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The exploration of gold by magnetic method in Hired Area, South Khorasan, a case study

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Abstract

Hired is a large gold prospecting area which is located in South Khorasan province, in the east of Iran. Gold mineralization is found in 4 target areas covering about 24 km^2. The host rocks are mainly Tertiary volcanics, some Jurassic and Cretaceous sediments. Sub-volcanic rocks are of magnetite series (gabbros to diorite) and ilmenite series (granite-granodiorite-monzonite) which have intruded the Tertiary and older rocks. Important styles of mineralization are: stockwork, skarn, vein, and replacement. Stockwork gold mineralization has only pyrrhotite and is found within or around the granite-granodiorite-monzonite. Detail core logging was carried out in 4 target areas with respect to gold content, mineral paragenesis, types of veinlets, rock types, and measuring the magnetic susceptibility. Within the stockwork mineralization at east of target 1, there is good correlation between gold grade, amount of pyrrhotite, and magnetic susceptibility. At Hired, sub-volcanic rocks of the ilmenite series (granite-granodiorite-monzonite) have susceptibility less than 40×10^{-5} SI. The magnetite series (gabbros to diorite) have susceptibility of $150 – 900 \times 10^{-5}$ SI. Stockwork gold mineralization has susceptibility of $200\text{-}3500 \times 10^{-5}$ SI. Therefore the host rocks, granite-granodiorite-monzonite, have low magnetic susceptibility. Based on this sharp magnetic contrast ground magnetic was selected as a suitable geophysical method. The aim was to use the magnetic method for drill target identification of gold ore east of target 1. The total magnetic field intensity (TMI) was measured in 780 points along 25 lines. Measurement spacing was 2 meter. magnetic lines, contour maps, and images revealed large anomalies at east of target 1 representing the magnetic responses of gold ore. The depth of the anomalies is estimated to be shallow as indicated by their expression on the first vertical derivative map. This prediction is consistent with mineralogical observation on the surface and the continued map. The locations of the anomalies on the Reduced To the Pole (RTP) map are proposed as suitable points for drilling target.

Key words: Pyrrhotite, Magnetic susceptibility, Magnetic survey, Reduced to pole, Hired, Iran

اکتشاف طلا با روش مغناطیسی در منطقه هیرد، خراسان جنوبی، بررسی موردی

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چکیده:

هیرد منطقه اکتشافی بزرگ طلا است که در ناحیه خراسان جنوبی، شرق ایران، قرار دارد. کانی‌سازی طلا در چهار هدف اکتشافی به وسعت حدود ۲۴ کیلومترمربع یافت می‌شود. سنگ میزبان کلاً ولکانیک‌های ترشیری، رسوبات ژوراسیک و کرتاسه است. سنگ‌های نیمه‌عمیق از سری مگنتیت (گابرو تا دیوریت) تا سری ایلمنیت (گرانیت- گرانودیوریت- مونزونیت) است که به داخل سنگ‌های ترشیری و قدیمی‌تر نفوذ کرده است. سبک‌های مهم کانی‌سازی عبارت‌اند از: رگچه‌ای، اسکارن، رگه‌ای و جانشینی. فقط کانی‌سازی رگچه‌ای طلا دارای پیروتیت است و در داخل و اطراف گرانیت- گرانودیوریت- مونزونیت یافت می‌شود. بررسی‌های تفصیلی مغزه‌ها در چهار هدف اکتشافی، با توجه به محتوای طلا، پاراژنز کانی، نوع رگه، نوع سنگ و اندزه‌گیری پذیرفتاری مغناطیسی صورت گرفت. ارتباط خوبی بین عیار طلا، مقدار پیروتیت و پذیرفتاری مغناطیسی در کانی‌سازی رگچه‌ای در شرق هدف ۱ وجود دارد. در هیرد، سنگ‌های نیمه‌عمیق سری ایلمنیت (گرانیت- گرانودیوریت- مونزونیت) دارای پذیرفتاری مغناطیسی کمتر از SI $^{-5}$۱۰ ×۴۰ هستند. سنگ‌های سری مگنتیت (گابرو تا دیوریت) دارای پذیرفتاری مغناطیسی SI $^{-5}$۱۰ ×۹۰۰–۱۵۰ هستند. کانی‌سازی رگچه‌ای طلا دارای پذیرفتاری SI $^{-5}$۱۰ × ۳۵۰۰–۲۰۰ است. بنابراین سنگ میزبان دارای پذیرفتاری مغناطیسی کم است. براساس این تفاوت مغناطیسی زیاد، مغناطیس زمینی درحکم روش ژئوفیزیکی مناسب انتخاب شد. منظور، استفاده از روش مغناطیسی برای شناسایی نقطه حفاری کانسار طلا در شرق هدف ۱ بود. شدت کل میدان مغناطیسی در ۷۸۰ نقطه در طول ۲۵ خط اندازه‌گیری شد. فواصل نقاط اندازه‌گیری ۲ متر بود. خطوط مغناطیسی، نقشه‌های منحنی میزان و تصاویر، بی‌هنجاری‌های بزرگی را در شرق هدف ۱ آشکار ساختند که معرف پاسخ مغناطیسی کانسار طلا است. منبع بی‌هنجاری‌ها، کم‌عمق برآورد شد، همان‌گونه که اثر آنها در نقشه گرادیان اول عمودی نشان می‌دهد. این پیش‌بینی هم‌آهنگ با مشاهدات کانی‌شناسی در سطح و نقشه فراسو است. محل بی‌هنجاری‌ها در نقشه انتقال به قطب به‌منزلهٔ نقاط مناسب برای هدف حفاری پیشنهاد شد.

