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Gravity Field Interpretation for Subsurface Faults Detection in A Region Located SW- Iraq

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Abstract

This research deals with processing and Interpretation of Bouguer anomaly gravity field, using two dimensional filtering techniques to separate the residual gravity field from the Bouguer gravity map for a part of Najaf Ashraf province in Iraq. The residual anomaly processed in order to reduce noise and give a more comprehensive vision about subsurface linear structures. Results for descriptive interpretation presented as colored surfaces and contour maps in order to locate directions and extensions of linear features which may interpret as faults. A comparison among gravity residual field , 1st derivative and horizontal gradient made along a profile across the study area in order to assign the exact location of a major fault. Furthermore, quantitative interpretations applied to residual field in order to detect the depth to the center of a major fault by adopting geometrical modeling. Interpretation results are helpful in delineating the exact locations of lateral changes within the subsurface rock densities around the subsurface major normal fault where sudden variations in gravity values take place. A major fault which extends in NW-SE direction detected at the eastern part of the study area with an approximate depth of 2.8 km to its plane center.

تفسير المجال الجذبي لغرض التحري عن الفوالق تحت السطحية لمنطقة تقع جنوب غرب العراق

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قسم الفيزياء، كلية العلوم للبنات، جامعة بغداد، بغداد، العراق

الخلاصة:

يتناول هذا البحث معالجة و تفسير بيانات شواذ بوجير الجذبية باستخدام مرشحات رقمية ثنائية البعد استخدمت في فصل الشذوذ الجذبي المتبقي عن الشذوذ الجذبي الاقليمي و لمنطقة تمثل جزء من محافظة النجف الاشرف في العراق. تمت معالجة الشذوذ الجذبي المتبقي بهدف تقليل الضوضاء و توضيح رؤية مفهومة قدر الامكان عن التراكيب الخطية تحت السطحية. تم عرض النتائج لغرض التفسير الوصفي بشكل خرائط كنتورية واسطح لونية ثنائية البعد و التي وضّحت اماكن تواجد و امتدادات التراكيب الخطية التي قد تمثل فوالق في طبقات تحت السطح حيث انها تمثل حدود يحصل عندها تغاير جانبي ومفاجيء بالقيم الجذبية. تم اجراء مقارنة بين المجال الجذبي المتبقي والمشتقة الاولى والتدرج الافقي على طول مسار يقطع منطقة الدراسة لغرض تحديد موقع الفالق بدقة. بالاضافة الى ذلك، تم اجراء تفسير كمي لأحد الفوالق الرئيسية المقترحة في منطقة الدراسة من خلال تبني طريقة الموديل الهندسي. كانت نتائج التفسير ذات فائدة في تحديد المواقع الفعلية للتغايرات الجانبية والمفاجئة في كثافات الصخور تحت السطحية على جانبي فالق رئيسي في المنطقة. تم تخمين وجود فالق رئيسي يمتد بالاتجاه شمال غرب–جنوب شرق عند الجزء الغربي من منطقة الدراسة وقد بينت نتائج التفسير الكمي بأن العمق التقريبي الى مركز مستوى الفالق هو 2.8 كم.

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Introduction

For many years, gravity method have been used to study geological structures, which vary in depth and size from very deep crustal blocks to near-surface ore bodies. In general, large regional variations in the Bouguer gravity related to changes in the thickness of the earth's crust or are due to large-scale mass inhomogeneities, while local anomalous gravity values are attributed to near-surface inhomogeneities. Negative anomalies are indentified with sedimentary basins, salt, granitic bodies, and graben faults; and positive anomalies are identified with uplifts, horsts, and mafic rock masses. The gravity method could be applied on various problems related to regional and local subsurface structures. At the same time, despite the problem of ambiguity in interpretation, gravity anomalies can give highly meaningful information about the subsurface structures and density distributions [1].

The gravity method is helpful in assigning locations of lateral variations within the subsurface rock densities and to detect the geometry of buried bodies and their mass distribution. The results of gravity data interpretation are useful for some engineering and environmental goals. Some of gravity method applications are: finding the thickness of sedimentary rocks cover over basement rocks, detecting buried channels, cavities and sinkholes, and detecting fault locations [2].

The current study aims to use some processing methods to detect locations of subsurface sudden density variations related to subsurface structures, which are mainly faults. This could be maintained by applying some noise reduction 2D-filtering techniques, in order to clarify such features. Also , the quantitative interpretation of residual gravity anomaly along a profile that pass over major expected faulting location in the region used to give more information about its subsurface features.

