DOI: 10.24996/ijs.2024.65.10.22

ISSN: 0067-2904

Multiple Upward Residual Gravity and Magnetic Maps to Estimate the Deep Crustal Layers and Moho Discontinuity in Eastern Iraq

Ahmed Sh. Al-Banna*, **Hayder H. Majeed**

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

Received: 24/6/2023 Accepted: 26/8/2023 Published: 30/10/2024

Abstract

The upward continuation technique was applied to the gravity and magnetic data to obtain the residual anomalies maps in eastern Iraq. A new processing method is introduced to calculate the crustal layers depending on the relation between the total range of the residual anomalies of gravity, magnetic data and the upward continuation, with multi-elevations. The significant relationship shows slope variations, which may reflect the maximum contrast in the physical properties (density and/or susceptibility) and the intersection point representing the depth of layer contacts. This method was applied to the eastern central part of Iraq, adjacent to the Iranian borders. It is found that the average depth range to the Jurassic formations, top basement rocks, transition layer (Curie point), and Moho discontinuity are 3.1- 4.8 km, 8-12.9 km, 20.9-22.4 km and 43.6 km, respectively. The Sedimentary cover in the study area ranges from 8 to 13 km. The maximum depth to the Moho discontinuity obtained by gravity data in the study area is 43.6 km. The radially average power spectrum technique was applied in the study area to calculate the gravity depth and magnetic sources' depth. Three depth levels of sources from gravity and magnetic data were obtained. These depths are shallow sources, average basement rock and deep sources (Moho) at 3km, 13.2-12.1 km, and 32.2-34km, respectively. The obtained results concerning the main layers in the crust were compared between the two methods, and the new method shows more reliable results. The detected depth levels refer to top Jurassic, basement rocks, and Moho discontinuity. The new method is believed to be used to detect the crustal layers depth with good results.

Keywords: Upward, Power Spectrum, Crust, Basement, Moho discontinuity

خرائط الجاذبية والمغناطيسية المتبقية التصاعدية متعددة الارتفاع لتقدير طبقات القشرة العميقة وانقطاع موهو في شرق العراق

أحمد شهاب البناء*, حيدر حميد مجيد

قسم الجيولوجيا ، كلية العلوم، جامعة بغداد، بغداد، العراق

الخلاصة

تم تطبيق تقنية الاستمرار التصاعدي على بيانات الجاذبية والمغناطيسية للحصول على خرائط الشذوذ المتبقية في شرق العراق. استخدمت طريقة معالجة جديدة لحساب طبقات القشرة اعتمادًا على العلاقة بين النطاق الإجمالي لحالات الشذوذ المتبقية للجاذبية والبيانات المغناطيسية ولارتفاعات متعددة للمجال المستمر

* Email: geobanna1955@yahoo.com

لأعلى. امكن تحديد عدة اختلافات بارزة في الميل ، والتي قد تعكس أقصى تباين في الخصائص الفيزيائية (الكثافة والحساسية المغناطيسية)، وتقاطعات خطوط الميل تمثل الحدود بين الطبقات الاساسية في القشرة الارضية. تم تطبيق هذا الأسلوب على وسط العراق المحاذي للحدود الإيرانية. وجد أن متوسط مدى عمق التكوينات الجوراسية وصخور القاعدة العلوية والطبقة الانتقالية (نقطة كوري) وانقطاع موهو هي 3.1− 4.8 كم ، 8−12.9 كم ، 20.9−22.4 كم و 43.6 كم على التوالي. تم تحديد سمك الرواسب في منطقة الدراسة بين 8−13 كم. أقصى عمق تم الحصول عليه بواسطة بيانات الجاذبية في منطقة الدراسة والذي يرتبط بعمق انقطاع موهو هو 43.6 كم. تم تطبيق تقنية طيف الطاقة شعاعيًا في منطقة الدراسة لحساب العمق للمصادر تحت السطح. حصلنا على أعماق ثلاثة مستويات لمصادر الجاذبية و المغناطيسية ، والتي تمثل أعماق المصادر الضحلة ، ومتوسط الصخور القاعدية والمصادر العميقة (لانقطاع موهو)على بعد 3 كيلومترات ، 12.1 − 13.2 كيلومتر و 32.2 − 34 كيلومتر على التوالي. تمت مقارنة النتائج المتحصل عليها بخصوص الطبقات الرئيسية في القشرة بين الطريقتين. حيث تبين ان الطريقة الجديدة اعطت نتائج اكثر موثوقية لانقطاعات اعلى الجوراسي ، صخور القاعدة وانقطاع موهو يعتقد ان الطريقة الجديدة يمكن ان تعطي نتائج جيدة في تحديد عمق الطبقات الاساسية للقشرة الارضية.

1. Introduction

The gravity and magnetic methods are important geophysical surveys to delineate subsurface structures. These methods have been used to determine the sedimentary basin thickness and estimate the crustal layers [1 and 57]. The gravity method measures variations in the Earth's gravity field arising from differences in density between subsurface rocks [2]. The magnetic survey is one of the oldest geophysical surveys, which measures the Earth's magnetic field and object bodies that contain ferrous metals in their composition. The magnetic method deals with measuring magnetic susceptibility [3]. The geomaterial (i.e. rocks) loses its magnetic properties at a Curie temperature of 578°C [4]. The eastern central part of Iraq (including the study area) is characterized by many geological features and tectonic events that led to the formation of many folds and fault that appears morphologically as mountains (almost at the north and northeast parts) and the Mesopotamian basin (at the centre and south parts of Iraq), (Figure 1), [5, 6, 7,8 and 58].

The thickness of the sedimentary column in the eastern part of Iraq is relatively large. The deepest well in Iraq has not penetrated the basement. The challenge in geology and geophysics was deep formations. Therefore, the potential methods (Gravity and Magnetic) were used to estimate the depth of basement rocks. Many researchers [9, 10, 11 and 12] used geophysical methods such as gravity, magnetic and seismic to determine the basement, the Conrad discontinuity, Crust thickness, Moho discontinuity and Curie point depths in Iraq.

The residual anomaly separation is necessary to distinguish the gravity or magnetic effect of shallow sources. The separation process is done by determining the regional effect and then subtracting it from the original data to obtain the residual anomalies. The upward continuation method is a mathematical technique used to obtain the regional anomalies, which are then subtracted from the original maps to obtain the residual anomaly map [24]. The upward continuation is used to remove or minimize the effects of shallow sources and noise in grids [3, 25 and 27]. The upward technique transforms potential data (gravity and magnetic) from a surface to a higher level [26].

The radially average power spectrum technique is used to determine the depths of subsurface sources and has been used by many researchers [27, 28, 29, 30, 31, 32, 33, 34, and 35]. The radially averaged power spectra analysis of the data obtained is used to apply spectral analysis of potential field data to estimate the depth and extent of the gravity and magnetic anomaly sources. Power spectrum analysis is a frequency domain technique that can separate data from various sources at various depths [46]. The process involves 2-D Fourier Transform (FT) of gravity and magnetic data and computation of transformed data's radially averaged power spectra [27].

The gravity and magnetic maps were used to detect the main crystal layers in the study area using a new processing method depending on the upward continuation technique. The radially averaged power spectrum technique is used to check the result of the new method.

2. Data acquisition

2.1 Location of the site

The study site is located in eastern Iraq within Latitude 32.1 to 35.3N and Longitude 43.08 to 46.7E (Figure 1). The study area is bounded from the west and southwest by the Tigris River, passing through the Mesopotamian zone towards the east (near the Iraqi-Iranian border).