واژه‌های کلیدی: پیروتیت، پذیرفتاری مغتناطیسی، اندازه‌گیری مغناطیسی، انتقال به قطب، هیرد، ایران

1 INTRODUCTION

Despite the high density (19.3 gcm^{-3}) and electrical conductivity (5×10^{7} Sm^{-1}) of gold, it is almost impossible to get a direct geophysical response for it (Doyle, 1990). The small direct responses are a result of the low grades involved today (usually only a few grams per ton). Gold ores can have susceptibility values which are either lower (e.g., Youanmi and Queen Margaret) or higher (e.g., Mount Martin, Bounty and Greenfields) than those of the host rocks (Dentith, 1994). This has important implication for gold exploration because the type of magnetic anomaly sought will be different in each case. In the former case, where the deposit lies close to, or within, a body of strongly magnetized rocks, local magnetic minima could be highly significant in terms of targeting drillholes. If the magnetic response of the ore is greater than the surrounding rocks, as is the case for east of target 1 at Hired gold mineralization, the opposite will be true; positive magnetic anomalies representing the mineralization will appear.

Petrophysical studies have proved a useful, cost effective procedure for characterizing the physical properties of various styles of mineralization and how these may contrast with surrounding country rocks. The geophysical techniques employed and the data collection parameters have been determined after due consideration of the petrophysical results, geological and geochemical information of the survey areas (McMickan et.al., 1993). Detail core logging was carried out in 4 target areas at Hired gold mineralization with respect to gold content, mineral paragenesis, types of veinlets, rock types, and measuring the magnetic susceptibility (Karimpour et al, 2007). It indicated the presence of pyrrhotite associated with sulfide mineralization including gold only east of target 1. Core study also showed a good correlation between susceptibility and gold grade on the bases of susceptibility measurements and geochemical analysis (Karimpour et.al. 2007). At Hired, sub-volcanic rocks of the ilmenite series (granite-granodiorite-monzonite) have susceptibility less than 40×10^{-5} SI. The magnetite series (gabbros to diorite) have susceptibility of $150–900 \times 10^{-5}$ SI. Stockwork gold mineralization has susceptibility of $200\text{-}3500 \times 10^{-5}$ SI (Karimpour et al., 2007). Important styles of mineralization at Hired are: stockwork, skarn, vein, and replacement. Stockwork gold mineralization which has pyrrhotite is only present east of target 1 and is found within or around the granite-granodiorite-monzonite (Karimpour et al., 2007). The host rocks for gold mineralization east of target 1 are shale and ilmenite series intrusion which are not magnetic. This sharp magnetic contrast made the magnetic method suitable for direct identification of gold ore. The aim was to locate magnetic anomalies representing gold ore for drill target identification using magnetic method. This work presents only the results of ground magnetic survey. Small scale image (1:50000) of high resolution aeromagnetic data from Geological Survey of Iran (GSI) was used as a guide for the regional magnetic responses of the area. Detailed geology, mineralogy and geochemistry of Hired mineralization are given by Karimpour et al. (2007).

2 GEOLOGY OF THE SURVEY AREA

Hired gold mineralization, is located 160 km to the south of Birjand and 80 km to the north of Nehbandan (figure 1).

Shale and sandstone of Jurassic overlie unconformably on the shaly-conglomeratic-sandy sediments of Cretaceous at Hired mineralization area figure 2. Tertiary volcanic-plutonic intruded the older sediments. Silicifide shale and S type acidic intrusive (granite-granodiorite-monzonite) are the dominant host rocks east of target 1. The geology of the survey area and the position of the magnetic survey lines are presented in the geological map (figure 2).

