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Identification of alteration zone and gold mineralization based on magnetic anomaly and 3D model of geomagnetic satellite data inversion of Mount Pongkor Area, West Java

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Abstract

Mount Pongkor is one of the areas in Indonesia with the largest gold mineralization potential in Java. One of the geophysical methods to identify the distribution of gold mineralization zones is the geomagnetic method that utilizes magnetic properties in the subsurface due to the influence of rock magnetization. Geomagnetic research has been conducted at Mount Pongkor, Bogor Regency, West Java with an area of 22 x 17 km as much as 793 magnetic satellite data from the *National Oceanic and Atmospheric Administration* (NOAA) *website* that has been corrected daily. This study aims to determine the distribution of alteration zones and mineralization of the study area. The results showed that the RTP map shows the distribution of magnetic anomalies ranging from -4.786 – 4.663 nT, with high anomalies in the north-south direction associated with mineralization zones with anomaly values ranging from 1.881 – 4.663 nT and low anomalies in the north-south direction associated with rock alteration zones with anomaly values ranging from -4,786 - (-2.174) nT. In the 3D inversion model, the alteration zone has an average depth of 350 - 2600 m from topography with susceptibility contrast values ranging from -0.35 - (- 0.25) SI and the mineralization zone has an average depth of 350 - 2800 m from topography with susceptibility contrast values of 0.25 - 0.35 SI.

Keywords: alteration; Mount Pongkor; geomagnetic method; mineralization

1. Introduction

Indonesia is located at the meeting zone of the Eurasian Plate, the Indo-Australian Plate, and the Pacific Plate which forms a variety of magnetic and volcanic arc lines. Indonesia's magnetic arcs are in the Sunda-Banda Arc, North Sulawesi Arc, Halmahera Arc, and Papua Arc [1]. Based on data from the Ministry of Energy and Mineral Resources (ESDM) in 2013, Indonesia ranks ninth as the country with the largest gold mineral potential in the world, with gold reserves of 3000 tons and resources reaching up to 6000 tons [2].

Gold minerals are formed due to the rise of hydrothermal fluid from the earth's core magma through intergranular cavities (primary permeability) or fault structures (secondary permeability) [3]. The reaction to sedimentary rocks with changes in pressure and temperature produces altered minerals from precipitation below the earth surface [4].

Gold minerals can be predicted from the presence of iron sulfide minerals such as pyrite (FeS_2), chalcopyrite ($CuFeS_2$), troilite (FeS), magnetic minerals such as pyrrhotite ($Fe_{1-x}S$) and siderite ($FeCO_3$), and porphyry igneous rocks [5]. Gold potential zones have anomalous contrasts in physical properties such as density and magnetic susceptibility that are different from the surrounding environment [6].

Gunung Pongkor is one of the areas in Indonesia with the largest gold mineralization potential in Java that has been exploited since 1974. Gold and silver deposits at Gunung Pongkor are epithermal adularia-sericite types with abundant manganese oxide and limonite, but very minimal sulfide [7].

In other words, gold deposits at Gunung Pongkor are found in volcanic rocks in the form of agglomerates, tuffs, breccias, and andesite lavas [8]. Mount Pongkor is a volcanotectonic caldera with andesitic constituent rocks resulting from alteration of quartz veins and carbonates due to fractures during the formation of calderas or faults in the vicinity [9].

The geology of Mount Pongkor and its surroundings is composed of the Middle Miocene aged Bojongmanik Formation (Tmb) in the form of sandstone, tuff pumice, marl with mollusks, claystone, and limestone members of the Bojongmanik Formation (Tmbl).

Tuff and breccia (Tmtb) of Late Miocene age in the form of clayey tuff, andesite-sorted tuff breccia, tuffaceous sandstone, tuffaceous clay, and sandstone. Pleistocene-aged formations consist of sandstone tuff (Qvst), lava formation, tuff breccia and lapilli, basaltic andesite (Qvsb), volcanic lava formation (Qvl) in the form of basaltic lava flows with labradorite, pyroxene, hornblende, volcanic breccia formation (Qvb), and inseparable volcanic rocks (Qvu) in the form of breccias, lava flows, and andesite [10].