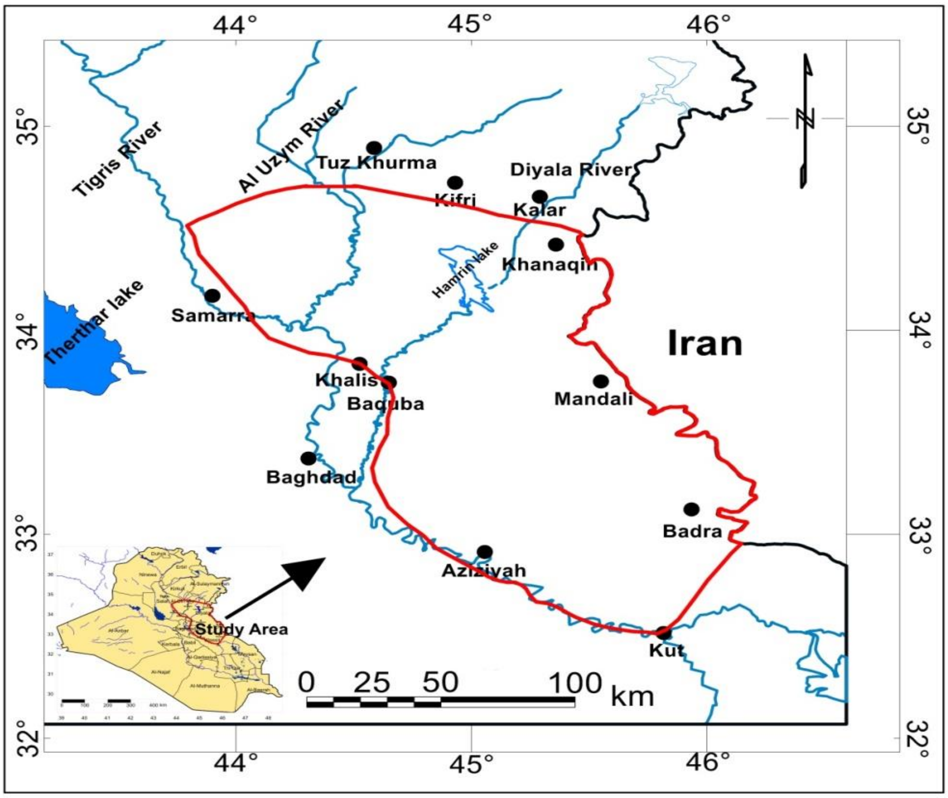

Figure 1: Location site bounded the study map.

2.2 Geology and tectonic setting of the study area

The study area is covered mainly by Quaternary and Pre-Quaternary sedimentary formations [36]. The Pre-Quaternary sedimentary rock formation includes the Fatha (Lower Fars) Formation (Middle Miocene), is composed of carbonate and marl. The Late Miocene-Pliocene age consists of a fluvial system of Fatha, Injana (Upper Fars), Mukdadiya (Lower Bakhtari) and Bai Hassan (Upper Bakhtari) Formations [5]. The Tigris and Diyala Rivers deposited quaternary sediments of the Mesopotamian zone. Alluvial fans emanate from the surrounding elevated areas. Floodplain deposits include channel deposits and flood plain depression, Sabkha and deltaic deposits [37], (Figures 2A). According to the tectonics division, the study area is situated on an unstable shelf (Mesopotamia basin) in Iraq [38, 39, 40 and 41]. The study area contains two longitudinal tectonic boundaries and three transversal fault systems [5] (Figure 2B).

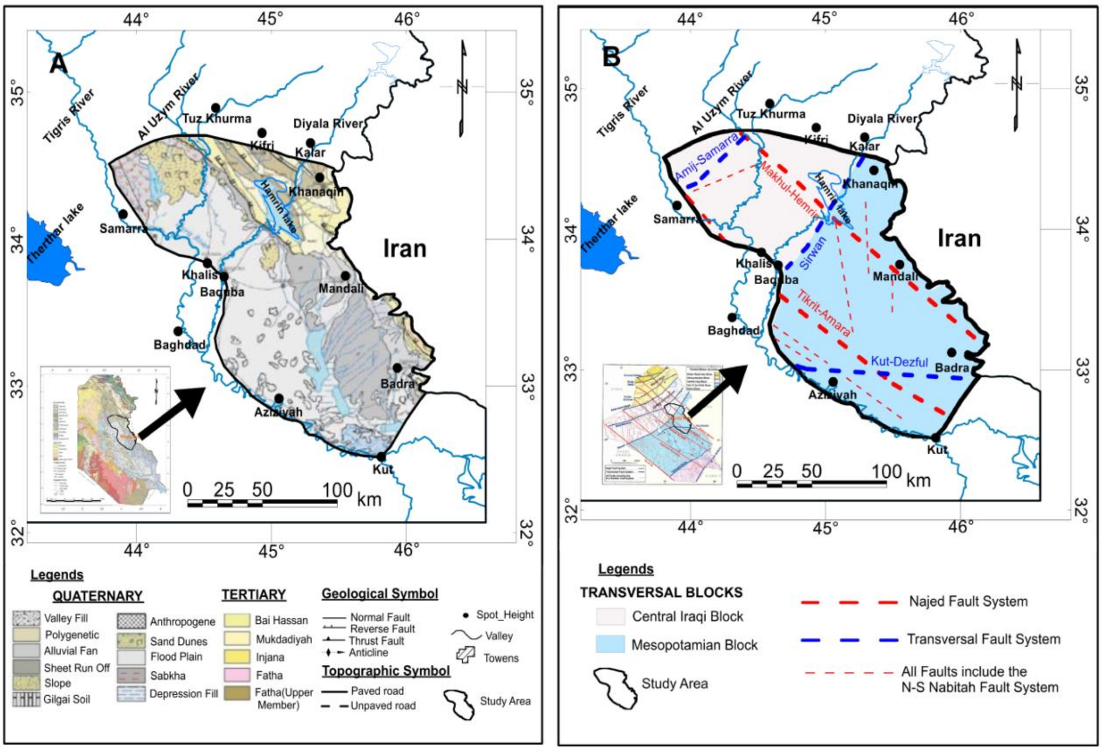

Figure 2: (A) The Geological map for the study area modified after [36] (B) The Tectonic map of the study area modified after [5].

3. The Radially Average Power Spectrum

The Radially average power spectrum technique uses the Fast Fourier Transform (FFT) for Bouguer Gravity and RTP Magnetic data. This method calculates the depths of the sources using spectral analysis [28], and the depths of the sources H through the slopes of the linear spectral analysis resulting from the gravity and magnetic grid. That is done by dividing the resulting spectral slope by 4π. Usually, three or four parts of different linear slopes are detected, which reflect deep, shallow, and noise source components .The high frequencies are associated with shallow sources, while low frequencies are associated with deep sources[46]. Estimation calculated by the Eq. (1).

$$H = - slope/ 4\pi \quad [27] \qquad (1)$$

Where H= depth

4. Materials and methods

4.1 Data acquisition and processing

The gravity ground surveys in Iraq, including the study area, were carried out in 1959 and 1979; the gravity data were unified by the Iraqi geological survey company staff (32, in 33). The gravity data was reprocessed by Getech Group/ British in 2010. The regional view of the gravity map gives an approximate idea of the sedimentary basin in Iraq [44]. The Bouguer gravity anomaly grid with 1 X 1 kilometre has a range (from -22 to -64 mGal) (Figure 3A). The C.G.G French Company carried out the aeromagnetic surveys of Iraq at an elevation of 140 meters above the topographic surface in 1974. The data were processed and interpreted to construct the basement depth map of Iraq [42]. The original data was reprocessed and reinterpreted by Getech for the oil exploration company and the geological survey of Iraq [43]. The Total Magnetic Intensity (TMI) values of the study area range (from 4835-5086 nT) (Figures 3B). The gravity and magnetic data are obtained from the Oil Exploration Company.

The dipole magnetic source effects in the aeromagnetic anomaly map were converted to a one-pole anomaly source using the Reduction to Pole (RTP) technique [27]. The RTP map of the study area is shown in Figure 3C. Many researchers discussed the density in Iraq, and they considered the density for the sedimentary cover from 2.5 to 2.61 cm/gm^3 [17,47, 48, 49, 50 and 51, and 52], the basement to lower part of crust density range 2.77-2.95 cm/gm3 [17,32, 43, 53], and to upper mantle density 3.25-3.3 cm/gm3 [32, 54]. The processing steps of gravity and magnetic data to obtain the depth of the main layers boundary within the crust were shown in the flow chart, Figure 4.

