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Identification of Metal Sulfide Mineralization Zone using Time Domain Induced Polarization Method in Pakenjeng Region, Garut, West Java, Indonesia

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***Abstract*— *Research using Time Domain Induced Polarization (TDIP) method to delineate metal sulfide mineralization in Pakenjeng, Garut has been conducted. As many as 5 lines of TDIP was measured, using dipole-dipole configuration by 15 meters spacing for 400 up to 500 meters lengths in southwest – northeast direction. Geomagnetic as secondary data was used to verify the interpretation of TDIP data. The geomagnetic data was reprocessed to obtain Reduced to Equator map in order to eliminate the effect of magnetic dipole. Our result shows a correlation between geomagnetic and TDIP measurement. The resistivity values in the area are between 6 – 40.000 Ohm-meter, indicating lithology variation. The chargeability values are between 0 – 800 msec, with the cutoff value is more than 100 msec, where it is expected to be the zone of mineralization. The closures expected to be mineralization zones were identified in first, second, and fifth lines with chargeability values more than 100 msec. The mineralization associated with high resistivity values was estimated to be silicification zone and the one associated with low resistivity was assumed to be argillic zone. Based on the cross section of resistivity and chargeability, supported by geomagnetic map, there are two mineralization zones in the area.*

***Keywords*— *Induced Polarization, mineralization, resistivity, chargeability, geomagnetic.*

I. Introduction

Based on surface geological study, Pakenjeng region indicated a potential of metal mineralization. The study area is a part of upper Jampang Formation comprising andesite, tuff, and tuff breccia. The morphology of our research area generally consists of two morphology units, mountains and valleys. Geological structure developed in the area is reverse fault in relatively north – south direction, controlling Jampang Formation along Cipancong River. The normal fault of Ciarinem has orientation of N69^0 E/57^0, extending in west – east direction along Ciarinem river.

Pattern of mineralization in the area reveals that shapes of the fault plane has been affected by dilatation. The movement could be identified both laterally and vertically. The primary mineralization is continued jog in relatively north – south direction, accompanied by northwest – southeast continuation of splay. The trend is repeating up to the north due to inclination of the hanging wall. The shape of gash vein is yet to be identified, and the shear vein oriented in northwest – southest and north – south direction is the potential main direction.

An approach to effective, efficient and economical exploration method for estimation of sulfide mineralization prospecting zone is by combining geomagnetic, resistivity and Induced Polarization (IP) method. The combination of geomagnetic and induced polarization method has proven to be able to accurately identify metal sulfide mineralization potential (Johansson and Dahlin, 1996; Savvaidis et al., 1999; Titov et al., 2000; Song et al., 2005; Johansson et al., 2007). Zohdy (1974a, 1974b) had conducted comparison analysis on cross section of resistivity and chargeability to identify metal mineral potential. Chargeability is capability of a medium to store instantaneous current (Telford et.al, 1990). IP method is common as it has high spasial resolution, relatively shorter duration of acquisition in the field and low cost. Geoelectrical method have been performed by few researchers in investigation of subsurface structure (Griffiths dan Barker, 1993; Lapenna et al., 2005; Soupios et al., 2006; Alhassan et al., 2015).

Figure 1. Location of research area

II. Research Method

The research was performed using Time Domain Induced Polarization (TDIP), which utilize the characteristics of electrical current injected into the ground through two electrode rods. The response of potential difference between the two rods that stuck to the ground is to be measured (Lowrie, 2007).

