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APPLICATION OF MAGNETIC METHOD IN MINERAL EXPLORATION: IRON ORE DEPOSIT, SOUTH ZAGROS SUTURE ZONE, IRAQ

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تطبيقات مغناطيسية على استكشاف المعادن (ترسيبات الحديد) قرب منطقة جنوب زاجروس بالعراق

الخلاصـة: . تقع منطقة الدراسة فى الجزء الشمال الشرقى من أقليم كردستان بمنطقة جنوب زاجروس وكما هو معروف أن المنطقة تكونت من حركات تكتونية وبركانية. وتتميز المنطقة بوجود موارد حديدية محتملة. ونحاول فى هذه الدراسة، نرسيم التراكيب التحت السطحية للحديد بدراسة متكاملة لاستخدام تفسير البيانات المغناطيسية والجيولوجية. وشمل المسح المغناطيسى الأرضى للمنطقة حوالى (٣,٥ * ٢,٥)= ٨,٧٥ كم٢. وكان العدد الإجمالى للمحطات المغناطيسية تصل إلى ٦٨٠ ومتوسط التوزيع للمحطات حوالى ٨٥ محطة فى الكيلو متر المربع.

أشارت تفسيرات التحليل الموجى والتدرج الأفقى للبيانات المغناطيسية التى تمتاز بها المنطقة إلى وجود البيانات المغناطيسية عالية الانحدار المرتبطة بتكوين الحديد ومظاهره. تمكن تحليل التدرج الأفقى أيضا تمكن من تتبع التراكيب الجيولوجية التحت السطحية حيث تتجه شمال شرق – وجنوب غرب ، ولها امتدادات أكثر من ٢ كم. وطبقت طريقتا أويلر الاختزالية والطيف المغناطيسى للبيانات والتى تعطى معلومات سريعة عن عمق التراكيب الحديدية الضحلة فى المنطقة حيث تتروح أعماق رواسب الحديد من ١٥٠ حتى ٣٠٠ متر مع متوسط ٢٢٥ متر. وفقا لهذه القياسات المغناطيسية فان التقدير الأولى للخام الحديدى فى المنطقة حوالى ١٢٥ ملبون طن فى مساحة حوالى ٨,٧٥ كم٢.

ABSTRACT: *The south Zagros Suture Zone (ZSZ) is located in the Northern Eastern part of Kurdistan region-Iraq and known as volcano-tectonic area. It is characterized by its potential iron resources. In this study, we attempt to delineate the subsurface structures using integrated interpretation of existing magnetic and available geological data. The land magnetic survey of the area under study is about (3.5 * 2.5) ≈ 8.75 km^2. The total number of magnetic stations was up to 680 and the average distribution of stations was approximately 85 stations per km^2.*

Interpretation of analytical signal and horizontal gradient of the magnetic data indicated that the area is characterized by the existence of high gradient magnetic anomalies associated with existing iron mineralization and manifestations. Horizontal gradient analysis also enabled tracing several subsurface geological structures (iron mineralization zone) are trending NE-SW and have extensions more than 2.0 km. The 3-D Euler deconvolution and 2-D Power Spectrum methods have been applied to the magnetic data and provided fast information about both the depth and trends of the shallower subsurface structures in the area. The depths of iron deposits vary from 150 to 300 m with average 225 m. according to these magnetic measurements (680 stations only). The preliminary estimation of the iron bodies in the region is about 125 million tonnes.

1. The Geologic and Tectonic Settings:

Kurdistan region is located north-east Iraq (*Figure 1*). It is close to one of the continental fracture system *(Zagros Suture Zone)* at the convergence boundary of three big lithospheric plates (Arabian, Turkish and Iranian). Also, Iraq is affected by the opening of the Arabian Gulf *(Mid Oceanic System)* and its branches *(transcurrent and transform fault systems).* Thus the seismicity (earthquakes) is due to the interaction between the three plates of Arabian, Turkish and Iranian plates.

The area under study (NE-Kurdistan) is a part of the Zagros Orogeny between latitude 35 36.1 N and longitude 45 57.9 E and its elevation 1450 m. above sea level. It is located south Zagros Suture Zone (ZSZ). At the Kurdistan-Iranian border, the land rises to the complex Zagros belt. Thrust zone structural trends are similar in Iran and Arabian Peninsula. The Zagros foothills trend is NW-SE. The folds frequently have surface expressions (Figure 1), which is the main tectonic regime in north and northeastern of Iraq whereas the rest of Iraq is covered with young sediments. The Katar Rash Andesite and Ophiolite (volcanic-intrusions) outcrop in the surface and extends near surface at great distances. Economically, this area is considered the most important place in NE-Kurdistan due to the mineral accumulating (Fe, Cu, Ni, and Mn) resources (Jassem &Goff, 2006).

Jassem and Budy (1982) divided Iraq into three geologic units: Stable shelf, Unstable shelf, and Zagros Suture. The unstable shelf is the main geologic division of NE Kurdistan and is characterised with different geological units. It is mainly built up of the ophiolitic sequence and mélange which is thrusted in NW-SE trend. The main structural elements were often related to structures caused by the Alpine Orogenic events. The principal tectonic trend is parallel to the Alpine Chain

NW-SE in NE Iraq (Figure 1). Zagros Suture can be divided into three tectonic zones from SW to NE zone as follows: Qulqula-Khwakurk zone, Walash zone, and Shalair zone (Jassem & El Hassan, 1977). Sediments ranging in age from Triassic to Paleocene cover the area. They unconformably overlie the Precambrian Basement (Figure 2). Overlying the Averon limestone, Qulqula group (Jurrassic-Cretaceous) formations in some places are Gimo, ophiolite and Andesite.