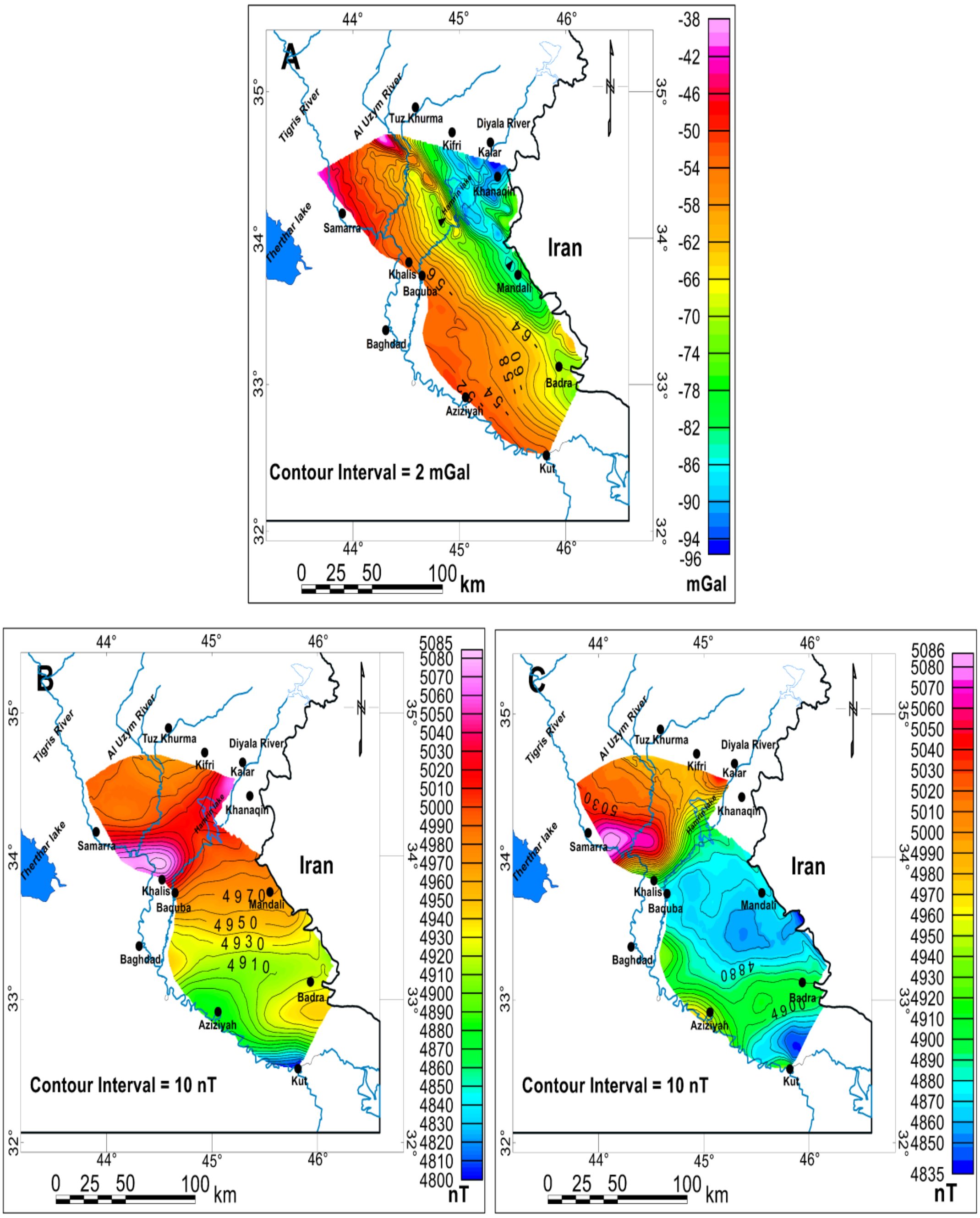

Figure 3: (A) The Bouguer Gravity anomaly map (B) The TMI map (C) The RTP magnetic map of the study area [43].

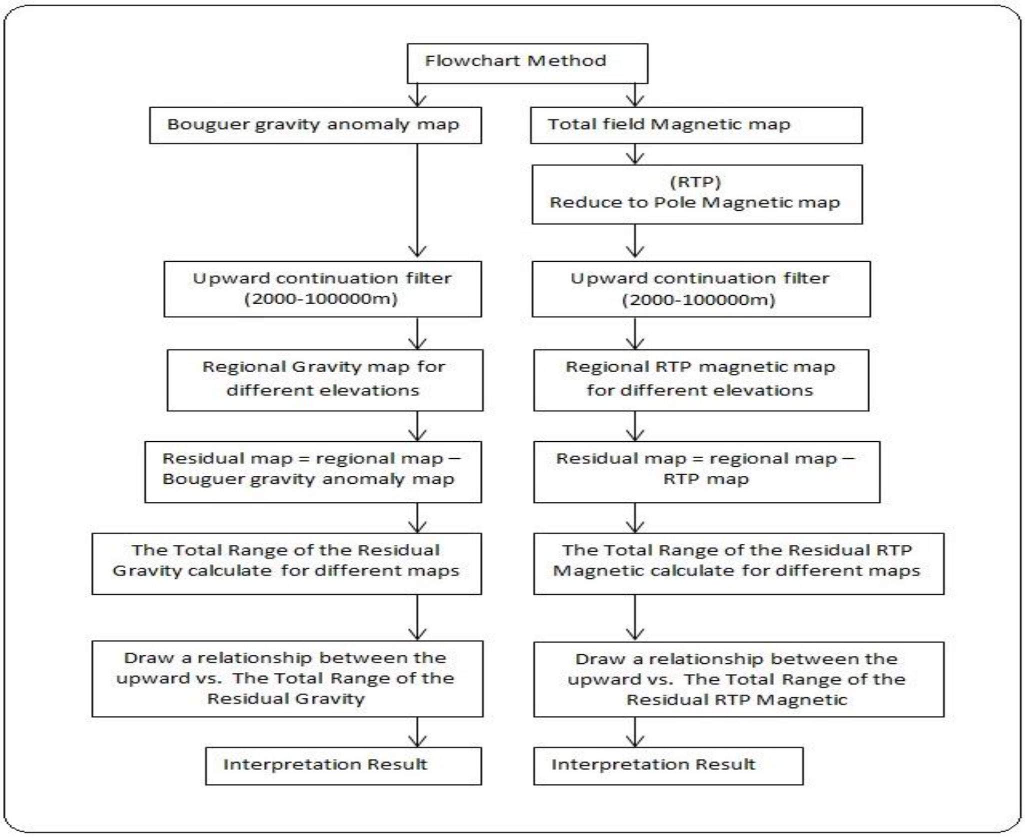

Figure 4: The flowchart summarises the processing steps to obtain the depth of the main layers within the crust.

4.2 Regional - Residual separation methods

The residual anomaly separating is necessary to distinguish the relatively shallow geology features from the regional anomalies. This process is mathematically performed by subtracting the regional anomaly from the Bouguer or Magnetic maps [45]. Upward continuation is a clean filter process, without side effects like the other filters, to obtain the potential data (gravity or magnetic) at different elevation levels. The obtained maps are considered regional maps subtracted from the original maps to obtain the residual anomalies map. These processing steps are achieved using the Oasis montaj™ software (2015, V. 8.4). The platform can be used for the separation process.

5. Results

An upward continuation separation has been applied to the twenty-one elevations to obtain the regional - residual Bouguer gravity and RTP magnetic anomaly maps in the study area. The variation in regional gravity, regional RTP magnetic, residual gravity, and residual RTP magnetic anomalies maps were shown through the selected upward elevations 1 km, 6 km, 10 km, 16 km, 32 km, and 50 km, respectively (Figures 5, 6,7 and 8). The gravity values in the regional maps increase toward the northeast study area, which coincides with the increasing basement depth (Figure 5). This is due to the increase in the thickness of the sediments from the surface to the basement, and this means that the effect of the basement is less effective on the surface, even if those rocks consist of dense igneous or metamorphic rocks. The RTP magnetic values in the regional map show two main anomalies: high values in the northern part and low values in the southern part of the study area. The maximum gradient at the regional RTP

