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Application of Magnetometry in Manto-type Copper Deposit Exploration, Case study: Meyami, Iran

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Original scientific paper

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Abstract

This study has aimed to introduce a novel strategy for exploring the Manto-Michigan copper deposits, considered a principal copper resource after the porphyry type. Faults and crushed zones have a prominent role in this deposit type, and so we hope to detect unique patterns in magnetic responses that provide a helpful indicator to determine the mineralized zone. Accordingly, we want to test the magnetometry in Manto-type exploration. We performed a magnetometry survey in the Dochileh copper deposit that other researchers have claimed to be a Manto-Michigan type with a distance of 10 meters between survey lines and a spacing of 5 meters among stations on each profile. After processing the required maps, the residual magnetic map does not show any typical dipole magnetic anomaly, but some linear trends exist. One of those linear trends belongs to a faulted and crushed zone with a length of almost 2.5 km and different widths between 50 and 250 meters. The previous mineralized zones indicated by other prospectors who relied more on geological evidence in the Dochileh area have mostly stayed inside this negative value on the residual map. Four new boreholes were made in the negative anomaly to evaluate our hypothesis, and the derived cores confirmed the native copper, malachite, and cuprite mineralization.

Keywords:
copper exploration; Manto-type; magnetometry; drilling; Iran

1. Introduction

Exploration geophysicists use measurements of physical quantities made at or above the ground surface or, rarely, in boreholes to deduce the concealed geology. For a geophysical technique to be helpful in mineral exploration, there must be contrasts in the physical properties of the rocks related directly or indirectly to the presence of economically significant minerals (**Mostafaei and Ramazi, 2018**).

Magnetic surveying is a geophysical technique that investigates the subsurface based on magnetic susceptibility variations. It has various applications, such as mineral prospecting, oil and gas exploration, archaeological studies, and environmental assessments. As a standard method in the mining industry, geoscientists widely use it to explore different mineralization types, from porphyries and skarn to kimberlites and placer deposits (**Gunn and Dentith, 1997; Mashahdi and Safari, 2020**). Magnetic surveys are the quickest and often the cheapest form of geophysics that can provide helpful exploration information.

A magnetic survey aims to investigate subsurface geology based on anomalies in the Earth's magnetic field resulting from the magnetic properties of the underlying rocks (**Kearey et al., 2016**). Targeting magnetic anomalies in mineral exploration is expected, mainly as explorers search beneath the increasingly deeper cover for the next large ore body (**Austin and Foss, 2014**).

Magnetometry has many applications. For example, it was used for the investigation of magnetic responses in mineral deposits (**Gunn and Dentith, 1997**). The history of magnetometry in mineral exploration is presented by **Nabighian et al. (2005)**. Furthermore, the data of airborne magnetometry has been used for iron mineral exploration in Brazil (**Filho et al., 2007**). Prospecting for the ferromagnetic mineral accumulations was done using the magnetic method in the Eastern Desert, Egypt (**Rabeh, 2009**). A 3D model of magnetometry data has been prepared for archaeological studies in Mexico (**Argote et al., 2009**). A combination of magnetometry and gravimetry was used for lithology and structure investigation (**Castro, 2011**). Archaeological magnetometry was used in an Arctic setting: a case study from Maguse Lake, Nunavut (**Hodgetts et al., 2011**). The hematite mineral exploration was also investigated by magnetometry (**Martin- Hernandez, and Guerrero- Suarez, 2012**). The application of magnetometry and gravimetry in polymetal deposit exploration was investigated (**Louro and Mantovani, 2012**). The geological nature of magnetic and gravimetric anomalies has been also

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studied (**Vitte and Vasileviskiy, 2013**). Magnetometry data has been used for oil and gas exploration in the Caspian Sea (**Gorodnitskiy et al., 2013**). A combination of magnetometry data and drill-hole has been used for iron mineral exploration in Brazil (**Carlos et al., 2014**). Regional magnetic structures and lithologies were investigated in Iran as controls on porphyry copper deposits (**Kheyrollahi et al., 2014**).

One of the most exciting research projects in a magnetic survey for mineral exploration is hydrothermal alteration detection. Hydrothermal alterations are a vital sign for mineral exploration; many kinds of research have been done regarding a magnetic survey in a hydrothermal alteration that mainly focused on porphyry deposits; however, it does cover some other deposits, such as massive sulfides (**Townley et al., 2007; Van Kerkvoort et al., 2009; Riveros et al., 2014; Clark, 2014: Hope and Andersson, 2016; Amirpour et al., 2016**).

In this research, we present the application of magnetic surveys in Manto-type deposits, which have not been done before. Furthermore, we introduce a new method for Manto-type deposit exploration based on magnetic survey.

2. Research area and its description

Manto-type copper deposits are stratiform deposits among volcanic sequences enriched in fugacious fluids and in close vicinity to volcanic centers (**Samani, 2002**). The distribution of faults and crushed zones play a significant role in this type of mineralization, and also the presence of anticlinal could ease the circulation of hydrothermal fluids. There is not a wide variety of geological units observed in such deposits, and instead, the alterations make a considerable concentration of valuable minerals. A paragenesis of bornite, chalcocite, chalcopyrite, and pyrite are dominant in Manto deposits (**Kojima et al., 2009**). Manto deposits are stratiband and usually have a vein-veinlet texture (**Kojima et al., 2009**). Alterations in these deposits involve silicification, calcite, chlorite, epidote, and oxidation (**Wilson et al., 2003; Cabral and Beaudoin, 2007**). Carbonate, chlorite, quartz, hematite, and alkali feldspar constitute gangue minerals in Manto deposits (**Wilson and Zentilli, 2006**). Principal mineralization is chalcocite, which has a zonality of pyrite, chalcopyrite, and chalcocite from the margin into the center on the mineralized zone, and chalcocite is associated with zeolite, calcite, albite, and quartz (**Samani, 2002**).

The study area is located 30 km to the east of Meyami, Semnan Province, Iran. This area is near the main road of Miami-Sabzevar that is named Dochileh. There are considerable stratiform copper potentials within the northeast of Iran that are estimated to belong to the tertiary era and have value for being investigated. From the point of structure classification by Aghanabati (1986), the Dochileh copper deposit is situated in the northern part of the Central Iran Microcontinent named the Sabzevar Zone. A structural geology map of Iran is shown in **Figure 1**. A rift occurrence in the Central Iran Microcontinent caused the formation of the Sabzevar Ocean with the late Triassic to Cretaceous age, which disappeared at the end of cretaceous as a consequence of tectonic movement in North Central Iran and the eastern Alborz Belt (**Stöcklin, 1968**). The three significant faults that play a fundamental role in forming the Sabzevar Zone are Meyami and Atari in the northern and the famous Doruneh Fault in the southern part.

