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Gravity Field Interpretation for Faults Detection At Al-Ghadaf Valley West Razazzah Lake – Iraq

Wadhah Mahmood Shakir Al-Khafaji [1]*, Khader Salam Turki[1], Anfal Muhaimin Khaled[1] and Zainab Hamza Jaafjir[1]

[1]*Department of Geophysics, College of Remote Sensing and Geophysics, Al-Karkh University of Science, Baghdad, Iraq.*

Abstract

This research deals with the processing and interpretation of Bouguer gravity anomaly field for Al-Ghadaf valley region, which located to the west of Razazzah Lake of Iraq. Total Bouguer field gridded manually and input to computer software to get processed digitally in order to detect the subsurface structural setting which was responsible of producing the positive gravity anomaly in the middle of the region. Regional gravity field was conducted by using the polynomial regression graphical method. Residual field was conducted mathematically and was helpful in detecting the boundaries of abrupt change in gravity or density at the sedimentary cover depths. The abrupt density variation linear features are mostly representing faults. A directional 1stderivative filtering applied on the residual field in order to assure the locations of linear features (faults) which were showing abrupt variation in density. Quantitative interpretation achieved for the profiles (A-B and C-D) which were taken for the residual gravity field and depth to the center of the causative body was calculated by applying the X1/2 method to be about (21-25 Km).

1. Introduction

The aim of most gravity surveys is to detect the subsurface geology by investigating the variations of Earth's gravitational field which produced by differences of density between subsurface rocks. An underlying concept is the idea of a causative body, which is a rock unit of different density from its surroundings. Gravity anomalies are conventionally displayed on profiles or as contoured Bouguer anomaly maps. Interpretation of the latter may be facilitated by utilizing digital image processing techniques similar to those used in the display of remotely sensed data. In particular, color and shaded relief images may reveal structural features that may not be readily discernible on unprocessed maps. This type of processing is also appropriate to magnetic anomalies. Usually in gravity surveying the local anomalies that are of prime interest and the first step in interpretation is the removal of the regional field to isolate the residual anomalies. These anomalies are elongated in one horizontal direction so that the anomaly length in this direction is at least twice the anomaly width. Gravity interpretation proceeds via the methods of direct and indirect interpretation (Kearey al., 2002)

The gravity method is based on the observation of changes in the gravitational field caused by horizontal variability of density within the subsurface. This method has been extensively used in Iraq to delineate subsurface structures such as salt domes, faults, and sedimentary basins.

* Email: wadhah.mah@kus.edu.iq

The gravity method is also used to determine the depths of the bedrock and the distribution of different densities in sedimentary layers, which helps in understanding the tectonic history of the region and assessing the potential for natural resources such as groundwater, (Jassim and Goff,2006).

Interpreting gravity data requires the application of analytical techniques such as the calculation of first and second derivatives, the use of frequency filtering to separate signals, and numerical modeling to construct three-dimensional representations of geological structures. Although the gravity method offers extensive data coverage at a relatively low cost compared to other geophysical methods, its results are often non-unique. Therefore, integrating gravity data with geological information or other geophysical datasets is essential to achieve more accurate and reliable interpretations. (Telford, Geldart, & Sheriff, 1990).

Several analytical methods of regional field analysis are available and include trend surface analysis (fitting a polynomial to the observed data). The lateral variations of gravity readings on earth surface reflects the lateral density contrast of subsurface rocks which considered as a prime interest for the geophysicist to extract information about the subsurface geological structures at various depths .This information is always subject to a certain ambiguity in the interpretation of gravity data; therefore, this ambiguity could be reduced by assisting gravity data with other geological and geophysical data from additional studies performed previously on the gravity surveyed area (Al-Khafaji., 2019).

The objective of this study is to interpret the Bouguer gravity anomaly particularly for Wadi Al-Ghadhaf area. it is located to the west of Al-Razzaza Lake. In order to better understand the anomaly and its details according to the subsurface structural point of view. Computer software was utilized to generate a series of maps that aid in the analysis and interpretation of the observed data.

The research includes the generation of gravity derived maps by using multiple digital filtering approaches. The primary goal of processing the total gravity field is to detect both shallow and very deep gravitational sources. Following that, the regional field is used to investigate the depth to center of basement rock structure (anticline) in the middle part of the study region. Linearly extended geological structures which are mainly faults within the sedimentary cover and some which extends deeper through the basement crustal rocks require to be detected according to density lateral and vertical variations within the region.

It is required to separate the Bouguer gravity residual field in order to understand the density lateral and vertical variations with depths related to sedimentary cover rocks and basement rocks within the study region. High gradient located on the zero contour lines of the residual Bouguer anomaly assures the locations of linear features extension in the region which mainly represent faults.

The directional derivative 2-D filtering techniques were also applied in the analysis of the residual field as the following:

-The 1st directional derivative highlighted the contrast between high and low gravity values, indicating zones of significant variation which are mainly faulting locations.

-The 2nd directional derivative pinpoints the locations where these variations begin and ends, this referring to the start and end effect linear locations of faults.

When applying the directional derivatives rule of thumb is considered that derivative direction must be taken perpendicularly to the elongation direction of the residual gravity anomalies in the region.