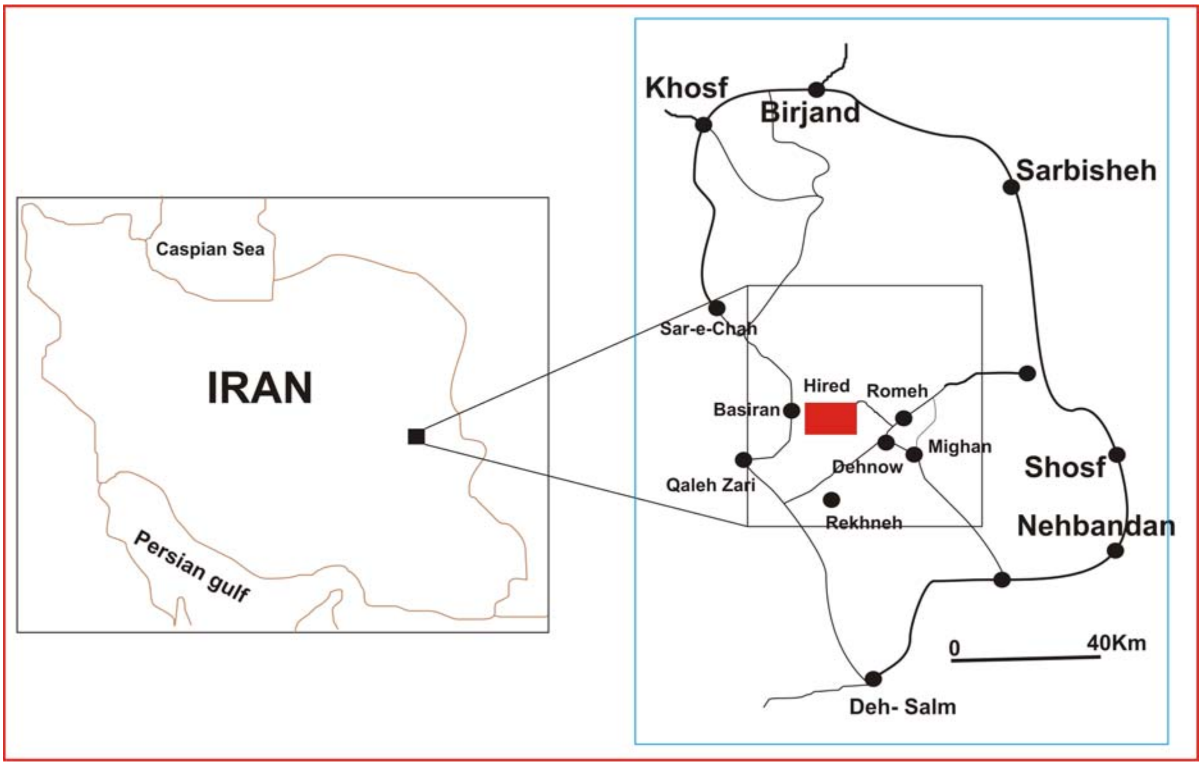

Figure 1. Location map of Hired mineralization area. (After Karimpour et al., 2007).

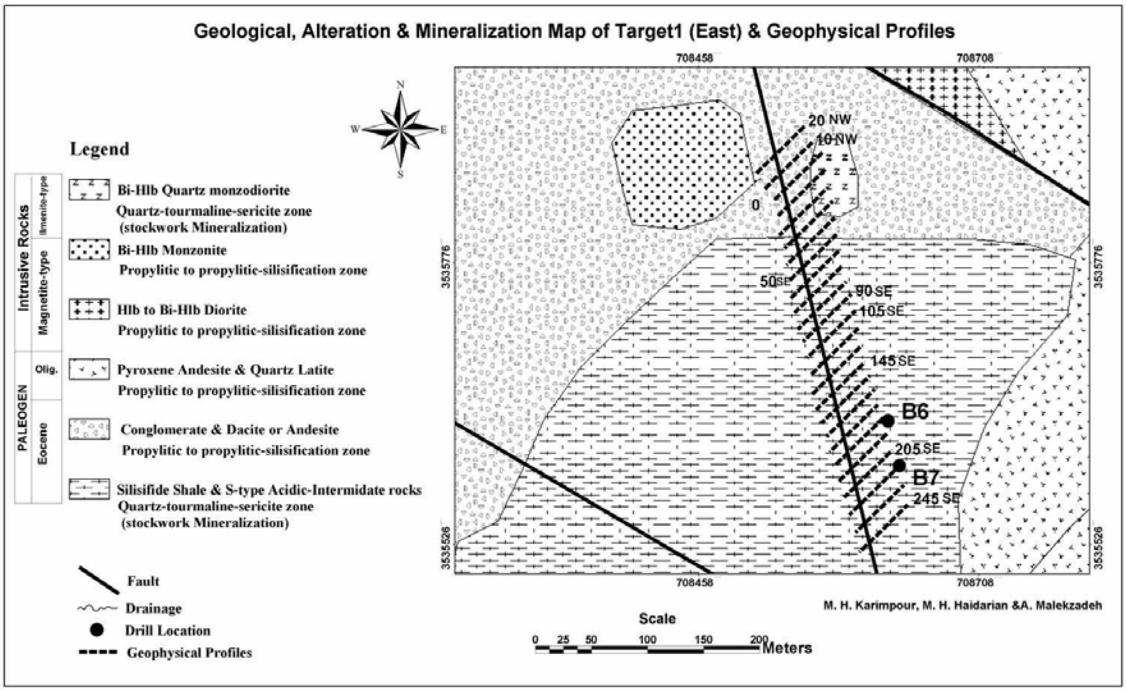

Figure 2. Geology, alteration, and mineralization map at east of target 1. (After Karimpour et al, 2007).

3 MAGNETIC SURVEY

Ground magnetic measurements were collected with ENVI magnetometer (Scintrex, Canada) with an accuracy of 0.1 gamma at Hired gold mineralization area in three exploration targets (east of target 1, west of target1 and target 3). This work will present only the magnetic survey from east of target 1 as the gold ore at other target areas (west of target 1 and target 3) had no pyrrhotite and consequently no magnetic responses (Haidarian Shahri, et.al., 2007). East of target 1, survey lines were oriented NE-SW and spaced 10 and 15 meter with measurement spacing of 2 meter (figure 2). Susceptibility measurements were made on drilled cores and surface samples using GMS 2 (Scintrex Canada) instrument with an accuracy of 1×10^{-5} SI. Total Magnetic field Intensity (TMI) was measured in 780 points along 25 lines. Diurnal variation was removed using a loop type collecting data due to lack of an extra base station magnetometer. Atmospheric variation of the magnetic field (inquired from the geomagnetic observatories in Iran and the USA) was reported to be quiet during the period of magnetic survey. Small scale image (1:50000) of high resolution aeromagnetic data from the Geological Survey of Iran (GSI) is a guide for the regional magnetic responses of the area (figure 3). This image shows the magnetic responses of granitoide intrusion with magnetic highs corresponding to gabro-diorite (I type granitoides) and lows to granite-granodiorite-monzonite (S type granitoides) as susceptibility measurements indicated (Karimpour, et. al., 2007).

4 RESULTS AND DISCUSSION

The information available in magnetic data is generally underutilized and this is in part due to poor display of the data. Magnetic data either airborne or ground measurements cannot be interpreted until it is displayed. To maximize the amount of information extracted from the data set and overcome the limitations imposed by using only one kind of display format, several displays should be used to provide different perspectives. A wide range of presentations and enhancements are possible for magnetic data.