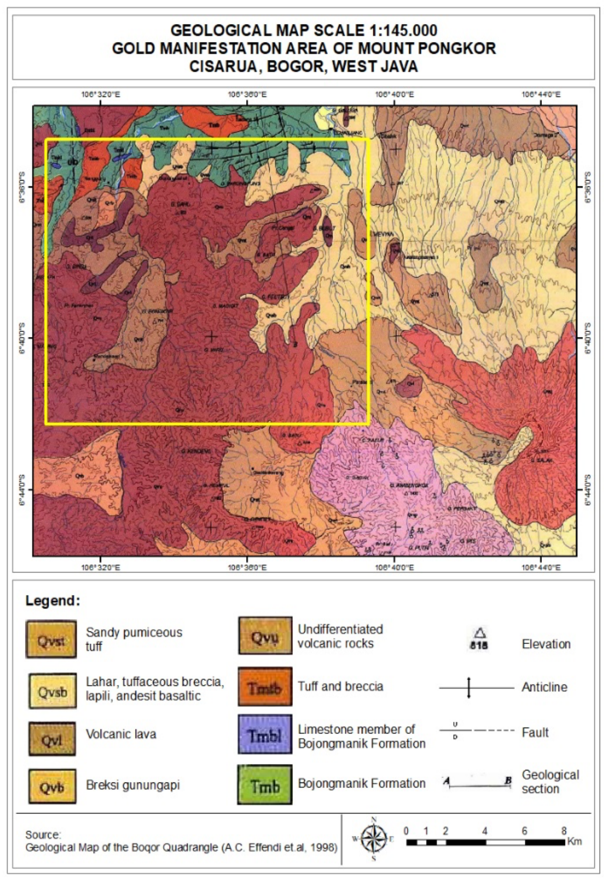

Figure 1. Geology of Mount Pongkor [10]

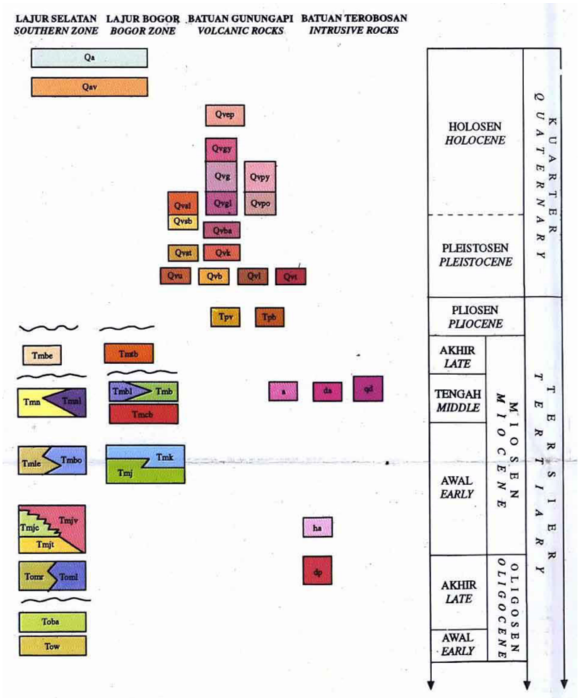

Figure 2. Correlation of Bogor sheet map units [10]

Gold minerals have a very small content in the depositional environment, about 2-30 gr/ton. Therefore, the detection of gold minerals will not produce a direct geophysical response [11]. Gold mineral detection can be done indirectly by knowing the presence of gold deposits based on terterized rocks and geological structures that are important clues to the presence of gold deposits [12].

The geophysical method that can be used to identify the distribution of gold mineralization zones is the geomagnetic method [13]. The geomagnetic method is a method to determine magnetic properties in the subsurface due to the influence of rock magnetization, which causes variations in the earth's magnetic field to be inhomogeneous [14]. From the rock susceptibility value, it can separate rocks that contain magnetic properties from those that do not contain magnetic properties, to determine the direction of the distribution of the rock itself [15].

