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Comparison between the Lineament Trends at Western Euphrates River and Eastern Parts in Central Iraq, Depending on the Total Horizontal Derivative of Residual Magnetic Maps Obtained from Four Upward Continuation Levels

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Abstract
The upward continuation was used to obtain the residual RTP magnetic maps at elevations 2, 12, 16 and 22 km. These maps are processed by the Total Horizontal Derivative (THD) technique to detect the main lineaments that represent the boundary of subsurface sources or fractures. The high background of THD in the central part of the study area supports the presence of a group of faults between the western and eastern parts of the area. The obtained lineaments trends were represented on the rose diagram, as were the main trends in the study area. The predominant lineaments (faults) trends in the western part in descending are N55W, N35W, N05W, N65W, N45W, N25W, N05E, N15E, and N35E, respectively, for the four considered upward elevations. The lineament in eastern part found trending N55W, N35W, N35E, N45W, N45E, N05E, N25E, and N05W, respectively. The lineaments of the western and eastern parts indicate that the main trend in shallow sources is NW-SE, which coincides with the Najd fault system (540-620 Ma) in the Arabian Plate. The deep-level lineaments are trending N-S, which coincides with the Nabitah fault system (680-640 Ma).

Keywords: Lineament trends, RTP Magnetic, THD, Upward technique, Central Iraq

مقارنة بين اتجاهات التراكيب الخطية في غرب وشرق نهر الفرات في وسط العراق اعتماداً على المشتقة الافقية الكلية للخرائط المغناطيسية المتبقية التي تم الحصول عليها من أربعة مستويات استمرارية تصاعدية

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الخلاصة
تم استخدام الاستمرارية التصاعدية للحصول على الخرائط الاختزال الى القطب المغناطيسي المتبقية على الارتفاعات 2 و12 و16 و22 كم. تتم معالجة هذه الخرائط بواسطة تقنية المشتق الأفقي الكلية للكشف عن تراكيب خطية الرئيسية التي تمثل حدود المصادر أو الكسور تحت السطح. قيم الخلفية العالية للمشتقة الأفقية الكلية في الجزء الأوسط من منطقة الدراسة تدعم وجود مجموعة من الصدوع بين منطقة الجزء الغربي والشرقي. تم العثور على اتجاهات الخطوط التي تم الحصول عليها والممثلة في مخطط الوردة والاتجاهات

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الرئيسية في منطقة الدراسة. اتجاهات الظواهر الخطية (الكسور) السائدة في الجزء الغربي تنازلياً هي N55W، N35W، N05W، N65W، N45W، N25W، N05E، N15E، وN35E، على التوالي، للارتفاعات الأربعة المدروسة. وجد الخط في الجزء الشرقي اتجاهًا N55W وN35W وN35E وN45W وN45E وN05E وN25E وN05W على التوالي. وتشير خطوط الأجزاء الغربية والشرقية إلى أن الاتجاه الرئيسي في المصادر الضحلة هو الشمال الغربي-الجنوبي الشرقي، والذي يتزامن مع نظام صدع نجد (540-620 مليون سنة) في الصفيحة العربية. يبدو أن التراكيب الخطية في المستويات العميقة تتجه نحو شمال-جنوب، والتي تتزامن مع نظام صدع نبتة (680-640 مليون سنة).

الكلمات المفتاحية: الاتجاهات الخطية، الاختزال الى القطب المغناطيسي، المشتقة الأفقية الكلية، التقنية الصاعدة. وسط العراق.

Introduction

The geological and geophysical data provide information about the subsurface features (folds and faults). The magnetic survey is one of the oldest geophysical surveys that depended on measuring magnetic susceptibility. The unit of measurement for magnetic intensity is the nano Tesla (nT) [1, 2 and 3]. These techniques are typically used to identify faults and their trends in the basement because any long, continuous natural geological feature, like folds or faults, can be reflected on the geophysical measurements as anomalous lineaments [4]. The Arabian Plate (including Iraq) suffered many events from the pre-Cambrian era to the present, which passed through many movements [5 and 6]. The process of collision of the Arabian Plate with the Eurasian Plate, which began during the Early Tertiary and continues, resulted in modern tectonics (Zagors Thrust Fault), represented at the surface by mountain features in the eastern and northeastern parts of Iraq, as well as the development of sedimentary basins in central Iraq [7]. The tectonic processes control the formation and diversity of the characteristics and structures of the earth's crust and its evolution through geological times, which include the movement of continents, the building of mountains, the reactivation of faults, and other geological processes within the earth's crust [8].

The magnetic method is sensitive to detect the susceptibility contrast of sub-surface geology features and surrounding areas. It is a method used to explore major sedimentary basins, which shows contrast between the sedimentary rocks and the de underlying rock basement rocks [9, 10 and 1].

Many researchers in Iraq conducted studies to locate the faults and their trends using different geophysical methods. The southern part of Iraq was studied using gravity and magnetic data to identify the lineament group from the Palaeocene to the lower Eocene [11]. The western desert of Iraq and part of Syria's lineaments were studied depending on gravity data. The lineaments trend in western Iraq found N35W, N35E, and N65E [12]. In many areas of Iraq, the definition of the geological lineaments was based on satellite images and geophysical field surveys [13, 14, 15, 16, 17, 18 and 19]. Gravity, magnetic, and Seismological interpretation results were used in many regional studies in Iraq to detect the lineament trends, which are considered faults [20, 21, 22, 23, 24, 25, 26 and 27].

Geographically, the study area was split into the western and eastern regions of the Euphrates River. The study attempted to compare the differences in fault trends between the eastern and western sections because the Euphrates River runs through the center of the study area and has major faults along its length, including the Abu Jir Fault (Euphrates Fault). Using THD of residual magnetic data from central Iraq, this study compares the trends of lineaments in the eastern and western regions of the Euphrates River.