Polarization measurement in time domain was performed by conducting rectangular current pulses into the ground. As the current was stopped, the eletcric potential between two measurement rods decreased to secondary response level. The secondary potential then decays with time (Sumner, 1976). In

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time domain measurement, there is chargeability, a quantity showing the decay of secondary potential towards time. This quantity characterize the potential decay property representing the polarization level of a medium. Theoretically, it is defined as:

$$M = \frac{1}{Vp}\int_{t_1}^{t_2} Vs(t)dt$$

where
M = chargeability (msec) or (mV/V)
V*p*= primary voltage (mV)
Vs = secondary voltage (mV)

The measurement was conducted at 5 lines in southwest – northeast direction, using dipole-dipole configuration with 15 meters spacing and the length vary from 400 up to 500 meters depending on field condition. The design of data acquisition was made to cut through the vein and consider the conjecture of outcrop continuity in the field. The length of the line was adjusted according to the field condition, as steep hills are dominating the area.

Data of voltage, current, and chargeability were obtained from field measurement. It was then calculated using equation involving geometrical factor in order to obtain proportional values between the injected current and measured voltage. The result obtained is values of apparent resistivity and apparent chargeability. We then proceed to do inversion of the apparent resistivity on each line. Interpretation was carried out by correlating between 2D inversion cross section of resistivity and chargeability. The next process was modeling of alteration distribution accompanied by metal mineralization. In order to improve our interpretation we use geomagnetic method as supplementary data.

III. Result and Discussion

a. Geomagnetic Data Interpretation of Research Area

The geomagnetic data is secondary data from measurement in 2011 which then reprocessed, including diurnal correction and IGRF correction to obtain total magnetic intensity map. As geomagnetic method has dipole characteristic, the total magnetic intensity map has yet represents the actual anomaly position. To represent geomagnetic anomaly position, we *monopole* it using filter. Some filter can be applied to monopole geomagnetic data such as reduction to equator, reduction to the pole, pseudo gravity, etc. In this research, we use reduction to equator as a filter. The map of total magnetic intensity and reduction to equator are provided in Figure 1 and 2 which were overlaid with measurement lines.

Figure 2 shows the total magnetic intensity map in study area overlaid with 5 lines of IP measurement (red lines). Total magnetic field anomaly is due to the difference of rock susceptibility beneath the Earth surface. The values of magnetic field intensity are from 44.725 nT to 45.525 nT, depicted by the color contrast on the map where the low magnetic field intensity is about 44.725 nT up to 44.950 nT in blue color. The magnetic field intensity values between 45.000 nT and 45.200nT fall under green to orange color and is regarded as intermediate magnetic field intensity. And the values of magnetic field intensity between 45.250 nT and 45.525 nT in red to pink color is high magnetic field intensity.

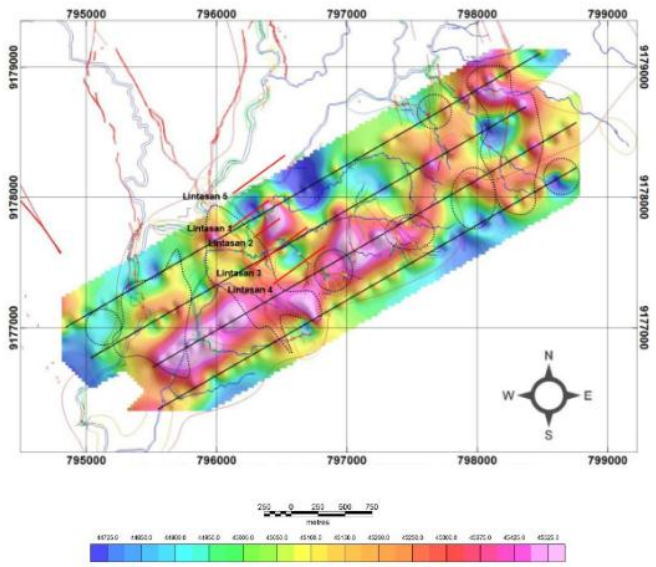

Figure 2. Total Magnetic Intensity Map overlaid with IP measurement (the red lines are IP measurement lines, the black lines are geomagnetic measurement lines)

The map of total magnetic intensity shows that the high values of magnetic field intensity is in the eastern – western part, indicating a structural zone of host rock that might be filled with strong silicification alteration. It is confirmed by river channel as one of the structural zone and andesite as origin rock of which the presence of pyrite mineral and structural zone really affect the formation of mineralization zone (quartz vein). Moreover, the features of mineralization zone visible in the geological map of research area is in the eastern and western part as well. The low to intermediate magnetic field intensity is generally in southern – northern part indicated by young volcanic rock such as lapilli tuff, breccia, and the presence of chlorite and epidote mineral indicating propylitic alteration.