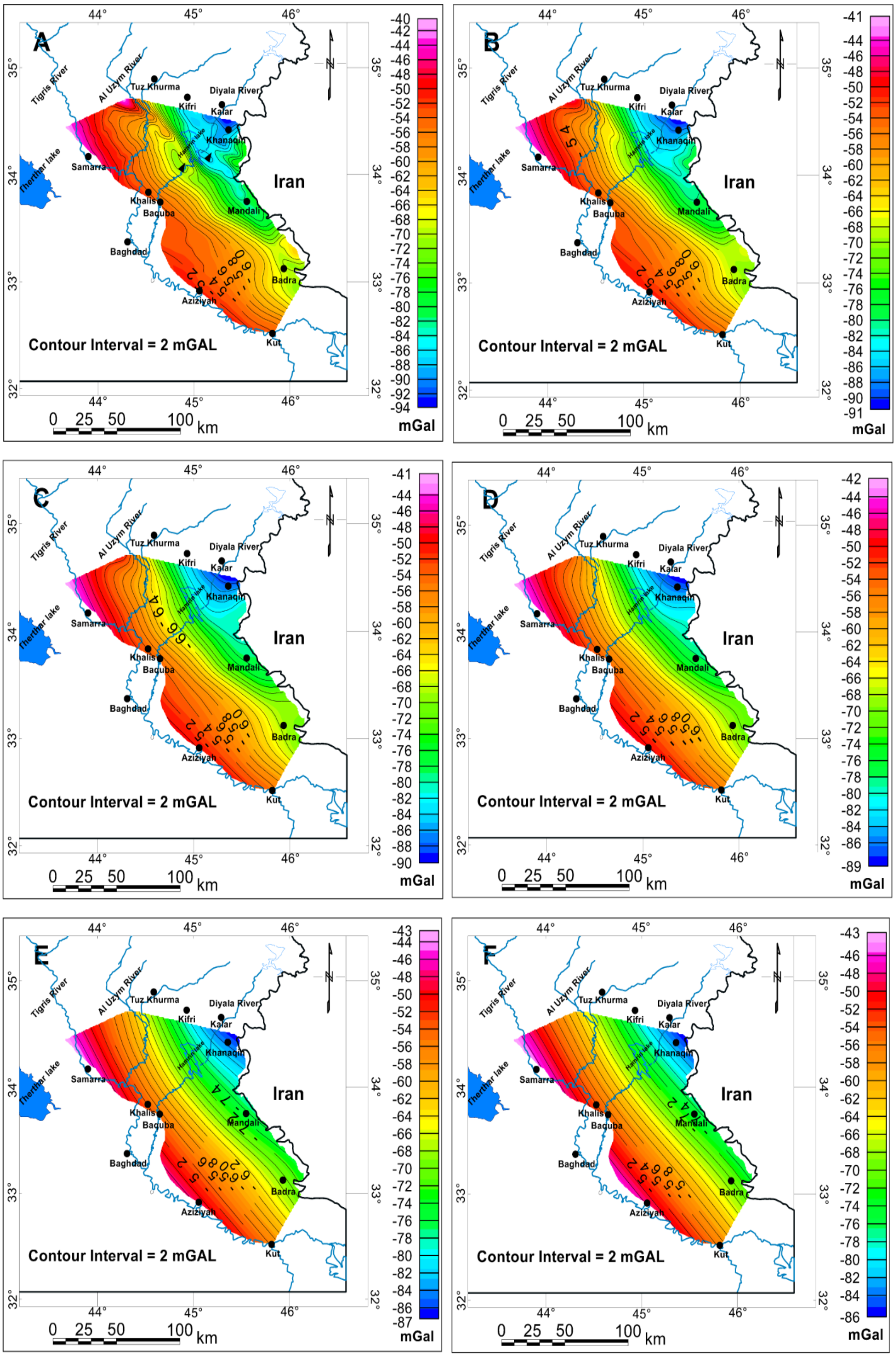

Figure 5: (A) The upward regional gravity maps at elevation (A) 2 km, (B) 6 km, (C) 10 km, (D) 16 km, (E) 32 km, and (F) 50 km.

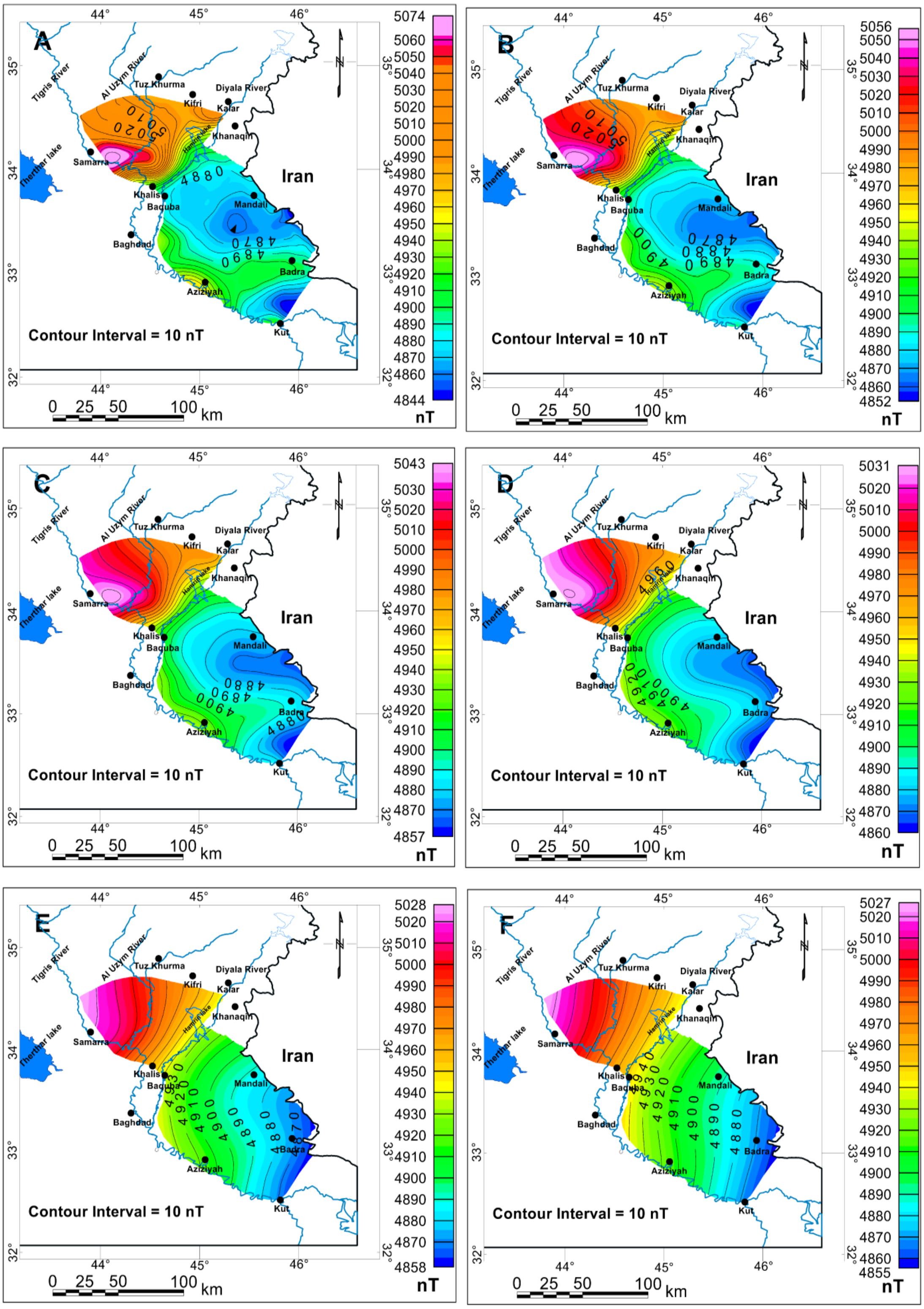

Figure 6: The upward regional RTP magnetic maps at elevations (A)2 km, (B) 6 km, (C) 10 km, (D) 16 km, (E) 32 km and (F) 50 km.