Location of the study area

The study area is located within the stable shelf of SW Iraq, and bounded by the coordinates: longitudes (42°54`00`_43°39`37\\ E) ; latitudes (31°00`00`_31°44`00`N). The study area covers Wadi Al-Khir region at Al-Najaf Ashraf province close to the boundaries of Saudi Arabia. The area is calculated according to map scale, to be about (5100 Km^2). Figure-1 shows the study area location and its surface geology.

Geology of the Study Area

According to [3], the geological map of Iraq, the near surface or exposed rocks, Figure-1, are divided into:

1- Most of the eastern part of the region is covered by Dammam Formation rocks that belong to middle Eocene which are mainly composed of dolomite, limestone and marlstone and appear in dark yellow on Figure-1.

2- Most of the western part of the region is covered by Jamal and Dammam Formations which are mainly composed of chalky and organic detrital limestone rocks that belong to lower Eocene and appear in pink color at the geological map of Figure-1.

3- At the western part Akkashat and UmRdhima Formations expose in some spots (brown) in map of Figure-1. Its composed of fine detrital limestone, dolomite, dolomitic limestone and its upper parts composed of chert and phosphate rocks that belong to Paleocene.

4- At the SW part of the region Ghadaf rocks are exposed which belong to middle and upper Miocene and appear in pale yellow in the map of Figure-1.

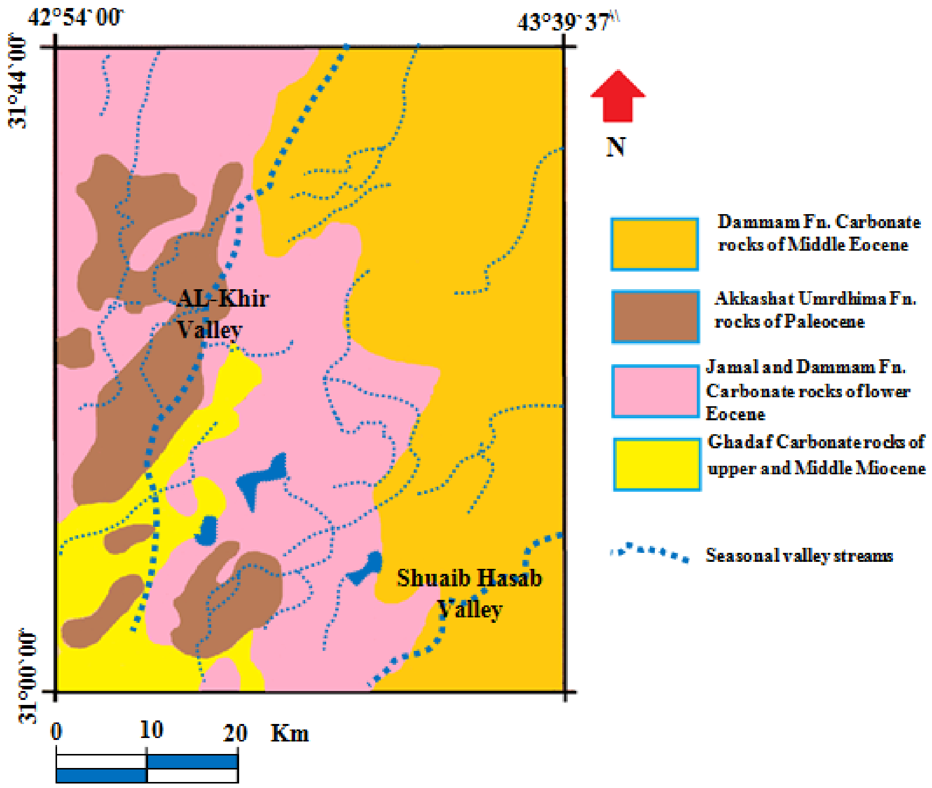

Figure 1- Geology of the study [3], modified

The region could be divided according to the type of basement rocks as in Figure -2. The basement rocks in the study area are divided according to the observations on the map of Figure-2, into [4]:

1- The western part that covers about (50%) of the study area and represents low density basement rocks which appears in green color. It consists of phyllite (metamorphic rocks).
2- The eastern part which covers about (45%) of the study area represents high density basement rocks which appear in light pink, it consists of phyllite, schist (metamorphic rocks), and granodiorite (igneous rocks).

