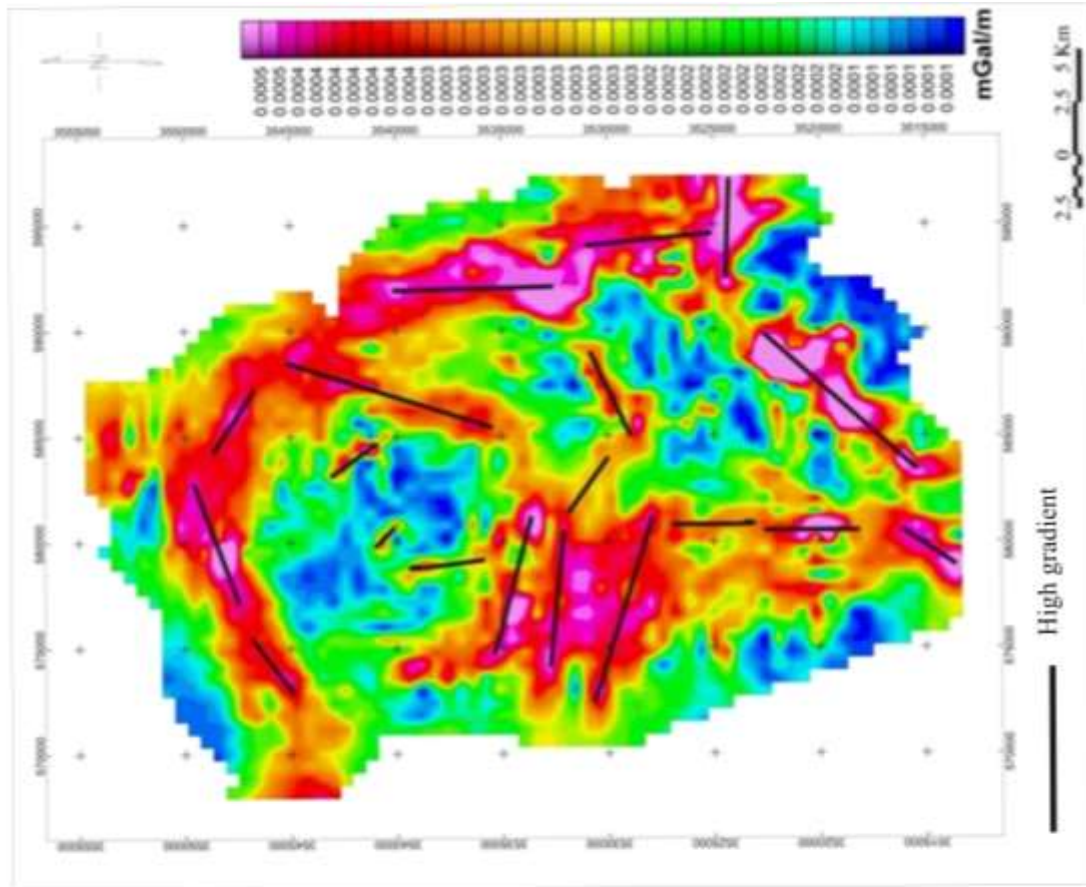


Fig.7: Total Horizontal Derivative filter (THD) of Bouguer map

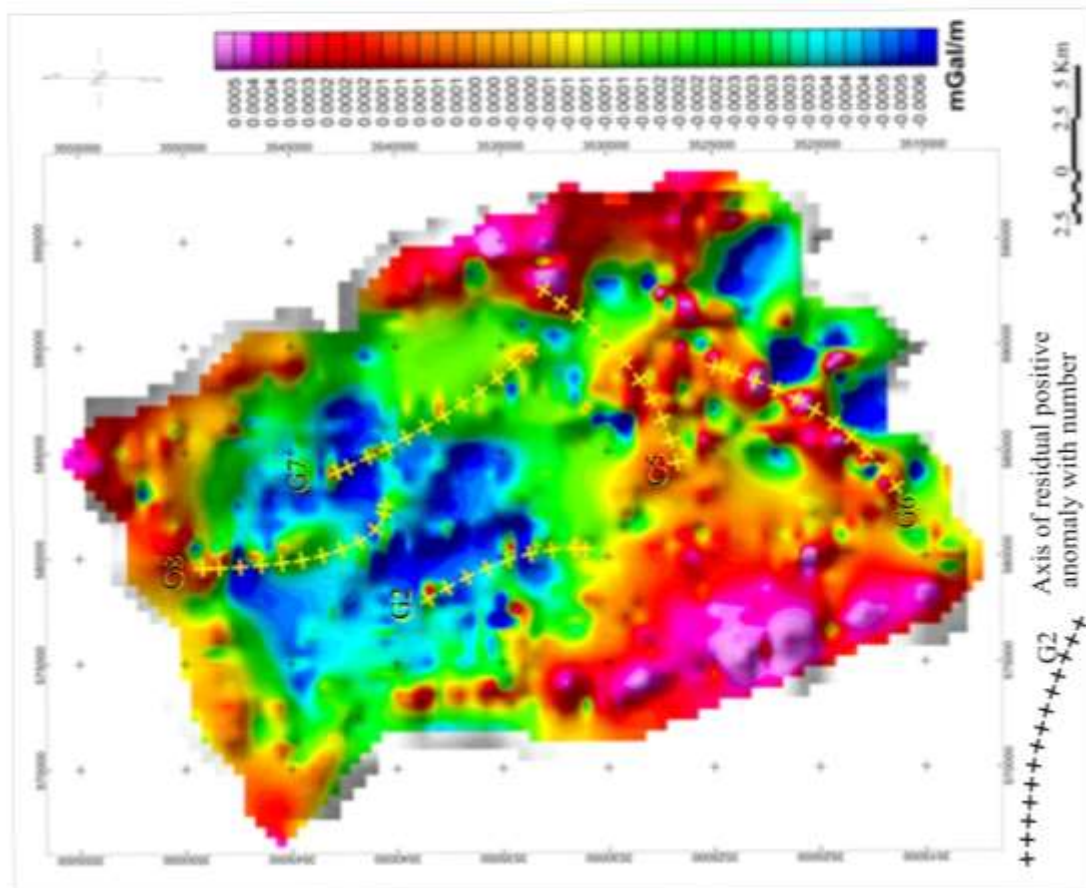