The basic principle of the geomagnetic method is the Coulomb force (nT), which is when there are charges or poles (p_1 and p_2) that are at a distance of r then the two charges or poles will repel if similar, while if the opposite will attract with force (F) [16]. The equation is as follows with the equation [17]:

$$F = \frac{p_1 p_2}{\mu_0 r^2} \hat{r} \quad (1)$$

where p_1 and p_2 are magnetic poles r (m) apart, μ_0 is the permeability of the vacuum medium ($4\pi \times 10^{-7}$ N/A^2), and $\hat{r}$ is the unit vector [17].

The geomagnetic method requires several corrections, including corrections used to eliminate deviations from the influence of the outer magnetic field due to electron ionization in the ionospheric layer. The external magnetic field includes all outer space objects, both in the form of fields generated by the sun, moon, and planets [18].

If the daily variation value is negative, the daily correction is done by adding the daily variation value recorded at a certain time to the magnetic field data to be corrected. Daily correction is expressed by the equation [19]:

$$\Delta H = H_{total} \pm \Delta H_{daily} \quad (2)$$

with ΔH is the daily correction value, H_{total} is the observed anomaly field value, and ΔH_{daily} is the correction value at the *base* [19].

IGRF correction *(International Geomagnetic Reference Field)* is a regional correction carried out to eliminate the influence of the Earth's main magnetic field which always changes over time due to the movement of the magnetic field from the poles to the equator [20]. IGRF correction can be done by subtracting the IGRF value from the daily corrected total magnetic field value at each measurement point at the appropriate geographical position [21].

Pole correction or *Reduce to Pole* (RTP) is performed to remove the influence of the magnetic inclination angle by changing the inclination angle to 90° and declination to 0°. This correction is done because the direction of the earth's magnetic field and the direction of its magnetization induction are downward. The result of the reduction to the pole shows the magnetic anomaly to be one pole [22].

Inversion modeling is often said to be the "opposite" of forward modeling because inversion modeling is obtained directly from data [23]. The inversion process uses analysis with a statistical approach in the form of *curve fitting* between observational data and mathematical models. In this study, the inversion process was used to analyze the subsurface conditions of the study area [24].

In general, inversion modeling is based on the following equation [25]:

$$m=F^{-1}(d) \quad (3)$$

where F is the operator associated with the model, m is the model calculation data, and d is for the observation data, where the value of the calculation data and the observation data is done by trial and error so that the shape of the curve is the same [26].

2. Research Methods

The research location is on Mount Pongkor, Bogor Regency, West Java with an area of about 22 x 17 km. The data used is magnetic satellite data taken through the *National Oceanic and Atmospheric Administration* (NOAA) *website* as much as 793 daily corrected data.

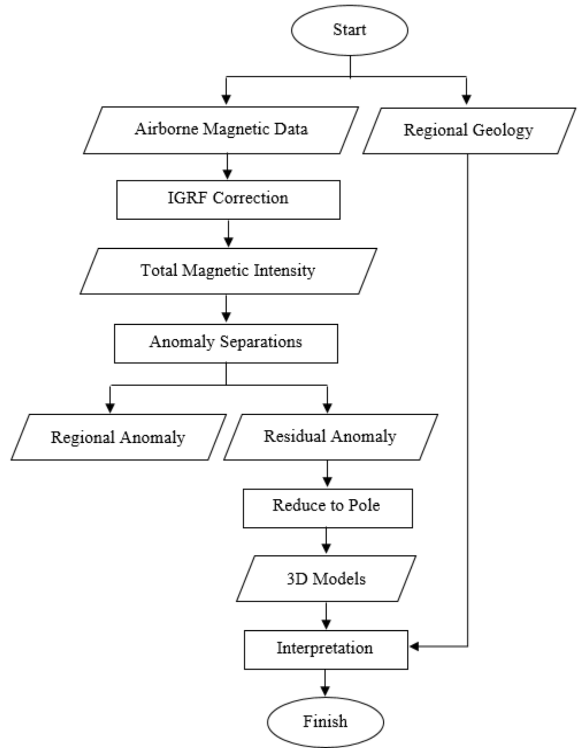

Figure 3. Research flow chart

3. Results and Discussion

Total Magnetic Anomaly

On the total magnetic anomaly map, it can be seen that the distribution of magnetic field anomalies at the research location ranges from -132.6 - (-59.9) nT.