In directional derivative maps, anomalies of high gradient elongated anomalies between maximum and minimum values of the processed residual field are particularly useful to locate faults extension. This is because faults typically represent boundaries between two rock blocks where certain displacement took place and showing detectable density contrast around.

2. Materials and working methods

2.1 Location and Geology of the Study Region

The concerned region of interest is bounded by the decimal coordinates: long.:42.5W-43.5E; Lat.:32.25S-33.5N. Al-Ghadhaf Valley region includes a seasonal river which located to the west of Lake Razazzah. Razazzah itself lies between the provinces of Karbala and Anbar, approximately 15 kilometers north to the city of Karbala and to the northeast of the city of Ramadi of Anbar Province. Figure1 shows the location of the study region on the longitudinal tectonic zones of Iraq map (Jassim and Goff,2006).

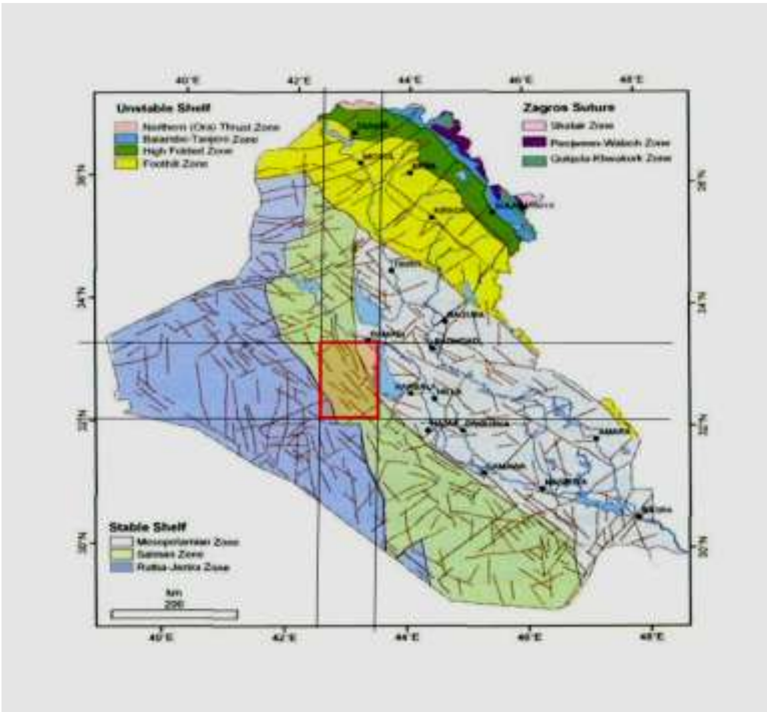

Figure 1: The study region according to the longitudinal tectonic zones of Iraq showing that study region is located at AL-Salman Tectonic zone and the prominent fault s direction is in NW-SE Direction (Jassim and Goff, 2006 modified)

Al-Ghadhaf Valley (Wadi Al-Ghadaf) is located at the western desert of Anbar in Iraq. It represents a seasonal valley that flows into the Euphrates River during rainy seasons. Geologically, the valley passes through various rock formations from different geological eras, making it an area of geological and hydrological significance**.**

According to geological studies of the western desert of Iraq, the valley passes through several rock formations, Figure 2 shows a geological section passing through the region and published by (Jassim and Goff,2006), the main rock formations in the region includes:

• Ratga Formation: Primarily composed of carbonate rocks from the Eocene epoch.

• Euphrates Formation: Composed of carbonate rocks dating to the Miocene epoch.

• Ghar Formation: Also made up of Miocene carbonate rocks.

• Nfayil Formation: Contains Miocene carbonate rocks.

• Um Er Radhuma Formation: Composed of Paleocene carbonate rocks.

• Dammam Formation: Eocene carbonate rock formation.

These formations are characterized by the presence of carbonate rocks such as limestone and dolomite, which are subject to karst processes, resulting in karstic features like caves and stalactites. These formations play a major role in the area's hydrogeological system, serving as important aquifers (Sissakian, 2000).