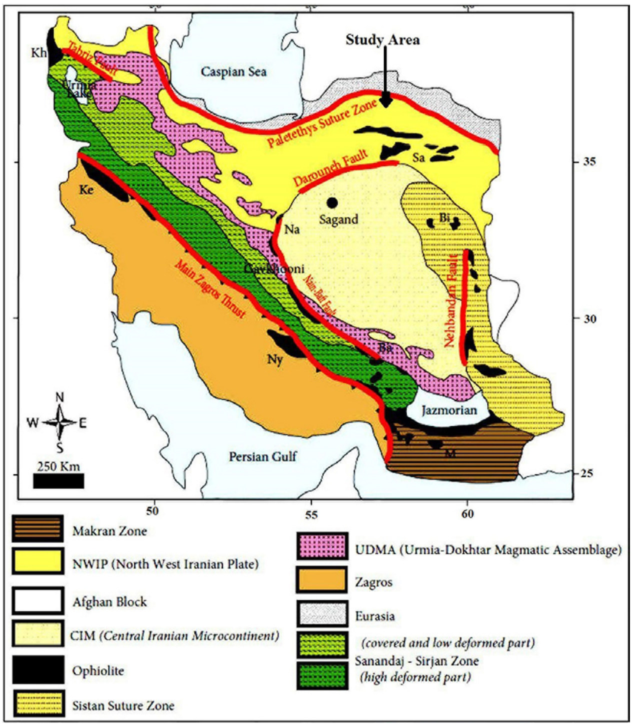

Figure 1: Structural geology map of Iran (**Aghanabati, 2009**), and the location of the study area

The central geological units of the Sabzevar Zone consist of:

1. Ophiolite assemblage including dunites, peridotites, and gabbros with an oceanic origin which surrounds the margin of central Iran and is accompanied with sedimentary rocks related to late cretaceous that indicate back oceanic arc zone (**Baroz et al., 1984; Agard et al., 2007; Rossetti et al., 2010**).
2. The Volcano- sedimentary late cretaceous units with no connection to ophiolitic assemblage (**Vatanpour et al., 2009**).
3. Flysch sedimentary sequences with Eocene to Neogene period (ages) (**Mousivand et al., 2015**).

The Dochileh deposit is a part of Abbas Abad's metallogenetic state which covers an area of about 130 square meters. The Abbas Abad metallogenetic state occupies the northwestern terrains of the Sabzevar Zone with petrology of andesite, basalts, agglomerate, and tuff. **Rashidnejad (1992); Shamanian et al., (2004) and Haghighi et**

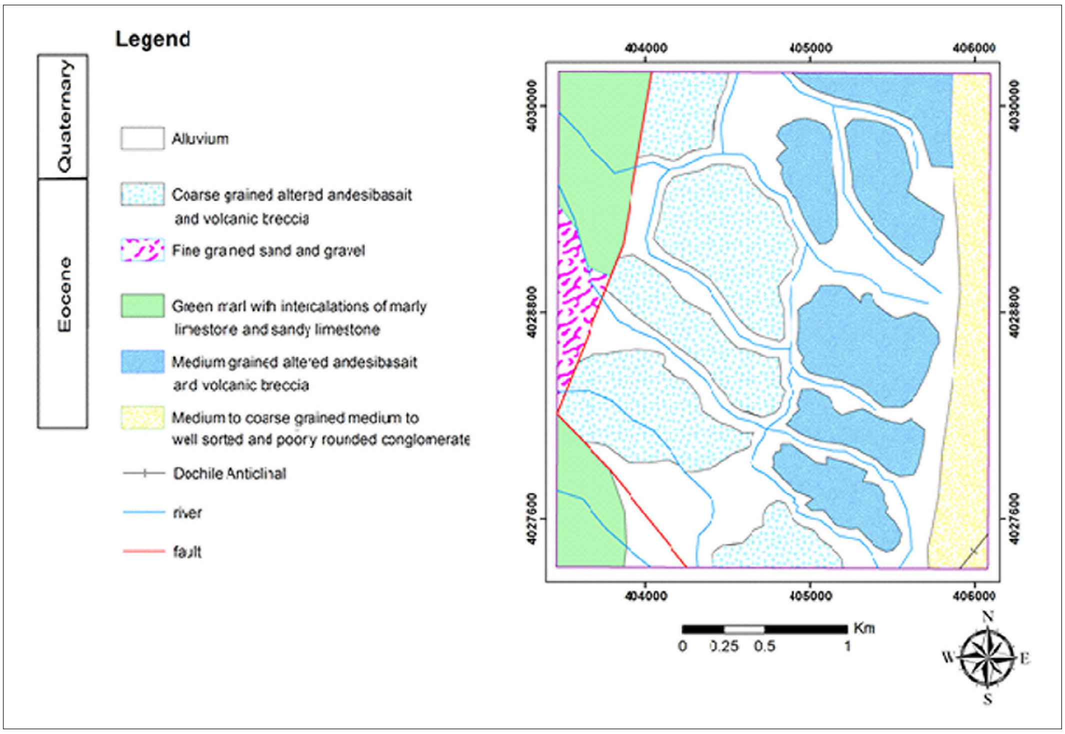

Figure 2: The simplified Geological perspective of the Dochileh deposit, coordinate is based on the UTM (WGS1984-Zone: 40N)

al., (2013) attributed the Abbas Abad zone to a subduction zone. **Salehi et al. (2016)** reported the eight most important copper deposits of the Abbas Abad districts.

Mineralization in the Dochileh area is among basaltic and trachybasaltic units whose age has been claimed to be about upper Eocene with hundreds of meters of depth and has been covered by quaternary sediments (**Ebrahimi et al., 2019**). The texture of these basaltic and trachybasaltic units is fine to medium grain and coarse grain, and the mineralization host is fine to medium grain rocks. **Figure 2** shows the geological map of this area. Coarse-grain basaltic units occupy the western and southern parts of the study area, while the eastern part of the Dochileh area is generally composed of basaltic fine and medium grains. These structures differ in the percentage of plagioclase, albite, olivine, and pyroxene phenocrysts, equal to twice as much for finer-grain basaltic rocks.

The anticlinal in the area's southeast could have provided suitable conditions for mineral-bearing fluid to flow within faults. The upper horizon consists of a higher grade of copper. It has a composition of minerals such as chalcocite, cuprite, native copper, malachite, azurite, and Fe hydroxide. A deeper horizon characterizes itself with a lower grade intensity and a paragenesis of magnetite, pyrite, chalcopyrite, chalcocite, bornite, and native copper (**Ebrahimi et al., 2019**). The results of new boreholes confirm the previous findings of the occurrence of mineralization in two main phases: the shallow level in the form of the vein and veinlet-mostly related to fault structures and deeper ones, including strata layers.