Data

Location of the site

The study area is geographically divided into two distinct regions: the western and eastern Euphrates Rivers parts, which are situated within the latitudes of 30° 69' to 34.5° N and longitudes of 38° 79' to 46.7° E. The western portion stretched to the Euphrates River in central Iraq, close to the borders of Saudi Arabia and Jordan. The eastern part extends from the Euphrates River in central Iraq to Khanaqin city near the Iraq-Iran border (Figure 1).

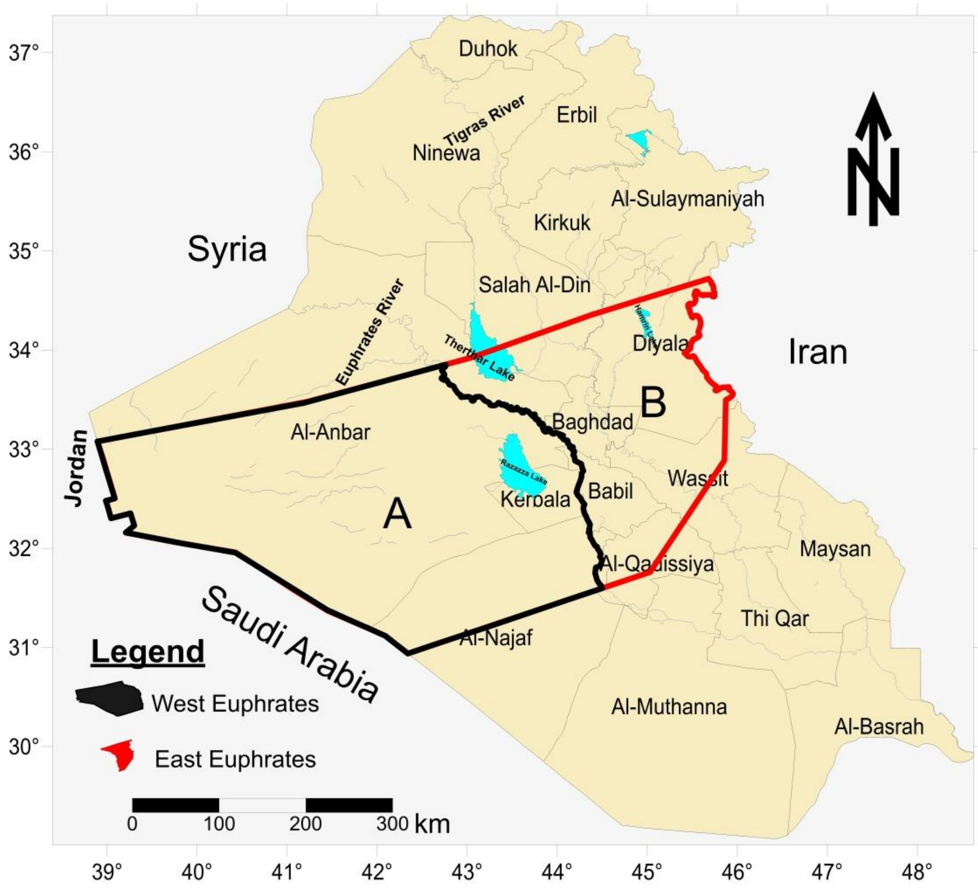

Figure 1: Location map of study area.

Geology and tectonic setting of the study area

The surface geological map of the study area exhibits Mesozoic formations that dominate the western part, while the eastern side is covered with Quaternary sediments [5]. According to geology, the central part of Iraq is characterized by strata that dip northeasterly and are slightly more inclined than the surface terrain. However, in the vicinity of Rutba Town in western Iraq, the strata dip westward, away from the axis of a prominent ENE-WSW trending anticlinorium, featuring rocks dating back to the Permian period [28, 29, 5, 30, 31 and 32]. The gravity and magnetic data analysis in western Iraq indicate that the basement rocks primarily comprise acidic or ultra-basic regional groups [33]. The basement rocks in central Iraq consist of Granite, Granodiorite, Schist, and Phyllite rocks [5]. A variety of geological formations stretch from Quaternary sediments in the eastern area to the late Permian Ga'ara formation in the western area [5 and 34] (Figures 2). Iraq has experienced many events from the late Precambrian period to the present because it is located in the northeastern region of the Arabian Plate. These events encompass the collision of accreted continental, followed by periods of cessation, fault formation, tectonic plate movements, subsidence, and sedimentary deposition. The sedimentary sequence in Iraq is subdivided into 11 AP Megasequences [5].

The tectonic of Iraq has been affected by the collision of the Arabian Plate with the Eurasian Plate. This process commenced during the Early Tertiary period and continues to the present time. This ongoing collision has given rise to various tectonic features, including mountain ranges in Iraq's eastern and northeastern regions and the formation of sedimentary basins [7]. Many researches conducted by geologists and geophysicists have aimed to categorize Iraq's tectonic divisions using different theories, geological available information and geophysics data such as [35, 14, 13, 36, 37, 38, 11, 39, 6 and 40]. The study area can be divided into two units: the inner platform (relatively stable) in the western part and the outer platform (unstable shelf) in the eastern part (Mesopotamia basin) [39, 41 and 40] (Figures 2 and 3).