Fig.6: Vertical derivative filter shows residual anomalies of the studied area

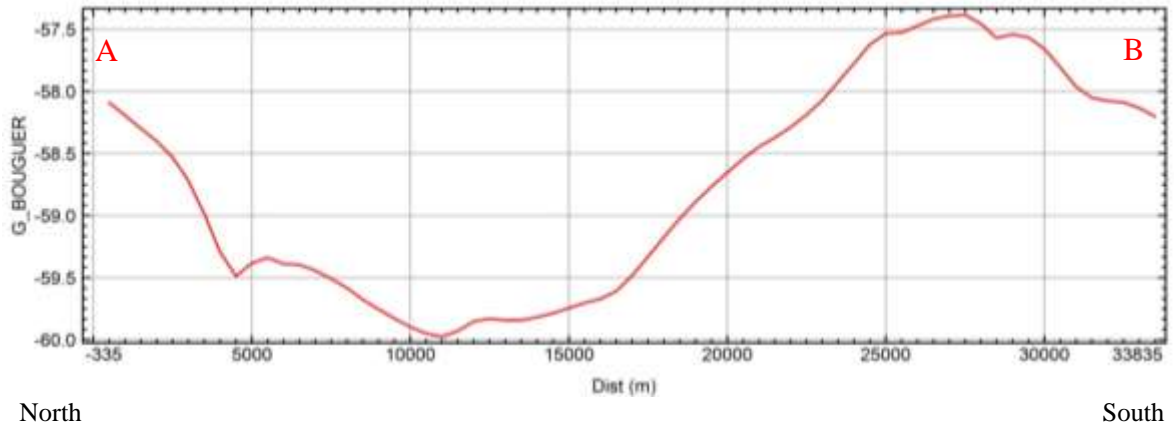


Fig.8: Gravity profile across the gravity high (For location, refer to Fig.4)