3. Methods

Geophysical anomalies, defined as differences from a constant or slowly varying background, are recorded (**Charles et al., 2006; Mostafaei and Ramazi, 2019a**). Anomalies may take many different forms and are not necessarily centred over their sources (**Charles et al., 2006**). Magnetic surveys can be performed on land, at sea, and in the air. Consequently, the technique is widely employed, and the speed of operation of airborne surveys makes the method very attractive in searching for types of ore deposits that contain magnetic minerals (**Kearey et al., 2016**). Magnetic surveying is a rapid and cost-effective technique and represents one of the most widely used geophysical methods in terms of line length surveyed (**Haliday et al., 2007**).

Magnetic separation of minerals originates from different behaviours of mineral particles when in an applied magnetic field (**Jordens et al., 2014**). The most common rock-forming minerals exhibit a shallow magnetic susceptibility, and rocks owe their magnetic character to the generally small proportion of magnetic minerals they contain. Magnetic anomalies caused by rocks are localized effects superimposed on the standard magnetic field of the Earth (geomagnetic field; **Kearey et al., 2015**).

3.1. Magnetometry survey and data processing

An optimized and precise network consisting of 99 north-south profiles with a spacing of 10 meters among lines and 5 meters between stations in each line was designed and surveyed, considering previous studies

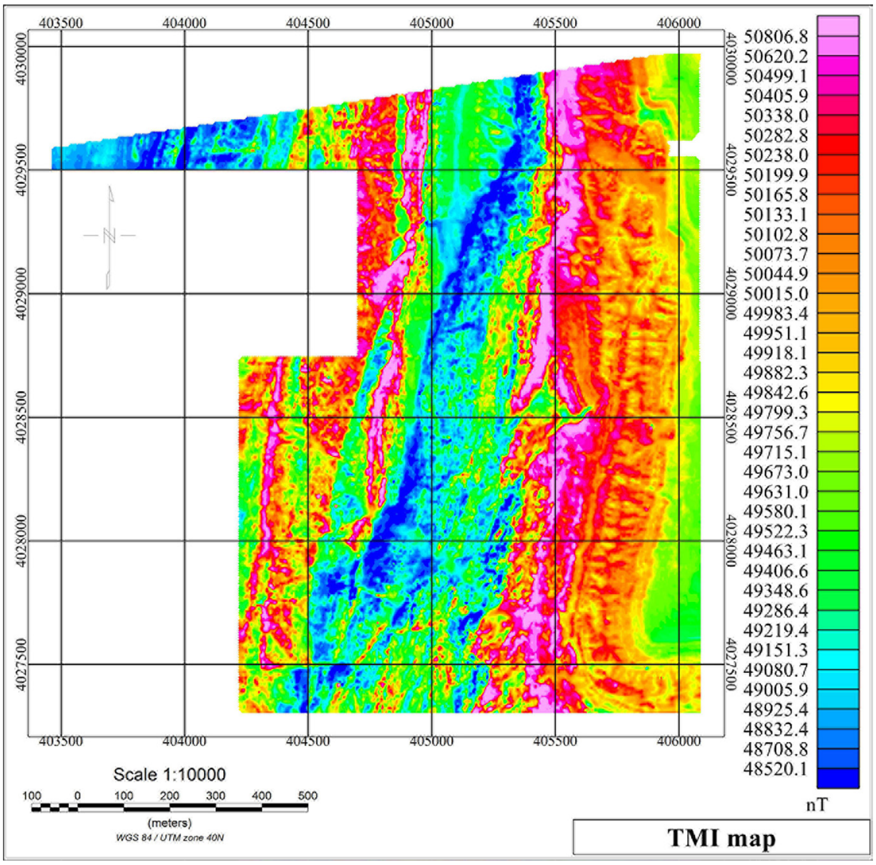

Figure 3: Total magnetic intensity (TMI) map of the study area

(**Ebrahimi et al., 2019**) including geology, geochemistry, and mineralized outcrops. In this survey, we used GEM-19T magnetometers, and the data collection method was a stop-and-go approach with a base station, that magnetic intensity was recorded every 10 minutes automatically by one magnetometer. The total number of acquired data is about 86000.

There are various methods for data processing and inversion (**Louro and Mantoyani, 2012**). Through the processing of the collected data, incorrect ones were modified. A total magnetic intensity map should be prepared, then based on the IGRF (International Geomagnetic Reference Field) a residual map is prepared.

Pole reduction corrects the shift between sources and magnetic anomalies due to the non-verticality of both the standard field and magnetization. The Reduced to Pole (RTP) was made in the Fourier domain (**Blakely, 1995**), assuming induced magnetization.

The upward continuation is equivalent to measuring the potential field higher than the desired level. The amplitude decreases, and wavelength increases with an increase in the measurement level (**Dentith and Mudge, 2014**). So, surface and weak noise disappear, an upward filter would lead to valuable and reliable results to estimate the approximate depth of the mineralized zone. The upward continued ΔF (the total field magnetic anomaly at higher level (z=-h) is given by **Equation 1** (**Kebedeh et al., 2020**):

$$\Delta F\left(x,y,-h\right)=\frac{h}{2\pi}\frac{\Delta F\left(x,y,0\right)dxdy}{\left(\left(x-x0\right)\right)^{2}+(Y-Y0)^{2}+h^{2})^{3/2}} \quad (1)$$

Where:

ΔF – *the total field magnetic anomaly (nT),*

h – *the desired level in calculation (m),*

(x, y) – *the secondary location of point (the desired) (UTM coordinate),*

(x_0, y_0) – *the primary location of point (UTM coordinate).*

Derivative or gradient maps are one of the investigations and simplification ways for magnetic data processing. Horizontal and vertical derivative maps have good ability for body edges identification (**Dentith and Mudge, 2014**). The vertical derivative map reveals the positions of magnetic lineaments and the location of magnetic borders or boundaries between lithological units (**Adewumi and Salako, 2017**). The horizontal derivative map shows improved edges of linear features linked with shallow and deep magnetic sources (**Miller and Singh, 1994**).