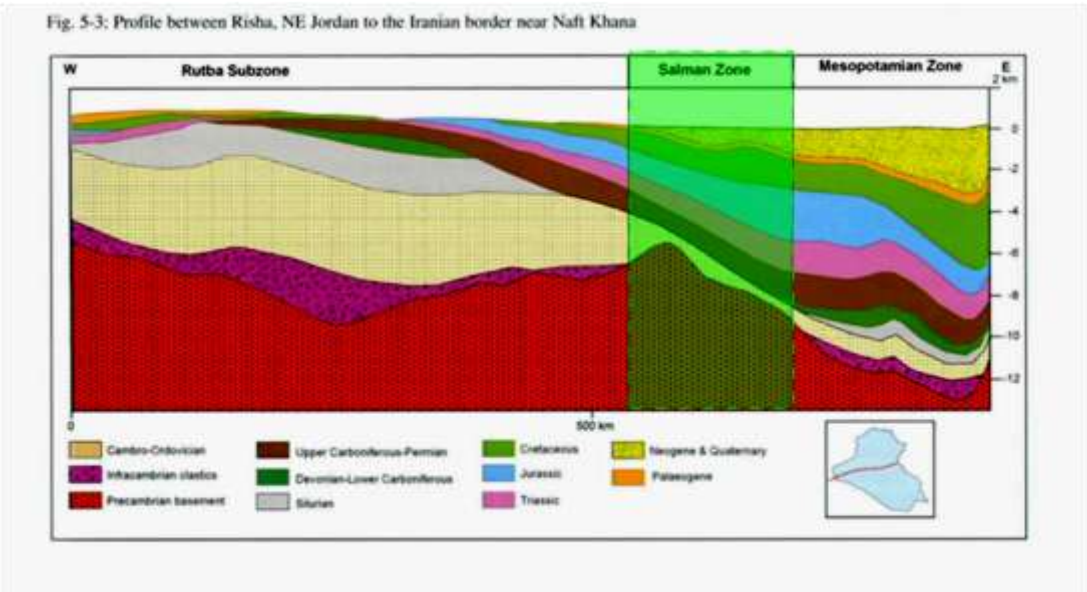

Figure2 2: A Geological section between Risha, NE Jordan to the Iranian border near Naft Khana passing through the study region, the section passes through the study region in the NE-SW direction, the highlighted part of the section represents the Stratigraphic sequence in the region (Jassim and Goff, 2006) modified.

Wadi Al-Ghadaf is located in the western desert of Iraq, specifically within Al-Anbar Governorate. It is a seasonal Wadi that flows into the Euphrates River during the rainy season. Geologically, the valley passes through formations from various geological eras, making it a region of significant geological and hydrogeological interest**.** By observing maps of,(Figures 1 and 4). One may observe the faulting traces which affected the region of interest. Mostly, folding and faulting structural features are produced by the effect of tectonic force which is mainly act in the direction SW-NE.

The area through which Wadi Al-Ghadaf flows is classified as part of the Inner Stable Platform of the Arabian Plate. This region is characterized by relatively undisturbed horizontal or sub-horizontal sedimentary layers that date back to the Paleozoic and Mesozoic eras.

Although the region is considered tectonically stable, some minor structural features exist:

• Minor folds: These occur in certain parts of the western desert, but they are much less developed compared to those in the Zagros Fold Belt.

• Ancient faults: Some faults dating back to older geological periods exist, though there is no evidence of recent tectonic activity.

The Figure 3, shows the tectonic map of Iraq where the study region boundaries were superimposed to show the prevalent structural features in the region of interest.

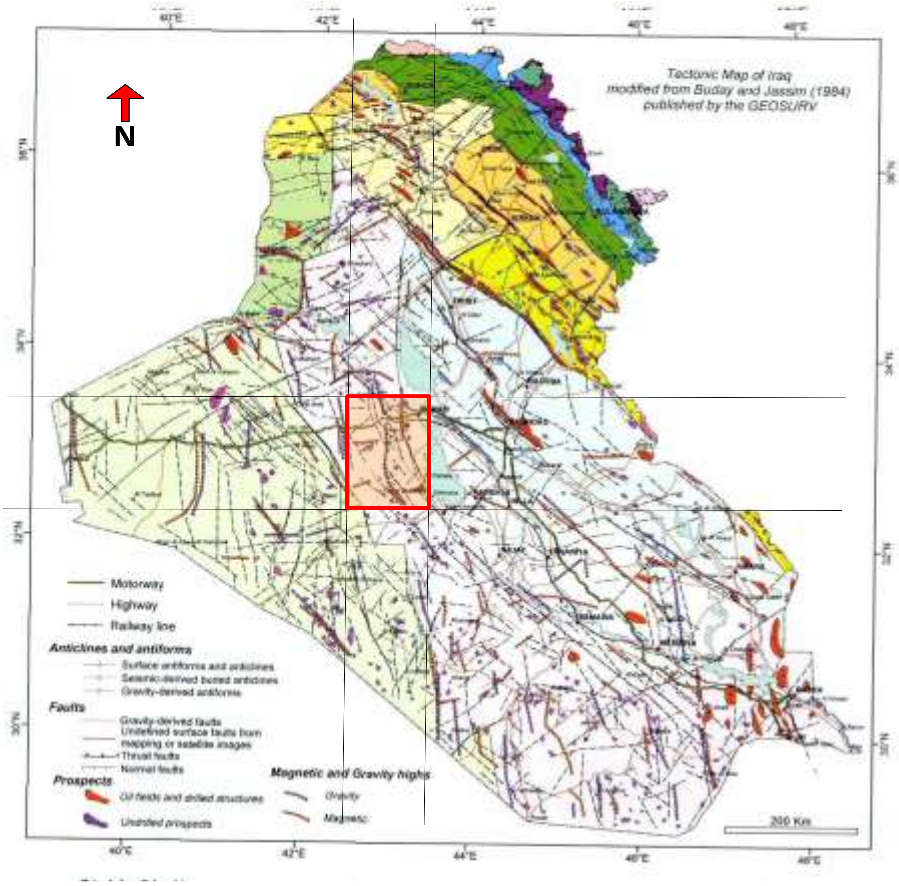

Figure 3: The study region according to the tectonic map of Iraq showing the prevalent structural features and the prominent fault s direction is in NW-SE Direction (Jassim and Goff, 2006 modified).