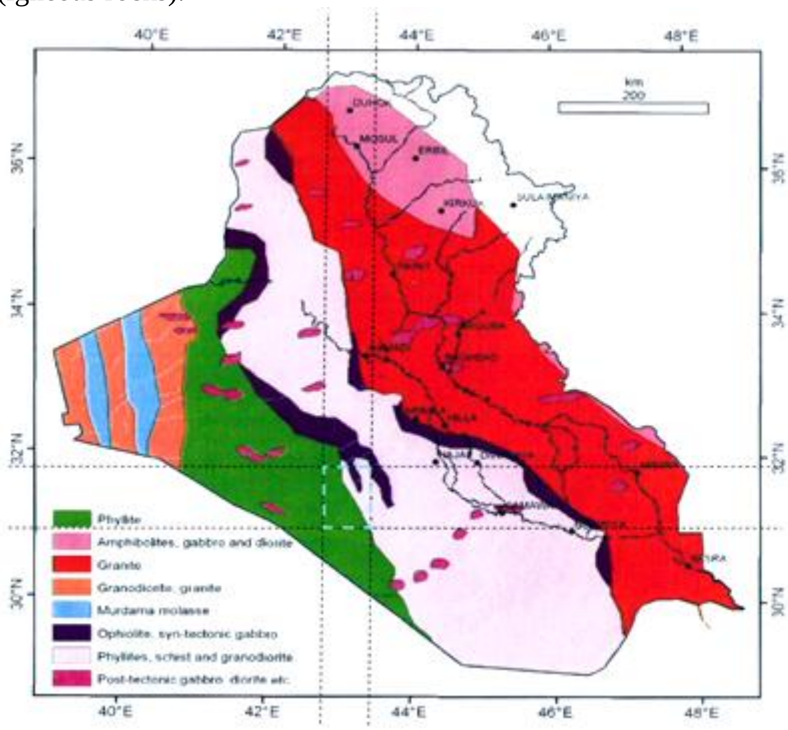

Figure 2- Basement Rocks of the study area,[4], modified.

3- The northeast part covers about (5%) of the study area and has higher density and appear in a form of tongue with dark violet . It consists of ophiolite and gabbro rocks.

The major fault zones in the region are the NW-SE Najad fault system, and the NE-SW transversal system. Furthermore, five major transversal blocks are identified which bounded by transverse faults. The three major fault systems are the N-S Nabitah (Idsas) system, the NW-SE Najad system and the NE-SW or E-W transversal system. These fault systems formed during Late Precambrian Nabitah Orogeny. They were re-activated repeatedly during the Phanerozoic [4, 5].

Methodology

Gravity anomalies whose wavelengths are long relative to the dimensions of the geologic objectives of a particular investigation are called regional anomalies. Regional anomalies are usually thought to reflect the effects of relatively deep features. Anomalies whose wavelengths are small relative to the dimensions of the geologic objectives of a particular investigation are called local anomalies. In the processing of gravity data, it is usually preferable to attempt to separate the regional and local anomalies prior to interpretation. The regional anomaly can be estimated by employing a variety of analytical techniques. Once this is done, the simple difference between the observed gravity anomalies and the interpreted regional anomaly is called the residual anomaly. The techniques used to separate regional and local gravity anomalies take many forms and can all be considered as filtering in a general sense. Many of these techniques are the same as those employed in enhancing traditional remote sensing imagery. The process usually begins with a data set consisting of Bouguer gravity anomaly [6].

All data are subjected to gravitational order of processing called qualitative interpretations. The qualitative interpretation studies the gravitational intensity and extensions to explain the nature of certain structural phenomena such as fault, folds , salt domes, and others. Gravity data interpretation also includes the separation of gravity anomaly compounds (regional and local gravity fields) and the digital processing of those fields in order to improve the 2D-signal, or to highlight the various subsurface structural features and to assign the hidden boundaries of such structures. The Graphical residual anomaly formula is: Residual gravity anomaly = (Bouguer gravity anomaly - regional field). The calculation of regional anomaly attended by applying the Polynomial Surface Fitting , then presenting results of the residual field as contour map and colored surfaces.

The directional derivative provides information about the slope, or rate of change of slope, of the gridded surface in a specified direction. Because this takes a specified direction into account, this slope, or rate of change in slope, might not be the steepest slope at a given point. For example, if the specified direction is due East, but the gradient is due North, the directional derivative slope is zero at that point. In the specified direction, there is no slope at that point, although there is a slope to the North. In directional derivative the values given are the direction of the slope which defined as the gradient, or the direction of steepest ascent at a given point (i.e., straight uphill at that point). In the above example, the model would report the slope in the north direction at that point. The two methods would report different values at that particular point on the grid [7].

The Bouguer anomaly map of Iraq is published by GEOSURV, Figure-3 .Only the concerned part of the study area was processed. The gravity data were reprocessed and interpreted to give a better view about subsurface features by applying modern filtering software, then interpreting the given maps qualitatively to identify proposed subsurface structural features.