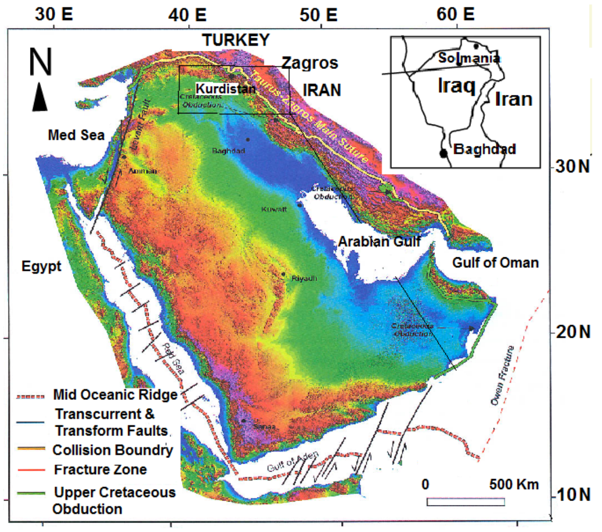

Figure 1: Location map of the Kurdistan region and the main tectonic zones that affected the region in the Southern part of the Zagros Suture. The northern & northeastern boundaries are compressional due to the Late Tertiary collision of the Arabian with Turkish and Iranian localities. The green boundary represents a Late Cretaceous Suture Zone (After Jassem & Goff, 2006).

Volcanic and metamorphic intrusions are distributed in several localities on the area and constitute the main geologic formation of the eastern side (Figure 2). There is no information from the boreholes indicating the average thickness of the whole sedimentary and mineral occurrences. The main units are Penjween-Walash and Shalair units. The Walash consists of Mawat Group (Gimo, Sirginil, Ultamafic and Gabbro of lower cretaceous) and banded Walash volcanic and Naopurdan of Paleocene. The Shalair unit (shalair valley and Andesite) is important for its iron mineralization zone, which consists of Katar Rash Andesite (upper Cretaceous), Shalair valley (Lower Cretaceous) and Darokhan limestone (Upper Triassic).

The exposed rock units in the study area are described by Abou Zeid & Khaled (2010) as follows: Ultramafic and Serpentine, Gabbro, Actinolite-Tremolite Schists-Talc, Meta volcanic (Banded Volcanic) and Marble and Albitite.

Geomorphologically, the area is not flat with a relief varying from 1450 to 1750 m above mean sea level. (Figure 3). The landscape is broken by the rise of black hills, ridges and low scarps of limestone, shale and sandstone. The topography is complicated by structural dislocations and also by the presence of several banded volcanic and ophiolitic ring complex.

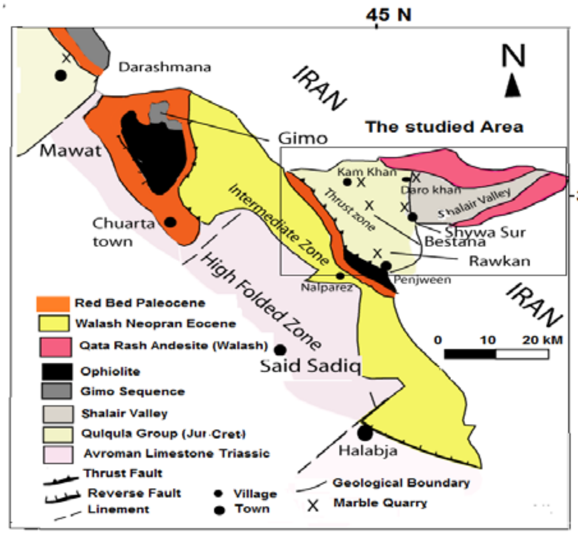

Figure 2: Geological map of the studied area and its surroundings (Jassem & El Hassan, 1977).

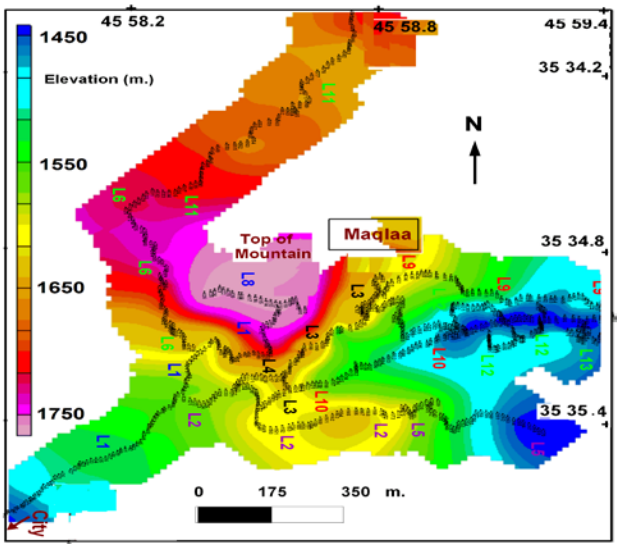

Figure 3: The topographic map (elevation) of the area under study using GPS Data. The red color represents highest points while the blue color represents lowest points.

2. Iron Mineralization Zone in NE Kurdistan:

The geology of Zagros in N & NE Iraq is favorable for the occurrence of metallic mineral deposits of hydrothermal origin connected directly or indirectly with igneous (volcanic rocks) activity. The Zagros Suture is characterized by iron and copper ores. Some indications of nickel, chromite and manganese ores were also indicated in the area (Jassim & Goff, 2006). Metallic mineralization is restricted to the Neo-Tethyan Suture Zones and its related to various phases of the plate tectonic history of the region. Magmatic (Cr, Ni, Cu and Fe) mineralization is associated with basic and ultrabasic igneous intrusive (e.g. Fe, Cr, Ni and Cu) see figure 4. Hydrothermal and strata-bound volcano-sedimentary deposits of Mn-Fe are associated with the Qulqula Group.

Iron mineral deposits of magmatic origin occur in magmatic segregation associated with chromite or related to serpintinzation of ultramafic bodies. Magnetite-chromite bodies are restricted to two main district: Penjween and Rawanduz. Numerous and small viens-like and irregular magnetite bodies accompanied by chromite occur in ultramafic rocks (mostly serpintized) in the intrusive massif. The most extensive mineralization in the intrusive Massif occurs at three localities: Karigapla, Buban and Kani Manga (Jassim & Goff, 2006). According to (Vanecek, 1972), iron mineralization is accompanied by about 4% chromite and nickel, Cu and Co concentration 0.5%. Iron mineralization in serpentinite containing 2-3 % chromite and about 0.5% Ni.

