Analysis of Geomagnetic and Geoelectric Data to Identify the Potential of Gold Deposits (Case Study: Randu Kuning, Wonogiri, Central Java)

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Abstract. The gold deposit of the low sulfidation epithermal system at the Randu Kuning prospect, Wonogiri, Central Java is the effect of magmatism during the Oligocene due to microdiorite intrusion. The magmatism causes a mineralization process that fills the fractures in the rock. The mineralized of ores that formed in the study area are pyrite, chalcopyrite, sphalerite, galena, electrum and native gold, magnetite and hematite. The appropriate geophysical method to this case study is using the geomagnetic and geoelectric Induced Polarization method. The application of the geomagnetic method aims to delineate mineralized zones and geological structures as channel way for hydrothermal fluids. The results of the geomagnetic method are in the form of a map of Total Magnetic Intensity carried out by filters such as Reduce to Pole (RTP) - High pass (HP) and Horizontal Gradient (HG). The west side of RTP - HP anomaly shows a low response of -4.9 to -0.8 nT due to intensely mineralized rock and the presence of fractures. The comparison between RTP - HP anomaly and HG anomaly shows the suitability due to intense mineralization which reduces the fault anomaly. A high HG value area of 0.001 - 0.0017 nT/m is interpreted as a mineralized fault. This can be seen from the alteration map which shows the continuity of veins from measurements in the field. The application of the geoelectric Induced Polarization method aims to identify associated mineral of gold vertically subsurface. Based on the results of geoelectric Induced Polarization data shows that there are chalcopyrite minerals at a depth of 20 - 30 m with a chargeability of 4 - 9 msec which is located in intrusion of igneous rock with a resistivity > 200 Ωm. Based on geomagnetic geoelectric data, it can identify potential gold deposits in the Randu Kuning area, Wonogiri, Central Java.

Keywords: chalcopyrite, fault, induced polarization, mineralization, vein

1. Introduction
Indonesia is a country that flanked by three major plates namely the Eurasian plate, the Indo-Australian plate and the Pacific plate. This condition formed a ring of fire in the subduction zone and resulting frequently tectonic activity [1]. Tectonic activity as a trigger for the mineralization process will change the composition of bedrock minerals into sulfide minerals, one of which is gold. Wonogiri Regency, Selogiri Sub-District is one of the areas that has the prospect of gold deposits that result from the mineralization process. The area includes
Jendi village, Kepatihan village and Keloran village which is included in randu kuning hill area. The main geological structure that controls mineralization is a part of the Southern Mountains system which is normal fault with orientation is northwest – southeast [2]. The role of geological structures in the mineralization process is a requirement for the development of mineralization on geological structures [3]. The residual of magma fluid or hydrothermal fluid will break through the fracture in the rocks and be deposited until physical and chemical changes will occur that will form sulfide ore deposits. In fact, at the research site, there are people's mines that operate by following the pattern of structures and relics filled with sulfide minerals to obtain gold.

The potential of gold deposits in sub-surface needs a detail research in order to be known its existence. So in this study, secondary data analysis and literature studies were conducted using geophysical methods, namely geomagnetic and geolectric induced polarization method. Geomagnetic methods are applied to deliniation the alteration zone and local structure of the research area in mapping. The estimate structure utilizes magnetic filters and geological references to research areas. As for knowing the potential of gold deposits vertically used the geoelectric Induced Polarization (IP) method with the approach of identifying gold association minerals such as pyrite, chalcopyrite, and other sulfide minerals. So with the integration of this methods as well as the reference study of the research area can be known the spread of potential gold deposits in Randu Kuning, Selogiri, Wonogiri Regency. And the results of the data can be utilized for further and more detailed research and advance exploration activities.