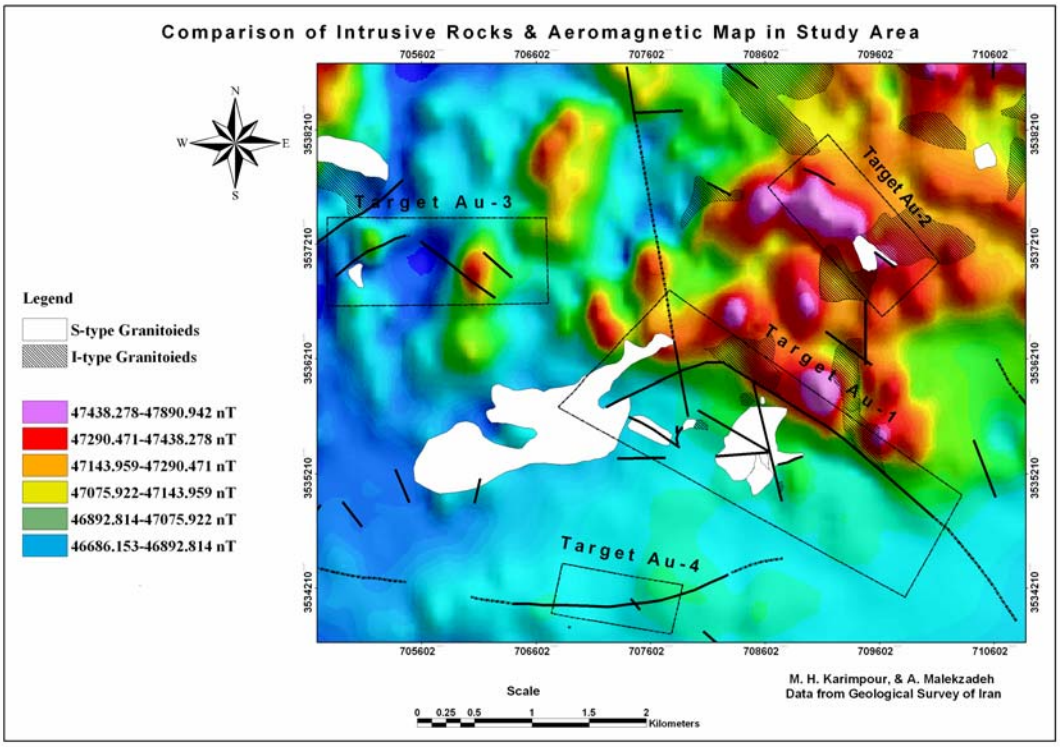

Figure 3. Regional aeromagnetic image of Hired area. (After Karimpour et al, 2007).

Many examples can be found in the literature particularly in ASEG, SEG and CSEG publications. Broom, 1990; Isles et al, 1991; Teskey and Hood, 1993; Milligan and Gunn, 1997; Liu and Mackay, 1998 have all discussed the presentation and interpretation of magnetic data. Considering limited available facilities for magnetic interpretation in educational institutions in Iran particularly at the geology department of Ferdowsi University of Mashhad, a systematic approach leading to the selection of the most effective displays is presented. Ground magnetic survey for gold exploration in South Khorasan province, Iran, is studied and displayed as a case study.

Data display along Lines and also the use of contour maps are both needed to have a preliminary idea about the amplitude of the anomalies and the magnetic trend. Although there was a simple contouring routine which was included with the ENVI magnetometer, the choice of griding method and pixel size was not possible with this program. The minimum curvature method was used for griding using ER Mapper and 2 meter pixel size was selected considering 10 meter line spacing. Minimum grid cell size that can accurately be mathematically interpolated is normally 20-25 % of the line spacing (Gunn, 1996). Images should be used together with more conventional presentations, such as a contour map. Unenhanced color image of TMI with magnetic survey Line path on it is superimposed on the contour map figure 4. This map provides better information about the gradients of the magnetic field and the anomaly amplitude than the color image alone.

Since survey area was small in size (245 × 60 meter) a large scale contour map was produced to provide the variation of the magnetic field in more detail. Contour intervals were of 50 gammas. Contour intervals less than this would overcrowd the contour map. Both contour map and image clearly show a discontinuous anomaly with three highs. The trend of these anomalies is northwest- southeast which was not observable on Line display. The anomaly extends to the southeast beyond the survey area. The central anomaly which is seen on the Lines 120SE up to 175SE is the largest on the contour map. Inspection of individual Lines in terms of anomaly amplitude and width showed that a discontinuous anomaly extends through Line 0SE to 245SE. Selected magnetic survey Lines (70SE, 90SE, 120SE, 175SE, and 245SE) are presented here figure5. Maximum amplitude is 550 gammas which continue from Line 120SE up to 175SE and is also shown here on line 165SE (figure 6). The sources of the magnetic anomalies are pyrrhotite in the gold ore.