The total magnetic intensity map influenced by magnetic dipole was then subjected to reduction to equator so that the minimum magnetic field anomaly is located exactly on the object causing the anomaly. Reduction to equator is magnetic data filtering which adjust the obtained magnetic measurement to be as if at 0° inclination angle. It is a convertion from dipole anomaly to monopole anomaly where we need to change the inclination angle from 32,9° to 0° and declination angle from 0,9° to 90°.

Figure 3 shows the map of reduction to equator where the magnetic field intensity values is ranging from 44.700 to 45.325 nT. The intensity values of dipole total magnetic field intensity map was converted to monopole. In the map of reduction to equator, the mineralization zone is still visible in the eastern – western part where the distribution of mineralization zone (quartz vein) gets thicker as it went to the north, characterized by high magnetic field intensity.

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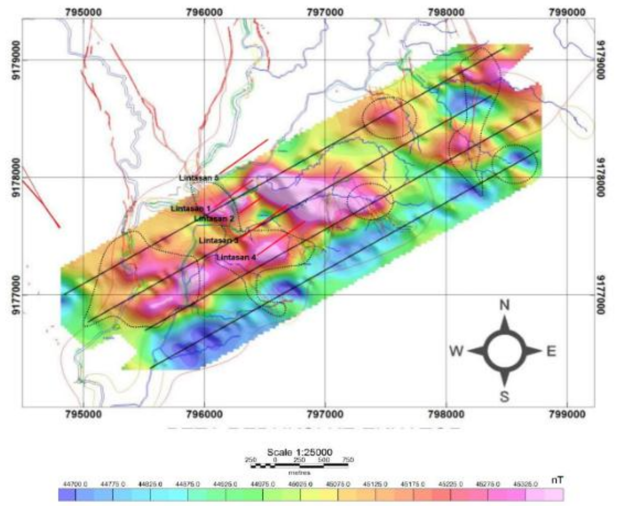

Figure 3. Map of Reduction to Equator overlaid with IP measurement lines (red lines) combined with geomagnetic measurement (black lines)

The alteration zone of silicic, argillic and structures still give significant impact on the mineralization zone formation. In the southern part the mineralization zone tends to be thinner, covered up by young volcanic lithology in the form of thick lapilli tuff, indicated by intermediate to low magnetic field intensity response.

b. Interpretation of Resistivity and Chargeability of line 1 to 5

The result of data processing is inversion cross section, that is, resistivity cross section depicting the distribution of rock ability to inhibit electrical current (Ωm). The chargeability cross section depicts the distribution of how long rock is able to keep the current (millisecond). Interpretation is completed both on chargeability and resistivity cross section. The chargeability interpretation is simply based on the electricity theory that conductor materials will be able to conduct electrical current and are able to keep electrical field longer than resistor materials. While resistivity is based on the ability of rock to resist the flow of electrical current. Based on the processing result we obtained chargeability values between 19 – 660 msec. In this research, a cutoff of chargeability value for metal sulfide mineralization prospecting zone was made to be > 100 msec.