2. Method

This research was conducted in Selogiri sub-district more precisely in Jendi village, Kepatihan village and Keloran village. The research methods used are geomagnetic methods in the form of secondary data and induce polarization methods in the form of reference studies. Geomagnetic methods utilize the properties of rock magnetism to determine geological conditions based on the value of magnetism. Geomagnetic data retrieval is sourced from the official website of BMKG which is on the Page of Earth Magnetic Calculator – BMKG [4]. The main data obtained is the intensity value of the Earth's magnetic field. The data was reduced by the Earth's magnetic field by 44,000 nT and then filtered reduce to pole (RTP) to polish the poles to facilitate quantitative interpretation. Furthermore, the RTP Map is filtered back using the High Pass so that the local anomalies of the research area are read. The latter uses a horizontal gradient (HG) filter to determine the geological structure in the research area as a mineralization controller. Meanwhile, the induce polarization (IP) method utilizes the precipitous nature of electrical currents injected into the ground to map subsurface conditions based on resistivity and chargeability values. IP data is processed using Res2DInv software to produce a cross-section of resistivity and sub-surface chargeability so that it can interpret the changing minerals of both parameters. The results of both methods are integrated to illustrate the potential for mineralization at the research site.

2.1. Magnetic Method

Geomagnetic method is a method in geophysics that uses the magnetic properties of the earth. The output obtained is a map of the subsurface rock susceptibility distribution in the horizontal direction. Geomagnetic survey targets are variations in the measured magnetic field on the surface that arise due to the contrast of the susceptibility of rocks to their surroundings. Basically, the measurement of the earth's magnetic field is influenced by two magnetic poles which have different directions in each place according to the angle of inclination and declination. The difference in the orientation of the magnetic field causes the anomaly to be incompatible with the location of the rock body. Reduce to pole filter transforms two magnetic poles (dipole) into a monopole by eliminating the effects of inclination and declination.
To interpret the fault structure and anomaly boundaries using a horizontal gradient filter. Horizontal gradient analysis squares the anomaly value so that the boundaries of the anomaly can be seen clearly. Horizontal gradient with the steepest pattern can be interpreted as an anomaly boundary that shows the horizontal change in magnetization [6].

2.2. Induced Polarization Method
The resistivity method is a geophysical method used to identify the properties of electric electricity flow below the earth's surface. It is based on the injection of currents by the electrodes into the earth's surface so that the potential difference of each rock layer can be measured. In the geoelectric method, induced polarization of electric current is injected into the earth through two current electrodes, then the potential difference that occurs is measured through the two potential electrodes. The time domain method is used to measure the decay time of the electric current stored in the rock after the injection current is turned off with the final unit of chargeability (msec), which characterizes rock mineralization as it is affected by electrode polarization due to mineral deposits.

3. Result and Discussion

3.1 Geology Alteration Data and Geomagnetic Method
Analysis of geomagnetic methods to determine zoning alteration and geological structure needs to do geological reference study of research area first. The map below is an alteration map that supports research sites that include Randu Kuning and its surroundings.
Figure 3 explains that the main structure of the study area that forms minor faults is included in the southern mountain fault with a northwest-southeast orientation. Local structures to control the channel way of hydrothermal solutions in the study area are the north-south and northwest-southeast dextral faults, northeast-southwest sinistral horizontal faults, and northwest-southeast upward faults. The extension area in the research area is relatively northwest-southeast trending with a relatively upright slope pattern [2]. The position of this field is a brecciation plane which is formed relatively the same as the orientation of the local fault as a mineralization control. This structure serves as a medium for mineralization of deposition in the form of a vein system filled with altered minerals in rock fractures. Mineralization is the formation and deposition of ore minerals originating from metasomatism, pneumatolytic processes, and rising hydrothermal magmatic fluids. The mineralization system formed is a vein system which can be observed megascopically in rocks. Filling minerals were observed such as pyrite, chalcopyrite, and galena. Apart from being filled in the vein, the filler minerals are disseminated in the wall rock. This system of veins is found around the fault zone but is not continuous (discontinuous).