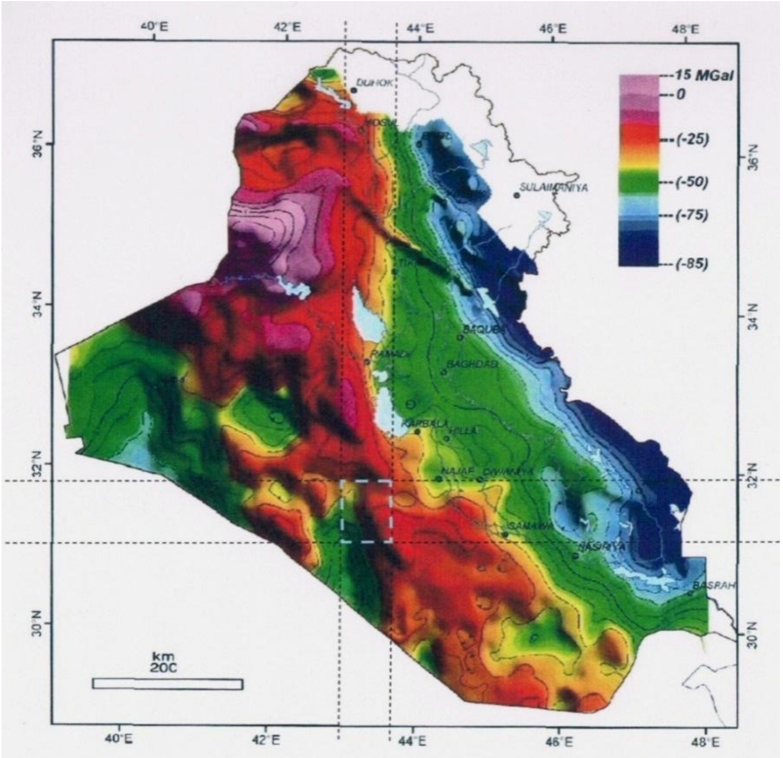

Figure 3- The Bouguer anomaly gravity map of Iraq showing the study area (Jassim and Goff, 2006) modified.

Gridding the Bouguer Anomaly original map of the studied area has been done by using (4.3 x 4.3km) grid squares. Nodes used to draw a new total Bouguer anomaly map for 280 manually picked nodes using computer mapping software [7, 8]. By subtracting map data of Figure-4b from map data of Figure-4a, the resulted residual anomaly obtained as it shown in Figure-5.

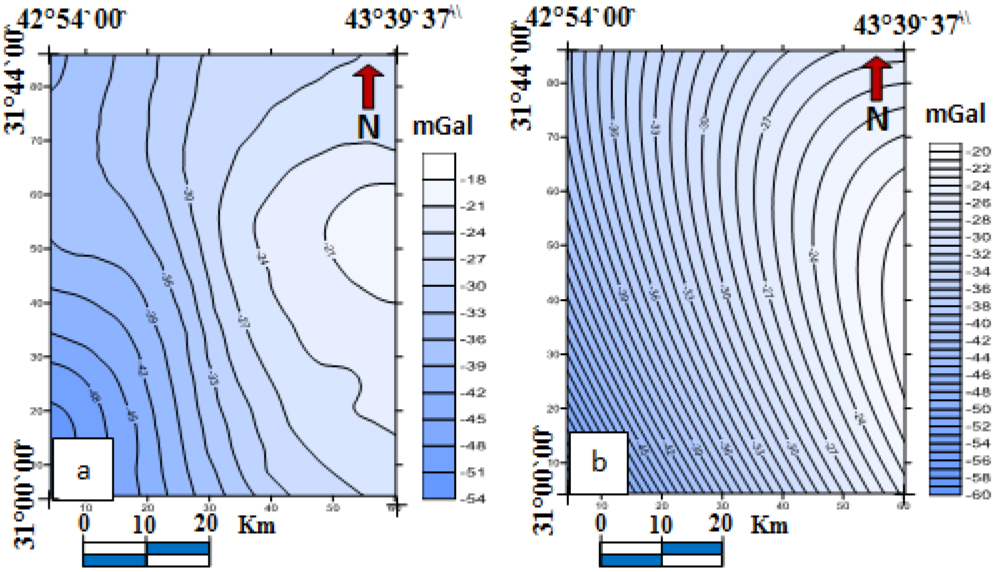

Figure 4- a) the total gravity anomaly field ; b) the regional gravity anomaly field

The locations between sharp positive and negative residual anomalies (areas of high density in contour lines) assign the locations of sudden variation within the subsurface rock densities (limits of density contrast) which are mainly proposed to be fault locations (showed in blue lines) in Figure-5b. Actually these blue lines expected to represent the boundaries of a typical graben structure which appears clearly in the 3-D presentation, (green color), of Figure-5a.