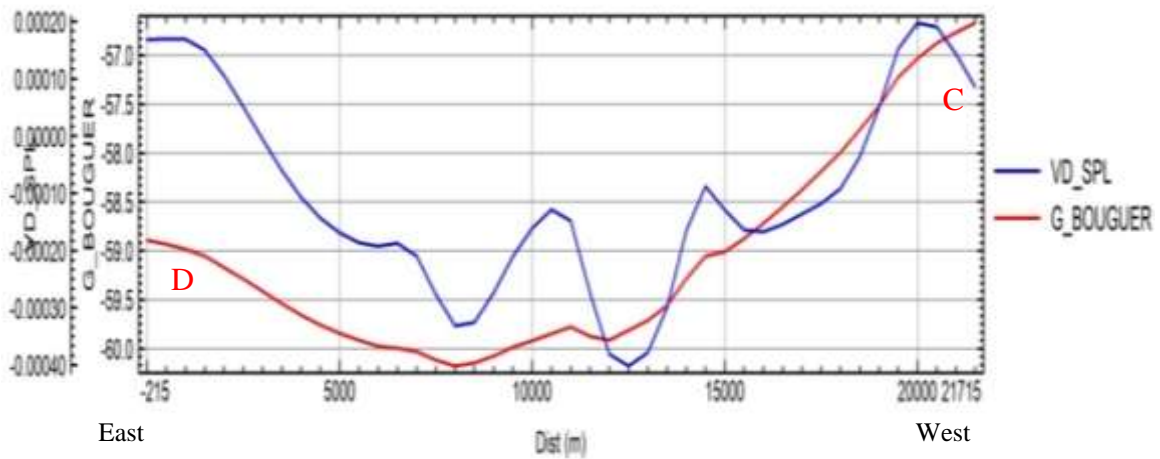


Fig.9: Gravity profile across the gravity high (For location, refer to Fig.4)

▪ Qualitative Interpretation

The TMI map of the studied area (Fig.10) shows a magnetic high situated at the southwestern part. The high has an extension in ENE – WSW direction for a distance of about 20 Km with amplitude of about 54 nT. The extension is assigned in Fig. (10) as marker M1. Basically, all the regional magnetic anomalies, which appear in the aeromagnetic map, including the present magnetic high, are related to the crystalline basement.

The magnetic picture of the studied area is relatively disturbed by superficial or Local Magnetic Anomalies (LMA) caused by Quaternary gray-sand sediments that contain small quantities of magnetite mineral (Al-Bahadily *et al.*, 2012 and Al-Bahadily and Yousif, 2012). The LMA have amplitudes, which did not exceed 6 nT, with short wavelengths and different shapes. The residual map after subtracting the regional field from the TMI is displayed in Fig. (10). The effect of the LMA on the total field is eliminated and it is clearly shown in Fig. (11). However, to remove this effect, the upward continuation filter with 1000 m elevation has been applied on the TMI map to produce the regional map (Fig.12). Figure (12) shows a considerable enhancement of the TMI map, where the effects of near surface magnetic sources is totally removed, the contour lines become smoother and the regional picture appears much better. Moreover, marker F has been added on this map in the direction of ENE – WSW, it can be delineated as a fault or boundary between two distinctive materials

of different magnetic susceptibilities. Obviously, two impressive negative anomalies pointed out as markers M2 and M3 on the TMI map, have been enhanced clearly, when applying the upward continuation filter. These anomalies are probably related to deep weakness zones within the magnetic source.

To explain the shape of the magnetic field across and along the magnetic high, two magnetic profiles in N – S direction (Fig.13) and in E – W direction (Fig.14) have been constructed. In Fig. (13), the variations of the total magnetic field from the north and south with TMI value 45675 nT and 45730 nT, respectively are explained. Clearly, the gradient is not constant, the highest gradient occurs at a distance around 15000 m and this reflects high variation in magnetic susceptibility. Moreover, the profile at its southern end refers that the magnetic high has an extension outside of the studied area. Similarly, in Fig. (14), the magnetic profile exhibits a continuous increase in the magnetic field towards the west, while it shows a relative constancy in the field at the middle part of the profile. However, the high gradient part near to a distance of about 18000 m may refer to the area of high contrast in magnetic susceptibility.

RESULTS AND DISCUSSION

Many recent detailed gravity measurements (e.g. Al-Bdaiwi, 2004 and 2005, and Al-Bdaiwi *et al.*, 2007) have been carried out in the Western Desert showed very low resolution of the Unified Bouguer Gravity (UBG) map (Al-Kadhimi and Fattah, 1984). However, the present work in addition to a more recently work performed by Amin *et al.*, (2010) in Hor Al-Hwaizah area, south of Iraq, showed good matching with that of UBG maps (Figs.2 and 4). As a result, the gravity measurements plain of the Mesopotamian of the UBG are more confident than those of the Western Desert.