Geophysical studies are among the most important modern methods for understanding the geological structure of the Earth. One of the most prominent tools in this field is gravity mapping, which is used to detect variations in the Earth's gravitational field caused by subsurface density contrasts. These maps enable the identification of gravity anomalies that may indicate geological features such as faults or various rock bodies. (Telford, Geldart, & Sheriff, 1990).

In this study, the specialized software Surfer will be utilized for the visualization and analysis of geographic and geophysical data, with the aim of generating a gravity map that highlights the positive gravity anomaly observed in Wadi Al-Ghadf. This anomaly represents a significant feature for investigating the geological structure of the area. The available gravity data will be analyzed, gravity contour lines will be drawn, and the results will be interpreted to contribute to a better understanding of the region's geological nature and to provide a preliminary insight into potential subsurface structures.

2.2 Data Processing

Gravity data were obtained from the [Iraqi GEOSURV, Bouguer anomaly map of Iraq], a dedicated copy for scientific research with 1:1000000 scale to Al-Karkh university of Science / College of Remote Sensing and Geophysics/ Department of Geophysics.

Computer Software used to analyze the attraction data and email correspondence. This software allows masking of geophysical data to create high-resolution contour maps. The manual Grid of the original map made with a mesh of 5X5 Km in order to get digitized and prepared to input to computer as excel sheet.

The total Bouguer surface built by computer software, (Figure 4). It represents the gravitational field for both deep basement rocks and shallower sedimentary cover rocks. Regional Bouguer gravity map, (Figure 5) represents the gravitational field of the basement rocks. Residual Bouguer gravity field map, (Figure 6) is the residual Bouguer gravity field which reflects the field of the sedimentary cover thickness. The usefulness of profiles is to find the depth to the center of the causative bodies. The profiles are taken perpendicularly to the elongation direction of the anomaly. Later, profiles were interpreted by adopting the $X_{½}$ method in order to find the depth to the center of the causative body in the region which represents subsurface anticline within the basement rocks.

The derived Total Field Map. (Figure 4), represents gravity anomalies resulted by the summation of both deep and shallow subsurface sources field. A central positive anomaly is observed, and may mostly refer to the uplifted basement rocks due to major folding action (regional scale Anticline stroked by different directional faults) depicted in light blue, figure 5.

The broadened positive anomaly, suggests the presence of a high-density subsurface structure, which may correspond to basement uplift or anticline structure due to the folding action of the tectonic force. The sharp gravity gradient toward the northeast indicates the presence of a tectonic boundary (yellow color) which detected by previous studies as the location of Abu-Jir major fault.

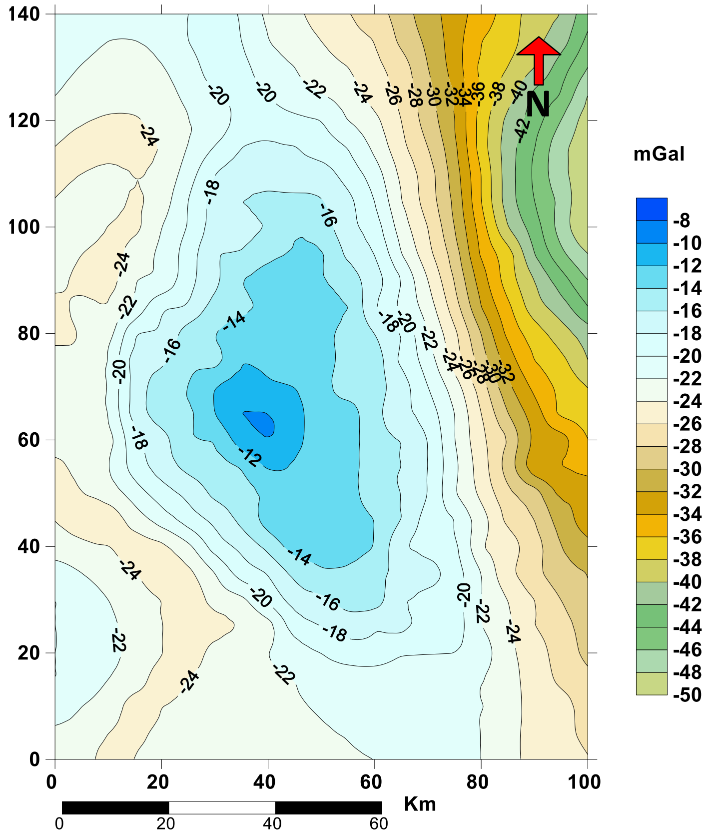

Figure 4: The digitized total Bouguer anomaly map of the study region built by computer mapping software.

2.3 Regional and Residual Gravity Anomalies

The gravity anomaly of regional field appears as a broadened one with an extension that covers a large area, and considered as regional anomaly. Geological formations or structures of closer to surface depths have relatively limited dimensions and gives multiple minor sharp anomaly, while deep structures gives low amplitude and smooth surfaced anomalies of vast area coverage. The studied region shows anomalies consisting of both (local minor anomalies and regional major anomalies). The isolation of local anomalies is of interest for exploration purposes and gives information about structures located within the depths of the sedimentary cover over the basement rocks; on the other hand, regional anomalies are important in studying density variation across earth's crustal rocks.