3.2 Alteration Zone Spread Analysis Based on RTP Filter

Basically, to interpret the magnetic anomaly map, reduce to pole filter first. This filter assumes that the earth's magnetic field value data has a constant direction and value so that the magnetic field anomaly is located right on the anomaly body [9].
Figure 4. Correlation of Geological Data with Reduce to Pole - High Pass Anomaly Map

Figure 4 is a Reduce to Pole map, where the High Pass filter has been carried out so that local anomalies can be seen. The anomaly responses on the RTP map are grouped into 4 lots based on the magnitude of the anomaly value. The alterations that form from west to east are advanced argillic, argillic, phylic, and propylitic alterations. If we pay attention to the magnetism anomaly that the more west the map the magnetic value gradually weakens. This shows that the closer to the west is the main system of alteration. According to [10] the alteration arrangement can be classified based on the alteration intensity. The highly altered group is advanced argillic (-4.9 to -1.9 nT) and argillic (-1.8 to 1.8 nT) alteration which is composed of clay minerals (illite, smectite, and kaolin). The alteration is exposed in the form of strongly altered rock in lot A. The intermediate (altered) alteration group is a filic (-0.8 to 0.4 nT) alteration composed of clay minerals (smectite and opaque). The weak alteration group (intermediate altered) is a potassic alteration (-4.7 to 1.5 nT) characterized by the presence of biotite and clay minerals as accessories, so that the C plots of rock are still massive. Plot D refers to the geological map and the alteration of the research location is unaltered diorite rock so that the magnetic anomaly that is read will be very large (2.1 to 2.53 nT).

3.3 Structure Analysis Based on Horizontal Gradient Filter

Horizontal gradient (HG) analysis was applied to determine the anomalous bodies of the magnetic response boundaries. This filter concept is interpreted by the boundary anomaly that shows a sudden horizontal change in magnetization [6].

Figure 5. Correlation of Geological Data with Horizontal Gradient Anomaly Map
The results of the comparison of the HG anomaly with the alteration map (Figure 5) were divided into 3 lots, namely A, B, and C area. Plots A and B showed very low HG anomalies of -0.002 to -0.003 nT / m. The low response magnetic anomaly pattern is wide and bounded by the geological structure in the southwest-northeast indicating that the alteration rate is more intense. The magnetic anomaly response is low in the effect of argillic, advanced argillic, and filic alteration which are the highly altered groups [10]. Meanwhile, advanced argillic can be found in strongly altered rock outcrops in lot B. High HG anomaly of 0.001 - 0.0017 nT / m is a geographical structure anomaly. The anomaly is high because of the surface anomaly object that changes its magnetic value drastically. There are 3 HG anomalies with high response located in lot C and the southwest of the HG anomaly map is indicated as a fault (dashed blue line). If the HG anomaly in lot C is compared with the alteration map, it can be said that the existence of the fault is a local fault that develops from the main fault as a channel way. Hydrothermal solution from the alteration process will fill the fractures in the local fault and follow the fault pattern. So it can be seen that the developing veins follow the structural pattern with a dominant north-south direction. In addition, the argillic alteration distribution relatively follows the structural pattern and is followed by the presence of veins. This shows that the mineralization that develops dominantly occurs in argillic alteration with a relatively north-south vein stretching direction. The urate filling minerals are pyrite, chalcopyrite, galena, and gold as shown in Figure 6 which is in the appendix.

Figure 6. Rock samples in A Area. (A) rock samples showing gold (Au) and gold-associated minerals such as galena (Gn) [8]. (B) the results of supergen into azurite, malachite, and sphalerite minerals. (C) Pyrite (Py) minerals. (D) moderate mineralized fractures are filled with quartz > 5cm. (E) Vein filled with quartz.