On the other hand, it is not easy to interpret the negative anomalies (– Ve 1 and – Ve 2), which appear in Fig. (4), in terms of deficiency in density or even as structural low. Generally, such lows are related to the negative background that may be related to the effect of Zagros root as well as the effect of Mesopotamian Basin, i.e. the decreases of gravity field towards the center of the basin due to thickness increment of the post Lower Miocene sediments. However, the gravity high superimposed the negative background and separates it into two gravity lows (– Ve1 and – Ve2) and it creates a broad high saddle between them (Figs.2 and 4).

Either the gravity high has the same source of the magnetic high or it has different source. Hereinafter are two possible interpretations concerning the sources of the gravity and magnetic highs that could be discussed in this study.

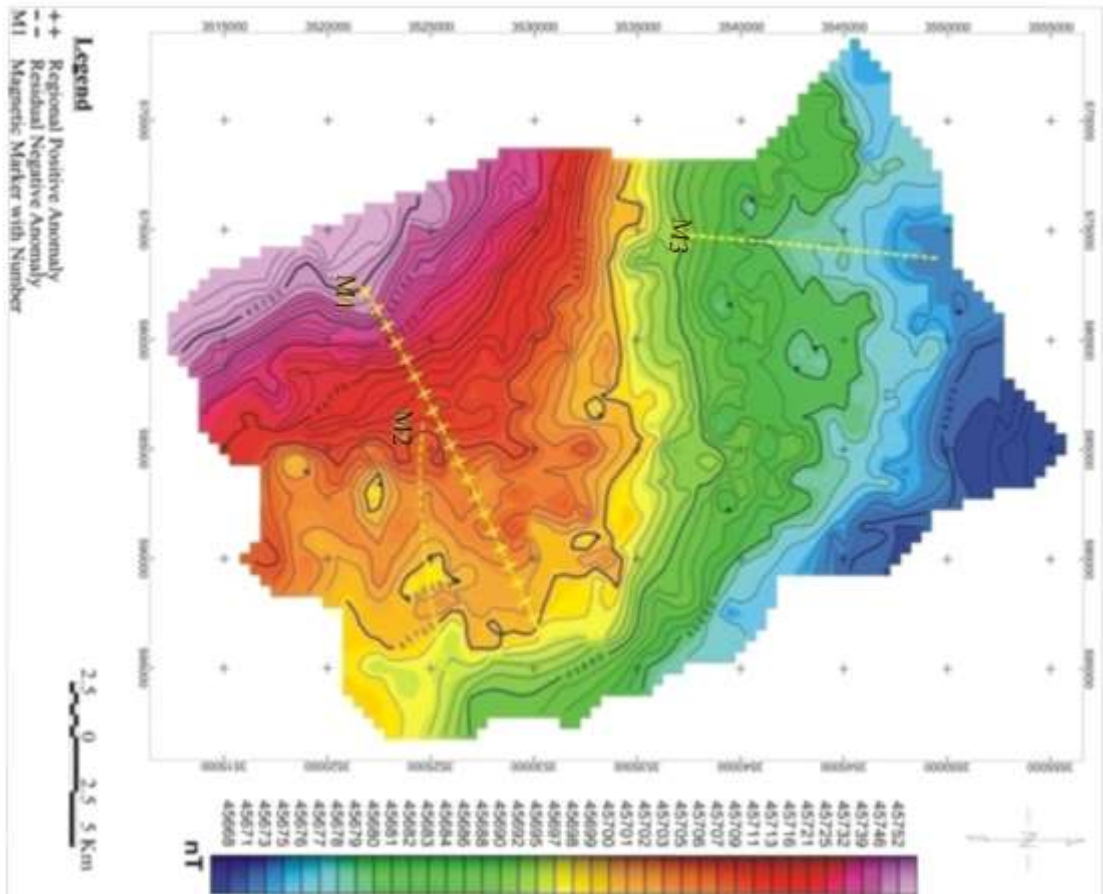


Fig.10: Contour of Total Magnetic Intensity (TMI) of the studied area

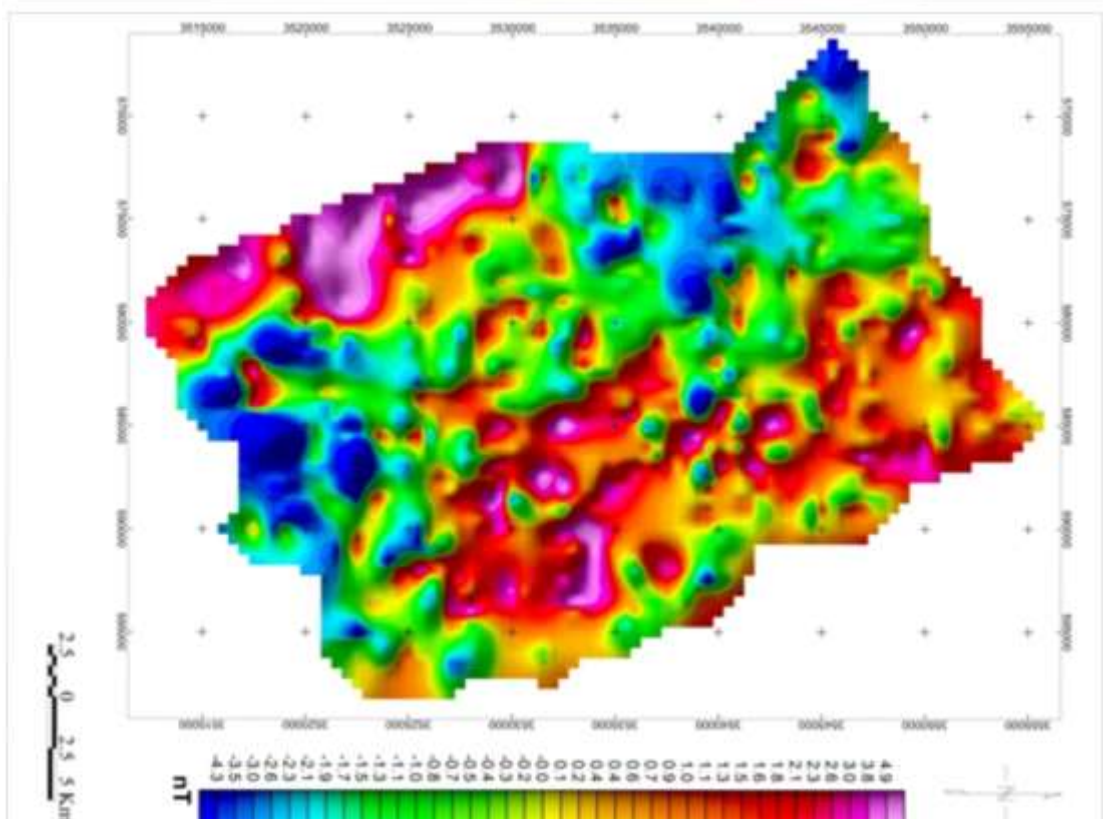