Copper ores in the Zagros Suture occur in two forms: disseminated mineralization in ultramafic and mafic magmatic rocks and as hydrothermal mineralization in quartz veins. Copper Occurrences are widespread but most are not of economic interest. They are related to serpintinized ultramafic rocks and gabbro (Figure 4). Copper deposits at Mawat massif were studied and detailed mapping using Electromagnetic (EM) survey in 1990. A 300 m. deep exploration borehole was drilled. Copper is associated with metabasalts of the Mawat Group, as lenses malachite between volcanic flow (300 m. thick) or as disseminated chalcopyrite within volcanic (Jassem & Goff, 2006).

The exposured iron ore deposits (Maqlaa) lie in the intersection of Latitude 35 35.15 N and Longitude 45 58.66 E at the elevation of about 1665 m. above Sea level, near Iraq-Iran border and about 3 km. The mineralogical map (Figure 4) shows the distribution of metallic mineral deposits (Fe, Cu, Cr, Au and Mn) and occurrences in the study area. Jassem and Goff (2006) reported three types of iron mineralization in the Zagros Suture zone. Most of these types and occurrences lie in the vicinity of the region as:

- Contact metasomatic or Skarn deposits
- Magmatic Segregation deposits, and
- Hydrothermal veins and lenses of Siderite.

The iron mineralization in the studied area is represented by lenticular shape with 30*60 m. as an exposed area (Maqlaa). The country rock around this lens is bounded by tuffs which contain marble lenses and Albitite. These volcanic rocks are subjected to shearing and iron oxides stained along shear planes (NW-SE) direction. The field observation showed that these volcanic rocks captured this iron lens. The Walash zone comprises metamorphosed volcanic and sedimentary rocks of Cretaceous age derived from Neo-Tethys, Eocene arc and fore-arc units.

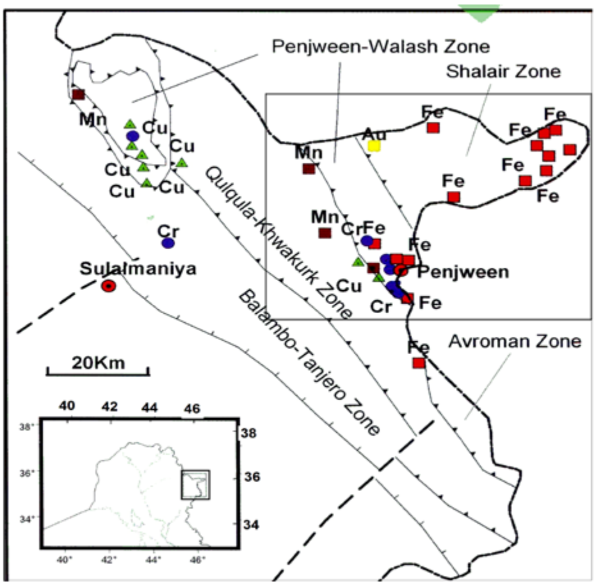

Figure 4: Distribution of metallic mineral deposits and occurrences in the southern part of the Zagros Suture (After Vaneeck, 1972).

3. Geomagnetic study:

This work is done to explore the iron mineralization in the NE Kurdistan region. The very reason for this study is the geological understanding of the site setting, the associated iron mineralization and subsurface structures (extension & depth). The Iron (Fe) is the most common element in the Earth's crust and forms magnetic minerals in combination with oxygen and heavy minerals (Au, Ag, Cu, Mn, Cr, Fe-titanium, some Fe-sulfide) structures. The occurrence of these minerals is modulated by various geochemical processes. Quantity and properties of magnetic minerals yield information about ambient formation and alteration conditions and transport paths. In mineral exploration the secondary effects in rocks that host ore deposits associated with hydrothermal systems are important and magnetic surveys may outline zones of hydrothermal activity.

The land magnetic survey has two tasks in this work: the first objective is to confirm the existence and location of iron deposits. The second objective is to estimate the depth of the iron mineralization zone. The magnitude depends on the quantity, composition, and size of magnetic- mineral grains. Magnetic anomalies may be related to primary igneous or sedimentary processes that establish the magnetic mineralogy, or they may be related to secondary alteration.

3.1. The Total Land Magnetic Survey:

In the present magnetic surveying, the field strength is measured with a magnetometer placed a few meters above the ground level. Measurements can be taken either along profiles or on a mesh of points. High sensitivity device (G-856, sensitivity 0.1 nT) is utilized for the measurement of the total earth's magnetic field (Figures 5a &b). Before the survey, one homogenous magnetic station will be selected within the study area to be used as a base station for diurnal correction. Ferrous metallic objects or inhomogeneity in the magnetic properties of soils will cause variations in the measured field which can easily be detected on the ground surface.

Figure 5a: G-856 Proton-Precession Magnetometer (Geometrics, 2010).

Figure 5b: magnetometer assembled & magnetic Data Acquisition in the studied area.

The ground magnetic survey and the base station measurements were conducted using the proton-Precession magnetometer (G-856). The magnetic profiles were taken in the available Paths around and crossing the iron mineralization zone (Maqlaa). However, the distance between profiles was not enough to establish a reliable grid (e.g. the distance between profiles L11 and L9). Figure 6 shows the profiles positions with respect to the Maqlaa location.

The direction of traverses of each profile and number of stations per profile are given in Table 1. The station separation along profiles was 20 meters while the distance between profiles varied according to safe paths. The station position, elevation with the time of measurement was recorded using handheld GPS. Later on, the data were corrected to the base station to remove the diurnal variation of the Earth's magnetic field and latitude correction (by removing 3.8 nT from the data for each 1 km toward north direction). The diurnally corrected magnetic data are shown in Figure 7.

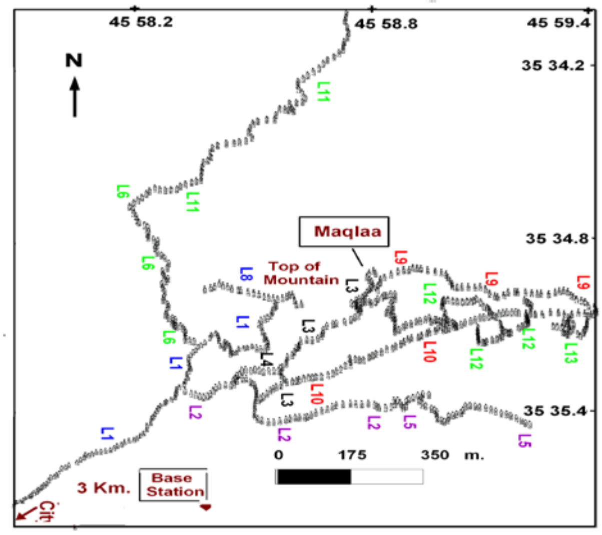

Figure 6: showing the magnetic profiles (L1-13) and Maqlaa location.