The analytical signal technique known as the total gradient is a pattern recognition technique (**Kenating and Salilac, 2000**). Analytical signal combines the horizontal and vertical gradients of the magnetic anomaly. The amplitude of the AS of the magnetic field T is esti-

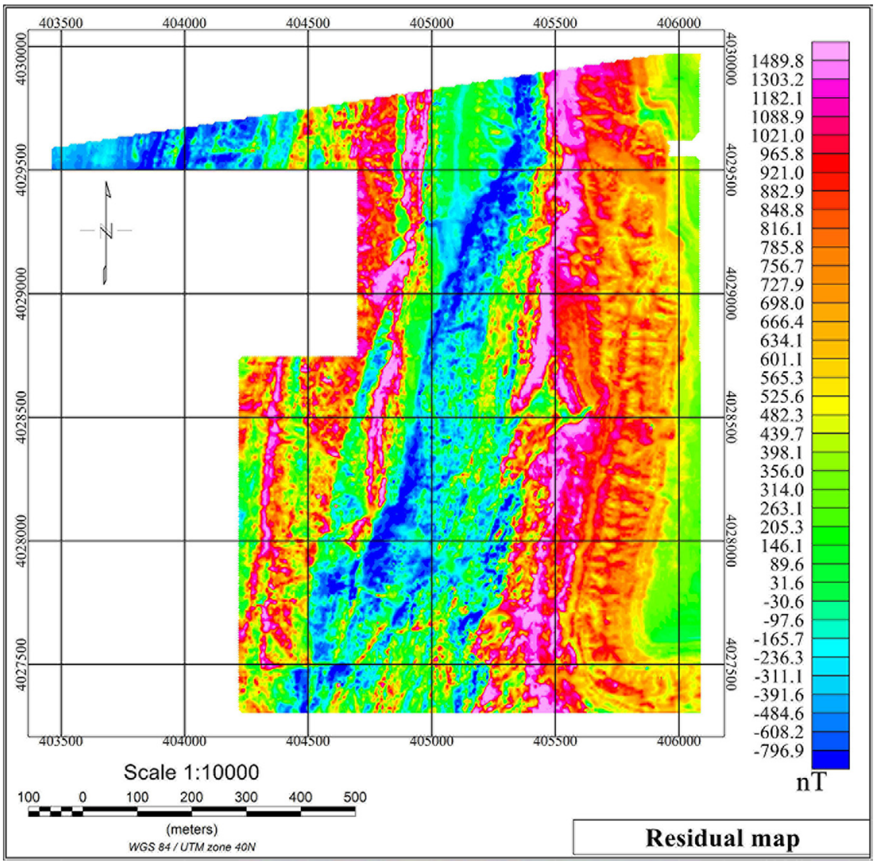

Figure 4: Residual map of the study area after IGRF correction.

mated as sum of the squares of its three orthogonal derivatives in the x, y and z directions according to **Equation 2** (**Roest et al., 1992**):

$$A(x,y) = square\left[(\frac{dT}{dx})^2 + (\frac{dT}{dy})^2 + (\frac{dT}{dz})^2 \right] \qquad (2)$$

Where:

dT/dx – derivative of magnetic field in x direction (nT/m),
dT/dy – derivative of magnetic field in y direction (nT/m),
dT/dz – derivative of magnetic field in z direction (nT/m).

3.2. Drilling

Mineral exploration is a complex process which is carried out through the integration of different methods (**Mostafaei and Ramazi, 2019b**). Drilling is the main method to get in-depth information from deposits, so after surface exploration studies, some boreholes should be drilled for confirmation.

In this study area, drilling has been done in two stages, as shown in **Figure 9**. Also, some trenches were dug. In the first stage, 6 boreholes were drilled from a depth of 50 to 80 meters. In the next, based on the magnetometry results, 4 boreholes were drilled. The depth of boreholes varies from 50 to 250 meters. To make a comparison between previous and new drilling results, the new boreholes 1 and 3 were analyzed to a depth of 45 meters. The choice of this depth was due to the presence of mineralization evidence and also due to the previous drilling results because previous analyses were available up to 45 meters.

4. Results

After the magnetometry surveying, data processing was done. In this stage, various magnetometry maps were prepared.

4.1. Magnetometry results

To interpret the collected data, first, daily correction was done, then the total magnetic intensity map was prepared. **Figure 3** shows the distribution of magnetic intensity as TMI. The minimum value of magnetic intensity is about 47500 nT, and the maximum value is about 52500 nT. The IGRF value was calculated for each point to determine the local anomaly; after subtracting measured values by magnetometer from the IGRFs, a residual map was prepared and is shown in **Figure 4**. Based on the mentioned maps, we can say there are two main parts: one part with a high value in the west and east of the study area, and the other parts with low-intensity values. The low value in the central part of the study area is a north-south band.

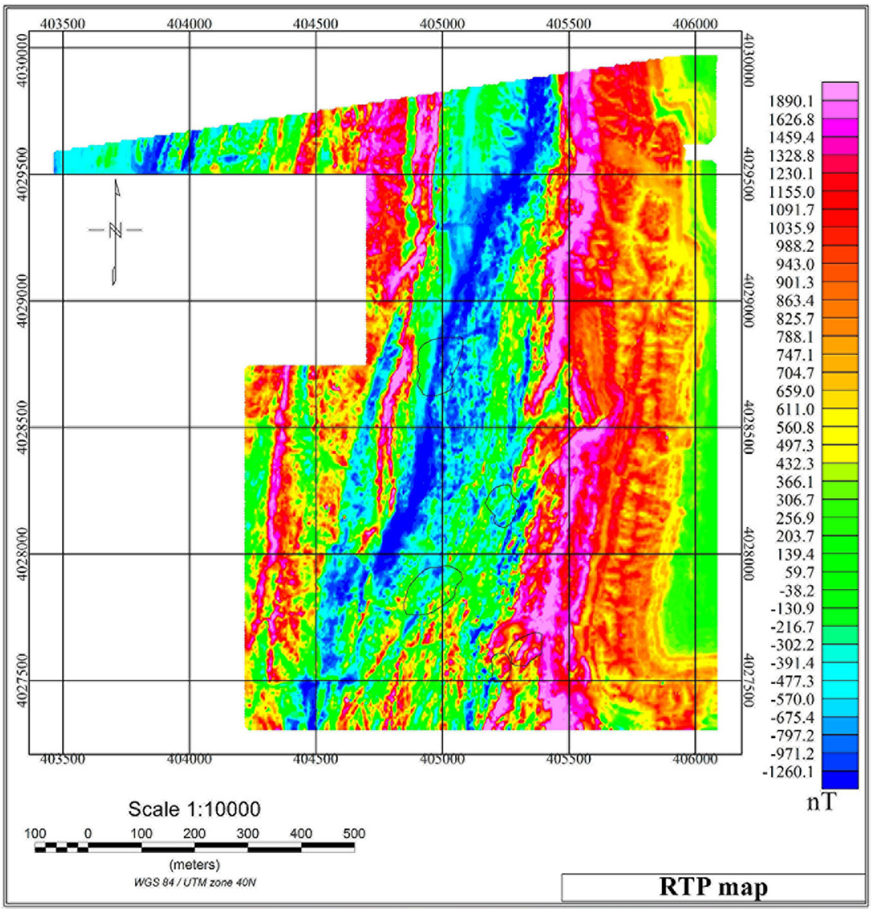

Figure 5: Reduced to Pole (RTP) map of the Dochileh deposit, also the mineralized zones identified by Ebrahimi et al. (2019) are shown in this map.