The regional trend appears in the gravitational map as a regular difference represented by parallel and equidistant contour lines, (Figure 5), it represents the regional Bouguer anomaly field, and the residual anomaly field could be derived by subtracting the regional field from the total field., (Figure 6).

Polynomial Regression is used to define large-scale trends and patterns in data. It doesn’t interpolate data because it does not attempt to predict unknown mGal values (Surfer ,2015). Therefore, regional field map, Figure 5, Highlights large scale and subsurface deep basement geological features. A gradual increase in gravity values is observed toward the northeast direction. This pattern suggests a progressive increase in subsurface rock density in the northeastern direction, which could be attributed to the uplift movement of deep basement rocks, or Proximity to a zone of crustal thickening or major geological features, such as dense sedimentary basins or ancient continental shields and majorly extended faults.

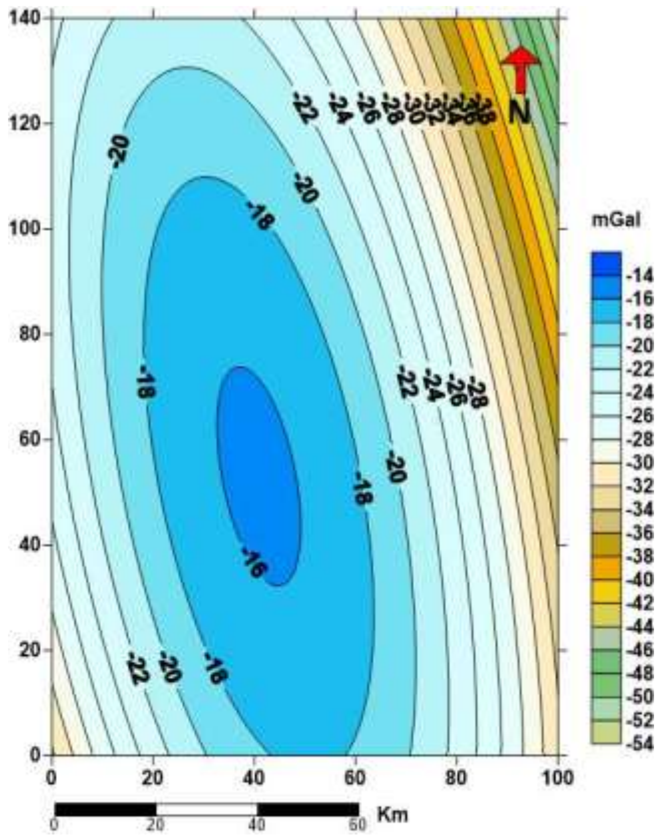

Figure 5: The derived regional gravity field after applying the polynomial regression 2nd Order. It shows the gravity field related to deep basement rocks in the region.

The deduced residual field is the concerned field in the current study. This field reflects the structures related to the depths of the sedimentary cover which overlays the basement rocks. Some of these structures may represent important structures economically, because they may form petroleum traps. One may observe the detected structural features which are mostly the high density contrast linear boundaries over the zero-line contour of the residual field, figure6. The zero-line contours refer to the locations of density highest gradients located exactly at the mid-distance between the maximum and minimum anomalies and represents the density contrast linear features which are mainly faulting or folding limb locations **(**Toushmalani, 2010).

The residual field map emphasizes local anomalies by removing the regional field component. It represents the anomalies related to the rock bodies of the sedimentary cover overlaying the basement rocks and represents the cornerstone of interpreting the subsurface structures which are mainly faults, fold axes or limbs…. etc.

Zero contour line (red), Figure 6, gives a preliminary vision about the linear features of subsurface density contrast. Such linear features represents a probable faulting locations which marked as (black disconnected lines) in the map of figure6.