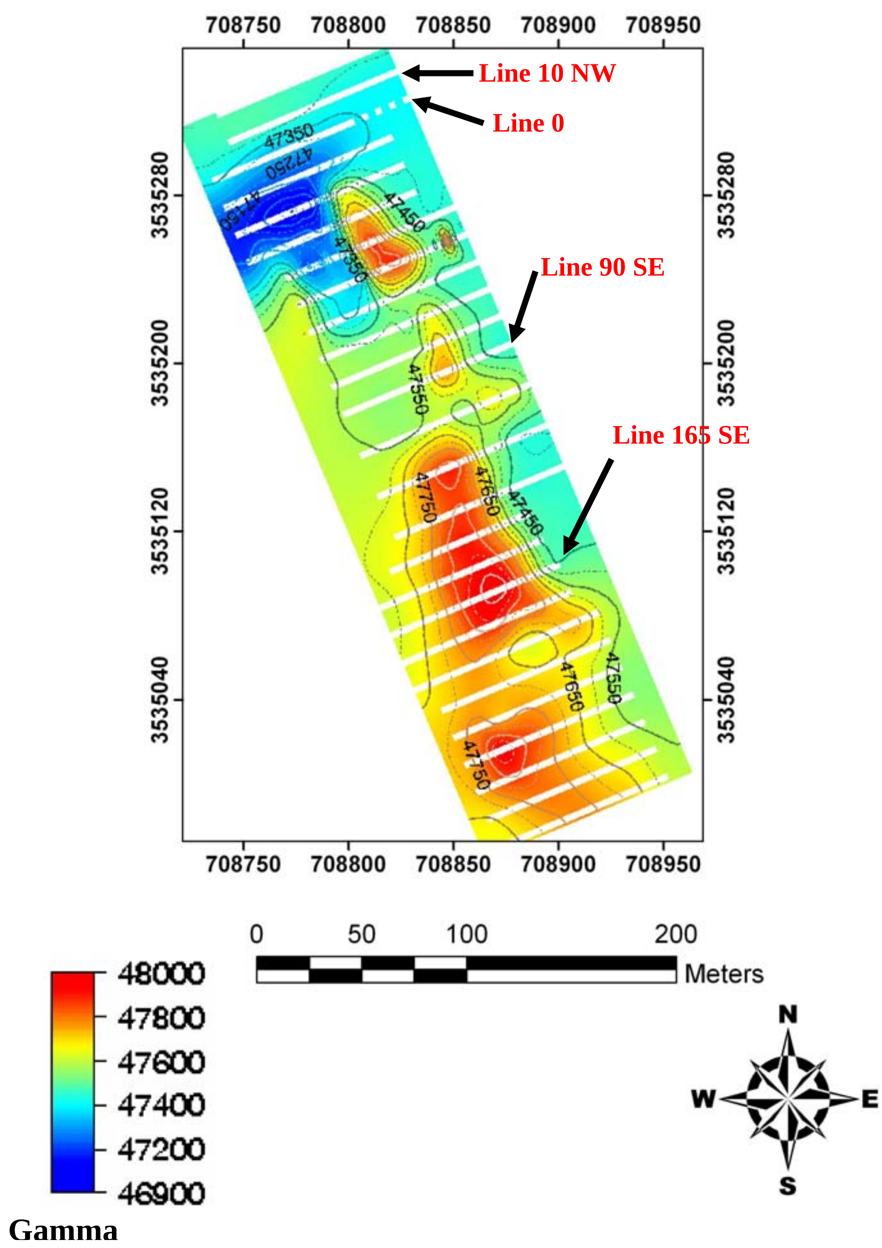

Figure 4. TMI color image with Lines and contour map superimposed.

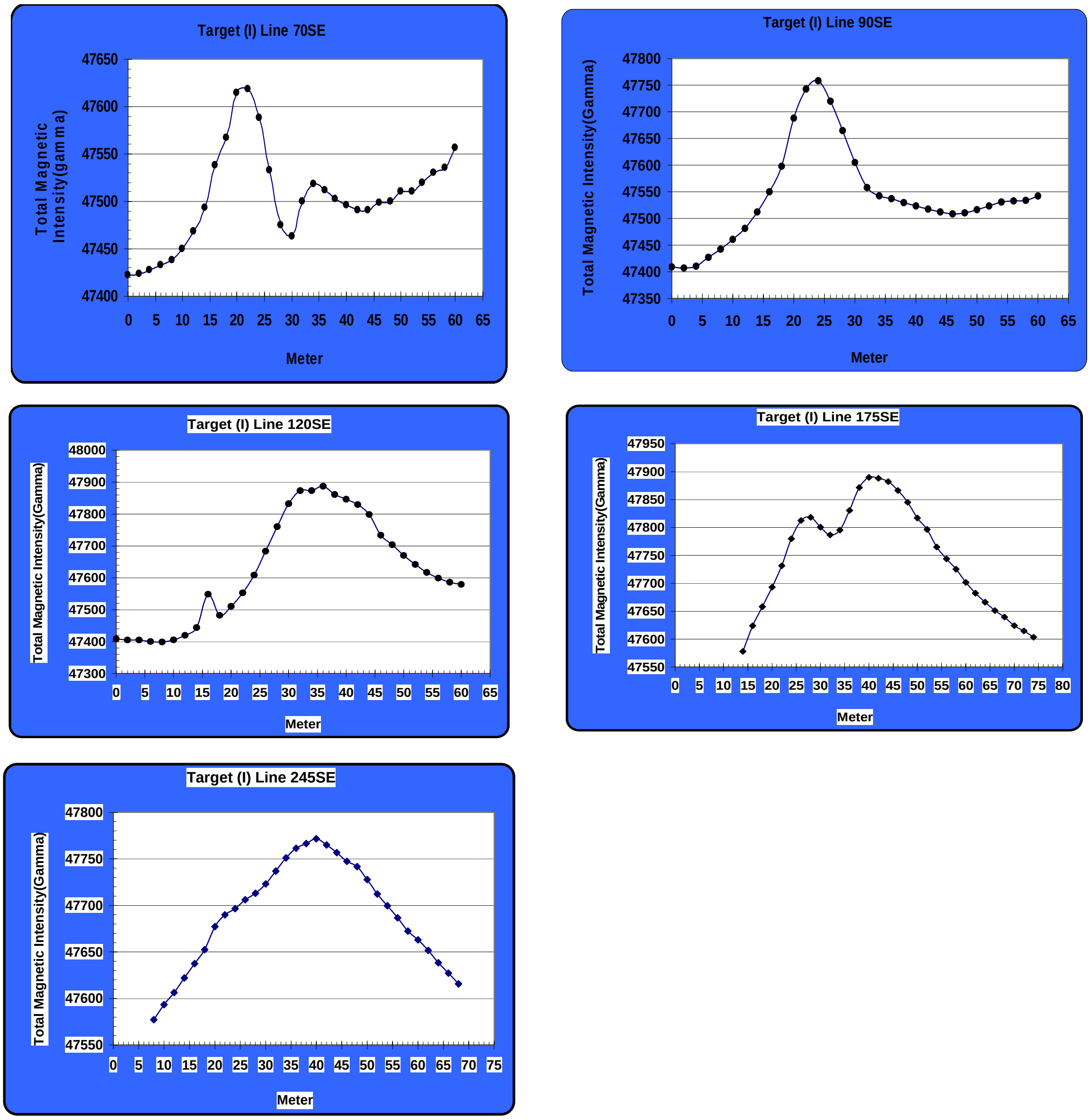

Figure 5. Lines 70SE, 90SE, 120SE, 175SE, and 245SE.