4.1.1. Reduction to Pole (RTP)

The Reduced to Pole (RTP) filter was applied on the residual map to evaluate anomalies with more precise accuracy. **Figure 5** shows the prepared RTP map. The geometric inclination of this area is 53.9227 and the declination is 3.0520. The RTP map shows a central linear negative zone (marked by blue on the map) extending from the north-central to the area's southwest. This trend is approximately 2.5 kilometres in length and a width ranging from 50 meters to 250 meters. The anomaly mentioned above covers the areas introduced by **Ebrahimi et al. (2019)** as a potential mineralized zone in geological surveys. It should be mentioned that **Ebrahimi et al. (2019)**, identified five mineralized zones in the study area, gaining the benefits of geochemical investigations, geological evidence, and geoelectrical surveys.

4.1.2. Upward continuation

Figure 6 presents upward filter results. According to the findings from the upward maps, the effect of the central negative anomaly zone starts reducing in extent and volume from 30 to 150 meters. The deepest part of this fault and the crushed zone has been placed in the centre of this anomaly.

4.1.3. Derivative map

The vertical and horizontal derivative maps were prepared and are presented in **Figure 7**. These maps distinguish the contact between sedimentary (conglomerate) and igneous (basalt) units (conglomerate) and various types of basalt. Also, the fault and crushed zones have identified themselves very well. These maps reveal magnetic structures that could indicate the presence of mineralization potential.

4.1.4. Analytical signal (AS)

Figure 8 exhibits a prepared analytical signal map for this area. The AS map has an excellent correlation with gradient maps. In the AS map, lithological contact is detectable. Also, the detected crushed, and flute zones are potential mineralization zones.

Since faulted or crushed zones are generally affected by circulating fluids and endure weathering interactions of magnetic minerals, they show negative magnetic responses, which mostly have a linear shape (**Aryamanesh et al., 2009**). Faults are essential factors in the formation of Manto and Michigan copper deposits, and the enlarged negative anomaly that appeared in the Dochileh area represents a faulted volcano-sedimentary zone bearing cop-

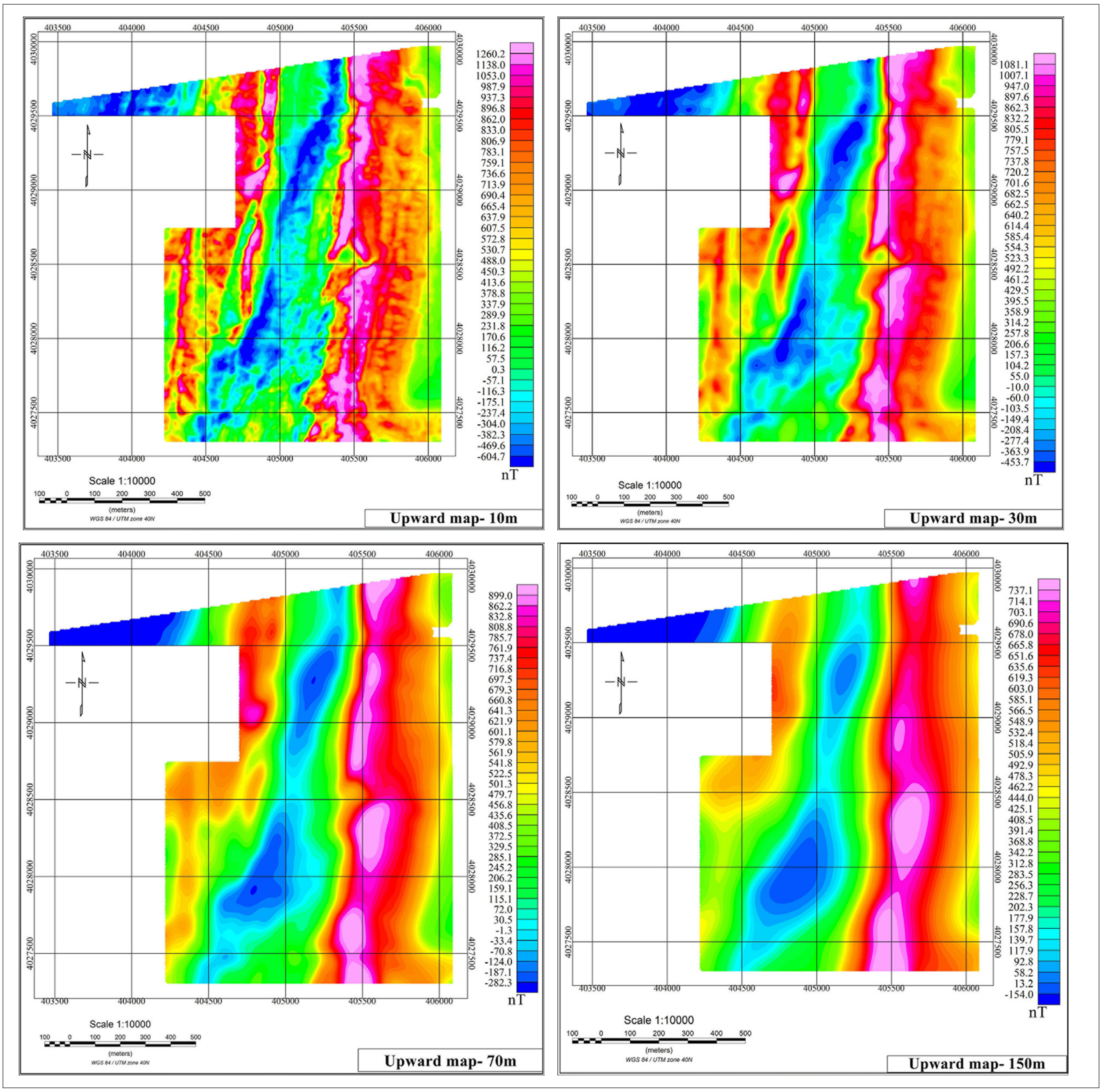

Figure 6: Maps showing upward filter on Reduce to Pole base map in the Dochileh area: Upward filter for 10, 30, 70 and 150 meters.

per mineralization. Based on the magnetometry results, we can say that the low magnetic intensity or negative anomaly locations are the best areas for copper mineralization because these locations are related to fault and crushed zones derived from the derivative maps as linear trends. The determined targets by magnetometry results have a great consistency with previous geological and geochemistry results.

4.2. Validation of Magnetometry results

For more investigation and checking magnetic results, some boreholes were determined and drilled. There were six boreholes and their adjacent trenches in the study area, which had been done based on **Ebrahimi et al.** (**2019**) due to geological investigations. Surprisingly, the locations of previously drilled boreholes are inside the negative anomaly zone (see **Figure 9**).