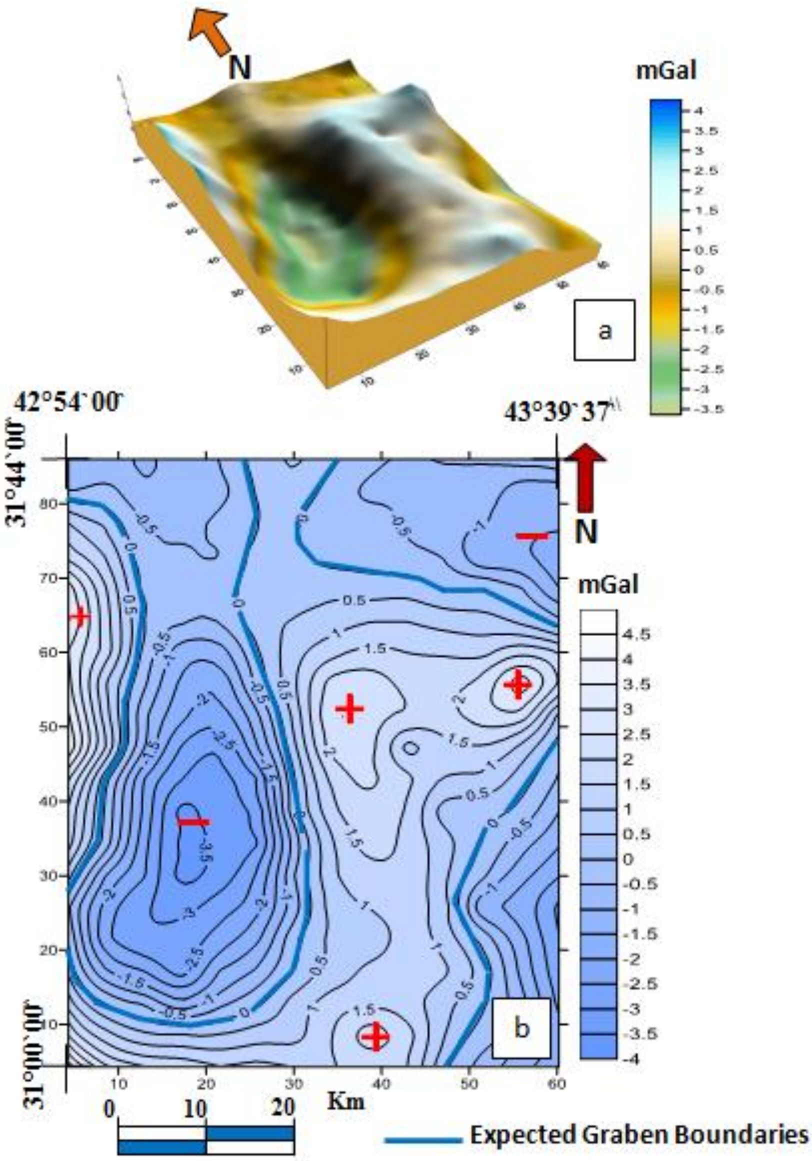

Figure 5- The Residual gravity anomaly: a) as a 3D- surface showing a typical graben structure; b) as a contour map showing the graben boundaries of zero value contour lines.

The 1st derivative filters have been applied to the residual anomaly in order to assign linear limits or faulting line directions. Directional derivative applied toward NE-SW.

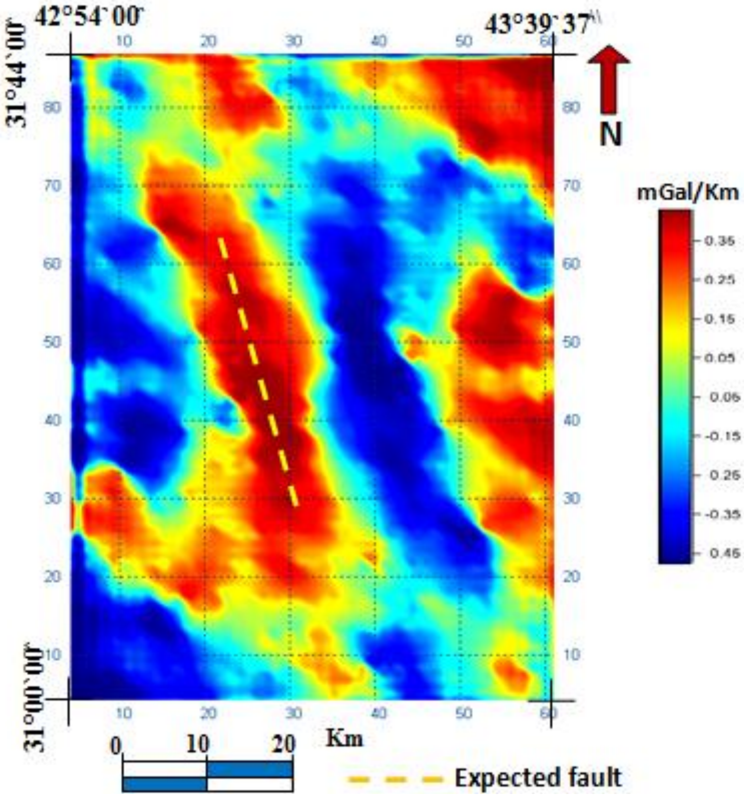

Figure 6- The horizontal gradient for the residual anomaly showing the probable faulting line over maximum values.