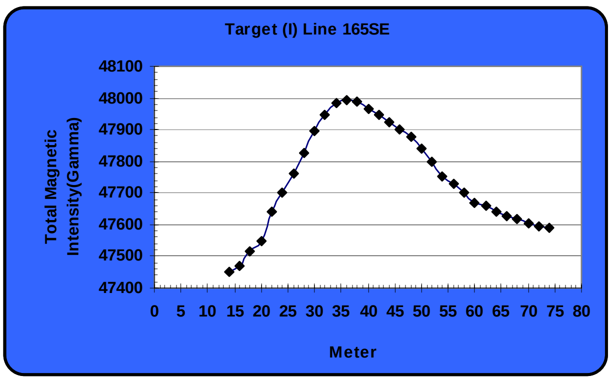

Figure 6. Line 165 SE.

For individual magnetic anomalies, it is important to determine the location and geometry of their sources. For planar sources, their attitudes — vertical or dipping (and dip angle) — are important criteria. For this reason, magnetic data generally need to be Reduced To the Pole (RTP) particularly for areas close to the magnetic equator in order to remove the asymmetry in magnetic anomalies due to the inclination of the Earth's magnetic field (Liu and Mackey, 1998). RTP data place anomalies directly above their sources. TMI color image of RTP was produced (figure 7). Comparison of figure7 and 4 shows that RTP function shifted the position of the anomaly to the east. The northwestern anomaly became smaller and the central anomaly did not change. The RTP color image also shows the continuation of the anomalies from the northwest to the southeast.

TMI – RTP - grey scale image, with gradient (sun angle) enhancement was also produced (figure 8).

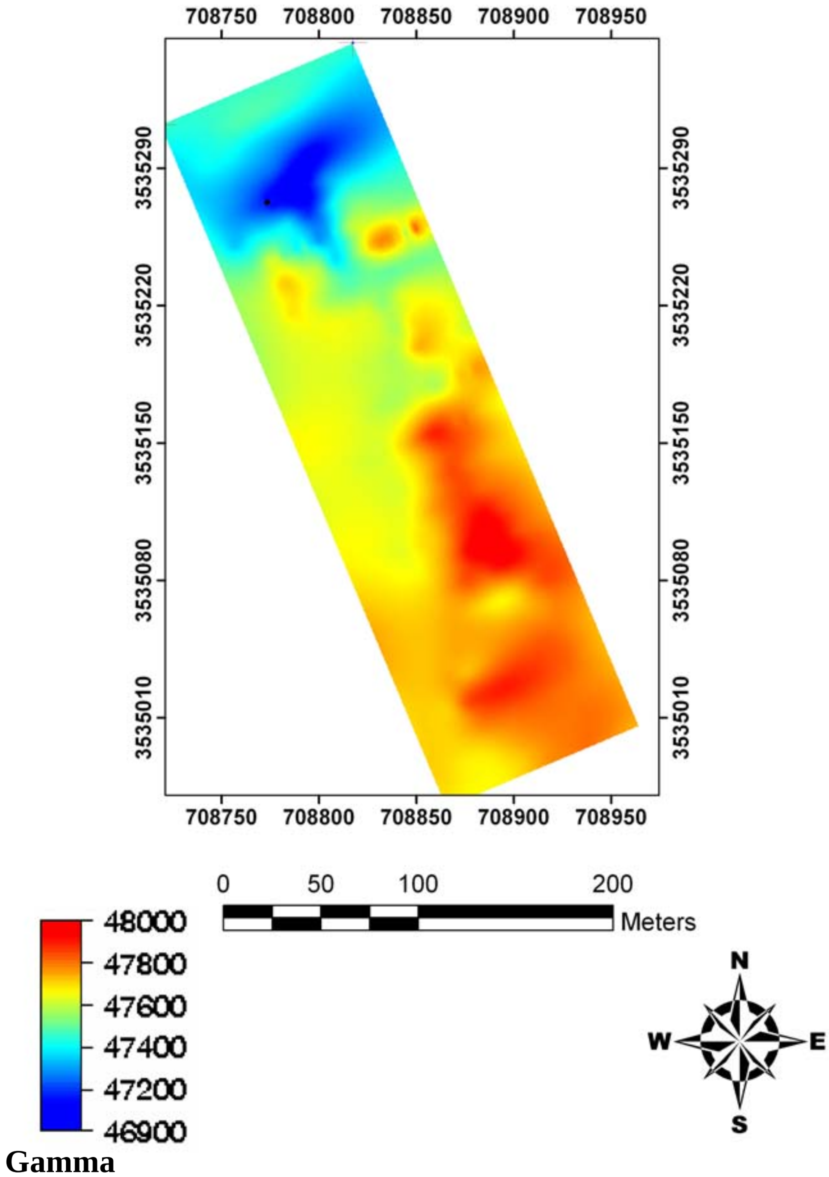

Figure 7. Reduced To the Pole image.