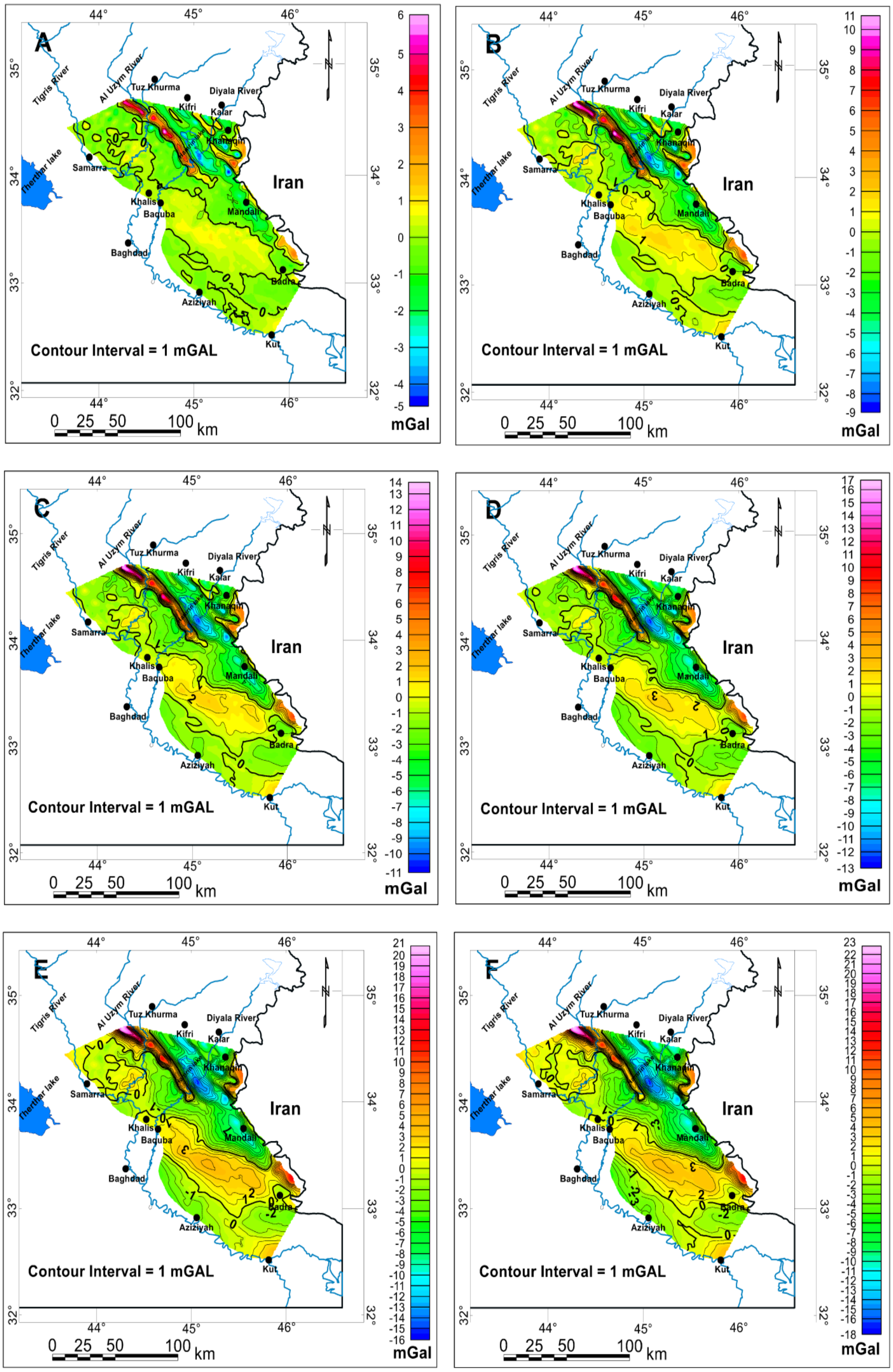

Figure 7: The upward residual gravity maps at elevations (A) 2 km, (B) 6 km, (C) 10 km, (D) 16 km, (E) 32 km and (F) 50 km.

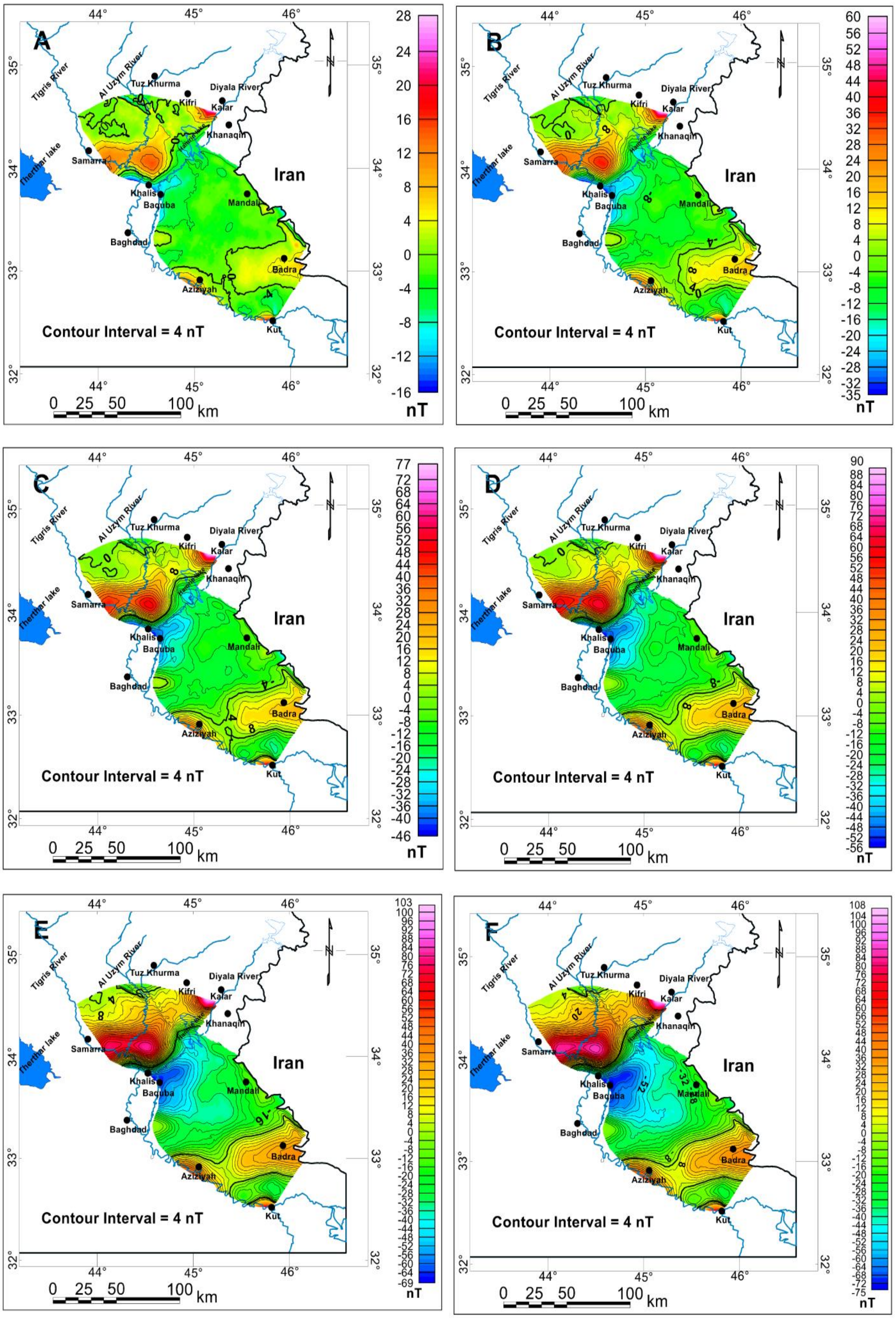

Figure 8: The upward residual RTP magnetic maps at elevations (A) 2 Km, (B) 6 Km, (C) 10 Km, (D) 16 Km, (E) 32 Km and (F) 50 Km.

Magnetic map coincides with the Diyala River path, indicating one of the main transverse faults in Iraq (Sirwan Fault). The low magnetic values in the study area correspond with the main sedimentary basin (Mesopotamian basin), including the Kut- Dezful Fault (Figures 2B and 6). The residual gravity anomalies maps show many positive anomalies, most trending northwest-southeast. The maximum residual gravity amplitude at Hamrin Anticline, East Samarra, and Baquba-Badra anomalies (Figures 2B and 7). The Residual RTP magnetic maps show many positive magnetic anomalies in the west Khanaqin, east Samarra, Badra, and Aziziyah anomalies (Figure 8).

The residual gravity and magnetic anomalies map, obtained from the upward continuation with elevations from 2-100 km and power spectrum techniques, were considered to delineate the crustal layers in the studied area. The total range of the residual gravity and the residual RTP magnetic anomalies (from the lowest values of the residua to the highest value) is compatible with the upward continuation elevation values. The upward elevation is plotted with the corresponding values of the total residual, residual gravity and residual RTP magnetic range,

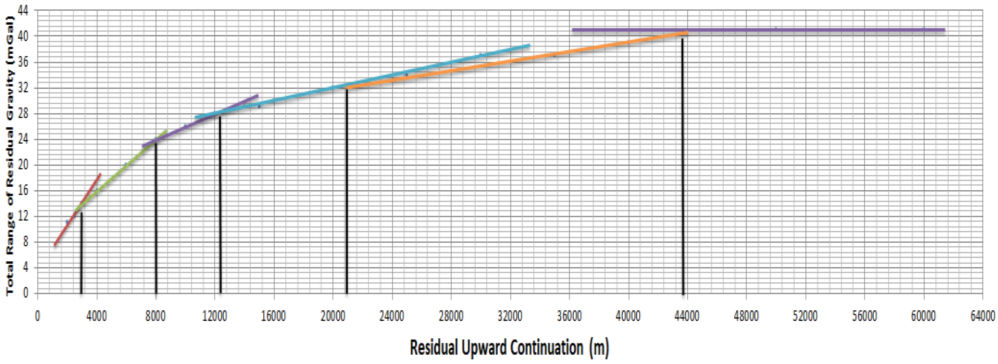

Figure 9: upward continuation elevation against the total range of the residual gravity of the study area.