Table 1: The profile directions and number of stations in each profile.

Line	No. of Stations	Direction
L1	120	NW and NE
L2	53	NW and NE
L3	38	NW
L4	14	NE
L5	41	NE
L6	48	SW
L7	80	NW, NE and E-W
L8	24	NE
L9	62	NE and N-S
L10	35	NW
L11	57	NW
L12	66	E-W and NW
L13	27	E-W and NE

3.2. Data Processing and Analysis:

The present study is based on qualitative and quantitative analysis of the magnetic data to delineate both shallow and deep iron ore structures. In that regards, each profile was corrected and smoothed using FFT (5*5 symmetric convolutions filter by using Geosoft program (7.1.0). The recorded magnetic anomalies (Figure 7) display a major trend (from NW to NE). It should be stated that magnetic structures do not occur at random, but are generally aligned along definite and preferred axes forming trends that can be used to define magnetic bodies. These anomalies could be related to significant susceptibility contrast between the highly magnetic volcanic rocks and the non-magnetic metasediments.

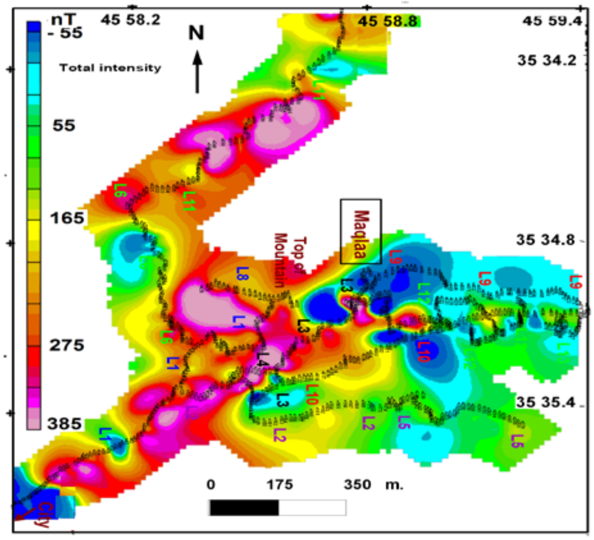

Figure 7: The total magnetic anomaly that around and crossed the Maqlaa. The color background of represented the corrected magnetic data. The red color represents high magnetic, the blue color represents low magnetic anomaly.

In order to trace the iron mineralzation from the profiles, the analytic signal method was applied to the corrected magnetic data. The amplitude of analytic signal (AAS) of the magnetic anomaly is given by Roest et al. (1992) according to the following equation: as

$$AAS(x,y) = \sqrt{\left(\frac{\partial T}{\partial x}\right)^2 + \left(\frac{\partial T}{\partial y}\right)^2 + \left(\frac{\partial T}{\partial z}\right)^2}. \qquad (1)$$

The horizontal $(\frac{\partial T}{\partial x} + \frac{\partial T}{\partial y})$ and vertical $(\frac{\partial T}{\partial z})$ derivatives of the magnetic anomaly are Hilbert transform pairs of each other. The analytic signal method has been successfully applied in the form of profile data to locate dike bodies. The most advantage of the analytic signal is that it has a maximum value (red contour) over the (contacts, dykes or veins). Figure (8) shows the analytical signal solutions. It could be realized that, the analytic signal is located over the iron mineralization.

The Horizontal Gradient (HG) method has been used intensively to locate contacts of magnetic susceptibility contrast from magnetic data. It is also robust to delineate shallow or deep in comparison with the vertical gradient, which is useful only for the shallower structures. The amplitude of the horizontal gradient (Cordell and Grauch, 1985) is expressed as:

$$HG = \sqrt{\left(\frac{\partial T}{\partial x}\right)^2 + \left(\frac{\partial T}{\partial y}\right)^2} \qquad (2)$$

where $(\frac{\partial T}{\partial x}$ and $\frac{\partial T}{\partial y})$ are the horizontal derivatives of the magnetic field in the x and y directions. The amplitude of the horizontal gradient of the magnetic data of the studied area was calculated in the frequency domain and is illustrated in Figure 9. It shows a tentative qualitative interpretation of the horizontal gradient data. Generally, the area may be dissected by major faults striking in the NE-SW direction. The most interesting result is that the location of the (Maqlaa) as is well correlated with the horizontal gradient anomalies. This indicates that the iron ore bodies in the area are structurally controlled, especially for the shallower sources. This result is important as a selection of new areas for mineral exploration can be made based on the horizontal gradient map.

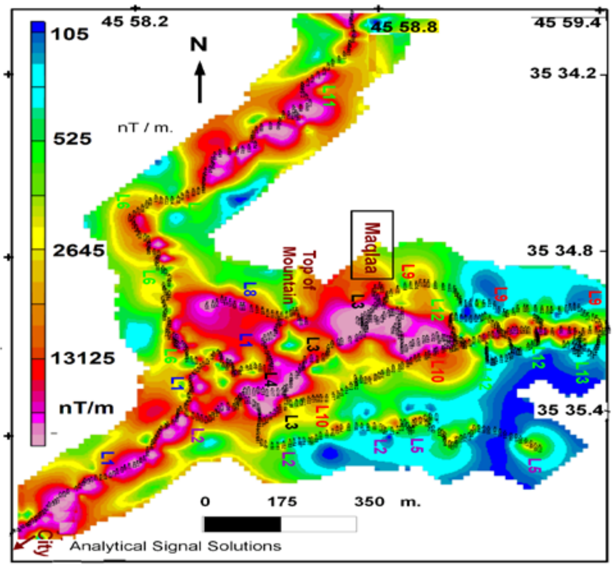

Figure 8: The Analytical Signal magnetic map. The red color represents high magnetic anomaly while the blue color represents low magnetic anomaly.