- 2D cross section of resistivity and chargeability of line 1

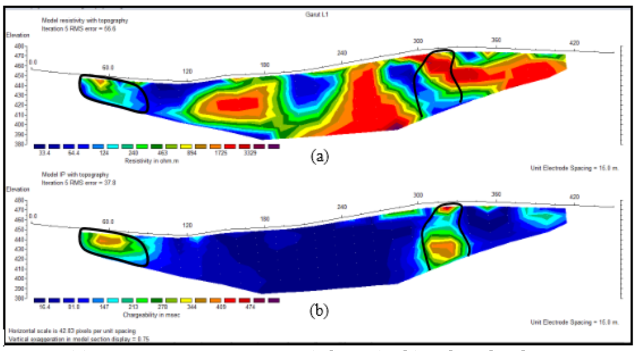

Figure 4. (a) Resistivity cross section (Ohm.m), (b) induced polarization cross section (msec) of line 1

Figure 4 is a cross section of resistivity versus chargeability of line 1. Based on the corss section above, the resistivity values are between 3 – 3500 Ohm.m and chargeability values are between 16.4 – 474 msec. The low resistivity zone in blue color with values between 33.4 – 124 Ohm.m is considered as rock that can conduct electricity quite well and generally have abundant clay mineral (argillic aleration). Intermediate resistivity visualized by green color at values ranging between 240 – 463 Ohm.m is considered as propylitic alteration, as the presence of chlorite is generally having or able to cause high resistivity property in rock.

The clay mineral in propylitic alteration can reduce the resistivity values in rocks. High resistivity zone depicted by yellow to red closures having values between 894 – 3500 Ohm.m, is considered as very dense and hard rock that can be associated with resistive mineral such as silica. In the IP cross section, there are three closures of IP values with range more than 100 msec. The first high IP closure is at the electrode of 60^{th} meters with chargeability values of 213 – 364 msec associated with high resistivity values ranging between 300 – 800 Ohm.m. This zone is estimated to be in depth of 10 – 30 meters with closure width of high chargeability is 10 meters, associated with mineralization in silicic alteration area.

The second high chargeability closure is near the surface with depth of 5 meter at electrode distance of 315 meter associated with high resistivity zone. The third high chargeability closure is at the electrode distance of 315 meter and depth of 30 – 60 meter, having low resistivity affiliated with mineralization occurred in argillic alteration.

The interpretation result of resistivity and IP is confirmed with geomagnetic data (Figure 2). Line 1 is flanked by 2 closures of high magnetic field anomalies. The magnetic response that come across line 1 undulates with relatively smooth magnetic response. The high magnetic values has magnetic field intensity of 45400 – 45700 nT and can be considered as mineralization zone.

- 2D cross section of resistivity and chargeability of line 2

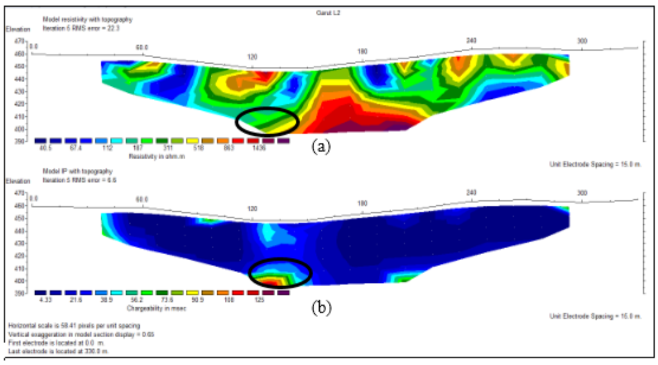

Figure 5. (a) Cross section of resistivity (Ohm.m), (b) Cross section of induced polarization (msec) of line 2.

Figure 5 is cross section of line 2, where the resistivity values is between 40 – 1500 Ohm.m and the chargeability values are between 4 – 125 msec. The low resistivity zone in blue color with values between 40 – 187 Ohm.m is considered as good conductor and generally has abundant amount of clay

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mineral (argillic alteration). Intermediate resistivity visualized by green color at values ranging between 190 – 483 Ohm.m is considered as propylitic alteration, as the presence of chlorite is generally having or able to cause high resistivity property in rock. The high resistivity zone depicted by yellow to red color having values between 518 – 1500 Ohm.m is considered as very dense and hard rock associated with relatively resistive mineral like silica.