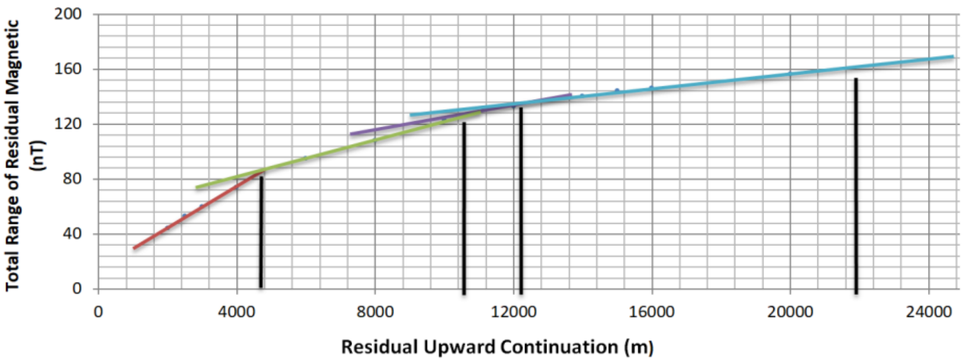

Figure 10: The Upward Continuation elevations against the total range of the residual RTP magnetic of the study area.

respectively (Figures 9 and 10). The upward continuation elevation values at the x-axis, and the corresponding total residual gravity or magnetic field content is on the y-axis (Figures 9 and 10). The points are drawn on the graph and aligned in several straight segments. The points are drawn on the graph and aligned in several straight segments. Straight lines drawn from the gravity data were intersected at five points, while those drawn from the magnetic data intersected at four positions (Figures 9 and 10). The slope of the lines (Straight lines) is related to rock groups with identical physical properties (density or susceptibility). So, the intersection point's position indicates the change in physical properties, which may detect the average depths of the main boundaries (Maximum variation in the physical properties of the layers). This method is considered a new one sensitive to significant changes in the physical properties (density or susceptibility) and is not susceptible to small changes, as is the case between sedimentary layers.

Radially average power spectrum techniques were applied to the Bouguer gravity and RTP magnetic Data. The gravity and RTP magnetic data identified four linear slopes of the spectral analysis. These lines represent the Deep, Shallow, nearest and noise sources. From gravity and magnetic data, three intersection points were detected. These three points correspond to the three-level depth (Figures 11 and 12). The level depths obtained from gravity data are 3 km, 13.6 km and 32.2 km (Figure 11). The RTP Magnetic data shows four subsurface depth sources: 3.2 km, 9 km, 15.2 km, and 34 km (Figure 12).

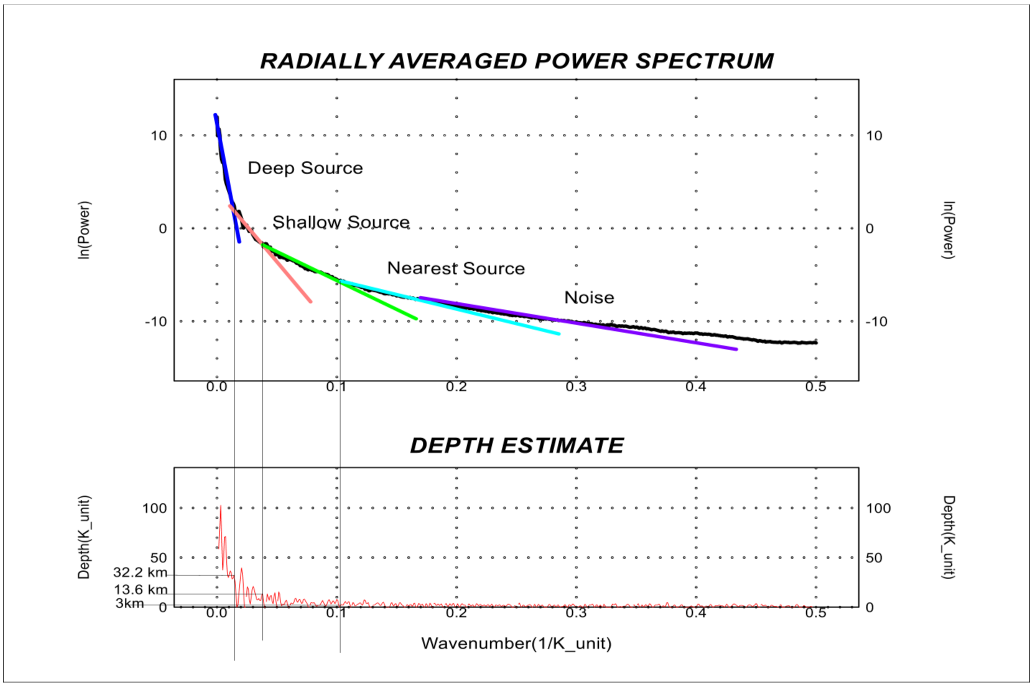

Figure 11: Radial Power Spectrum of the Bouguer gravity data for the study area.

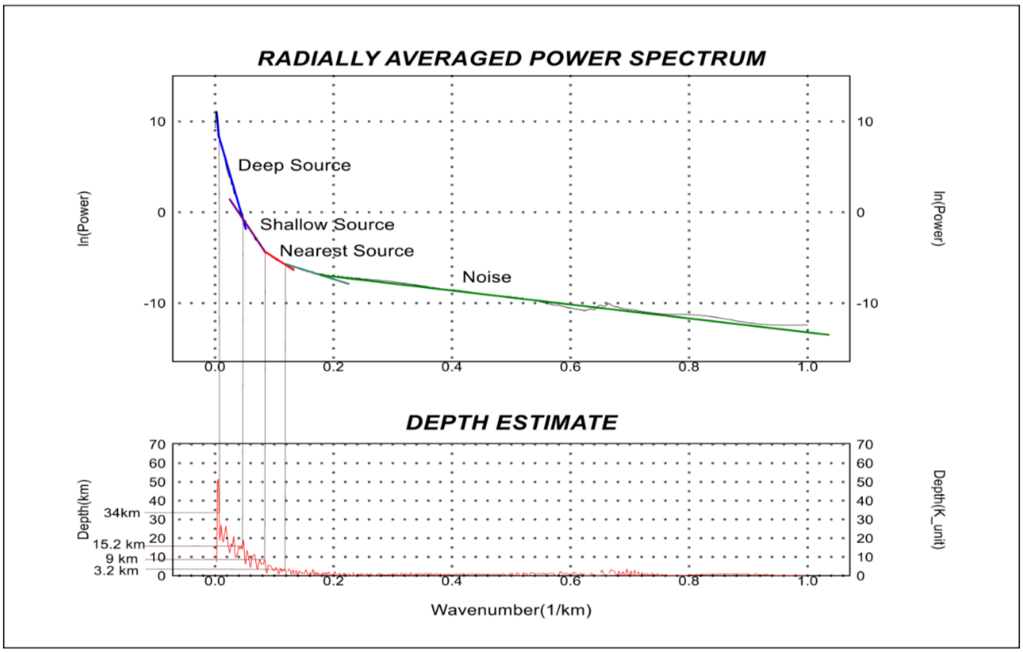

Figure 12: Radial Power Spectrum of the RTP Magnetic for the study area.

The depths obtained by the two methods are tabulated in Table 1, which shows a slight difference in the values of the gravity and magnetic depths observed by each method, as well as obtaining a certain depth from one of the two methods and not obtaining a parallel depth using the other, This is due to the difference in the bases of the considered methods and the level of its sensitivity to changes at each depth, as well as the difference between the physical properties (density and susceptibility).

Table 1: Depth results from Gravity and Magnetic methods.

No	Depth(km) from the Upward Gravity Method	Depth(km) from Upward Magnetic method	Depth(km) from Power Spectrum Gravity Method	Depth(km) from the Power Spectrum Magnetic method
1	3.1	4.8	3	3.2
2	8	11.3	-	9
3	12.4	12.9	13.6	15.2
4	21	22.4	-	-
5	43.6	-	32.2	34

In previous studies, the basement depth in the study area was 8-14 km [13 and 14]. According to Iranian studies, the basement depth of the eastern study area on the Iranian side varies between 7-16 km [15]. Many researchers use gravity data to determine the crustal thickness; in the studied area, it ranges from 37 to 42 km [16, 17, 18 and 19]. In the study area, seismological studies indicate that the Conrad discontinuity depth ranges from 18 km to 22 km whilst the Moho discontinuity depth ranges between 40 and 60 km. [20 and 21]. On the Iranian side the depth of the Moho was estimated between (38-46 km) [22, 23 and 10]. Comparison of the depth of the crust's main layers in the study of those obtained in this study seems more reliable than the layers depth from the other methods.