The high amplitude magnetic anomaly and the associated maximum value (red contour) of the analytical signal along with shape of the contour lines of the magnetic image gave the signature of subsurface structure in the same location of the assumed iron ore bodies. Therefore, the existence of the assumed geological iron mineralization is confirmed. Since the magnetic method observes the relief and structures of the ore bodies and that the amplitude of the magnetic anomaly associated with the expected iron mineralization is high enough to indicate that the iron existed in the basement (lower surface).

3.3. Depth of the iron Mineralization Zone:

The depth to the source of magnetic anomalies is valuable and important information in any geophysical interpretation of subsurface structures. In order to estimate the volume of the mineralization zone, 3D-Eular Deconvolution and 2-D Power Spectrum methods were applied to the magnetic data. The 3D form of Euler's equation can be defined (Reid et al., 1990) as:

$$x\frac{\partial T}{\partial x}+y\frac{\partial T}{\partial y}+z\frac{\partial T}{\partial z}+\eta T=x_0\frac{\partial T}{\partial x}+y_0\frac{\partial T}{\partial y}+z_0\frac{\partial T}{\partial z}+\eta b \qquad (3)$$

where $\frac{\partial T}{\partial x}, \frac{\partial T}{\partial y}$, and $\frac{\partial T}{\partial z}$ are the derivatives of the magnetic field in the x, y, and z directions, η is the structural index value that needs to be chosen according to a prior knowledge of the source geometry.

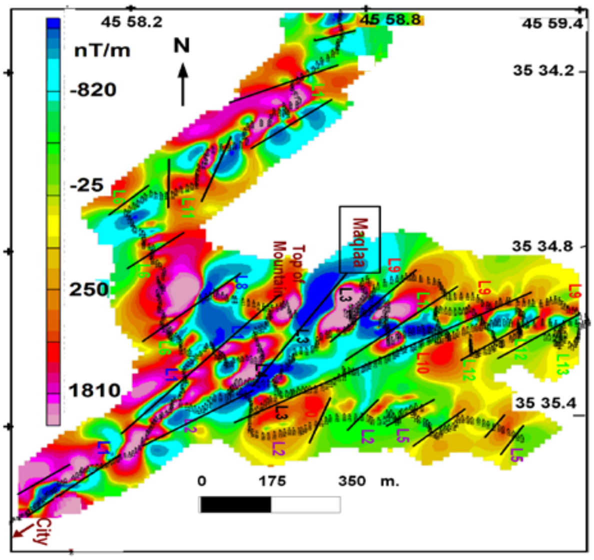

Figure 9: The Horizontal Gradient map.area. The red color represents high gradient, the blue color represents low gradient. Black lines represent the tentative shallower structure interpretation of the mineralization area.

The results of the 3-D Eular solutions are obtained in (Figure 10) using structure index 0.5 (for dykes, contact & veins).

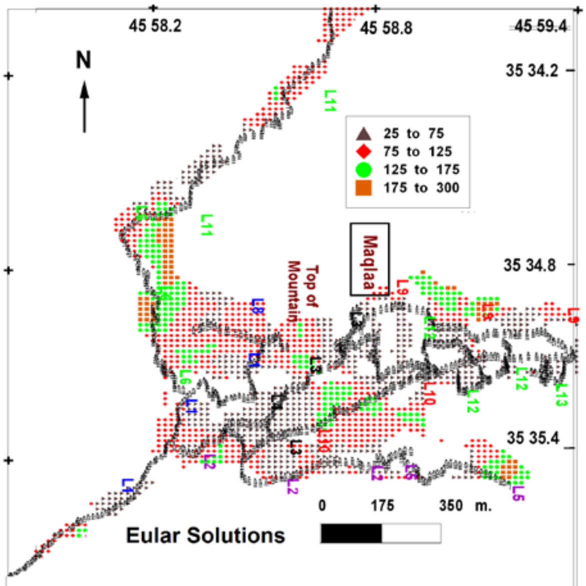

Figure 10: Euler solutions using a structure index of 0.5.

The average depths are 225 m. The 2-D Power Spectrum has been applied to land magnetic survey data. It is used to determine the depths of volcanic intrusions and basement complex (Spector & Bhattacharya (1966): Spector & Grant (1970). In the present study, the Fast Fourier Transform (FFT) was applied on the land magnetic data (Figure 7) to calculate the 2-D power spectrum. As a result, a two-dimensional power spectrum curve was obtained (Fig. 11) on which two main average levels (interfaces) at depth 175 m. (shallow intrusions) and 275 m. (deep basement layer).

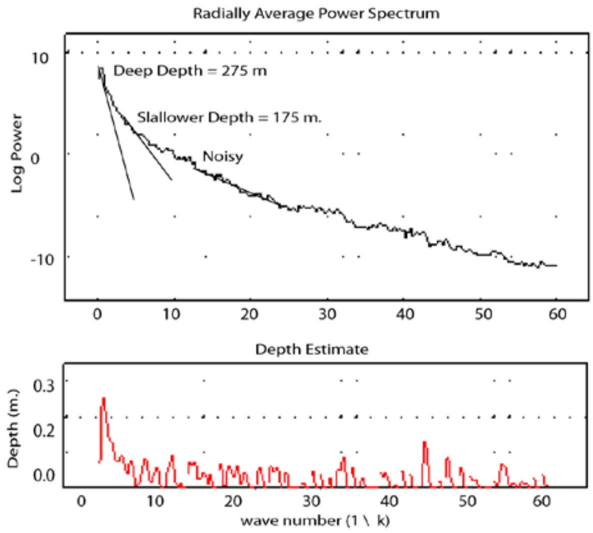

Figure 11. 2D average power spectrum of the studied area.

3.4. Results

Different Geological structures have different magnetic response especially on the magnetic image. The shape of the contour line is mainly controlled by the structure. The mineralization zones have various signatures on the magnetic image, i.e. sharp changes in contour lines, high density contour lines and sharp changes in contour lines direction. Therefore, interpreting the available magnetic data in terms of local structures reveals the existence of iron ore bodies structures in the area (see figure 9). The matching between the magnetically detected mineralization zones and the geologically assumed iron deposits (Figure 12) will expose the fact of the geological iron ore bodies. Brown shapes lines were placed in (Figure 13) derived from figure 9 to mark the iron mineralization zone.