Figure 7. Rock Samples in B Area. (A) Disseminated pyrit (py), (B) Vein quartz (Qr) filled with pyrite and sphalerite (Sp). (C) Sphalerite minerals and pyrite vein. (D) Sample A seen from loupe. (E) Sample B seen from loupe. (F) Covellite minerals.
3.4 Geoelectrical Induced Polarization Method

The results of geoelectric method provide two types of information, first is about the type of sub-surface rock (based on rock resistivity data) and the availability of sub-surface sulphide minerals (based on rock chargeability data). Sulfide mineral is one of the characteristic minerals for the presence of Au (gold mineral). The existence of these sulfide minerals can be obtained information on certain rock types if it is correlated with rock resistivity data. Judging from the lineation pattern of resistivity data [11] (Figure 8), it is obtained that the deeper there is a rock that has a higher resistivity value. In this case, it means that the rocks that are located deeper, the rocks are more compact. Rocks that have a resistivity value <30 Ωm (blue area) are interpreted as the presence of claystone, 30-80 Ωm (green-orange area) are interpreted as sandstones, and a resistivity value >80 Ωm (red area) is interpreted as the presence of igneous rock.

![Figure 8. Resistivity Cross Section [11]](image)

One of the sulfide minerals that characterize gold mineralization is chalcopyrite (CuFeS$_2$). The results of of induced polarization in Jendi Village, Selogiri, contained chalcopyrite mineral with a chargeability value 4-9 msec, located at a depth of 20-30m [12] (Figure 9). The range of chargeability values interpreted as chalcopyrite minerals according to the rock chargeability table [7] (Table 1), which is the value 9.4 msec.

![Figure 9. Chargeability Cross Section [13]](image)

| Mineral     | Chargeability (ms) |
|-------------|--------------------|
| Pyrite      | 13.4               |
| Chalcocite  | 13.2               |
| Copper      | 12.3               |
| Graphite    | 11.2               |
| **Chalcopyrite** | **9.4**          |
| Bornite     | 6.3                |
| Galena      | 3.7                |
| Magnetite   | 2.2                |
| Malachite   | 0.2                |
| Hematite    | 0.0                |

Table 1. Chargeability Value of Mineral [7]

If correlated with resistivity data, then at a depth of 20-30 m, the availability of chalcopyrite minerals located in igneous rocks with >200 Ωm resistivity, which is the research area is included in the Mandalika Formation consisting of dasit lava rocks and andesit rock [13]. Volcanologically, Mandalika Formation shows the characteristics of the development phase of a composite volcano body, the presence of repeated deposition of melt eruption products and eruptive eruptions [14].
3.5 Geological and Geophysical Data Integration
To know the potential of gold deposits clearly, the integration of data based on geological data, namely alteration map and geophysical data (Figure 10). So it was obtained to delinination zone of potential gold caught at the research site.

![Figure 10. Geological and Geophysical Data Integration](image)

Increasingly towards the high mineralized zone (low magnetic value) gold association minerals are rarely found in contrast to the intermediate mineralized zone (medium magnetic value) where minerals fill and follow a fracture structure pattern, while based on the geoelectric response Induced Polarization there is chalcopyrite mineral at a depth of 20-30 m with a chargeability value of 4-9 msec located in an igneous intrusion with a resistivity >200 Ωm which is identified as an association of gold minerals.

4. Conclusion
The geomagnetic method RTP anomaly response zoned strong (highly altered) to weak (altered) alteration with a gradation from east to west. There are 3 faults from the horizontal gradient reading valued at 0.001 - 0.00017, the northern fault and lot C are filled with sulfide minerals from the samples found. Increasingly towards the high mineralized zone (low magnetism) gold association minerals are rarely found in contrast to the intermediate mineralized zone (moderate magnetism) where the minerals fill and follow the fracture structure pattern. The geoelectric response of Induced Polarization indicates there are chalcopyrite minerals located in igneous intrusions at a depth of 20-30m with 4-9 msec chargeability and >200 Ωm.

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