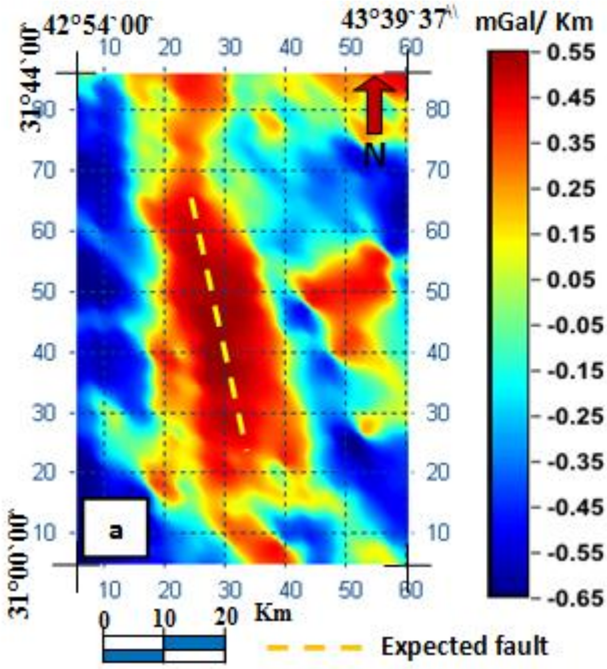

Figure 7- a) The 1st directional derivative for the residual gravity anomaly with the direction NE-SW showing the probable major fault line.

With the help of Surfer and MagPick softwares, gradient operator map was helpful in detecting the location of a major fault over the maximum values which appear in dark red as it shown in Figure-6.

The Figure-7 shows the 1st derivative map which was helpful in detecting the location of the expected major fault line (yellow disconnected line).The Figure-8a shows main limit of sudden variation between the residual gravity field from maximum to minimum. This limit assigned on the map with a blue disconnected line which proposed as a deep seated fault ,and also assigned as a red disconnected line over the maximum gradient values of the horizontal gradient map of Figure-8b.

According to reference [2], the location between maxima and minima of the residual anomaly expresses the actual location of the fault.

A comparison made among residual field, 1st derivative and horizontal gradient as they plotted with distance along the profile (A-A/) line to assign the location of the major fault, as it shown in Figure-9.