Fault Systems

The separation of the Arabian Plate from the Eurasian Plate in previous geological ages, as well as its collision with the Iranian Plate, has resulted in significant deformation within the study area, predominantly covered by Quaternary-age sediments. Consequently, numerous researchers have undertaken comprehensive studies utilizing various geological, geophysical, satellite imagery, well data, and other available information to identify the locations and characteristics of major and minor faults within this region.

conducted a regional study using geological and geophysical data to identify lineaments and faults [7]. used gravity and magnetic data to detect the main lineaments related to the faults or tectonic boundary in the Al-Jezira area of northwestern Iraq [20]. examined fault systems in Iraq, using a combination of geological and geophysical data to determine the locations and characteristics of faults [23]. Mohammed identifies and analyzes fault systems in Iraq using various data sources, contributing to understanding fault networks and their implications [42].

derived fault information from various sources, including satellite imagery, gravity and magnetic gradients, and, to a lesser extent, seismic data. They found that the Total Horizontal Derivative of gravity was a handy parameter for determining fault trends. The fault systems identified in the study area include the N-S Nabitah (Idsas) System: This fault system runs north-south and represents a significant tectonic feature in the region. NW-SE Najd System: This system comprises a network of faults, including the Tar Al Jil Fault Zone, Euphrates Boundary Fault Zone, Ramadi-Musaiyib Fault Zone, Tikrit-Amara Fault Zone, and Makhul-Hemrin Fault Zone. These faults trend in a northwest-southeast direction.NE-SW or E-W Transversal System: This system includes faults such as the Sirwan Fault Zone and Kut-Dezful Fault Zone, which exhibit a northeast-southwest or east-west orientation (Figures 3). These fault systems formed during the Late Precambrian Nabitah orogeny and were subsequently reactivated at various times during the Phanerozoic. These studies have contributed significantly to our understanding of Iraq's tectonic and geological features and have helped identify critical fault systems within the region [5].

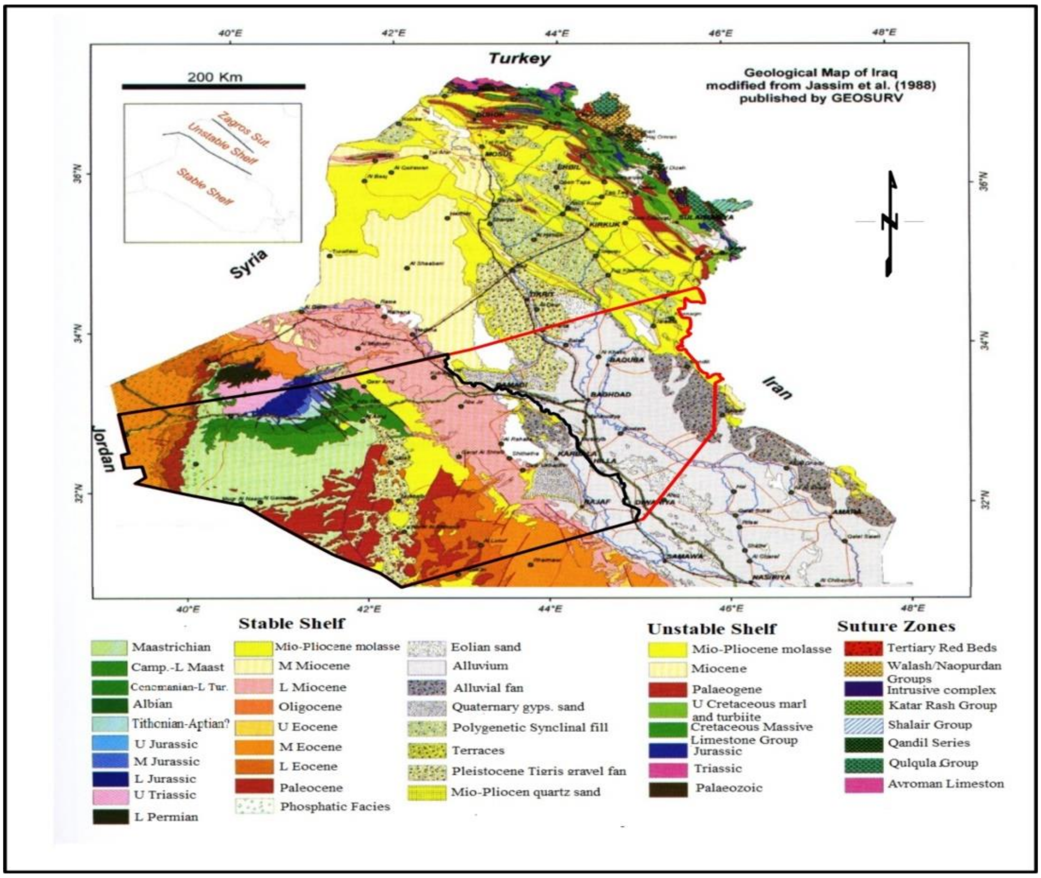

Figure 2: The geological map of Iraq, showing the study area inside the (red-black) polygon, modified after [5].