The cross section of IP has one closure whose value range is more than 100 msec. The high IP closure is at electrode distance of 135 meter with chargeability values range between 100 – 125 msec associated with high resistivity zone estimated to be at 60 meters deep and that the closure width of high chargeability is 5 meter. The zone is associated with mineralization in silicic alteration area. Similar to line 1, the line 2 is in high magnetic anomaly zone, as the presence of IP response is associated with high magnetic data (Figure 2).

- 2D cross section of resistivity and chargeability of line 3

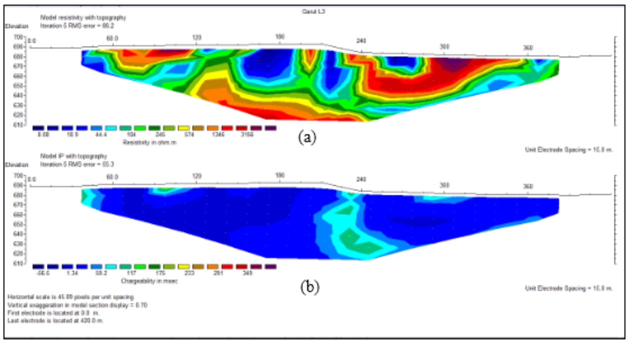

Figure 6. (a) Cross section of resistivity (Ohm.m), (b) Cross section of induced polarization (msec) of line 3.

Based on Figure 6, the resistivity value range between 8 – 3500 Ohm.m and the chargeability values are between 1.34 – 350 msec. The low resistivity area in blue color with values of 8 – 100 Ohm.m is considered as good conductor for electricity and generally has an abundant amount of clay mineral (argillic alteration). The intermediate resistivity visualized in green color with values ranging between 150 – 250 Ohm.m is considered as propylitic alteration, as the presence of chlorite is generally having or able to cause high resistivity values in rock, however, the presence of clay mineral

The high resistivity zone depicted by yellow to red closures in values between 574 – 3500 Ohm meter is considered as very dense and hard rock associated with resistive mineral like silica. In IP cross section, there is no closure with value more than 100 msec and no contrast visual. The mineralization zone might be relatively deep that it is not visible at this line. The resistivity cross section is correlated with magnetic anomaly that come across line 3. In the area where line 3 was passing through, there is high anomaly response due to high susceptibility. The high magnetic response anomaly is confirmed by high resistivity values depicted in the resistivity cross section at this line.

The mineralization zone at line 3 is probably relatively deep, by examining the magnetic anomaly response. At line 3, the measurement was conducted on high elevation hill thus the mineralization zone at this line might not be measureable (equipment limitation).

- 2D cross section of resistivity and chargeability of line 4

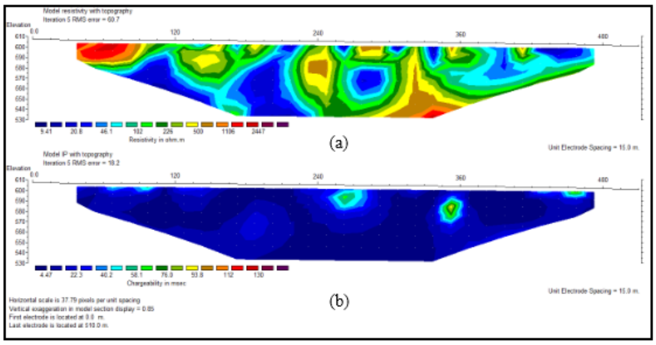

Figure 7. (a) Cross section of resistivity (Ohm.m), (b) Cross section of induced polarization (msec) of line 4