Figure 10 displays mineralization in one of the mentioned trenches near those old boreholes. Four new boreholes were proposed and drilled in the primary negative signal to examine the accuracy of our hypothesis. Triangular spots in **Figure 9** identify the locations of new boreholes. Grade distributions of Cu in the Newborehole1 and Newborehole3, to the depth of 45 meters, are presented in the **Figure 11** and **12** respectively, as a chart and log plot. These figures show that there is good copper mineralization in new boreholes. **Figure 13** contains some pictures

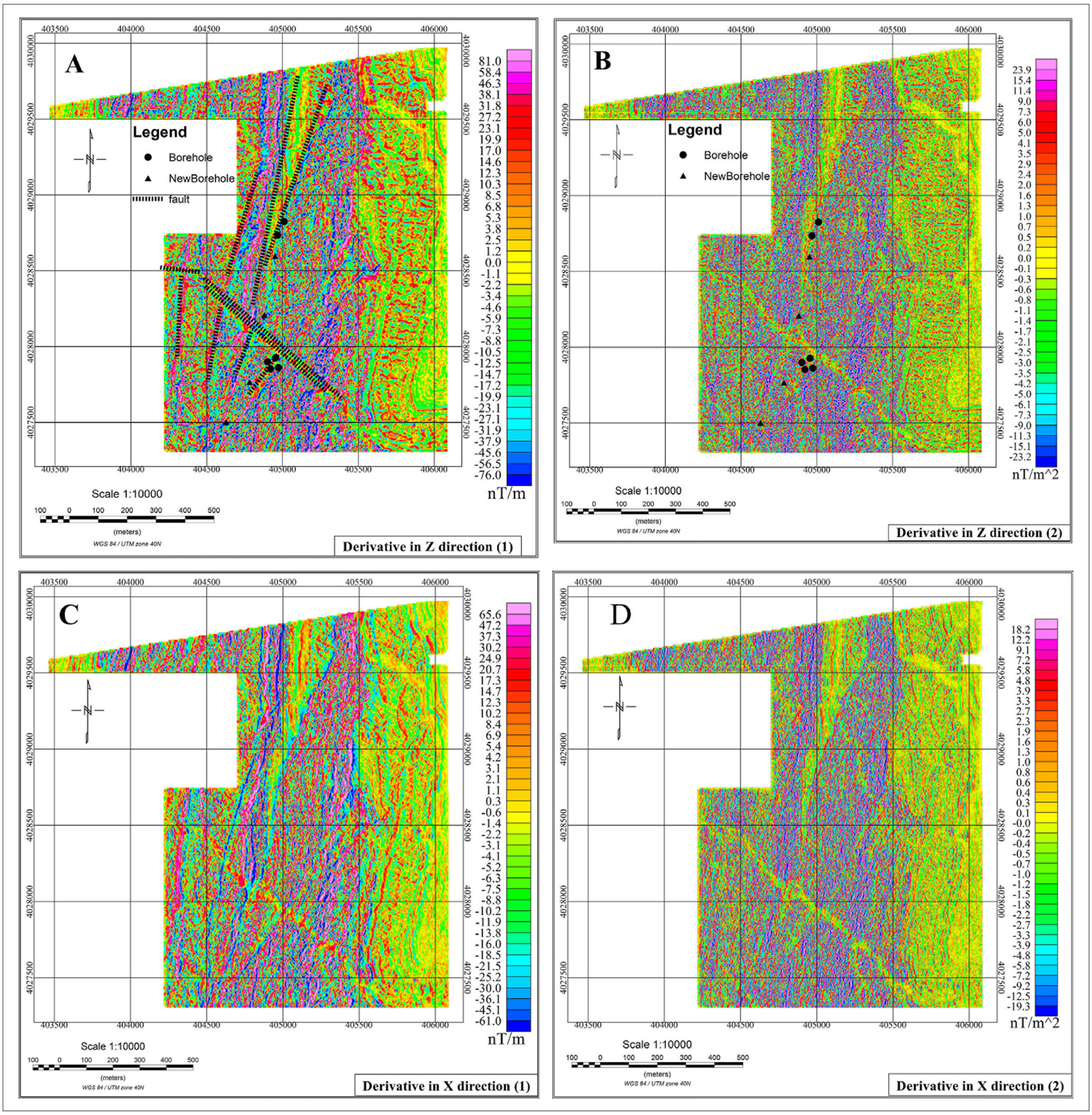

Figure 7: Maps showing derivative filter on Reduce to Pole base map in the Dochileh area: (a) first vertical derivative map (DZ1), black lines indicate the magnetic structures; circles and triangles indicate the borehole's locations. (b) Second vertical derivative map (Dz2), circles and triangles indicate the borehole's locations. (c) First horizontal derivative map (x-direction). (d) Second horizontal derivative map(x-direction). Black lines indicate the magnetic structures; circles and triangles indicate the borehole's locations.

caught from the cores related to New Borehole1 and New borehole3. Based on magnetometry, it was determined that there is mineralization in the new boreholes, seen as vines and veinlets. In previous boreholes, the primary mineralization was as a disseminated one.

5. Discussion

As previously mentioned, the aim of this study is the investigation of magnetometry in Manto-type copper exploration. The Meyami-Sabzevar copper belt represents a wide mineralization zone that is currently under reconnaissance and exploration (**Mostafaei and Ramazi, 2019b**). The vast area of this belt entails high cost and time-consuming exploration activities; therefore, we want to use magnetometry as the fastest and cheapest exploratory method. The Dochileh (case study) is a copper Manto-type located in the Meyami-Sabzevar copper belt. The Manto-type was described in part 2 (research area and its descriptions). These deposit types