High anomalies ranging from -87 - (-59.9) nT are located in the southern part of Mount Pongkor associated with zones of intrusion or mineralization with lava and andesite rock formations. Low anomalies ranging from -132.6 - (-121.1) nT are located in the northern part of Mount Pongkor associated with alteration rocks in the study area.

This total magnetic anomaly is still influenced by the presence of shallow (residual) and deep (regional) rocks, so to reduce this ambiguity, regional and residual anomalies must be separated using a *bandpass* filter.

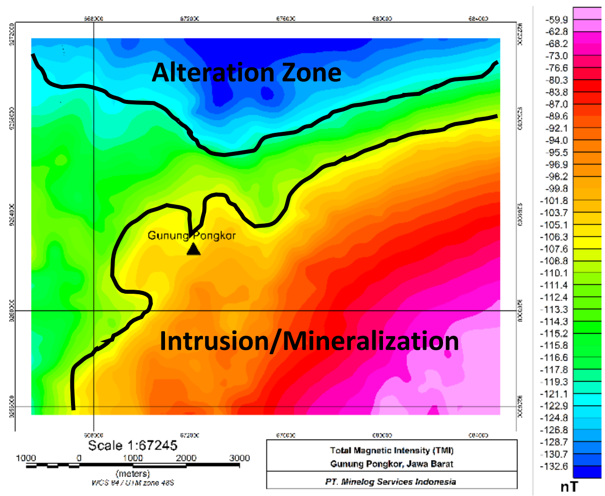

Figure 4. Total magnetic anomaly

Regional Anomalies and Residuals

After separating the anomalies, regional and residual anomalies are obtained. On the regional anomaly map, it can be seen that the contours are similar to the total magnetic anomaly, but the contours look smoother because they are associated with deep rocks with anomaly values ranging from -132.41 - (-59.56) nT .

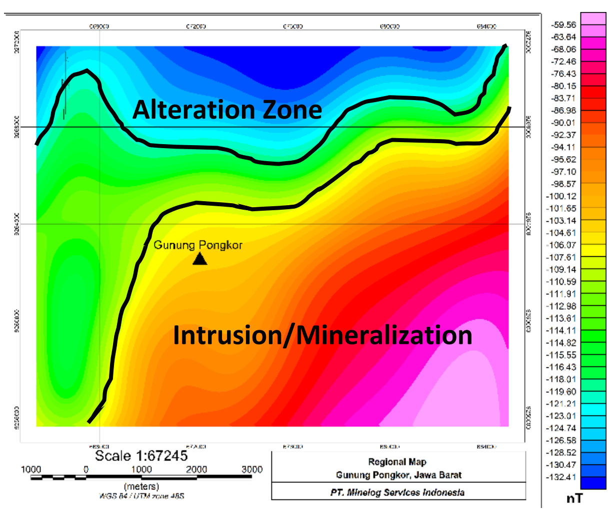

Figure 5. Regional anomalies

On the residual anomaly map, it can be seen that the contours are more heterogeneous because the residual anomalies are associated with rocks near the surface that are the target of the study. High and low anomalies are scattered in the north and south of the study area, but on this residual anomaly map there are still two poles so that the distribution of the neutralization zone and its alteration is still difficult to interpret.

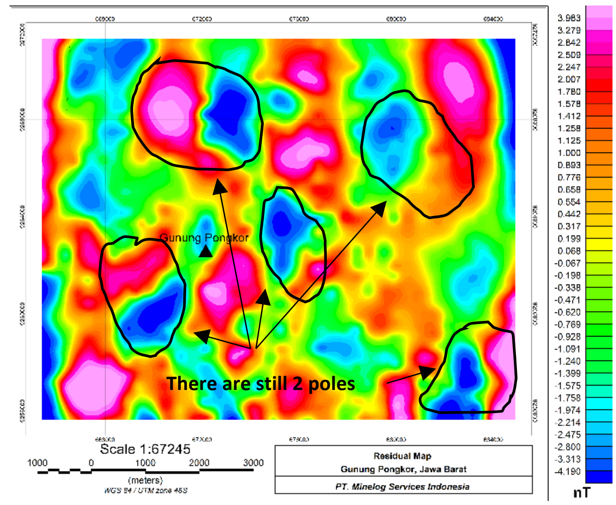

Figure 6. Residual Anomalies

Reduce To Pole (RTP)

The magnetic reduce to pole (RTP) process is carried out to remove one magnetic pole. The RTP map shows that the distribution of magnetic anomalies ranges from -4.786 – 4.663 nT.