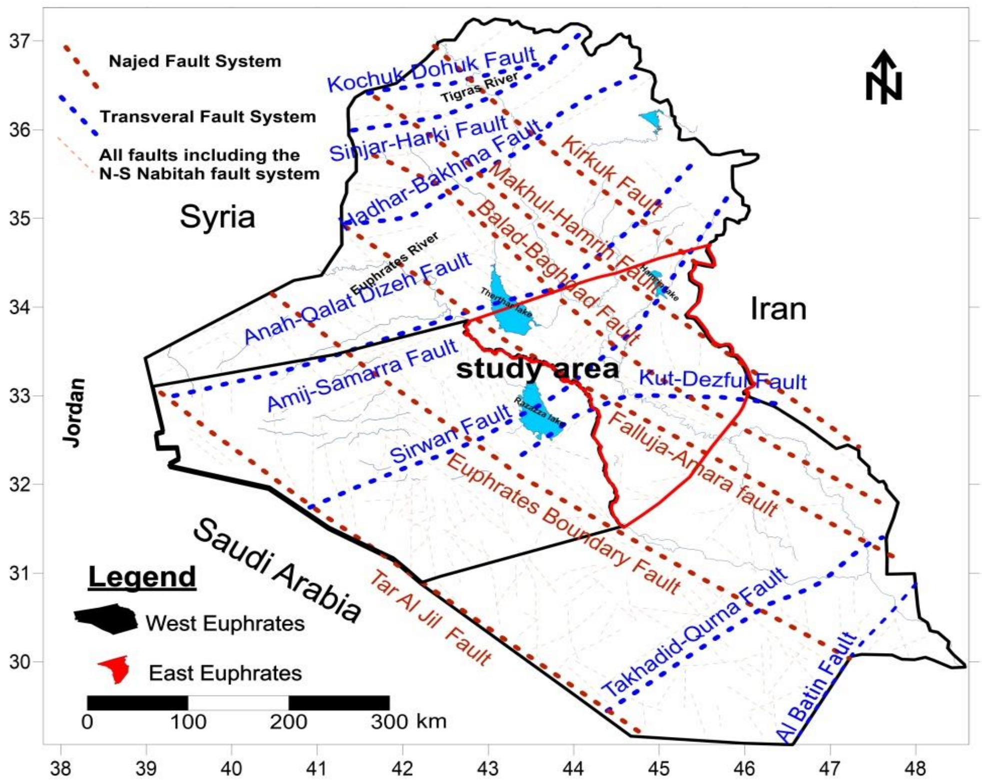

Figure 3: The Tectonic map of Iraq showing the study area inside the red and black polygon (modified after [43]).

Materials and method
Data acquisition

The aeromagnetic surveys conducted in Iraq in 1974 were carried out by the French company CGG at 140 m above the topographic surface. These data were subsequently processed and analyzed to create a basement depth map of Iraq, as reported by [44]. For further analysis and interpretation, the original data underwent reprocessing and reinterpretation in 2010, facilitated by [45], on behalf of the oil exploration company and the geological survey of Iraq. The Total Magnetic Intensity (TMI) anomaly map has values ranging from 4766 to 5230 nT(Figure 4). It is worth noting that the Oil Exploration Company supplied the magnetic data [46]. A technique known as the Reduction to Pole (RTP), based on the principles outlined by [47], was applied to enhance the interpretability of aeromagnetic anomaly maps. This mathematical process transformed the effect of a magnetic dipole source into a one-pole anomaly source. The resulting RTP map, derived from the TMI magnetic map within the study area, illustrates magnetic values ranging from 4836 to 5219 nT (Figure 5).

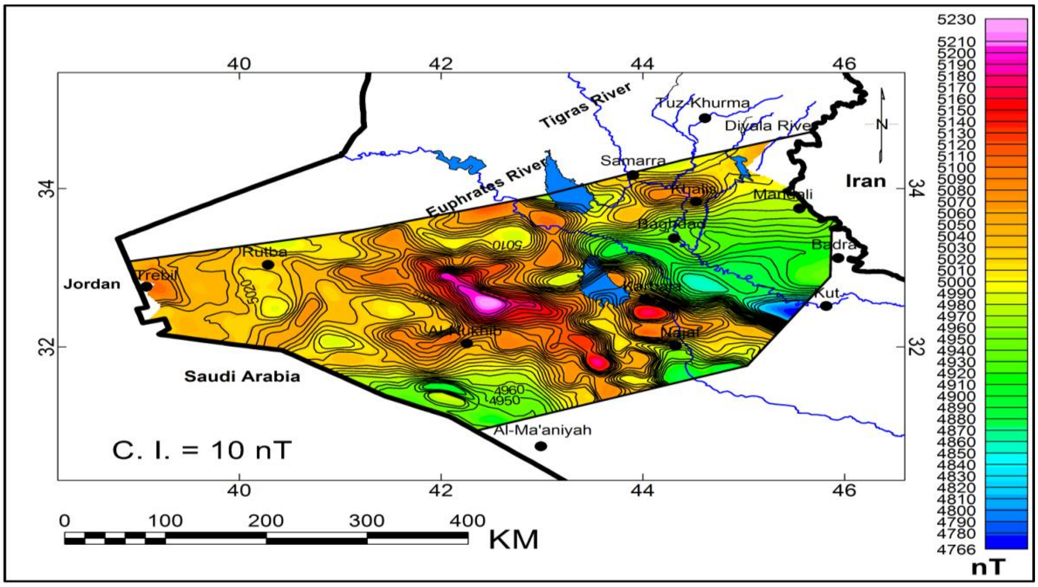

Figure 4: The study area's Total Magnetic Intensity (TMI) anomaly map [45].

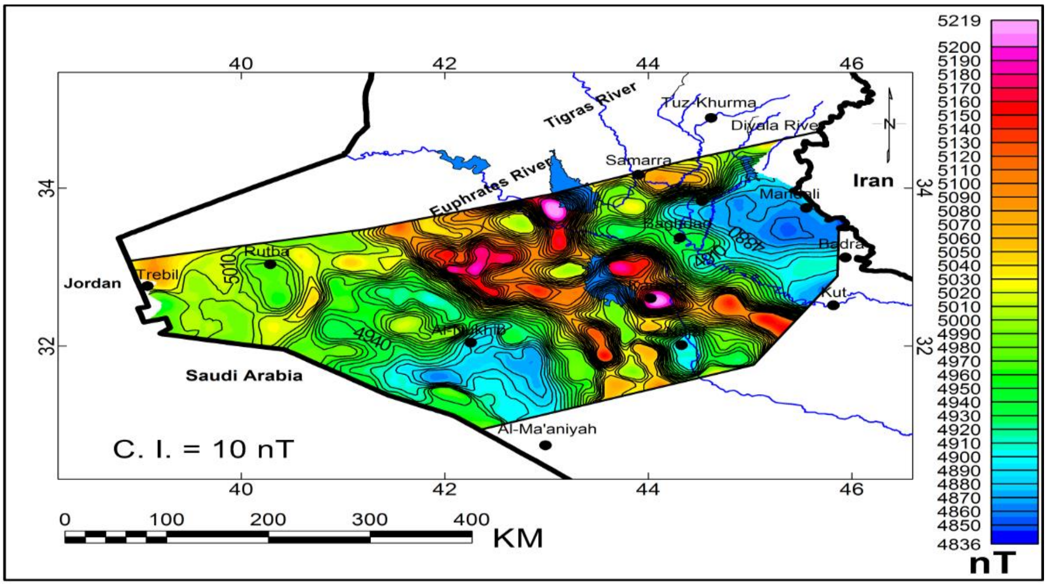

Figure 5: The RTP magnetic map of the study area [45].