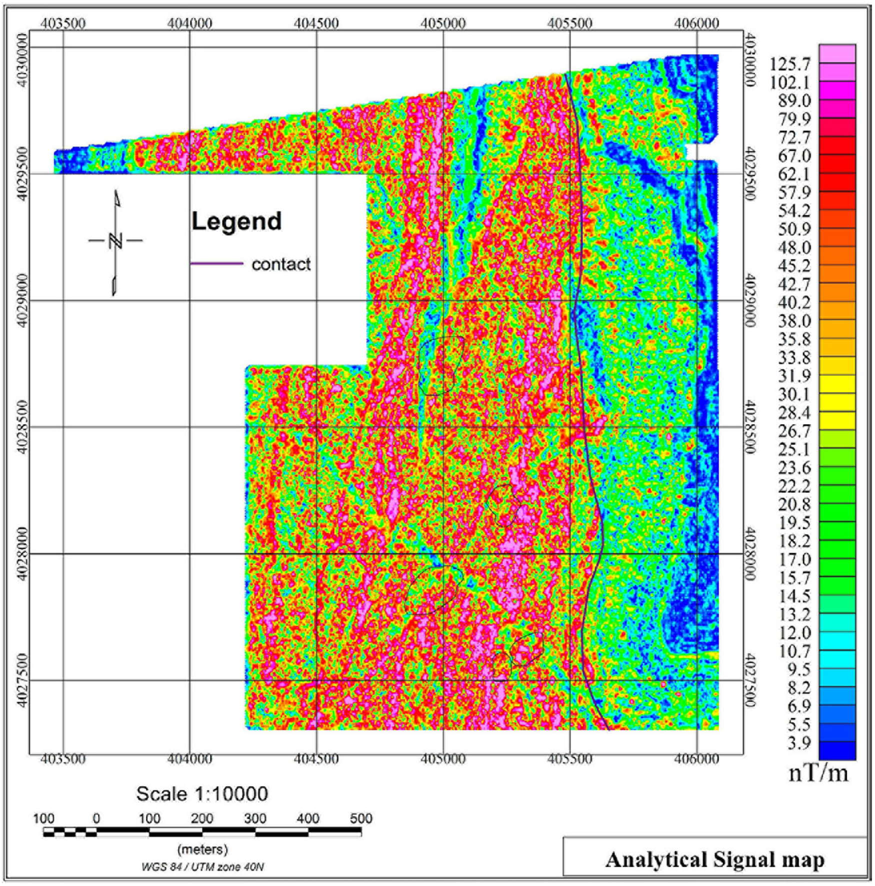

Figure 8: The prepared analytical signal (AS) map for Dochileh area, the black line indicates the lithological contact

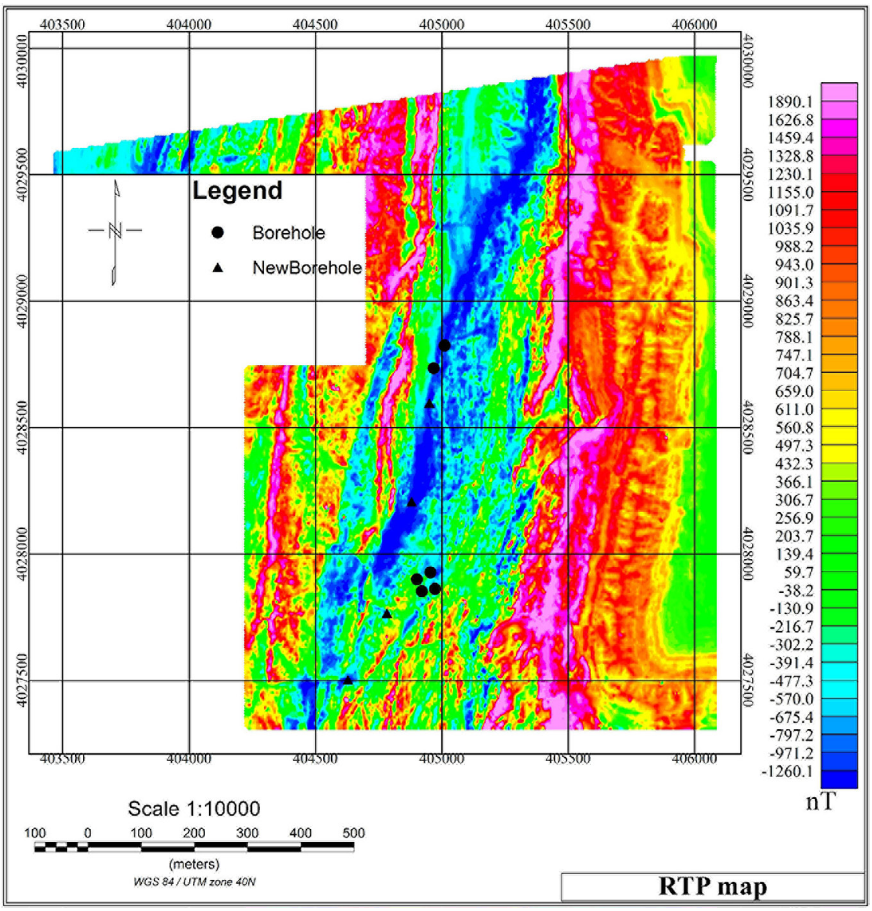

Figure 9: Map shows the location of previous cut borehole with a circular symbol and new drilled borehole with triangular marks on a Reduce to Pole base map.

Figure 10: Picture of a trench cut between the BH03 and BH05; a) and b) show mineralization in this trench, c) view of the trench

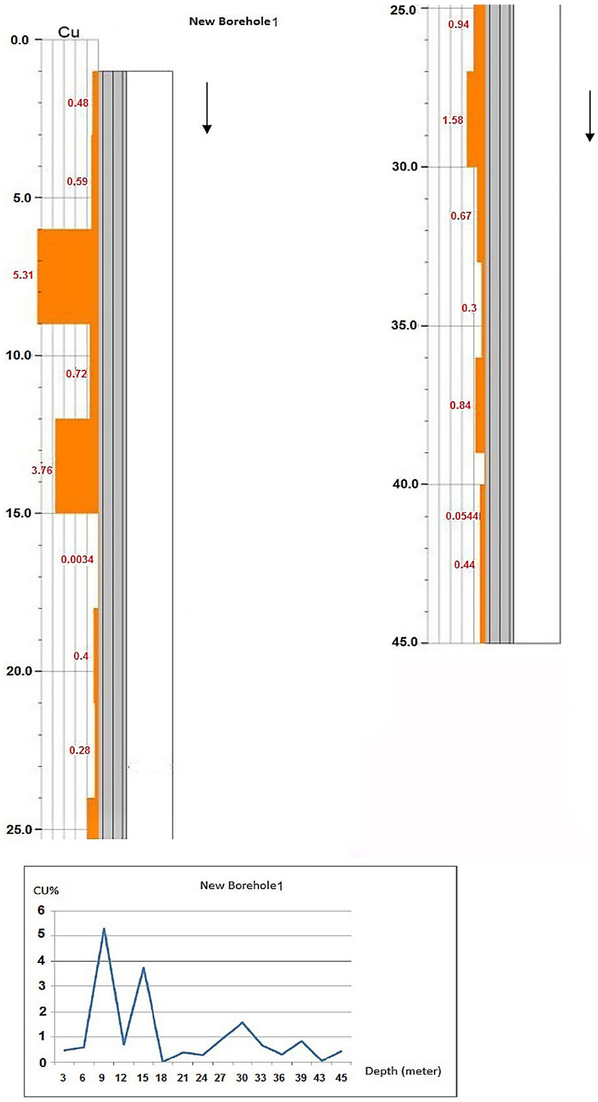

Figure 11: Copper grade (%) distribution among New Borehole 1 in the Dochileh area