Fig.11: Magnetic map of residual anomalies of the studied area

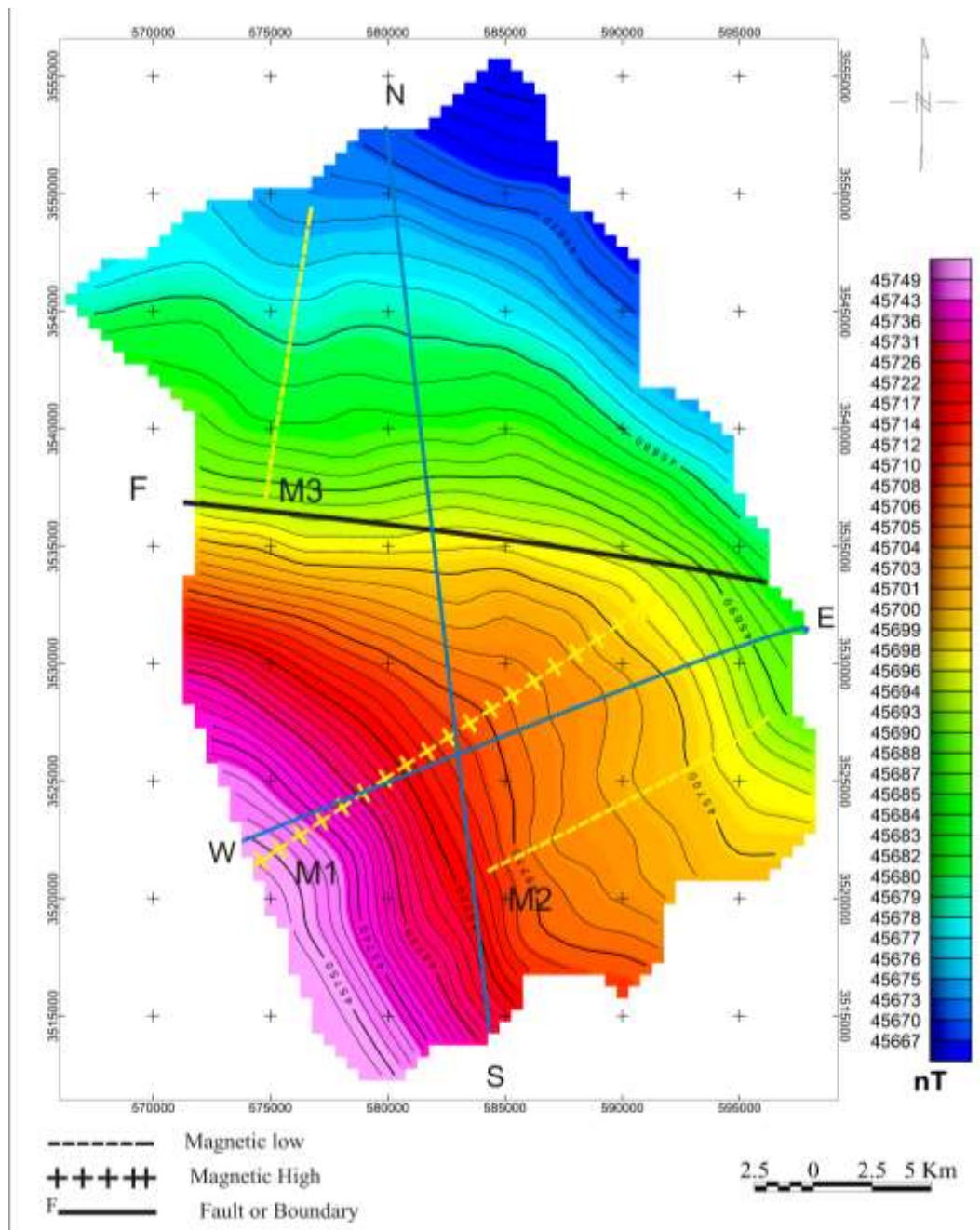


Fig.12: The upward continuation filter applied on TMI map up to elevation 1000 m.
The effect of LMA is diminished

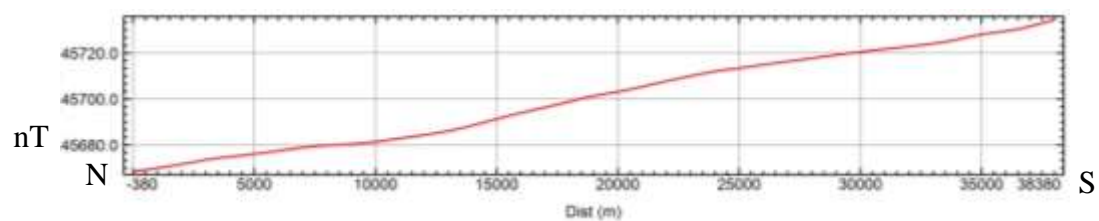


Fig.13: Magnetic profile across the magnetic high in N – S direction
(For location, refer to Fig.12)

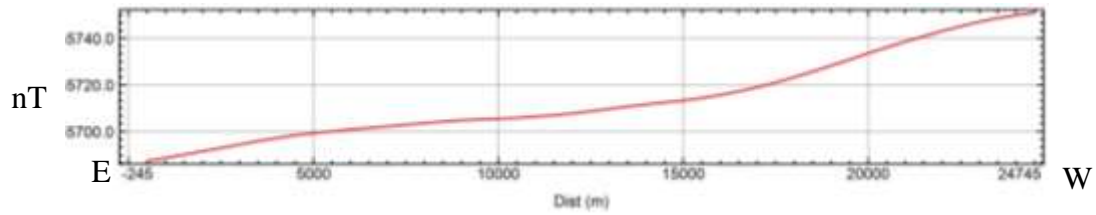


Fig.14: Magnetic profile along the magnetic high (For location, refer to Fig.12)