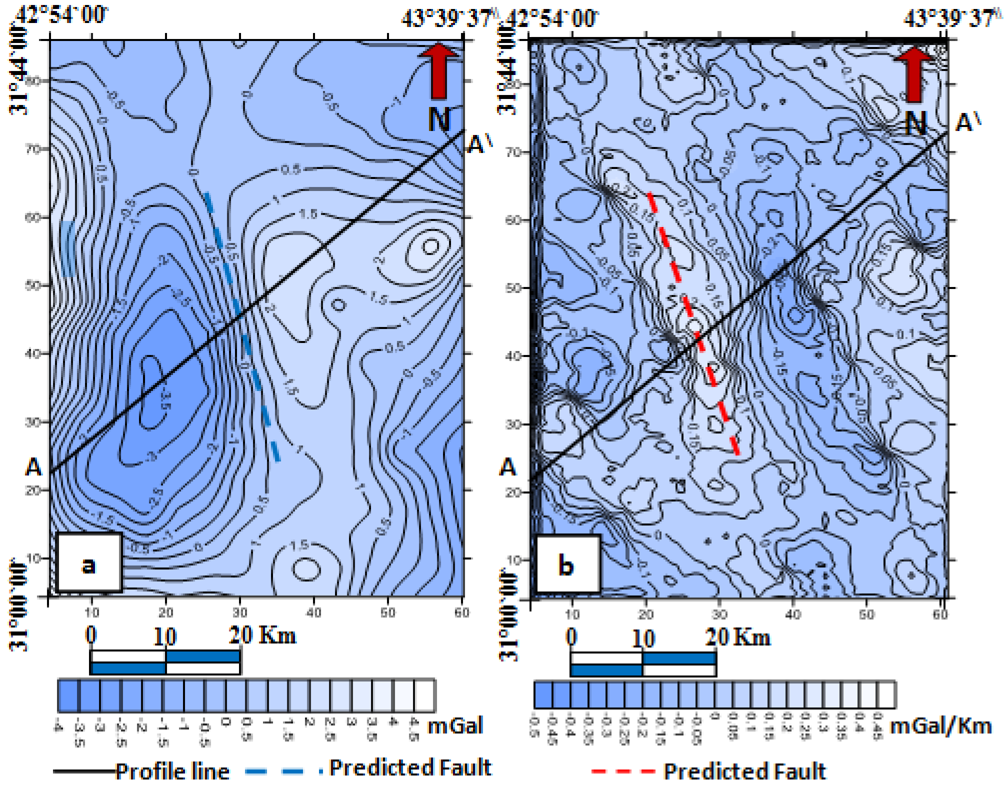

Figure 8- a) The residual gravity anomaly map showing the profile line A-A\ , and the predicted major fault line ; b) the horizontal gradient map.

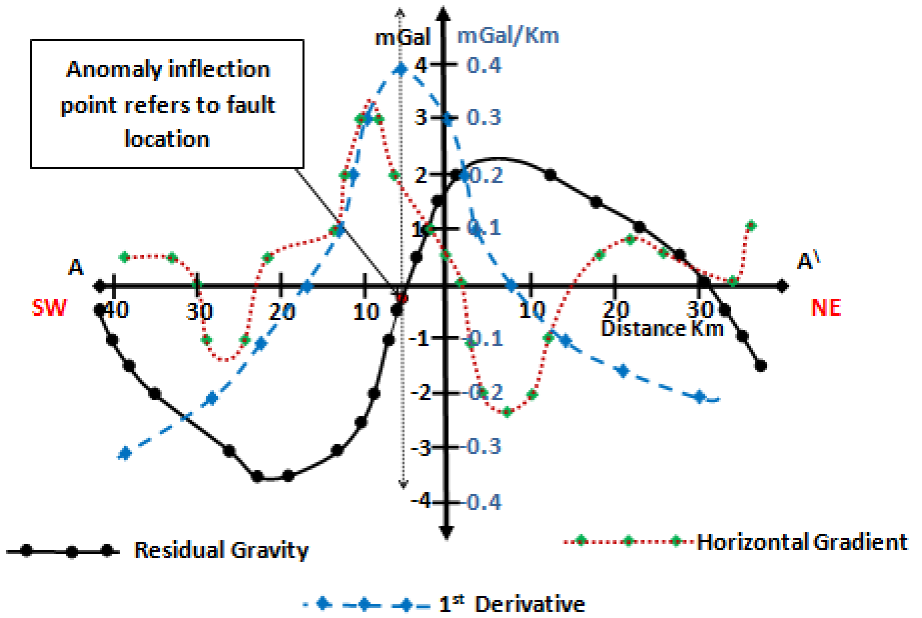

Figure 9- a comparison among the gravity residual field , 1st derivative and horizontal gradient along the profile A-A\ , showing the expected location of the major fault.

The residual anomaly shows positive maxima of about 2.2 mGal toward NE and negative minima of -3.6 mGal toward SW. Above the proposed fault location exactly, the fault plain point divides the residual anomaly into two symmetrical parts at its inflection point Figure-9.

For a gravity anomaly over fault trace, the total change in gravity (Δg_{max}), is located at its half value, Figure-10. The depth (z) represents the horizontal distance when the anomaly changes from ($0.5\Delta g_{max}$) to ($0.25\Delta g_{max}$). If its considered that (t<z), were (t) is the thickness of the slab which produces the anomaly, and (z) is the depth to the median plane ot the slab. The resulting gravity will be[1,9]:

$$(G \, \Delta\rho t)\phi \qquad \textbf{(1)}$$

where: G= gravity constant, $\Delta\rho$= density contrast kg/m^3, ϕ=solid angle subtend the slab at the point of observation.

If the slab considered as a semi –infinite sheet, the solid angle will be 2ϕ, hence the gravity effect Figures-10 and11, becomes [1,9]:

$$\Delta g = 2Gt\,\Delta\rho\phi = 2Gt\,\Delta\rho\left(\frac{\pi}{2} - \tan^{-1}\frac{x}{z}\right) \qquad \textbf{(2)}$$