The exact matching between the marked Maqlaa location and the detected magnetic anomalies brings the iron ore bodies to reality. The dashed shapes are expecting extensions of the iron ore bodies in the Penjween region. The NE-Kurdistan area shows comparable chemistry and is enriched in Fe, Mn, Ni and Cu, according to chemical composition of the iron mineralized rocks (30 rock samples), Abou Zeid & Khaled (2010)..They reported that iron percent (Fe %) is increasing from sample to another to reach 64 % in sample # 4. In order to estimate the volume *(x, y & z)* of the iron potentiality in the surveyed area, we need to make reliable grid (Cross * Traverse) and more information about subsurface conditions (near boreholes information in the region) with topographic map.

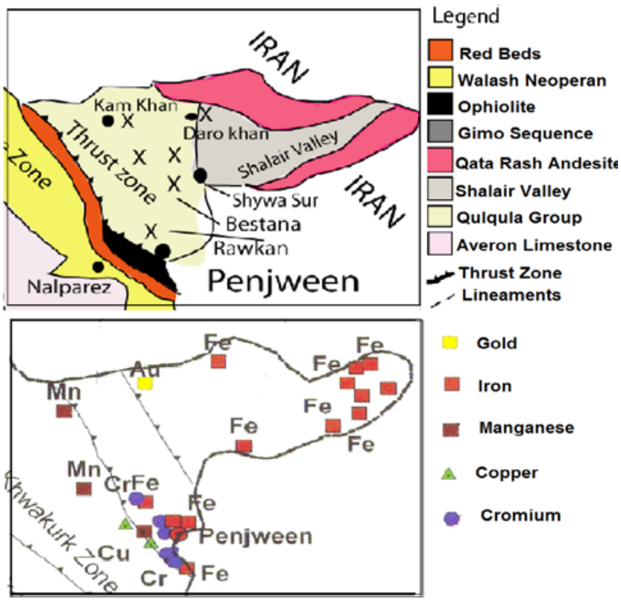

Figure 12: Geological and the distribution of metallic mineral deposits &Occurrences in the Southern part of the Zagros Suture (After Jassem & Golf, 2006).

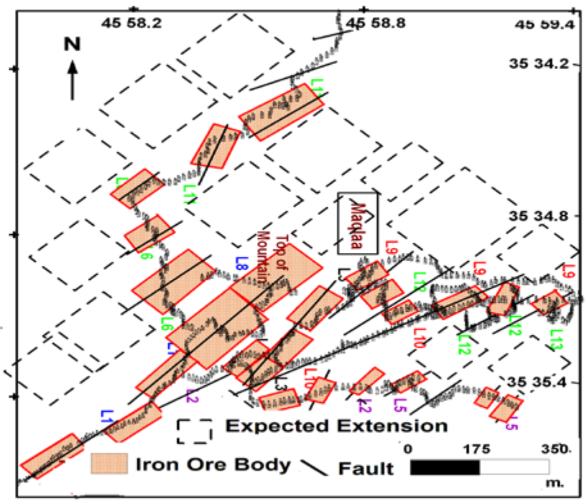

Figure 13: Geological interpretation and the distribution of iron ore deposits (red shapes) in studied area, (dashed shapes) represent expected extension of iron ore bodies.

However, if we take average depth z (derived from 3D Eular) length (x), and width (y) for each ore body (see figure 13). The volume will be equal 45 * 10^6 m^3. This value must be multiplied by the percent of the Iron (Fe) content in the rock which is about (average is 33 %), the volume becomes 15 * 10^6 m^3. The density of Iron is 7.87 gm/cm^3. The weight (Tone) = Volume * density ~ 125 million tones. This value is only of 26 small lenses detected. The surrounding area of Maqlaa by magnetic method and the expected value may be four times, about 500 million tones.

It is important to mention here that one or two boreholes should be drilled in the region to give us information about the great depth of iron mineralization. The best site I recommend for exploratory drilling well is (profile 4) between profile 1 and profile 3. See figure 6.

4. CONCLUSIONS

In this study we attempted to add a new insight on the subsurface structural setting within an area of about (3.5 *2.5) km^2 in the North Eastern part of Kurdistan, using the magnetic method. The study is based on application of Analytical signal, Horizontal gradient, 3-D Euler and 2-D Power Spectrum methods. Results of these methods help to define the main geological trends and depths of expected subsurface iron ores bodies. The similarity of the estimated depth values from the Euler and Power Spectrum methods suggested that these methods are very useful to locate subsurface magnetic sources (iron mineralization), which reflect the subsurface mineralization of the area. The study area is characterized by an iron deposit system taking the direction from NW to NE (The principal geological & tectonic trend parallel to the Alpine Chain in NE Kurdistan). The depth to the regional basement ranges from the surface to 275 m. and shallower structures (Iron Ore bodies) range from the surface to 150 m. These results came from Eular method and agree with the average power spectrum method.

The measured magnetic data values range between -55 nT and 350 nT. The high magnetic values strongly suggest that ferromagnetic minerals are accompanying the mafic metavolcanics along the shear zones of the studied area. We show a good correlation between the structures deduced from the magnetic analysis and the known mineral distributions. Most of these ore accumulations are restricted to the major tectonic shear zones with a *NW–SE* direction. The preliminary estimation of the iron bodies in this region is about 125 million tonnes. We conclude that mineralization is structurally controlled by faulting, probably as a result of hydrothermal circulation along fault planes.

5. Recommendations:

Some recommendations are listed as follows:

1. Detailed land magnetic survey of the NE Kurdistan area is necessary to delineate the expected extension of the iron ore bodies.
2. Exploration geophysical program must continue (like: Electrical Resistivity, Self potential and Induced Polarization methods) in order to be ensure that the area is economically productive.
3. At least one or two boreholes information may be needed in order to make two dimensional (2D) and

three dimensional (3D) modeling of the exact geophysical configuration

6- Acknoweldgement:

Special thank is due to Eng. Mostafa Abdel-Moaz, Vice Chairman of El-Moaz Group for their financial support and providing the chance to carry land magnetic survey in NE Kurdistan region. At Sulymania, we met Mr. Abdel-Kader Talibany, Vice Chairman of the Adel United and Mr. Habib. They gave us all support and encouragement during field trip. Also many thanks to Eng. Adly Abdel Salam and Dr. Ahmed Awad for assisting and helping us during hard field work in NE-Kurdistan region.