▪ **The Magnetic High and the Gravity High are Related to One Source**

Generally, there are many factors affecting the resulted shape of the magnetic anomaly; these are mainly the inclination of the magnetic field, the shape, orientation and inclination of the magnetic source, and also the interaction with the other magnetic anomalies and the angle between the profile and the strike of the magnetic body. All these factors are responsible for the final magnetic picture that appears in Fig. (12). However, because of the similarity in the position, extension, length and orientation of the magnetic and gravity highs; therefore, they may be related to the same source, which could be supra basement of basic or ultrabasic intrusion. This interpretation is based on the general direct proportional relationship between density and susceptibility of rock bodies, and the coincidence between the gravity and magnetic highs. According to structural maps derived from seismic data; the sedimentary cover overlying the Permian (~ 6000 m deep) shows no evidence concerning the magnetic or gravity source, which suggests that the age of the source (the age of the intrusion as mentioned early by the CGG, 1974) is older than the Permian and it is more than 6000 m deep. It is worth mentioning that the CGG (1974) mentioned a depth of (7.6 – 7.8) Km for this intrusion. However, top of the Permian surface shows impressive structures represented by a structural nose, which has good matching with the gravity and magnetic highs with NE – SW direction. Moreover, it shows two parallel normal faults and an anticline trending NW – SE lying in the northern negative of Bouguer gravity map.

▪ **The Magnetic High and the Gravity High are Related to Two Sources**

Commonly, the Reduction To the Pole (RTP) filter removes the north-side low of dipolar anomalies and centers the anomaly over the source, and enhances the special correlation between magnetic anomaly and its geological source (Fairhead and GETECH Group, 2011). Therefore, applying this filter will shift the axis of the magnetic source towards the north (marker M1 in Fig.15) and it leads to suggest a different source for gravity high. In this case, the gravity high (marker G1 in Fig.4) should be related to a source situated at relatively shallower depths within the sedimentary cover, which has more density contrast than that resulted from the magnetic source; near the basement (the gravitational effect of the marker M1 in Fig.15). Apparently, the negative area situated at the northern part of the studied area is not a part of the studied anomaly; it represents a regional gradient as appears in Fig. (1). The authors believe that the first interpretation (i.e. without applying RTP filter) is more acceptable because, obviously, Fig. (13) shows a negative gradient towards the north rather than an expected inflection point, i.e. no inflection point, which normally separates the positive and negative sides of the magnetic anomaly.

TMI map (Fig.10) shows the magnetic high and its extension in ENE – WSW direction (marker M1). Commonly, the regional anomalies appear in the TMI Map reflect the variations in basement lithology or topography. Marker M1 is almost related to an intrusion of basic rocks, because the changes in lithology, which give rise to lateral contrast in susceptibility, show up in the magnetic contour more conspicuously than topographic features on the basement surface (Dobrin, 1978).