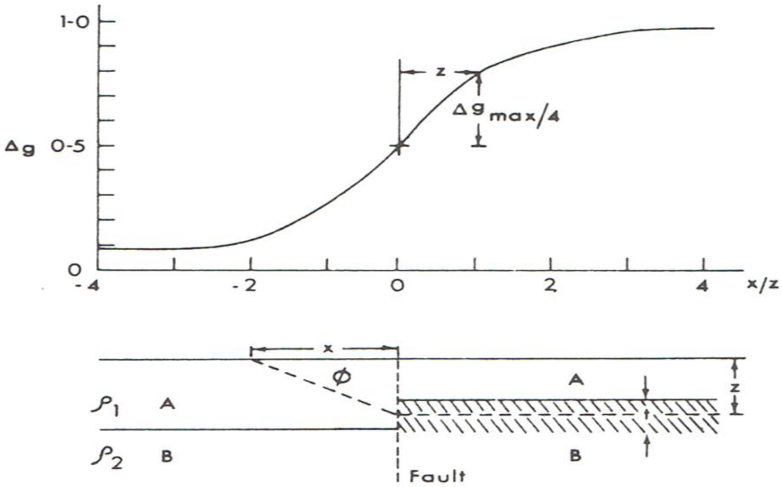

Figure 10- Gravity anomaly across a fault. Over fault trace the total change in gravity (Δg_{max}) represents its half value. The horizontal distance over which the anomaly changes from $0.5\Delta g_{max}$ to $0.25\Delta g_{max}$ is a measure for the depth Z, after [1].

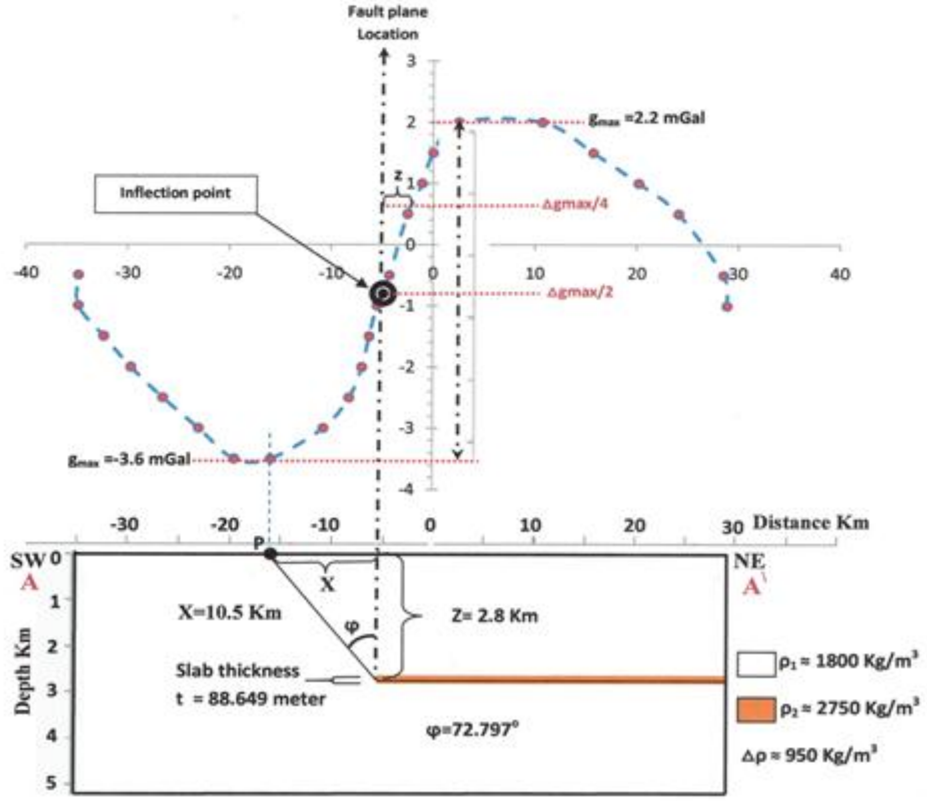

Figure 11- The geometrical model for the residual gravity anomaly along the profile (A-A$'$) showing the quantitative interpretation of the expected major fault.

It was considered that the dense rocks which produced the positive anomaly are composed of compact limestone, then it has a density of about (2.75 kg/m^3) ,and the surrounding less density sedimentary rocks which are composed of sandstone, perforated limestone and evaporates have an average density of (1.8 kg/m^3) according to reference [10] tables. Therefore $\Delta\rho$ calculated to be about (950 kg/m^3).

Conclusions

The positive residual gravity anomaly at the western part of the region is may due to a major fault extending with the direction NW-SE to separate between major positive and negative anomaly parts. The horizontal gradient and 1st directional derivative 2D- surfaces were helpful in visualizing the locations of the subsurface dense bodies. Comparison among gravity residual field, 1st derivative and horizontal gradient along the profile A-A$^{\backslash}$ across the area was helpful in assigning the exact location of fault plane center. Quantitative interpretation results refers that the depth to the major fault center is about 2.8 km, and the thickness of the dense slab that produced the anomaly is about 88.649 meters.

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