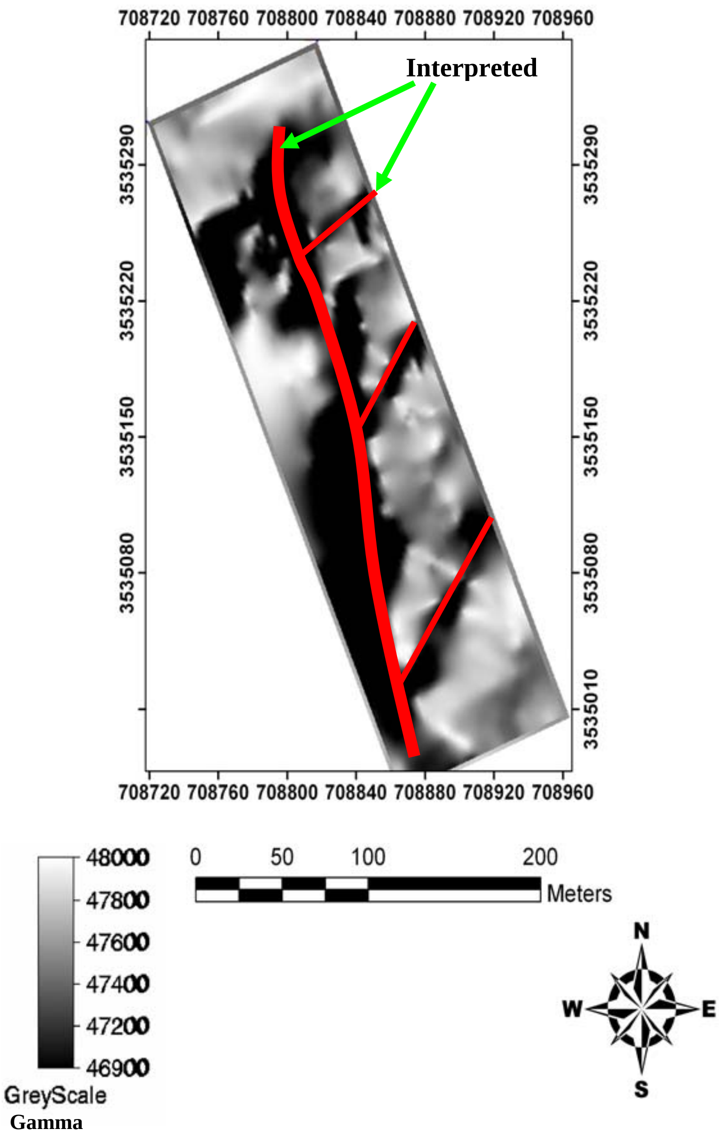

Figure 8. TMI -RTP- grey image sunshade.

Although grey scale images give no indication of anomaly amplitudes, most interpreters agree that illuminated grey scale images give better indication of subtle features than illuminated color images (Milligan and Gunn, 1997). The sun angle illumination is necessary to emphasize structural detail. It may be advantageous to produce several versions of these images with different illumination directions in order to have better definition of features with different trend directions. A major northwest southeast trend is evident at the illumination from 45 degree east. This trend is cross cut by subsidiary small northeast southwest ones (figure 8). These trends are interpreted as faults as the major one was evident on the ground surface.

A common filter which is applied to the potential field data is the vertical gradient. It enhances high frequency anomalies by 'sharpening' them. RTP First vertical derivative of the TMI was also produced (figure 9). This map indicates that the anomaly sources are near surface and correlates with mineralogical observation on the surface (Karimpour et al., 2007).

Comparison of the first vertical derivative image (figure 9) with the TMI image (figure 4) shows far better shallow and narrow magnetic anomalies on the former than on the latter. The TMI with RTP is continued upward at a step of 10 meters to get an estimate of the depth extension of the anomalies and also enhance the expression of the deep sources. The anomalies disappeared at the continuation of 50 meters (figure 10). This image shows only the regional effect and the narrow shallow anomalies which are evident on the first vertical gradient (figure 9) are suppressed with this function.

Contour maps, images and Lines only show the location, amplitude and the trend of the anomalies. First vertical derivative map and upward continuation give relative information about the depth of the anomaly sources. Modeling is needed to have a better estimate of the geometry of the sources producing the anomalies. The amplitude of the observed anomaly is the vectorial resultant of the remnant and induced components. No rough estimate of the geometry of the magnetic sources can be given unless the remnant component is known. Modeling is not accomplished here over the observed anomalies due to: 1- Non uniqueness of the solution to the potential field problem unless constrained with known geology, 2- Pyrrhotite frequently has remnant magnetization one order of magnitude greater than its induced magnetization which was not possible to determine at Hired gold ore and 3- Mineralization is observable on the surface and the optimum location of gold ore is important for drill target identification.