High anomalies (black polygons) in the north-south direction are associated with zones of mineralization or intrusion of andesite and lava rocks with anomaly values ranging from 1,881 – 4.663 nT. Low anomalies (red polygons) oriented north-south are associated with rock alteration zones with anomaly values ranging from -4.786 - (-2.174) nT.

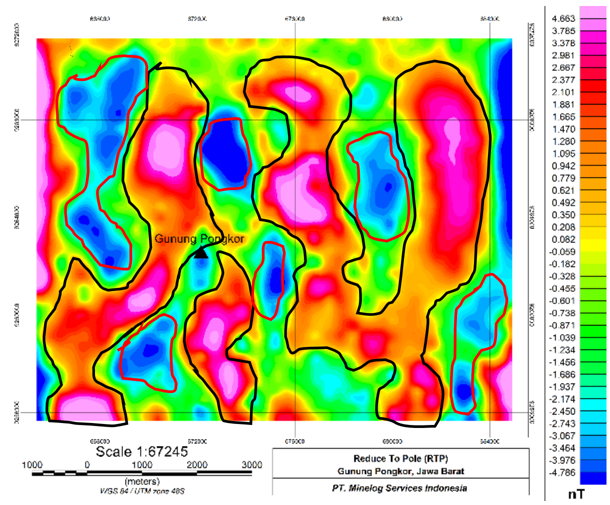

Figure 7. *Reduce to Pole* (RTP) magnetic

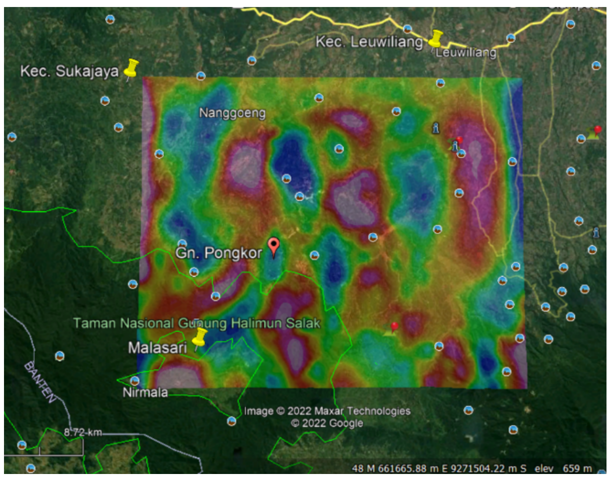

Figure 8. RTP *overlay* with *Google* Earth

3D Inversion Model

3D inversion modeling was performed to obtain the position of mineralization and alteration zones in the subsurface. Incision A-A' shows that the alteration zone in the west is located at a depth of 200 - 2750 m from the topography with susceptibility contrast values ranging from -0.35 - (- 0.25) SI. The mineralization zone or intrusion due to andesite and lava rocks in the east is located at a depth of 500 - 3000 m from the topography with susceptibility contrast values ranging from 0.25 - 0.35 SI.

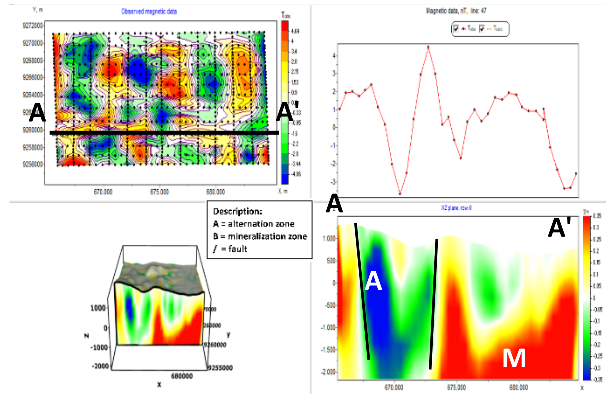

Figure 9. 3D model of incision A-A'

In the B-B' incision, it can be seen that the alteration zone in the west is located at a depth of 200 - 2800 m from the topography with susceptibility contrast values ranging from -0.35 - (- 0.25) SI. The mineralization zone or intrusion due to andesite and lava rocks in the east is located at a depth of 400 - 2900 m from the topography with susceptibility contrast values ranging from 0.25 - 0.35 SI.