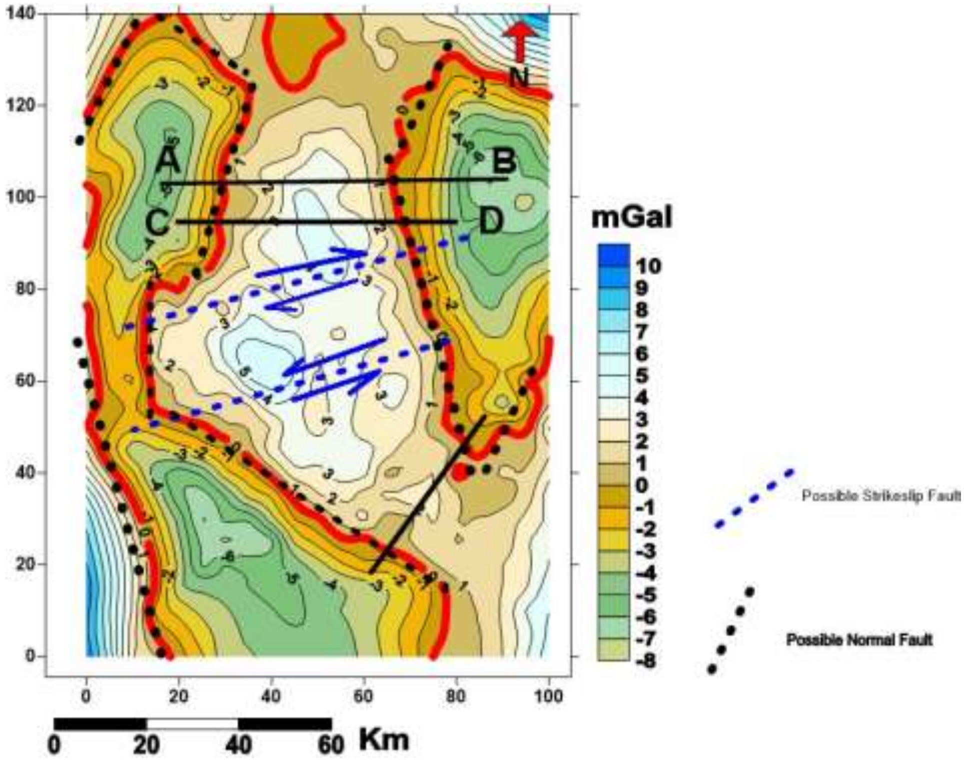

Figure 6: The derived residual gravity field showing the possible predicted fault locations within the study region.

2.4 First Directional Derivative

First directional derivative calculates the slope of the surface along a given direction. First derivative grid files produce contour maps that show isolines of constant slope along lines of fixed direction. At a particular grid node location, if the slope is uphill, the slope is positive; and if downhill, the slope is negative. Slope is reported as rise over run and can approach negative or positive infinity as the slope approaches vertical in the down or up direction (Surfer ,2015).

The directional first derivative is exactly as in the definition (Schwartz, 1974). Instead of a known function "Z(X,Y)" for which we can compute the necessary limits, Surfer uses a grid file, so directional derivative is approximated using difference equation (Al-Khafaji, 2020). Fig. 7, showing the derived 1st directional derivative field for the study region.

The First Derivative Map, Enhances the detection of sharp linear lateral changes of density, particularly at the boundaries of high-density bodies. It forms positive elongated anomalies over high density contrast linear structures which are majorly faults.

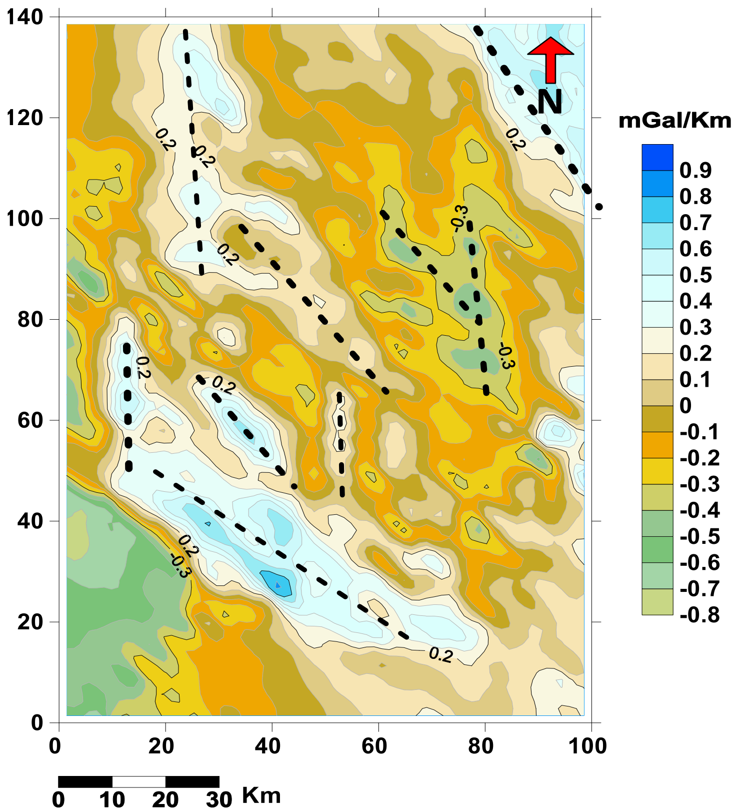

Figure 7: The derived 1st directional derivative of the residual field taken in the direction NE –NW, 45 Deg. for the study region, positive anomalies (light blue color) refers to locations of high density contrast linear features or possible faults extension.

2.5 The Residual Field Gradient Map

The residual field gradient map, Figure 8. , represents the result of applying the gradient operator filtering, or the Total Horizontal Directional Derivative (THD) calculation on the residual gravity field. This map highlights sharp local variations in gravity caused by near-surface geological structures such as faults or density contrast boundaries. These variations appear in the form of positive elongated anomalies which reflect the linear boundaries of abrupt change in sedimentary cover rocks density with distance and are possibly located over structural boundaries like faults and folding limbs.

The color distribution ranges in Fig.8 from purple to yellow and the gradient values are expressed in mGal/km, indicating the rate of change of gravity per unit distance. High gradient zones typically indicate potential geological discontinuities or sharp subsurface changes, making this map importance crucial in describing detailed subsurface geological interpretations.