6. Discussion

The change in the steepness of the lines found a relatively large slope at the beginning and then decreased gradually. The slope changes were found to be steep when the average depth is shallow or close to the surface (Figures 9, 10, 11, and 12). The gravity data shown in Figure 9, the first intersection point with a depth of 3.1 km, confirmed the top Jurassic formations in the wells in the study area. The second and third intersection points lie at distances of 8 km and 12.4km, representing the variation of basement rock from the surface. The fourth point is at a distance of 21 km which may represent the average depth of the Conrad discontinuity or Curie point in the study area. The fifth intersection point at an average depth of about 43.6 km may represent the depth of Moho in the study area. The magnetic result in Figure 10 also displays five intersection points. As oil wells indicate, the first intersection is at 4.8 km, within the Jurassic formations. The second and third intersection points, with a depth of 11.3 km and 12.9 km, coincide with the basement depth in the study area. The Magnetic Curie point depth may be located in the fourth intersection point at 22.4 km.

The variation in the depth of the boundaries depends on the variation effect of the physical properties (density and susceptibility) as soon as on the theoretical basis of the processing methods. The thickness of sedimentary rocks ranged between 8-13 km within the study area. The results were compared with the previous researchers using different geophysical methods in the region and were almost identical. The process used in this study, which depends on determining the relationship between the total range of a set of residual gravity and magnetic anomalies with the corresponding upward elevations, successfully detects the main crust layer in the study area. The new method used in calculating depths in this study from gravity and magnetic data successfully detected the main crust layer in the study area using a unique technique. The Radial Power Spectrum method shows three depth sources from gravity. The first depth level of 3 km refers to the shallow sources of rocks, and the second level depth of 13 km refers to the basement rocks in the study area. The last level depth represents the Moho discontinuity in the study area at a depth of 32.2 km. Four depth sources result from RTP Magnetic. The first level depth at 3.2 km represents the shallow sources. The second and third level depths at 9 km and 15.2 km represent variations in the depth of the basement. The fourth level of depth refers to the Moho discontinuity in the study area at 34 km.

7. Conclusion

A new method was successfully suggested for the first time in the study area to determine the crustal main layers using gravity and magnetic data. The average depth range of Jurassic formations, top basement rocks, and Conrad discontinuity or Curie point at the study area was found at depth 3.1- 4.8 km, 8-12.9 km, and 20.9-22.4 km, respectively. The Moho depth determines 43.6 from gravity. Therefore, the thickness of the sedimentary covers in the study area is approximately 13 km. The suggested method successfully determines the crustal main layers depending on the gravity and magnetic data interpretation. It is believed that the upward continuation process can be used to investigate the abrupt changes in physical properties (density and susceptibility). As a secondary technique, the power spectrum technique applied to the gravity and magnetic data compares its results with those obtained by the suggested method. The depth ranges from gravity and magnetic using the power spectrum for the study area are 3-3.2 km, 13.6-12.1km, and 32.2 km for the top Jurassic, basement rocks and Moho discontinuity, respectively. Comparisons between the two methods indicate that the results of the new method are more reliable and logical than the power spectrum technique.

Acknowledgements

The authors are very grateful to Mr. Aws Riyad, Mr. Salah Mahdi, Mr. Hussein Shuwail, Mr. Salar Hassan and all other employees of Oil Exploration Company for providing the data, their assistance in processing and valuable discussions.

References

[1] M. B. Dobrin and C. H. Savit, "Elementary gravity and magnetic for geologists and seismologists," *society of exploration, Fourth Edition, McGraw Hill Book Company, p.865, 1988.*

[2] L. L. Nettleton, "Introduction to Geophysical Prospecting," *Geophysics*, 1976, 121p.

[3] R. J. Blakely "Potential Theory in Gravity and Magnetic Applications," *Cambridge University Press*, 1996, 437p.

[4] N. Petersen, "Curie temperature, In: James, D.E. (ed.)," *The Encyclopedia of Solid Earth Geophysics*, New York: Van Nostrand Reinhold pp.166-173, 1990.

[5] S. Z. Jassim and J. C. Goff, "Geology of Iraq: Dolin," *Prague and Moravian Museum*, Brno, Czech Republic, 439p, 2006.

[6] S. Z. Khorshid, F. M. Duaij and H. H. Majeed, "Structural and Stratigraphic Study of Hartha Formation in the East Baghdad Oil Field, Central of Iraq," *Iraqi Journal of Science*, Vol. 58, No.4B, pp.2118-2127, 2017.

[7] M. Faridi, J. Burg, H. Nazari, M. Talebian and M. Ghorashi, "Active faults pattern and interplay in the Azerbaijan region (NW Iran)," *Geotectonic*, vol. 51, pp. 428-437, 2017.

[8] M. Nedaei, H. Alizadeh and M. Jahangiri, "the pattern and kinematics of deep deformation of 2012 Ahar-Varzaghan earthquake doublet (MW 6.4 and 6.2), a new seismotectonic interpretation," *Iranian Journal of Earth Sciences*, vol. 14, no. 2, pp. 112-130, 2022.

[9] N. Maden, A. Aydin and F. Kadirov, "Determination of the Crustal and Thermal Structure of the

Erzurum-Horasan-Pasinler Basins (Eastern Turkey) Using Gravity and Magnetic Data," *Pure and Applied Geophysics*, vol. 176, no. 6, pp. 1-16, 2014.

[10] P. Jalooli, H. Zomorrodian and H. R. Siahkoohi, "Middle East Moho Relief Estimation Using Spherical Prisms in Gravity Inversion," *Annalysis of Geophysics*, vol. 63, no. 6, pp. 673, 2020.
[11] A. S. AL-Banna and D. S. ALKishef, "Evaluation of the Tectonic Boundaries in Tikrit-Kirkuk Area Using Potential Data, North -Central Iraq," *Iraqi Journal of Science*, Vol. 60, No.3, pp. 528-535, 2019.
[12] A. Ibrahim, S. A. Saada, K. Mickus, Abdelrahman and F. I. Khedr, "Comparative study of estimating the Curie point Iraq," *Iraqi Geological Journal*, vol. 56, no. 1C, pp. 235-247, 2022.
[13] B. H. Jacobsen, "A case for upward continuation as a standard separation filter for potential- field maps," *Geophysics*, vol. 52, no. 8, pp. 1138-1148, 1987.
[14] W. C. Dean, "Frequency analysis for gravity and magnetic interpretation," Society *of Exploration Geophysicists*, vol. 23, no. 1, pp. 1-163, 1957.
[15] Geosoft Oasis Montaj, Version 8.4., "Gravity and Magnetic Interpretation and Modeling Software," Toronto, Canada, 2015.
[16] W. M. Telford, L. P. Geldart and R. E. Sheriff, "Applied geophysics," second edit, *Cambridge University*, press, 229p, 1990.
[17] B. K. Bhattacharya, "Continuous spectrum of the total magnetic field anomaly due to a rectangular prismatic body," *Geophysics*, Vol. 31, pp.97-121, 1966.
[18] F. J. Syberg, "A Fourier Method for the Regional-Residual Problem of Potential Fields," Geophysical *Prospecting*, Vol. 20, pp. 47-75, 1972.
[19] S. A. Saada, "Curie point depth and heat flow from spectral analysis of aeromagnetic data over the northern part of Western Desert, Egypt," *Journal of Applied Geophysics*, Vol. 134, pp. 100-111, 2016.
[20] A. S. AL-Banna and S. S. Al-Karadaghi, "Inversionto density andvelocity model by integrated with wells dataatregional area (centraland southwestern Iraq) ," *Iraqi Journal of Science*, Vol. 59, No.1A, pp. 156-172, 2018.
[21] A. Mousa, K. Mickus and A. Al-Rahim, "The thickness of cover sequences in the Western Desert of Iraq from a power spectrum analysis of gravity and magnetic data," *Journal of Asian Earth Sciences*, Vol. 138, pp. 230-245, 2017.
[22] S. M. Assran, "Application of ground magnetic and multi-frequency EM techniques for the Abu-Shihat radioactive prospect area, North Eastern Desert, Egypt," *Annals of Geophysics*, Vol. 45, No. 5, pp.609-620, 2002.
[23] H. Abdulrahim and A. M. Al-Rahim, "Determinations of The Depths to Magnetic Sources Over Al-Ma′aniyah Depression Area-Southwest Iraq Using the Aeromagnetic Data and Their Tectonic Implication," *Iraqi Journal of Science*, Vol. 60, No.1, pp. 91-102, 2019.
[24] O. F. Ojo and I. B. Osazuwa, "Estimation of Depth to Magnetic Basement in Ekiti State, Southwestern Nigeria from Aeromagnetic Data Using Spectral Analysis Technique," International Journal of Research and Innovation in Applied Science, Vol. VI, Issu. IV, ISSN 2, pp.454-6194, 2021.
[25] A. Spector and F. S. Grant, "Statistical models for interpreting aeromagnetic data," *Geophysics*, Vol. 35, pp. 293–302, 1970.
[26] V. K Sissakian, S. F. Fouad, "Geologic Map of Iraq," scale 1:1000000, 4th edit, GEOSURV, Baghdad, Iraq, *Iraqi Bulletin of Geology and Mining*, Vol.11, No.1, pp. 9 – 16, 2015.
[27] L. Yousif , "Active tectonic assessment of Mandili watershed using GIS technique," *Iraqi Bulletin of Geology and Mining*, Vol.13, No.1, pp. 1 – 13, 2017.
[28] J. A. Al- Khadhimi, V. K. Sissakian, A. S. Fattahm and D. B. Deikran, "Tectonic map of Iraq 1:1,000,000 scale series," *Publication of GEOSURV*, Baghdad sheet No 2, 1996.
[29] A. S. Al-Banna, K.E. Al-Sagri, L. Z. Humade , "the boundary between stable and unstable shelf in Iraq as inferred from using ideal gravity to elevation ratio," *Arabian Journal of Geosciences*, Vol.6, , pp.187-191, 2013.
[30] S. F Fouad, "Tectonic map of Iraq, scale 1: 1000000, 3rd edition, 2012," *The Iraqi Bulletin of Geology and Mining*, Vol.11, No. 1, pp.1-7, 2015.
[31] A. S. Al-Banna and K. K. Ali, "The Transition Tectonic Zone between the Two Parts of the