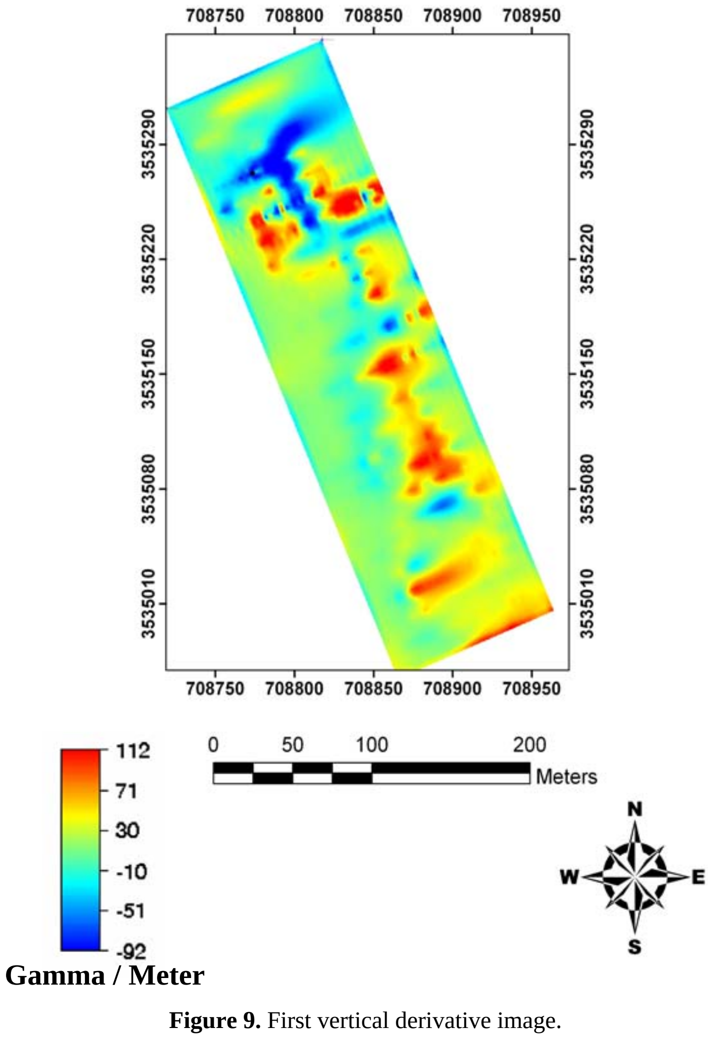

Figure 9. First vertical derivative image.

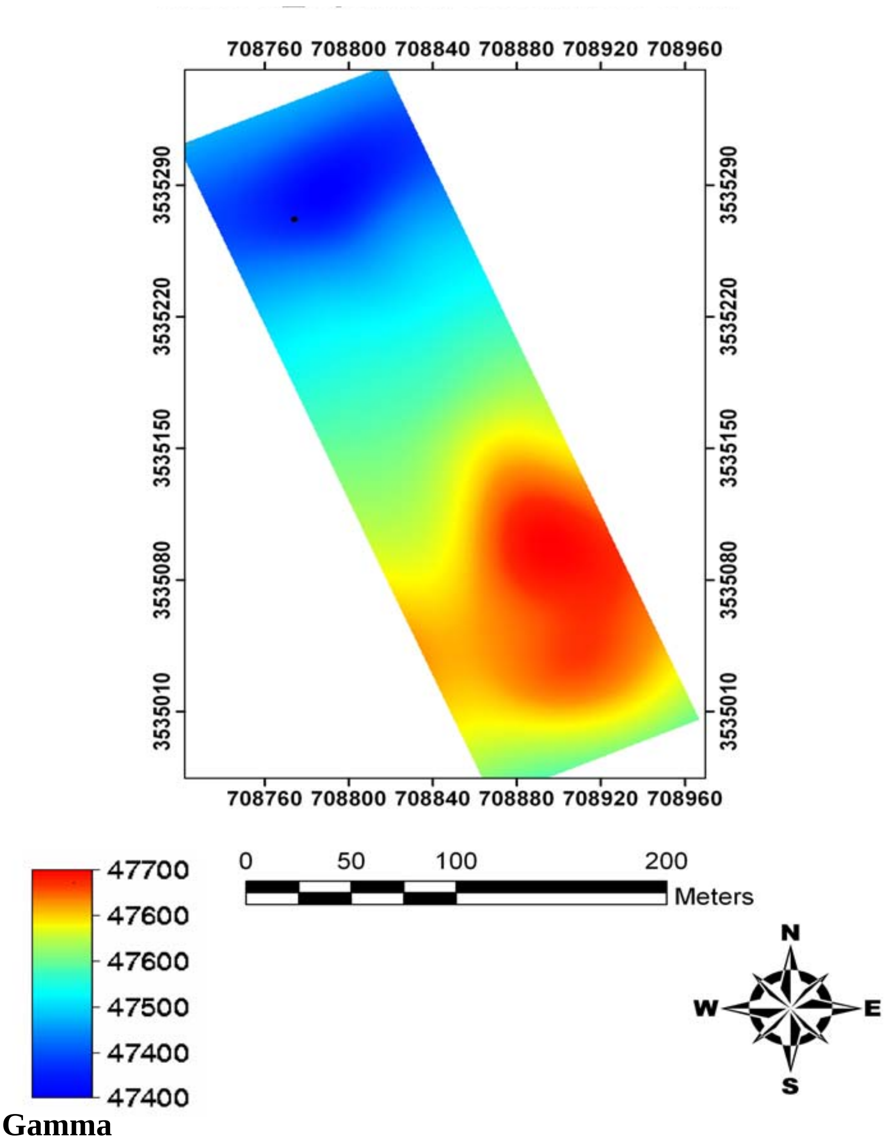

Figure 10. RTP- upward continued 50m.

5 CONCLUSION

Mineralogical studies at Hired gold mineralization indicated that pyrrhotite is present along with gold ore only in the stockwork mineralization east of target 1. Magnetic susceptibility measurements from surface and drill core showed that host rocks to the gold ore east of target 1 are nonmagnetic. Based on this sharp magnetic contrast ground magnetic was selected as suitable geophysical method for drill target identification. Ground magnetic survey revealed large anomalies on magnetic survey Lines, contour map and image representing gold ore east of target 1. The source of the anomalies is pyrrhotite along with gold ore. The depth of the anomalies is shallow as indicated by their expression on the first vertical derivative map. This prediction is consistent with mineralogical observation on the surface and the upward continued map. The position of the anomalies on the RTP image is important and proposed as suitable points for drilling target.

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