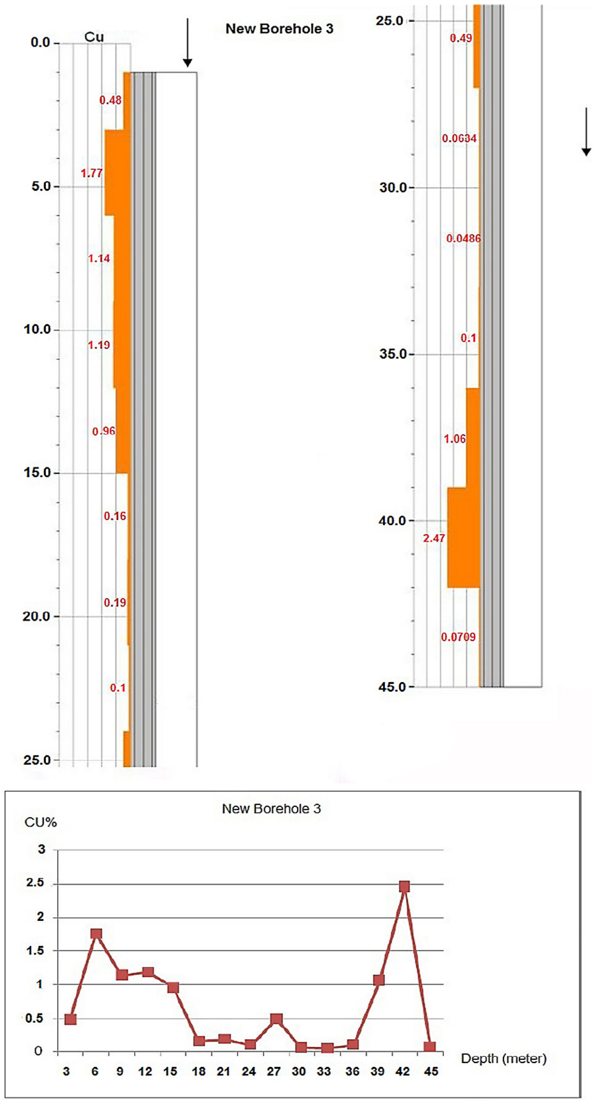

Figure 12: Copper grade (%) distribution among New Borehole 3 in the Dochileh area

Figure 13: Native copper mineralization in the cores of newly drilled boreholes

have their own characteristics (**Samani, 2002: Kojima et al., 2009**).

Based on the total magnetic intensity map, presented in **Figure 3**, the minimum value of magnetic intensity is about 47500 nT, and the maximum value is about 52500 nT. After preparing the residual map, shown in **Figure 4**, we found that the magnetic anomalies in this study area are different from common anomalies. In other words, the anomalies had a mostly linear trend.

The derivative maps (see **Figure 7**) show the lithological contact and structure very well. In these maps, probable locations of faults and crushed zones were detected. According to geological studies, faults and crushed zones have an important role in mineralization in Manto-type deposits (**Kojima et al., 2009**). Also, in the analytical signal map presented in **Figure 8**, lithological contact was detected.

So, based on the magnetometry, the locations with mineralization potential were detected. In exploratory studies, geophysical results as anomalies should be investigated and compared with geological and mineralization facts (**Mostafaei and Ramazi, 2019a**).

For checking the magnetometry results, some locations were proposed for drilling. In **Figure 9**, the location of the proposed drilling was presented. After drilling, the data were collected and analyzed.

Drilling results show that the proposed boreholes are located in the mineralization zones, and there is a good correlation between the magnetometry results and the mineralization locations.

According to the drilling results, we can say the magnetometry detected the mineralization locations well in the study area, and that magnetometry can be used in Manto-type deposits as an excellent primary method in the exploratory process.

Geological and drilling results show that mineralization is related to faults and crushed zones; also, basalt is the primary lithology type in this area. The host rock of mineralization is basalt, which has various granulations, including fine to medium and coarse grains. In locations where there are faults, fractures and alterations in basalt with fine to medium grain basalt, mineralization has occurred as veins and veinlets.

Also, mineralization occurred in various ore-horizons with various depths and thicknesses. Therefore, depth estimation and modelling magnetic data cannot be beneficial based on the mineralization type, which suggests that it is not possible to separate the ore-horizons by magnetic data modelling and depth estimation.

6. Conclusions

Within this study, magnetometry was applied to an indirect exploration of Manto-Michigan copper mineralization among faulted and crushed zones as a rapid and inexpensive method before other exploration methods. The results demonstrate that the derived magnetic maps have a great consistency with mineralized zone trends. Based on the derivative maps, the locations of the lithological contact, fault, and crushed zones were well detected.

The detected faults based on the magnetometry result in the study area have excellent consistency with the general geological theory of Manto-type copper deposits. The hydrothermal fluids responsible for mineralization in such deposits extract the copper concentration within volcanic sequences, and when they are warmed enough, they settle copper sulfide in the available space through the basaltic units as stratiform structures. In the following steps, this rich-copper fluid moves upward through the faults and fractures-formed by tectonic forces- and causes copper mineralization as veins and veinlets.

Magnetometry, drilled results, and geological studies demonstrate that in every drilled location, placed in faults (fault zone), vein-veinlet copper mineralization is followed by a strata copper mineralization zone. So, magnetometry could be used as a rapid and low-cost exploratory method to explore this vein-veinlet mineralization directly connected with fractures and faults, and consequently to uncover the Manto-type copper deposits.

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SAŽETAK

Primjena magnetometrije u istraživanju ležišta bakra tipa Manto, Meyami, Iran

Cilj je ovoga istraživanja bio primijeniti novu strategiju za istraživanje ležišta bakra tipa Manto-Michigan, koji se smatraju glavnim resursom bakra nakon ležišta porfirnoga tipa. S obzirom na to da rasjedi i zdrobljene zone imaju istaknutu ulogu u ovoj vrsti naslaga, očekivana je pojava jedinstvenih magnetskih obrazaca kao pokazatelja zone mineralizacije. U skladu s tim, testirana je magnetometrija u istraživanju ove vrste ležišta bakra Dochileh, tipa Manto-Michigan. Linije istraživanja bile su udaljene 10 metara uz razmak od 5 metara između stanica na svakome profilu. Nakon kartiranja karta magnetskih reziduala nije pokazala nikakvu dipolnu anomaliju, ali su zabilježeni određeni linearni trendovi. Jedan od njih pripada rasjednoj i zdrobljenoj zoni duljine gotovo 2,5 km i širine između 50 i 250 metara. Prethodno opisane mineralizirane zone, izdvojene na temelju geologije područja Dochileh, uglavnom se podudaraju s negativnim vrijednostima na karti reziduala. Načinjene su četiri nove ocjenske bušotine u granicama negativne anomalije, a izvedene jezgre potvrdile su mineralizacije bakra, malahita i kuprita.

Ključne riječi:
istraživanje bakra, tip Manto, magnetometrija, bušenje, Iran

Author’s contribution

Kamran Mostafaei (Assistant professor, senior explorer), responsible for project design and management, data processing, interpretations and presentation. **Mohammadnabi Kianpour** (MSc of mineral exploration, project advisor) performed the field work, surveying and field operations.