Identification of gold mineralization zone in “GB” field, Jambi, Indonesia using 3D inversion magnetic data

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Abstract. “GB” Field is a gold mineral prospect field located in Jambi, Indonesia. The gold zone is identified using 3D inversion magnetic data. The types of mineralization in this area are high epithermal sulfidation and porphyry copper-gold, which were formed in a hydrothermal environment. Characteristic of this type is a host rock of intermediate-acid igneous rock. This rock comprises mineral ores such as copper-gold and magnetic gangue minerals. Therefore, magnetic methods are very sensitive in identifying the gold prospect areas. Magnetic data were acquired at a 5 m spacing between stations along 51 lines with 100 m spacing between lines. To identify the position, type, and depth of the subsurface structure relating to the gold deposition environment, derivative analysis was performed using first horizontal derivative and Euler deconvolution calculations. Then, a 3D inversion model is constructed to objectively delineate the subsurface structure. Induced polarization as well as geological data are also used to identify the resistivity and chargeability parameters of the prospect zone and its environment. Thus, a gold deposition zone was identified based on the lithocap and intrusion body. The top of the intrusion rock was at a depth of 80 m from the surface.

Keywords: Gold mineral, epithermal sulfidation, porphyry, 3D magnetic inversion, Jambi

1. Introduction

The deposition of gold minerals in nature is a complex process. Wall rocks in contact with an acid-intermediate intrusion body undergo mineralization processes to form mineral deposits called porphyry. Porphyry is formed owing to a change in silicification containing copper and gold. It is the form of an intrusive rock channel that has undergone a process of silicification [1, 2]. The formation of gold is associated with hydrothermal activity around the porphyry precipitate, i.e., an increase in hydrothermal fluid flowing to the surface through cracks or fractures in the rock structure, which then undergoes differentiation and precipitation processes. The precipitation is influenced by several factors such as temperature, pressure, and geological conditions at the time of its formation. The epithermal deposit is a type of gold deposit that is mostly produced in Indonesia [3]. Such gold deposits are generally in the form of veins, the direction and size of which can vary greatly.

The focus of this study was the subsurface gold environment formed via hydrothermal processes. Such processes are controlled by structures such as faults, intrusions, and wall rocks. This hydrothermal system can be formed in a depositional environment in the form of gold porphyry sediment, high and low sulfidation epithermal deposits, and sulfide massive deposits. Based on the
chemical fluid content present in the sulphide deposits, epithermal deposits are divided into two types: low sulphide epithermal and high sulphide [4]. According to Heald et al. [5] the classification of these types is based on alteration and mineralogy, with high sulphide deposits considered acid sulfate and low sulphide deposits considered adularia sericite [5].

In nature, gold minerals are not typically found as pure gold. Certain minerals, such as magnetite and pyrite, are associated with gold, and these will also be effectively detected by magnetic methods. The magnetic response given by these minerals is high. Therefore, by analyzing magnetic data, gold mineralized zones can potentially be identified.

2. Methodology of study

This study is conducted according to the following steps by magnetic data were acquired by a mining company of PT. Antam Tbk and consisted of 51 measurement lines with 100 m spacing between lines and 5 m spacing between measurement stations. The measured data are corrected with daily variations and IGRF (International Geomagnetic Reference Field). The corrected data are then filtered using reduce to pole and upward continuation. An anomaly contour map of the total magnetic field is further interpreted by derivative analysis to calculate the first horizontal derivative, second vertical derivative, and Euler deconvolution. Maps produced for each are then used to determine the position, type, and depth of the subsurface structure. Analytical signals are also applied to magnetic anomaly data to determine the boundaries and reinforce the body that causes magnetic anomalies by displaying monopole effects. To estimate the subsurface geometry, 3D inversion modeling using MAG3D software is performed on the total magnetic field anomaly. The inclination and declination of the study area are -21.7361° and 0.3006°, respectively. The last stage is integrated analysis and interpretation of the 3D inversion model, horizontal gradient contour map, Euler deconvolution map, and supporting data such as IP (induced polarization) and geological data.

3. Results and discussion

The magnetic anomalies map is shown in figure 1. Estimated potential zones can be determined based on the contrast of positive–negative anomaly values, as indicated by a blue–purple color scale. Based on the magnetic anomaly map, the study was focused on the southerly zone (marked by a black box with dashed lines) as this appeared to be a potential zone of interest. Studies in this area are supported by IP and geological data. The positive–negative anomalies suggested potential zones and indicated the presence of two subsurface bodies (characterized by dotted white circles); these zones will require further filtering or other analytical methods.

The color scale in figure 1 shows a low magnetic value (shown as a green color) with a near-zero value, as well as a positive-negative anomaly with the most positive values shown in red–purple and the most negative values shown in blue. Negative values indicate a direction of polarity opposite to the direction of the Earth’s magnetic field. The value of the positive-negative anomaly falls between -199.3 nT and 244 nT. Big enough anomaly ranges of value to represent a mineral content.

Figure 2 shows the filtered magnetic anomaly field. The data have been filtered by both reduce to pole and upward continuation to 25 m height; therefore, the map is smoothed. Unfortunately, the monopole of the reduce to pole result is not clear. The anomaly bodies are still in the form of dipoles owing to the low latitude of the study area. The dipole of an anomaly body should be changed to a simple monopole anomaly body after the reduce to pole process. We applied the analytical signal as a useful alternative to show the anomaly body as a monopole (see figure 2b). There are two anomalous bodies clearly shown in figure 2b; these might be assumed to be intrusive rocks.