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BASELINES DETERMINATION USING SATELLITE LASER OBSERVATIONS

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حساب خطوط القاعدة باستخدام أرصاد الليزر للأقمار الصناعية

الخلاصة: فى هذا البحث نقوم بحساب خطوط القاعدة لبعض المحطات الموجودة ضمن الشبكة الدولية لمحطات تتبع الأقمار الصناعية بأشعة الليزر وذلك باستخدام طريقة القوس الأصغر وأرصاد الليزر المأخوذة من محطة حلوان . ويساعد تكرار حساب خطوط القاعدة لنفس المحطات لعدة سنوات يساعد فى الدراسات التكتونية لقارة أفريقيا . تم حساب ثلاث خطوط قاعدة تربط محطة حلوان لأرصاد الأقمار الصناعية بأشعة الليزر مع ثلاثة من المحطات ضمن الشبكة الدولية.

ABSTRACT: *Space Geodesy techniques have become a highly precise tool in detecting and monitoring recent crustal movements. Regular repeated measurements of the baselines between some stations on different plates give the possibility to construct precise and detailed models of the global tectonics. In this paper 3 baselines have been determined using the "short arc" method using satellite laser ranging data.*

INTRODUCTION

The mutual tectonic displacements of the lithospheric blocks take place within the deep fractures dividing them into hundreds and thousands kilometers long. It is possible to suggest that the reason of the accumulation of considerable local shift deformations is the change of the velocity of the tectonic motion in some parts of fractures as a result of different physical, chemical and mechanical processes.

Regular repeated geodetic measurements of the active zones furnish the possibility to study slow secular motions of the Earth's crust and to reveal the places of the accumulation of elastic deformations.

Methods of satellite geodesy are very effective from the point of view of monitoring the deformation of the Earth's crust on regional and global scales.

Changes of the length of chords between stations hundreds and thousands kilometers apart are calculated with the use of the Satellite Laser Ranging (SLR) data which agree well with the plate motions models (Hauck, 1987). The accumulation of the data makes it possible to construct a precise and detailed model of the global tectonics.

Geologic features and characteristics of the African continent exhibit all phenomena associated with crustal deformations, accumulation and release of crustal stresses and strains, inter-plate motions and volcanic eruptions. Therefore, Africa has to be involved in an international geodynamics and earthquakes research programs.

In Africa there are only two satellite laser stations one in Helwan (Egypt),and the other Hartebeesthoek (South Africa) while at least three stations are necessary to fix the motion of the plate as shown in Fig. 1.

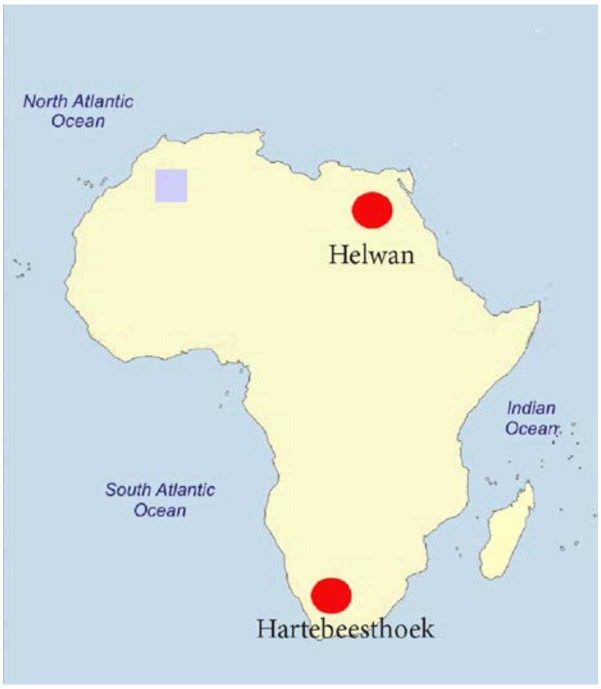

Fig. (1): The suggested position of the third station.

The short-arc method:

The distances and lengths of the chords between projections of the positions of the laser stations on the reference ellipsoid, are adopted to be called "baselines".

When we use the satellite geodesy, it is very important to determine the optimal length of the orbital arc along which laser measurements are to be carried out. It is clear for the dynamical methods that long arcs (one month or more) are to be used. Modeling of different physical forces (Earth's gravitational field, air drag, solar radiation pressure, etc.) produce different error levels which would influence the accuracy of the estimation of the satellites position. At the same time the measurement errors could be almost completely excluded and high stability in determination of relative coordinate system can be achieved. It is possible to diminish the influence of the errors of modeling by using short-arcs of the satellite orbit (several revolutions or days), but the station's coordinates estimated by different arcs could differ from each other by a larger quantity than statistical zero.

In (Dictrch and Genill, 1984, Fahim and Khalil et al., 2000 , Montag and Gendt et al., 1986 and Tatevian, 1980), under the semi -dynamical "short-arc" method one or several passes of the satellite in one of simultaneous visibility from both ends of the chord is available. The estimated parameter in this case is the length of the chord as shown in Fig. (2).

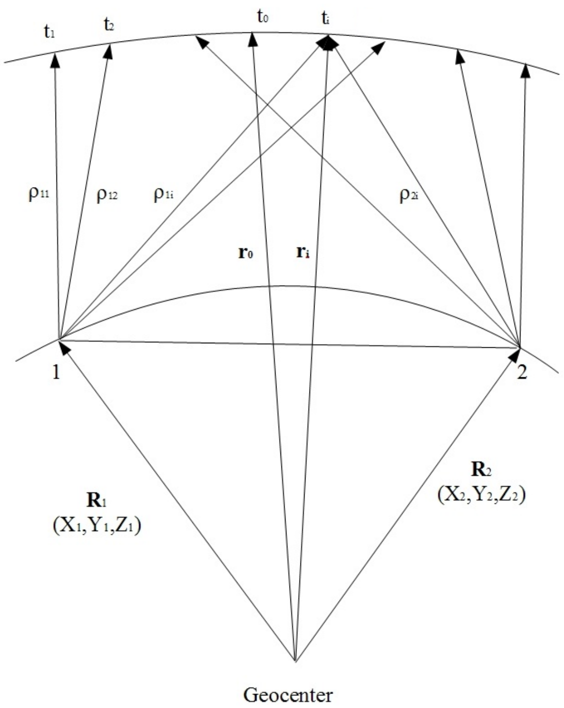

Fig. (2): Geometrical representation.