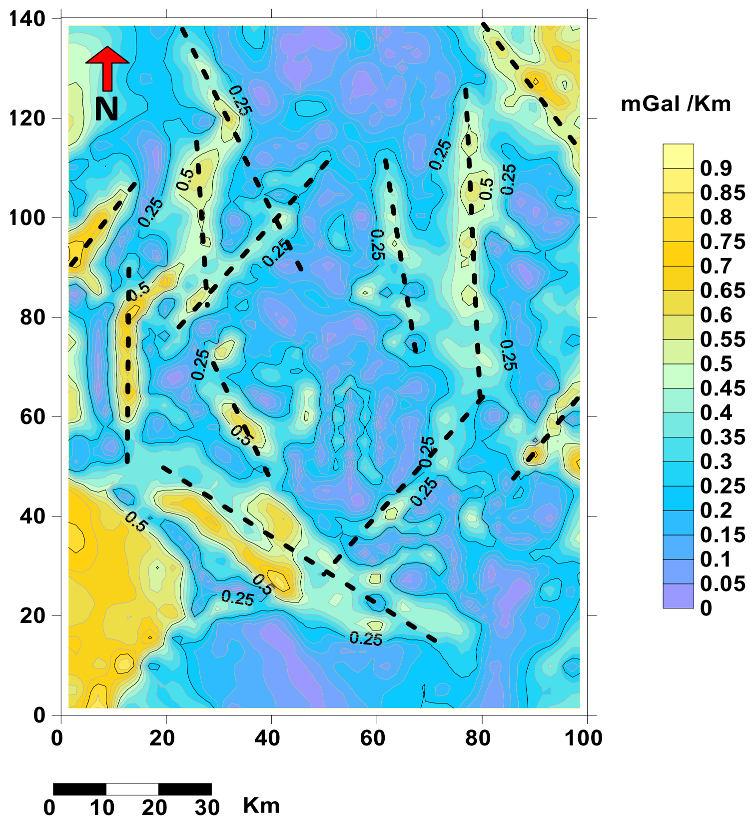

Figure 8: The derived Residual Gradient Operator map. The positive anomalies (yellow) indicate regions with high lateral density contrasts, which may correspond to subsurface structural features such as faults or fold limbs. The linear distribution of these anomalies suggests the orientation and possible extension of fault systems within the area. The contour interval (C.I) of 0.05 mGal/km chosen to enhances the detection of high gradient linear features and help in enhancing subsurface structural interpretations.

High-gradient zones correspond to areas of significant high-density change, typically faults or structural boundaries. Low-gradient zones are associated with more homogeneous or deeper geological structures, such as thick sedimentary basin rocks. The region subsurface structural patterns are complex, with multiple linear and curvilinear anomalies suggesting faulting, fracturing, or structural complexities.

Qualitative interpretation focuses on analyzing geophysical maps by identifying structural patterns and trends, particularly those aligned in the N–S and NW–SE directions. The goal is to understand the distribution of gravity anomalies and to interpret these patterns in relation to subsurface geological structures.

The map of Fig.8 clearly highlights the boundaries of subsurface structures trending in the north–south direction, where sharp gravity gradients are taking place. Previous studies have shown that such anomalies can be traced northward and southward beneath the Phanerozoic cover, suggesting the presence of deep-seated structural features (Jassim & Goff, 2006).

Gradient surface reveals prominent local anomalies trending mostly in the northwest–southeast (NW–SE) direction, which may be associated with linear subsurface density contrast features. Additionally, there is evidence of linear gravity gradient patterns aligned along the N–S direction, possibly indicating the horizontal extension of fault planes or deep structural alignments. The results of previous studies in Iraq like (Al-Khafaji, 2016), identified major fault trending direction NW–SE in southwestern Iraq using gravity data and derivative maps, supporting the interpretational results of the current research study.

2.6 Quantitative Interpretation

One of the common methods used in interpreting gravitational information is to perform calculations of the gravitational effects of some of the previously known geometric models and shapes, which serve as a useful guide for estimating the depth and shape of gravity anomalies subsurface causative bodies which are expected to be related to subsurface rock Formation and around geological structures density variations. The reason behind using and application of mathematical equations is to know the geometrical specifications of the subsurface bodies that cause these gravitational anomalies and to determine their depth. Whether these anomalies are remote or three-dimensional, and whether the cause is a subsurface fault, convexity or concavity where models and mathematical relationships are applied for each of these types. The objects that cause gravitational anomalies can be divided into different geometric shapes, (Jassim & Goff, 2006).

In gravity surveying, a cylindrical body with a horizontal axis represents a geological structure, such as synclines, anticlines, lava flow channels and buried channel features that extends laterally beneath the surface. This model is used to interpret gravity anomalies caused by elongated dense bodies. The gravity effect of such a body produces a characteristic anomaly, typically showing a positive gravity high if the body is denser than the hosting rocks. The shape and amplitude of the residual anomaly depend on factors like the cylinder's radius, density contrast, depth to the top, and the degree of horizontal extension.

Two profiles taken (A-B) and (C-D) to achieve the quantitative interpretation on the residual Bouguer maps, Fig.9, in order to find the depth to the center of the detected anticline by adopting the horizontal cylinder model. The profiles displayed in figure 9, are used to find the depth to the center of the elongated horizontal cylinder (anticline) by using the $X_{1/2}$ method. For profile A-B depth to the center of the causative body was found to be about 25 Km , While the depth was about 21 Km from the profile C-D for the same causative body.