Residual Anomalies of Gravity and Magnetic Data

Using the RTP magnetic data, the upward continuation filter was employed to generate regional and residual anomaly maps. This filtering operation was executed at four different elevations: 2 km, 12 km, 16 km, and 22 km. Notably, the locations of the conspicuous positive and negative anomalies observed in magnetic residual maps remained consistent. This consistency suggests a potential correlation between these anomalies and their origin from deep-seated sources (Figures 6 and 7).

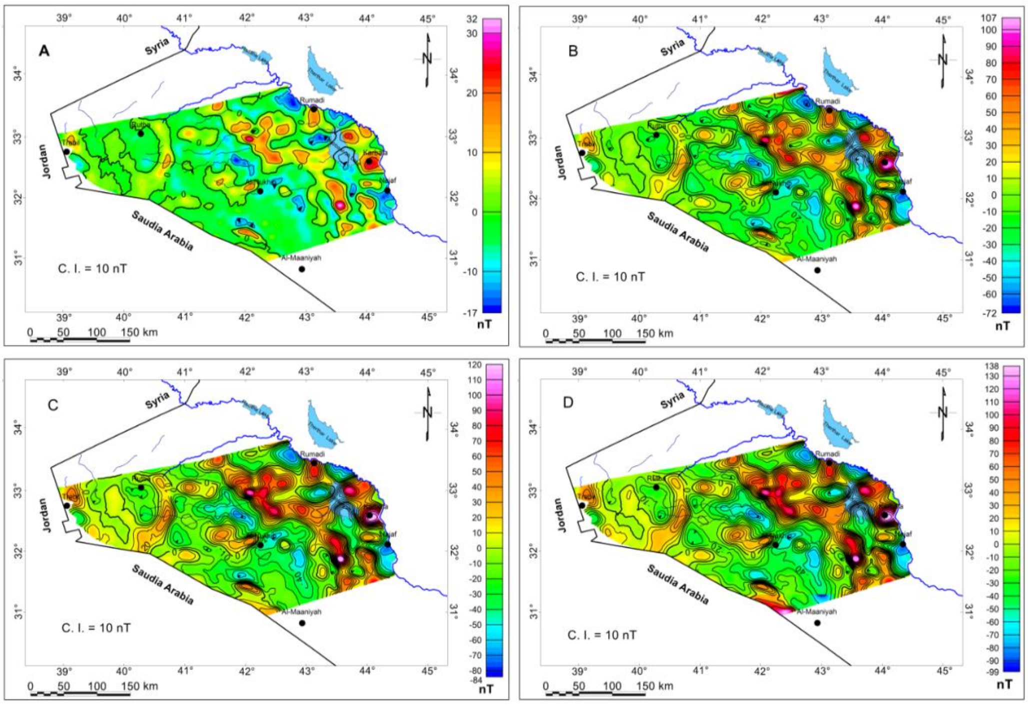

Figure 6: The residual RTP magnetic anomaly maps of the western part area, using upward continuation elevation levels: (A) 2 km; (B) 12km; (C) 16 km; (D) 22km.

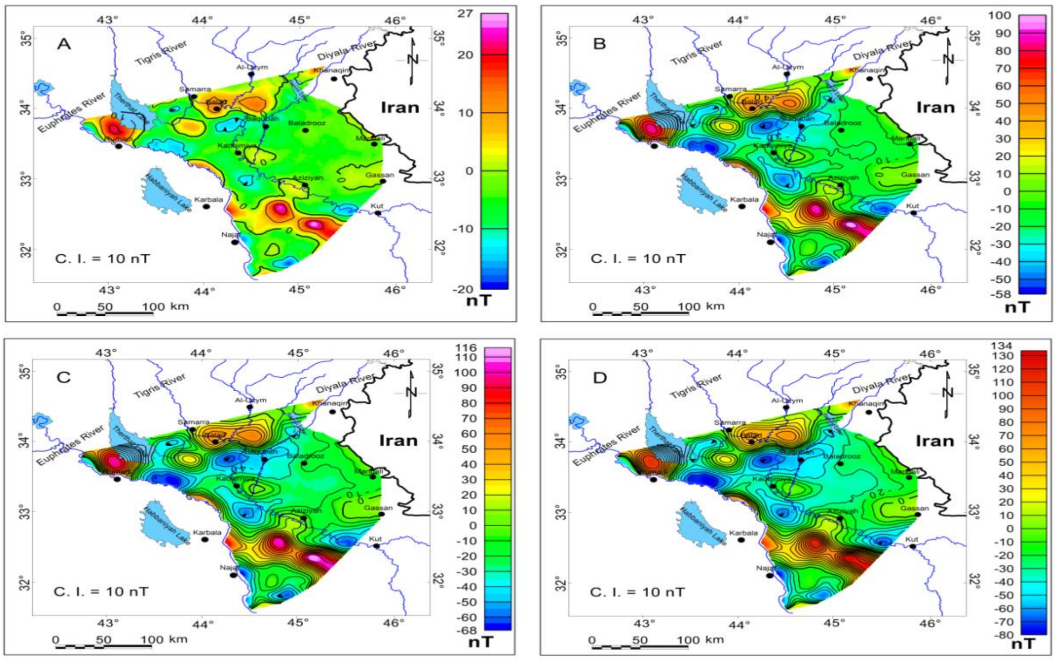

Figure 7: The residual RTP magnetic maps of the eastern part area, using the upward continuation of elevation levels : (A) 2 km; (B) 12km; (C) 16 km; (D) 22km.

Total Horizontal Derivatives (THD)

The Total Horizontal Derivative (THD) is a valuable tool in identifying the edges and subsurface characteristics of fault structures within geological formations. The highest THD values indicate lineaments associated with the boundaries or faults of geological bodies, as established by [48].