To confirm the presence of these two anomalous bodies, analysis of both the first horizontal derivative and the second vertical derivative of the magnetic anomaly are performed. The slicing results (AA’ and BB’) in both bodies (figure 3) indicate a reverse fault that formed the intrusion body.
Figure 1. Maps of (a) the magnetic field anomaly profile of the study area, and (b) the focused magnetic anomaly profile.

Figure 2. Contour map of magnetic anomaly (a) after reduce to pole and upward continuation, and (b) after analytical signal processes.

This is supported by geological data, which indicates a southwest–northeast structure. This structure might become the intrusion formation path.

The presence of the structure is also verified using Euler’s deconvolution. This showed the position and depth of the estimated structure, which is illustrated by the index structure. Euler’s solution describes the superficial structure because the residual structure is detected. The color legend of the Euler represents the estimated depth of the structure (in meters) below the surface. A number of small
circles of varying colors show the existing structural patterns. Figure 4 shows a map of the calculated Euler’s solution.

The 3D modeling results show concurrence with the results of derivative analysis and the analytical signal process. There are two bodies in the inversion, with high anomalies caused by bodies 2 and 3 (figure 5).

In the study area, magnetic anomalies are observed in high topographic areas. This is in accordance with the fact that mineral prospects should exist in the paleogeothermal zone. The highest topographic area indicates a caldera, which is typically a site of intrusive rock. This result reinforces the anomaly estimation of an intrusion body.

Figure 3. Indication of fractures on the (a) horizontal derivative, and (b) vertical derivative correlated with the geological faults.

Figure 4. Euler’s solution with index structure = 0 overlaying the contour map of magnetic anomaly.
High magnetic anomaly zones are also associated with diorite lithology and chlorite alteration zones. This correlation is clearly shown in the geological and alteration maps of figure 6. Chlorite alteration usually occurs at temperatures above 300 °C; as such, this indicates a position close to the source, which, in this case, is the intrusion. Based on the geological map, the intrusion body is young diorite rock that intrudes into the old andesite rock. The presence of chlorite in the potassic zone also indicates the presence of porphyry as a result of the alteration of igneous rock intrusion (which carries the economic mineral) in the surrounding area. The porphyry body in our 3D modeling has a magnetic susceptibility value of 0.031282 SI (see figure 7).

Besides high anomalous values, low magnetic anomaly values can also indicate a correlation with a strongly altered environment. This occurs because the lithology has been demagnetized by (i) heat from the hydrothermal solution and (ii) the acidic solution. Low anomalous values appear to be widespread in the breccia complex, suggesting the path through which the hydrothermal solution passed. This indicates that this area is a deposit system exhibiting a type of epithermal high sulfidation. The sulfidation is also confirmed by the development of advanced argillic alteration (such as dickite, kaolinite, alunite, pyroplite), which forms the lithocap. This also accords with the IP data (figure 8;
Figure 7. Sedimentation model reconstruction of epithermal high sulfidation (white dashed line).

Figure 8. Relationship of (a) magnetic anomalies with (b) resistivity and (c) chargeability data.

IP lines seen at points 200–800), which showed a low resistivity value (less than 100 Ohm.m) and high chargeability, indicating the presence of mineral sulfide as mineralization results in the formation of vuggy massive quartz of alteration. This deposit is a mineral deposit containing economic minerals such as gold, iron, copper, tin, zinc, and other minerals associated with sulfur elements [6].

The porphyry anomaly body was also confirmed by resistivity data, which showed a high value because the intrusion body is a very compact igneous rock and so its ability to conduct electricity is low. High chargeability values indicate the presence of metal minerals associated with gold.
Figure 7 illustrates the reconstruction of an intrusive rock (dark blue) forming two porphyry bodies (green) causing both high and low magnetic anomaly values at the surface (light blue within dashed white lines) indicating epithermal high sulfidation deposits (HSE). Magmatic gases are thought to rise to the surface rapidly from the intrusion rock of magmatic sources and do not interact with wall rocks or meteoric water. This very fast magmatic gas movement causes the gas pressure to drop rapidly. When the gas pressure drops, hydrothermal fluid becomes very acidic and will then react with wall rocks at the epithermal level.

4. Conclusion
Based on this study, the following conclusions are reached the zone of gold mineralization is located at x = (178,700–178,920) m and y = (9,697,300–9,698,000) m, as indicated by the high magnetic anomaly, high resistivity, and high chargeability, as well as the development of argillic and propylitic alteration zones. In the gold mineralization zone, gold-type deposits are developed in the form of copper–gold porphyry and epithermal high sulfidation precipitates. A structure on the “GB” Field is identified. This is in the form of a reverse fault that formed a diorite igneous intrusive body with a depth of ± 80 meters from the topography surface. 3D inversion modeling showed three intrusion bodies, there are body 1 (A large intrusive body originating from the north with a depth of 150 m below the topographic surface; has high susceptibility value ranging from 0.0313 to 0.0666 SI) and bodies 2 and 3 (Both bodies are most likely intrusion bodies that have the same source and originate from the south; these are separated by the structure. The depth of each is about ± 80 m from the topographic surface and the susceptibility value of 0.0313 SI as the porphyry susceptibility value with the development of propylitic and argillic alteration.)

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