Based on Figure 7, the resistivity value range between 9 – 3000 Ohm.m and the chargeability values are between 4 – 150 msec. The low resistivity zone in blue color with values of 9 – 100 Ohm.m is considered good conductor and generally has an abundant amount of clay mineral (argillic alteration). The intermediate resistivity visualized by green color with values ranging between 150 – 300 Ohm.m is considered as propylitic alteration,as the presence of chlorite is generally having or able to cause high resistivity values in rock. However, the presence of clay mineral in propylitic alteration can reduce resistivity values in those rocks. High resistivity area is depicted by yellow to red closures having values between 500 – 2500 Ohm meter, estimated to be very dense and hard rock that can also be associated with resistive mineral like silica. Similar to line 3, there is no closure whose IP value more than 100 msec and no contrast visual in IP cross section, thus it is not visible in the line of mineralization zone.

The response of magnetic anomaly that come across line 4 has high values which means there is a possibility of mineralization zone or the presence of a rock that cause high magnetic values in that area. It might also due to the high response that is not measureable by IP method as the penetration is still relatively shallow.

- 2D cross section of resistivity and chargeability of line 5

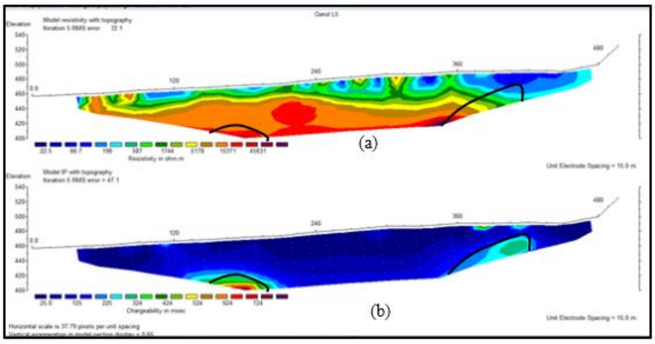

Figure 8. (a) Cross section of resistivity (Ohm.m), (b) Cross section of induced polarization (msec) of line 5.

Based on Figure 8, the resistivity value range between 22 – 40.000 Ohm.m and the chargeability values are between 25 – 800 msec. The low resistivity zone in blue color having values of 9 – 100 Ohm.m is considered good conductor and generally has an abundant amount of clay mineral (argillic alteration). The intermediate resistivity visualized by green color with values ranging between 300 – 700 Ohm.m is considered to be propylitic alteration, as the presence of chlorite is generally having or able to cause high resistivity values in rock.

The high resistivity zone depicted by yellow to red closures having values more than 700 Ohm meter is considered as very dense and hard rock associated with resistive mineral such as silica. The IP cross section has one closure whose value range is more than 100 msec. The high IP closure is at electrode distance of 180 meters with chargeability values range between 200 – 700 msec associated with high resistivity zone. It is estimated to be at 60 meters deep and that the closure width is 5 meter, considered to be mineralization in silicic alteration area. The second closure is at the electrode 360 – 420 meters and depth of 20 – 60 meters.

The interpretation of resistivity and IP is confirmed by geomagnetic data (Figure 2). Similar to line 1 and 2, the pattern of anomaly distribution at line 5 is also flanked by 2 high magnetic field anomaly closures. The magnetic response that come across line 5 undulates with relatively smooth magnetic response. The magnetic values are high with magnetic field intensity between 45400 – 45700 nT, thus it could be considered as mineralization zone.

IV. Conclusion

The resistivity values in study area are in the range of 6 – 40.000 Ohm.m, indicating lithology variation in the area. The chargeability values range between 0 – 800 msec where the cutoff chargeability values of mineralization zone is expected to be more than 100 msec. Closures estimated to be mineralization zone occur at the first, second, and fifth line with chargeability value > 100 msec. The mineralization is associated with high resistivity zone expected to be silicic zone and low resistivity zone expected to be argillic alteration zone. Based on the cross section of resistivity and chargeability, and confirmed with geomagetic map, there are two mineralization zones.

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