The THD computation involves combining two horizontal derivatives: the first horizontal derivatives are represented as dT/dx and dT/dy. Alternatively, it can be computed using the second horizontal derivatives, denoted as d^2T/dx^2 and d^2T/dy^2.

Typically, THD finds significant application in delineating magnetic anomalies within geological contexts. The mathematical expression for calculating the Total Horizontal Derivative (THD) is as follows [1]

$$THD = \sqrt{(\mathrm{d}T/dx)^2 + (\mathrm{d}T/dy)^2} \quad \text{------ (1)}$$

Where

T is the anomaly, dx is horizontal derivatives in the x direction, and dy is horizontal derivatives in the y direction.

The Total Horizontal Derivatives (THD) were derived from the residual magnetic data within the study area using software tools such as Oasis Montaj 2015, Arc Map 10.7, and Rockworks. These THD maps were then used to identify and delineate magnetic lineaments across four different elevations in the upward continuation residual maps (2 km, 12 km, 16 km, and 22 km) (Figures 8 and 9).

A rose diagram was constructed to gain insights into the predominant trends of these lineaments, capturing the main directional orientations (Figures 10 and 11). The outcomes and summaries of the magnetic lineament trends (Tables 1 and 2).

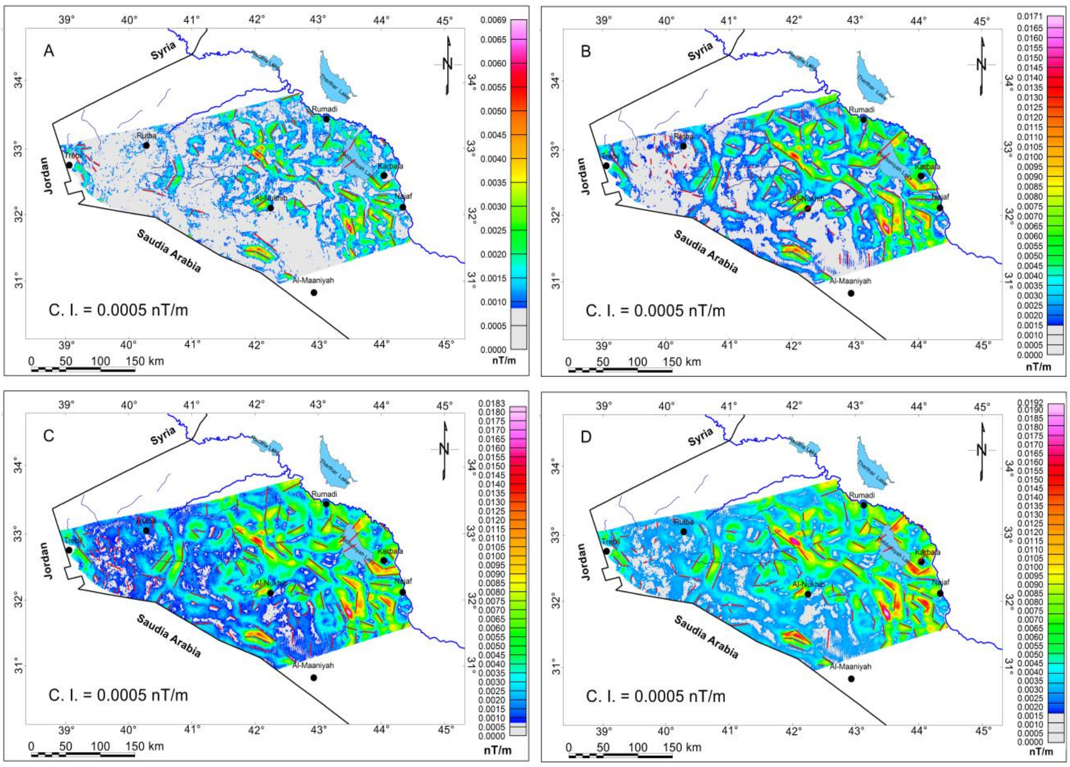

Figure 8: The main Lineaments detected on Total Horizontal Derivative (THD) of residual RTP magnetic data of the western part area, obtained from upward continuation for elevation levels. (A) 2 km ; (B) 12km; (C) 16 km; (D) 22km.