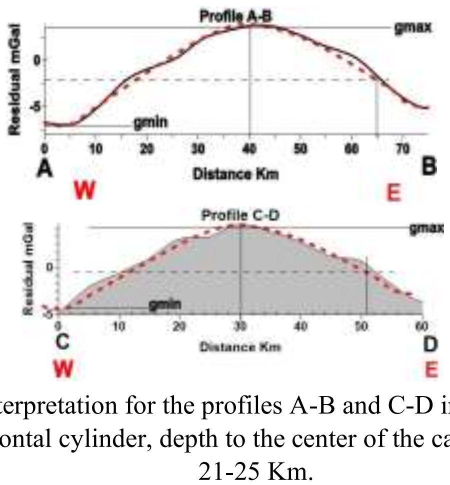

Figure 9: The $X_{1/2}$ method interpretation for the profiles A-B and C-D in map of Fig.6 , by considering the causative body shape is a horizontal cylinder, depth to the center of the causative body found ranging between 21-25 Km.

It worth to mention that depth to the top of basement rocks is about 5 Km as it referred by (Jassim and Goff, 2006), map of Fig. 10. That means the anticline extension depth is from about 5 Km at its hinge line, while the depth to the anticline core is about 21 - 25 Km at the center of the anticline this may refer to plunging effect on this anticline structure and produced the major positive anomaly in the middle of the region.

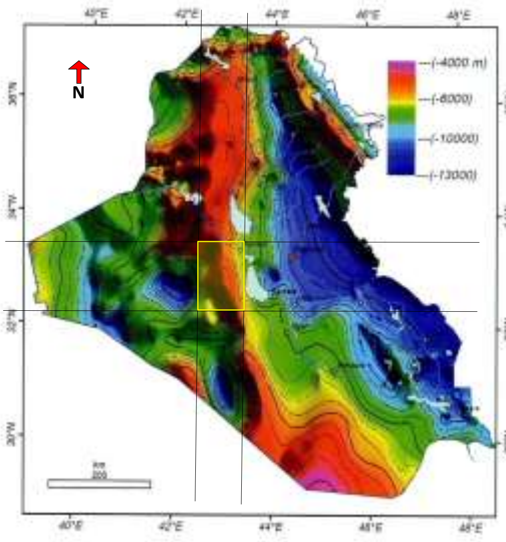

Figure 10 : Depth to the Crystalline Precambrian Basement (in metres relative to Sea Level) Derived from 3D Inversion of Gravity , showing the location of the study region where depth to the top of basement rocks is about 5 Km ,(after Getech and Jassim. 2002), (modified jassim and Goff 2006).

3. Results and discussion

By observing the calculated residual gravity field, Figure 6 one can conclude that the disconnected black lines referring to the possible locations of normal fault its prevalent directions are NW-SE and N-S. Two possible strike slip faults were also expected to be detected as they strike the major positive anomaly in the middle of the region and produced lateral movement of rock blocks (blue disconnected lines and arrows of motion), figure6. The associated fault features suggest recent local tectonic activity, which may have facilitated the uplift of these high-density structures.

The 1st directional derivative positive anomalies, Figure 7, delineated by (black disconnected lines) which are possible fault locations or edges of geological structures where high rock density contrast takes place. The first derivative helps effectively to define the sharp boundaries between contrasting lithological units. The identified sharp or high gradients linear features may be indicative of different depths fault locations or margins of structured bodies within sedimentary cover depths, or boundaries of potential petroleum traps.

The residual field gradient operator map or Total Horizontal Derivative map, figure 8, Highlighted subsurface geological features after. It differs from the 1st directional derivative surface calculation of being taking gradient effect for all directions instead of a certain chosen direction or user defined direction. High-gradient zones likely mark possible faults location and extension, lithological boundaries, or uplifted blocks. Low-gradient zones may indicate relatively undisturbed sedimentary basins or uniform density materials. The map of Fig.8 may represent a valuable result to be exploited for mineral exploration, hydrocarbon prospecting, and detailed geological mapping, where understanding subsurface structures is critical.

Quantitative interpretation achieved for two profiles across the residual field map, figure 6, then interpreted to find the depth to the core or center of the subsurface major anticline. This depth found to be about 21 Km for profile A-B , Fig.9 , while depth to anticline core was detected to be about 21Km for the profile C-D, Fig.9. Depth to subsurface anticline core reduction towards south may reflect the action of anticline axis plunging towards the south.

4. Conclusions

By observing the calculated residual gravity field, Figure 6 one can conclude that the disconnected black lines referring to the possible locations of normal fault its prevalent directions are NW-SE and N-S. Two possible strike slip faults were also expected to be detected as they strike the major positive anomaly in the middle of the region and produced lateral movement of rock blocks (blue disconnected lines and arrows of motion), figure6. The associated fault features suggest recent local tectonic activity, which may have facilitated the uplift of these high-density structures.

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Conflicts of interest

The authors declare that there are no conflicts of interest regarding the publication of this study.

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