Short arcs method shows a good agreement and even speaks in favor of the semi- dynamical one, as the number of observations required for solving the problem considerably decreases as well as the amount of calculations.

Let laser ranging ρ_{ik} ***; i = 1,2,…,n*** be carried from two stations for the same satellite's pass. We suggest that at the observation moment t_i the radius vector r_i of a satellite in Greenwich coordinate system is known . It can be obtained using the laser ranging data from a global network by integrating the satellite's motion equations, with a known model of perturbation forces on an interval of several days. (Saroken, 1984)

The geocentric vectors of the station R_k (X_k , y_k , z_k) are to be known with sufficient accuracy. It is suggested that the covariance matrix of the initial parameters of the satellite's motion Q_r and the rectangular coordinates of the station Q_{R_K} are also known.

The corrections of the estimated quantities, to the initial elements of the satellite's orbit for the mean time t_0 of the observation interval, are dr_0, $d\acute{r}_0$. In other words, corrections to geocentric vector r_0 and to the range rate $\acute{r}_0$ of a satellite, are corrections to the adopted values of a baseline and to the geocentric vectors of the two stations.

The general form of the expression for baseline L between two points R_1 and R_2 can be written as:

$$\overline{L}_{12} = \sqrt{\rho_{i2}^2 - \rho_{i1}^2 + 2\rho_{i1}\, L \cos\left(\overline{L}\,\rho_{i1}\right)}$$

$$\overline{L}_{21} = \sqrt{\rho_{i1}^2 - \rho_{i2}^2 + 2\rho_{i2}\, L \cos\left(\overline{L}\,\rho_{i2}\right)} \quad (1)$$

It is evident that for the case of satellite ranging from k - stations we have :

$$\rho_{ik}^2 = R_k^2 + r_i^2 - 2R_k\, r_i\, \cos\left(\overline{R}_k - \overline{r}_i\right) \quad (2)$$

After linearization of equations (1) and (2) and taking into account that the approximate quantities R_k^0 and R_i^0 are known, we can write the equation of measuring corrections in the following form where ρ_{ik}^0 is the calculated distance between the station and the satellite at the moment of measurements.

$$V_{ik} = \frac{\partial\rho_{ik}}{\partial\overline{r}_o} d\overline{r}_0 + \frac{\partial\rho_{ik}}{\partial\overline{r}_o} d\bar{r}_0 + \frac{\partial\rho_{ik}}{\partial L_{ik}} dL_{ik} + \frac{\partial\rho_{ik}}{\partial\overline{R}_{12}} d\overline{R}_{12} + \left(\rho_{ik} - \rho_{ik}^o\right) \quad (3)$$

where V_{ik} is the correction factor of measuring the distance L_{ik}

The covariance matrix Q_x of the estimated parameters *(dr_o , dr_0 , dL, dR_1 , dR_2)* is a block-diagonal

$$Q_{x_{0(9,9)}} = \begin{pmatrix} Q_{r(6,6)} & 0 \\ 0 & Q_{LR_1LR_2(3,3)} \end{pmatrix} \quad (4)$$

We can get the final solution of the estimated parameters from

$$\overline{x} = \left(Q_{\overline{x}_0}^{-1} + A^T Q_L^{-1} A\right)^{-1} A^T Q_L^{-1} l_{ik} \quad (5)$$

As for the calculation of the vector of free terms, we have used some kind of orbital model, so for getting strict solution of system equation (3) and particularly for the real estimation of the accuracy of parameters, it is necessary to take into account the influence of possible systematic errors of the adopted model by including them as unknowns in common adjustment.

Covariance matrix of the free terms of the equation (3) could *be* determined as

$$Ql_{(n,n)} = P^{-1}_{(n,n)} + B_{(n,9)}\,Q_{(9,9)}\,B^{T}_{(9,n)}$$

where $P^{-1}_{(n,n)}$ is weight of observation ρ_{ik}, while B and Q have the following form

$$B = \left(\frac{\partial \rho^{0}_{ik}}{\partial \bar{r}_{0}}\, , \frac{\partial \rho^{0}_{ik}}{\partial \bar{r}_{0}}\, , \frac{\partial \rho^{0}_{ik}}{d \bar{R}_{k}} \right)$$

$$Q = \begin{pmatrix} Q_{r} & 0 \\ 0 & Q_{R_k} \end{pmatrix}$$

RESULTS AND DISCUSSIONS

At Helwan observatory, a computer program was written using the Algorithm given in (Chapannov, 1990) using the laser ranging data of the satellites Lageos 2 which was observed for the year 2000 at Helwan and other stations. The location of the Helwan satellite laser ranging station No. (7831) and the other stations of numbers (7090) (Yarragadee, Australia), (7840) (Herstmonceux, United Kingdom), and (7835) (Grasse, France) as well as other stations are shown in Fig. 3.

Fig. (3): the SLR Stations Network.

The results of observations were used to estimate 3 different baselines, are shown in table 1 for the observations of the year 2000, respectively. It is clear from table 1 that the root mean square errors (rms) of the calculated baselines are within 5cm.

However, for the determination of the relative motion between the African and European plates, it is necessary to calculate the same baselines for many years. This study will be described in the coming paper.

Table (1): Baselines determinations

Stations	*MJD*	*Mean-weighted Baseline length L (m)*	*rms (m)*
7831-7090 Helwan-Yarragadee	51630.08609953	9706582.6176	0.023
7831-7840 Helwan-Herstmonceux	51716.91649999	. 3429766.4169	0.022
7831-7835 Helwan-Grasse	51852.96489820	2634229.0949	0.o27

CONCLUSION

We explained the short-arc method for the determination of the baselines between the Helwan station and three other stations, using the SLR. The accuracy of the determination of the baselines are within the range of 5cm which agree well with the plate motions models.

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