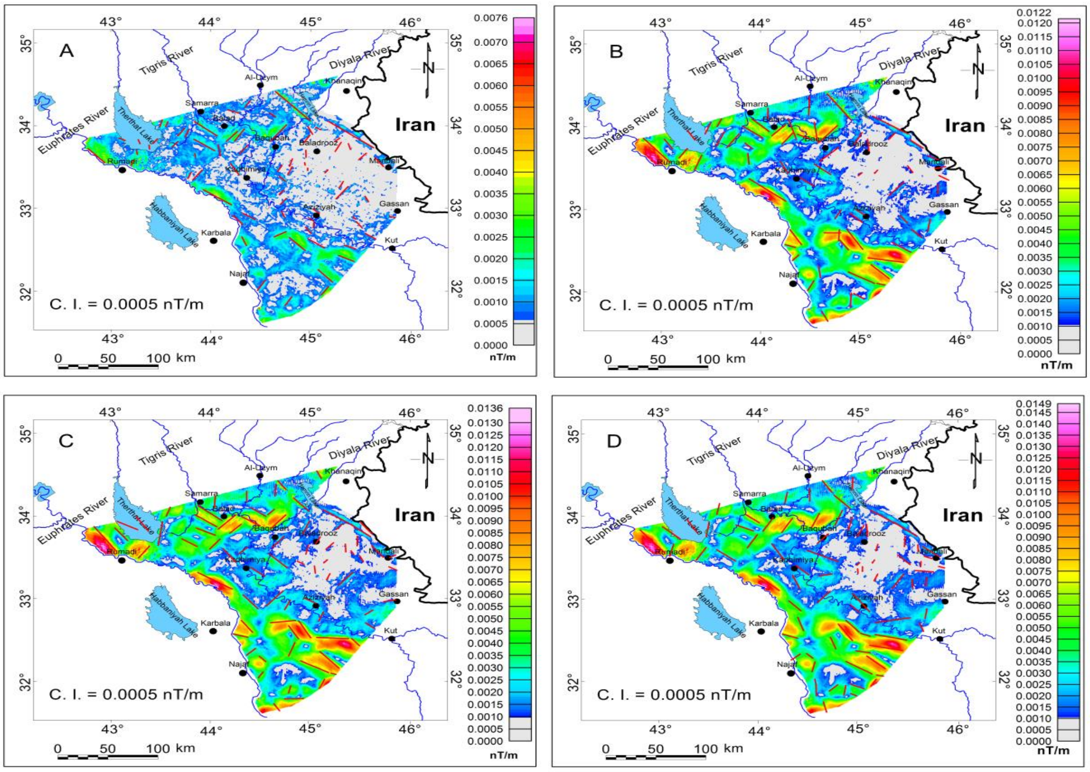

Figure 9: The main Lineaments detected on Total Horizontal Derivative (THD) of residual RTP magnetic data of the eastern part area, obtained from upward continuation for elevations. (A) 2 km ; (B) 12km; (C) 16 km; (D) 22km.

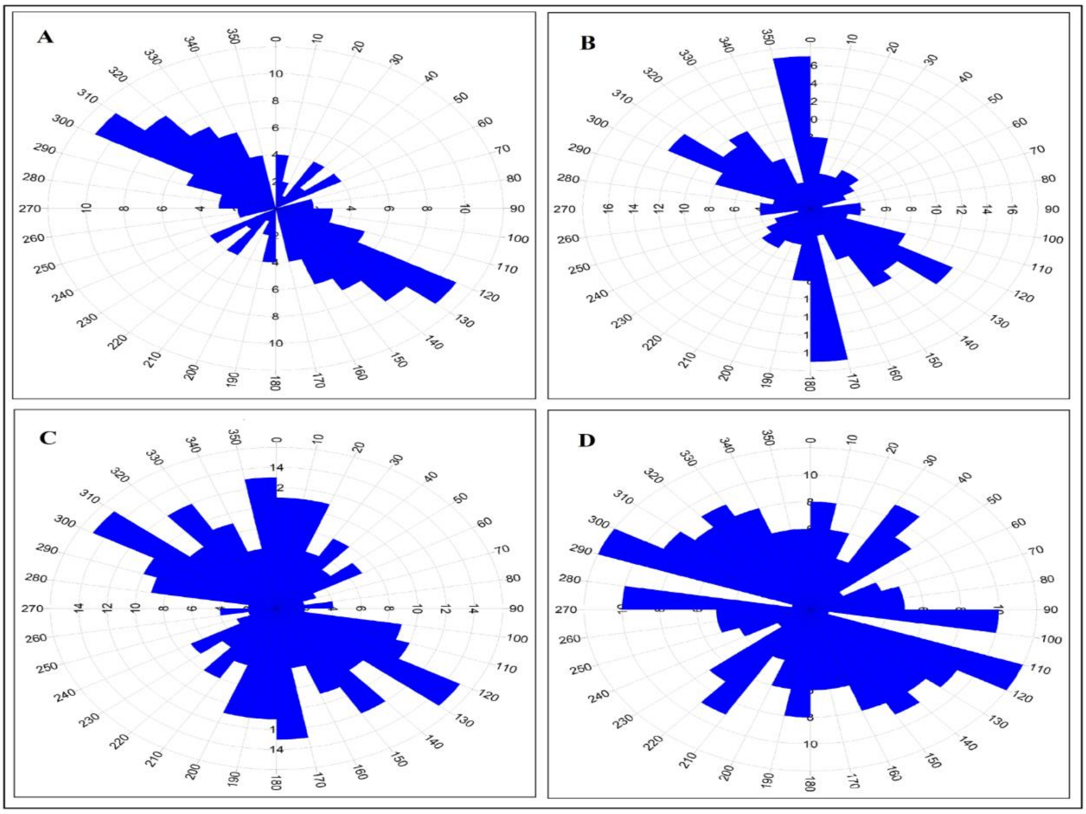

Figure 10: Rose diagram for lineaments (maximum THD) direction of residual RTP magnetic anomalies at the western part area, obtained using upward continuation with elevations: (A) 2 km; (B) 12km; (C) 16 km; (D) 22km.