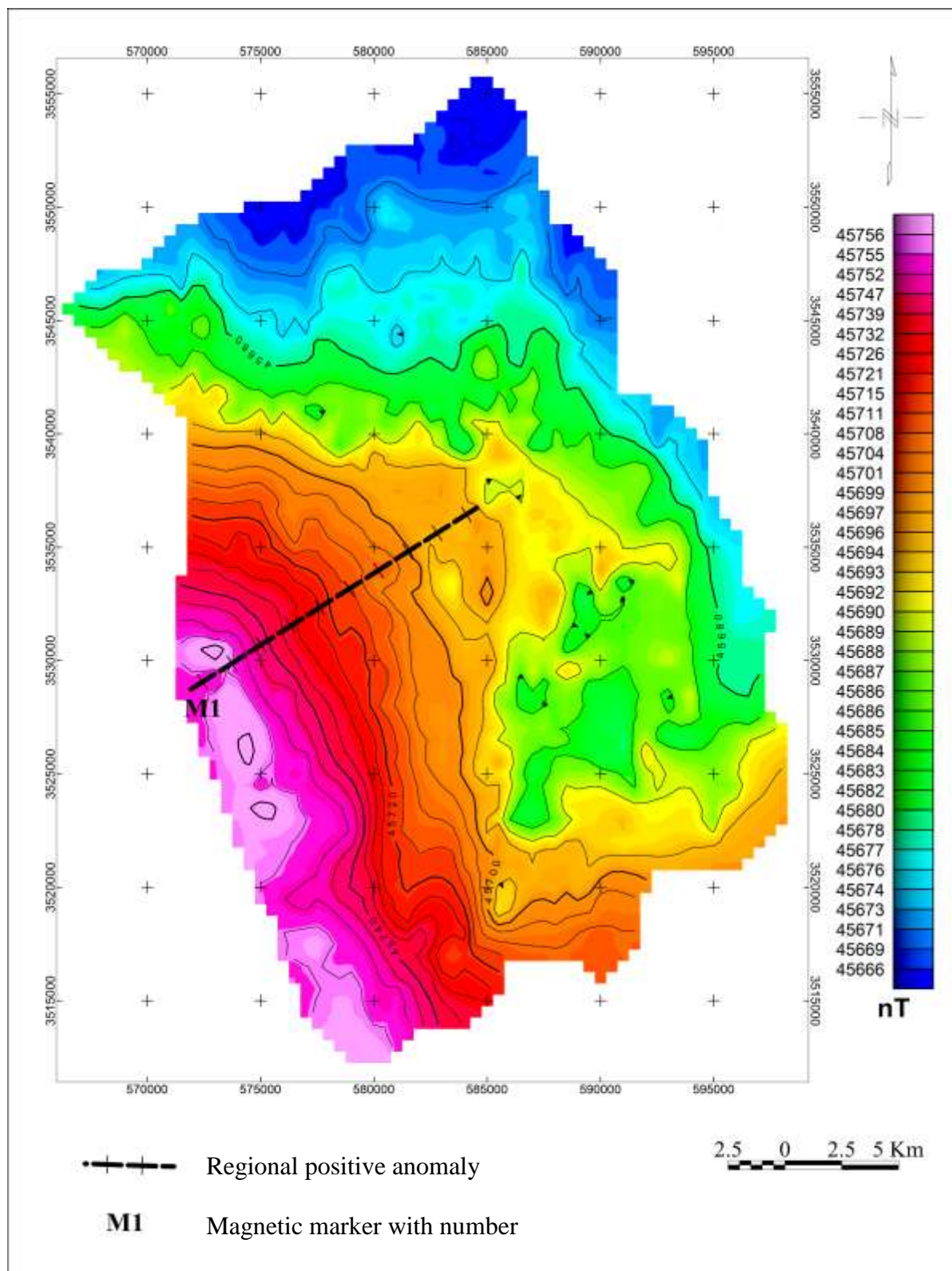


Fig.15: Reduction to the pole (RTP) map of the studied area. The axis of magnetic high M1 has been shifted to the north

CONCLUSIONS

The following conclusions are obtained from the forgoing qualitative analyses.

- Although, the present work is detailed gravity survey, the comparison between the present Bouguer anomaly map and UBG map (Figs.2 and 4) shows high matching, especially, in the regional picture or long wavelength anomalies. However, the resolution of the residual anomalies is much better in the present map.
- The intrusion (magnetic high) has no anomalous structures within the sedimentary cover that overlies the Permian surface. However, it could be a reasonable source of some paleostructures that appear at the Permian's depth map.
- The intrusion is older in age than Permian, more than 6 Km deep and it may be a vertical dipole.
- The regional gravity high has approximately the same shape, position and depth of the magnetic high, which means they appear to have the same source of a basement intrusion.
- The residual positive gravity markers (G2, G5, G6, G7 and G8), which are marked on the Bouguer gravity map, represent the suggested antiforms structures within the studied area.
- The residual or the Local Magnetic Anomalies (LMA) in the studied area, which almost related to Quaternary gray sand sediments, contain small quantity of magnetic minerals and cover many parts of the Mesopotamian Plain, and they may be the responsible source many near surface magnetic anomalies that appear in the aeromagnetic map of CGG (1974). The effect of the LMA can be easily recognized in the northern part of the aeromagnetic map of the studied area (Fig.1), where they disturb the contour lines evidently.
- Marker F in Fig. (12) may be delineated as due to deep seated fault, while the markers M2 and M3 are assigned to weakness zones in the same figure.

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