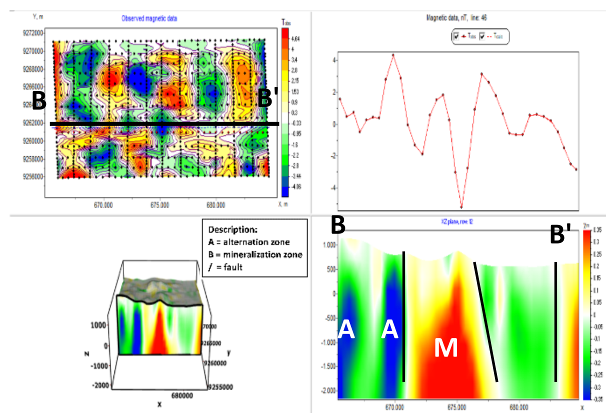

Figure 10. 3D model of incision B-B'

In incision C-C' it can be seen that the alteration zone in the west is located at a depth of 350 - 2600 m from the topography with susceptibility contrast values ranging -0.35 - (- 0.25) SI . The alteration zone in the east is located at a depth of 650 - 2400 m from the topography with susceptibility contrast values ranging from -0.35 - (- 0.25) SI. The mineralization zone or intrusion due to andesite and lava rocks in the central part is located at a depth of 200 - 2200 m from the topography with susceptibility contrast values ranging from 0.25 - 0.35 SI.

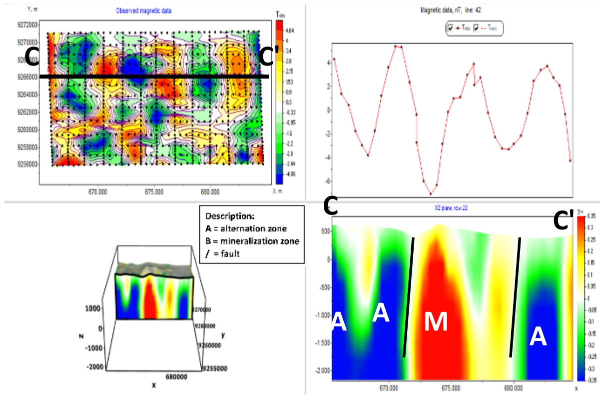

Figure 11. 3D model of incision C-C'

The isosurface cross section shows the shape of intrusive rocks in the subsurface with an average depth of 350 - 2800 m from the topography. These intrusive rocks press the hydrothermal fluid to the near surface so that the research area experiences crystallization of gold mineral formation.

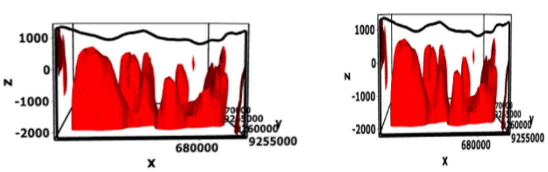

Figure 12. 3D model of intrusive rock *isosurface*

4. Conclusion

Based on the RTP map, the distribution of magnetic anomalies ranges from -4.786 – 4.663 nT, where high anomalies are associated with mineralization zones with anomaly values ranging from 1.881 – 4.663 nT, and low anomalies are associated with alteration zones with anomaly values ranging from -4.786 - (-2.174) nT.

Based on the 3D inversion model, the alteration zone has an average depth of 350 - 2600 m from topography with susceptibility contrast values ranging from -0.35 - (- 0.25) SI, and the mineralization zone has an average depth of 350 - 2800 m from topography with susceptibility contrast values of 0.25 - 0.35 SI.

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