Platform in Iraq: A Review Study, " *Iraqi Journal of Science*, Vol.59, No. 2C, pp.1086-1092, 2018.

[32] M. J. Abbas , J. A. Al-Kadhimi, and A.S.Fatah, "Unifying gravity map of Iraq," SOM, unpublished report, 1984, (in Al-Banna A. S. 1992, *Iraqi Journal of Science*, Vol.33, No.1-2, 63-68).

[33] A.S. Al-Banna, "Gravity lineaments, fault trends and depth of basement rocks in western desert, Iraq," *Iraqi Journal of Science*, Vol.33, No.1-2, 63-78, 1992.

[34] Iraqi Oil Exploration Company (O.E.C.), "Geological study of Merjan – West kifl oil fields (In Arabic)," *internal report*, 2005.

[35] Compagnie Générale de Geophysique (C.G.G), "Aeromagnetometric and Aerospectrometric survey interpretation report," *Geo Survey Mineral Invest*. Baghdad, Iraq, Vol. 32, 1974.

[36] G. Getech, "Reprocessing, Compilation and Data Basing the Aeromagnetic and Gravity Data of Iraq, aeromagnetic and gravity data of Iraq," *Kitson House, Elmete Hall, Elmete Lane, Leeds*, LS8 2LJ, UK, pp. 1- 16, 2010

[37] A. S. Al-Banna and E. A. Al-Heety, "Crustal thickness map of Iraq deduced from gravity data," *Iraqi Journal of Science* , Vol. 35, No. 3, pp. 749-764, 1994.

[38] V. Ditmar, and Iraq- Soviet Team., "Geological conditions and hydrocarbon prospects of the Republic of Iraq (Northern and Central parts) ," Manuscript report, INOC Library, Baghdad, 1971.

[39] Z. D.Shaikh, K. Saleh and H. Abdo. "Contribution to the geology of Shaqlawa Harir area, " *Jour. of Geol. Soc. Iraq*, Special Issu, 1975.

[40] T. Y. Ahmed. "Geophysical Investigation of the south and the southwest of Aski Kalak," *M.Sc. Thesis*, Mosul Univ. Ungub. 1980.

[41] F. A. Ghaib. "Geophysical study of the Erbil and Aqra plains and their Geological Implications, "*Unp. Ph.D. Thesis*/ Salahadin University, Erbil, Iraq. 185p, 2001.

[42] A. O. Farhan, A. M. Ahmed, and S. S. Farhan, "Estimation of the Radioactive Elements in Raw Materials Utilized in the Ceramic Industry, Anbar, Western Iraq," Iraqi *Geological Journal*, 55 (1B), pp. 113-120, 2022.

[43] Z.D. Al-Shaikh and A. M. Al-Mashhadani, "Gravity evidence of widespread solution below Salman area, the Iraqi Southern desert," *Iraqi Bulletin of Geology and Mining,* Vol.10, No.2, p 87 – 98,2014.

[44] A. H. Alhadiathy and I. Najar, "Tectonostratigraphic Evolution of the Western Desert of Iraq," *IOP Conf. Series: Earth and Environmental Science* 1080, 012006. 2021.

[45] R. A. Abdulnaby, W. N. Mahdi and H. Al-Shukri, "Crustal structure beneath seismic station-Central Mesopotamia, Iraq, using receiver function technique, " *Iraqi Geological Journal*, 53 (2A), pp. 77-87,2020.

[46] V. Baranov, "A New Method for Interpretation of Aeromagnetic Maps, Pseudo-Gravimetric Anomalies," *Geophysics*, Vol.22, pp.359-363, 1957.

[47] S. A. G. Mohammed, "Megaseismic section across the northeastern slope of the Arabian Plate, Iraq," *GeoArabia*, Vol. 11, No. 4, pp.77–90, 2006

[48] A. S. Al-Banna and A. N. Daham, "Applications of Source Parameter Imaging (SPI) technique to gravity and magnetic data to estimate the basement depth in Diyala area, eastern central Iraq," *Iraqi Journal of Science* , Vol. 60, No. 3, pp. 601-609, 2019.

[49] V. Teknik and A. Ghods, "Depth of magnetic basement in Iran based on fractal spectral analysis of aeromagnetic data," *Geophysical Journal International*, Vol. 209, No. 3, pp. 1878–1891, 2017.

[50] S. A. Alsanawi, A. S. Al-Banna, "An E-W transect section through central Iraq, Proceedings of the 9th International Conference on Basement Tectonic, " *Canberra, Australia*, pp. 195-200, 1990.

[51] E. M. Al-Heety "Crustal thickness map of the Arabian Plate from seismic data," *MESF Cyberb Geoscience Journal*. Vol. 9, No. 10, pp. 1-10, 2003.

[52] O. Q. Ahmad and W. G. Abdulnaby, "Crustal Structure of Sulaymaniyah Area, NE Iraq from Joint Inversion of Receiver Function and Surface Wave Dispersion Analyses Using SLY1 Station, " *Iraqi Geological Journal*,Vol. 56, No. 1C, pp. 235-247, 2023.

[53] W. Abdulnab, H. Mahdi, H. Al-Shukri and N. Numan, "Stress patterns in Northern Iraq and surrounding regions from formal stress inversion of earthquake focal mechanism solutions," *Pure and Applied Geophysics* , vol. 171, no. 9, pp. 2137-2153, 2014a.

[54] W. Abdulnab, H. Mahdi, N. Numan and H. Al-Shukri, "Seismotectonics of the Bitlis–Zagros fold and thrust belt in northern Iraq and surrounding regions from moment tensor analysis," *Pure and applied geophysics*, vol. 171, no. 7, pp. 1237-1250, 2014b.

[55] N. Afsari, F. Sodoudi, F. Farahman, G. Reza, "Crustal structure of Northwest Zagros (Kermanshah) and Central Iran (Yazd and Isfahan) using teleseismic Ps converted phases," *Journal of Seismology*, vol. 15, no. 2, pp. 341-353, 2011.

[56] F. F. Taghizadeh, N. Afsari and F. Sodoudi, "Crustal Thickness of Iran Inferred from Converted Waves," *Pure and Applied Geophysics*, vol. 171, no. 7, pp. 1089-1596, 2014.

[57] A. S. AL-Banna and A. F. Aziz, "Gravity and Magnetic Interpretation to Study Deep Crustal Structures In Karbala and Surrounding Areas-Central Iraq," *Iraqi Journal of Science*, Vol. 60, No.3, pp. 536-544, 2019.

[58] H. A. Al-Musawi, H. H. Abdallah and Th. M. Azzawi, "Neotectonic Activity of Segmented Alluvial Fans along Hemr in South Anticline, East Iraq," *Iraqi Journal of Science*, 2020, Vol. 61, No. 9, pp. 2266-2276, 2019.