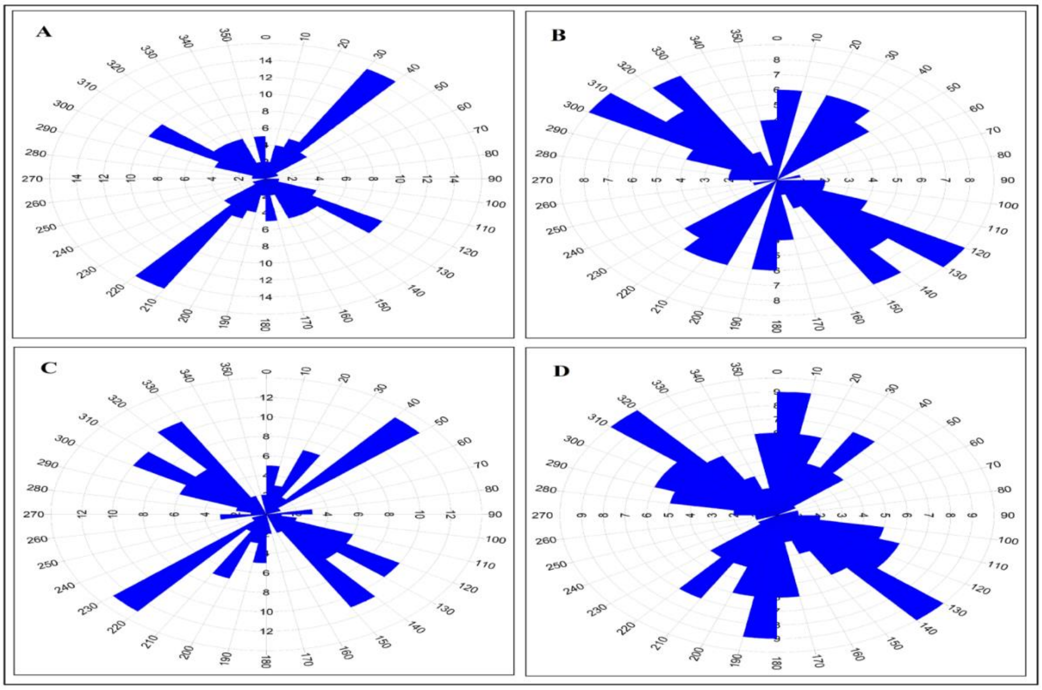

Figure 11: Rose diagram for lineaments (maximum THD) direction of residual RTP Magnetic anomalies at eastern part, obtained using upward continuation with elevation levels ; (A) 2 km; (B) 12km; (C) 16 km; (D) 22km.

Table 1 The main lineaments T trends of the western part, those obtained from THD of residual RTP magnetic, deduced from upward continuation elevation levels: 2km, 12km, 16km and 22km.

Lineament direction / Upward elevation	N85W	N75W	N65W	N55W	N45W	N35W	N25W	N15W	N05W	N05E	N15E	N25E	N35E	Predominate trend
2km	-	-	5	11	9	7	6	-	-	-	-	-	-	N55W
12km	-	-	8	13	9	10	6	-	17	-	-	-	-	N05W
16km	-	9	10	15	7	12	9	-	13	11	11	-	8	N05W
22km	10	-	12	9	8	9	8	6	6	8	6	-	9	N65W
Σ	10	9	35	48	33	38	29	6	36	19	17	-	17	
order			4th	1st	5th	2nd	6th		3rd	7th				

Table 2: The main lineaments trends of the eastern area, those obtained from THD of residual RTP Magnetic, deduced from upward continuation elevations 2km, 12km, 16km and 22 km.

Upward elevation / Lineament direction	N75W	N65W	N55W	N45W	N35W	N25W	N15W	N05W	N05E	N15E	N25E	N35E	N45E	Predominate trend
2 km	-	-	10	5	5	5	-	5	-	-	-	15	-	N35E N65W
12 km	-	4	9	6	8	-	-	4	6	-	6	6	5	N55W N35W
16 km	-	6	10	6	11	-	-	-	5	-	7	-	13	N45E- N55W
22 km	5	6	6	10	5	-	-	6	9	6	4	7	4	N45W- N05E
∑	5	16	35	27	29	5	-	15	20	6	17	28	22	
Trends Order		8th	1st	4th	2nd			9th	6th		7th	3rd	5th	

Discussion

The upward continuation method processed the RTP magnetic data to obtain the regional anomaly values, which were subtracted from the RTP magnetic to obtain the residual magnetic values. Figures (6 and 7) show the residual RTP magnetic with upward elevation levels of 2 km, 12 km, 16 km, and 22 km. The maximum values on these maps, which may be associated with the edge of sources or faults at the four levels of elevation under consideration, were identified using the THD technique (Figures 8 and 9). In Figures 8 and 9, the maximum values of THD were represented as lineaments. A rose diagram was created by plotting these lineaments. The predominant lineament trends at the west part area from RTP magnetic data were arranged in descending order N55W, N35W, N05W, N65W, N45W, N25W, N05E, N15E, and N35E, Figure (10), Table 1. The elevation level of 2km shows only the NW-SE trend, and levels 16km and 22km levels show the NW-SE, N-S and N35E trends. This result indicates that the NW-SE trends are related to the shallow features, while deeper geological features trend N-S and NE-SW in addition to the

NW-SE trend. The conjugate systems N55W-N05W and N65W-N05W indicate that the maximum stress directions are either N30W or N35W, especially at deeper levels. These faults and maximum stress direction are related to the Najd fault system at the Arabian Plate, which developed for the interval 540-620 Ma.

This study discusses the lineament in detail to coincide with previous studies' results, such as [17 and 18] for trends N-S, N25W and N80W. Meanwhile, the N10W, N50W, and N30E detected in the present study were mentioned by [12].

The lineament groups in the eastern part area show the predominant trends, in descending order, as follows: N55W, N35W, N35E, N45W, N45E, N05E, N25E, and N05W, figure (11), Table 2. Generally, two main groups of lineaments were characterized in the eastern part area: NW-SE and NE-SW. Two conjugate fault systems can be suggested for the east part of the area. These are N55W-N35E and N35W-N35E, which indicate that the maximum stress trend is either N10W or N-S directions. These trends referred to the N-S Nabitah fault system in the Arabian Plate (680-640 Ma). The shallow features trend mainly in the NW-SE direction, while the deeper features show the NE-SW and the NW-SE direction.

The lineaments trends in both studied areas, western and eastern parts, indicate that the NW-SE trend is the predominant trend, especially at shallow levels. The NW-SE trend of the Najd fault system is younger than the N-S Nabitah fault system trend.

Conclusion

Many conclusions were obtained from processing a magnetic map of the studied area. These are:

1- Most detected residual RTP magnetic anomalies related to sources within the basement rocks.
2- The high background value of the THD of the residual RTP magnetic supports the idea of many faults between the eastern and western parts, running along the Euphrates (Abu-Jir) Fault.
3- The faults at deep levels in the study area were found to drift toward the north trend.
4-The fault trends indicate that the stress direction at the western part is N-S, while N10W is at the eastern part. This case indicates the presence of a change in the direction of stress, which may be due to the effect of the collision of the Arabian Plate with the Iranian Plate.

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