MANGANESE (Mn) MINERAL DELINIATION AT THE "NAMASTE" FIELD BASED ON *INDUCED POLARISATION* (IP) METHOD

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Abstract: *Indonesia is one of the world's leading producers of manganese (Mn). Manganese is one of the essential elements required by humans and industry, making the exploration of manganese minerals crucial. This exploration often utilises geophysical methods. Research has been conducted on the "Namaste" field area located in Tulungagung Regency, East Java. The study aims to determine the presence and distribution of manganese minerals using the Induced Polarisation (IP) method, thereby enabling the identification of the lithology and the presence of manganese minerals in the study area. Measurements were made on 10 trajectories using a dipole-dipole configuration with a = 10 and a = 20 meters and n = 1-8. The measurement trajectory spans an area of 400 m x 400 m, with a length ranging from 100 to 260 meters. Data were processed using Res2DInv and other software such as Surfer, Oasis Montaj, CorelDraw, Rockwork, and Leapfrog. The results show the distribution of resistivity values in the range of (5-4500) Ohm-m and chargeability values of (1-295) msec. Low resistivity values, below 100 Ohm-m, are interpreted as indicating carbonate mudstone, while medium resistivity values (100-2000 Ohm-m) are interpreted as indicating limestone. High resistivity values >2500 Ohm-m are interpreted as intrusive igneous rocks. The presence of manganese minerals is spread at a depth of <27 meters with a high chargeability value of >100 msec. The distribution of manganese minerals is dominated in the central and northern areas of the study area.*
Keywords: *Chargeability, Induced Polarisation, Manganese (Mn), Resistivity*

INTRODUCTION

Indonesia is a country situated in the Ring of Fire and on three large active tectonic plates, which results in the country having numerous active volcanoes. Tectonism and megmatism that occur in Indonesia make Indonesia rich in mineral resources. One of the mineral resources found in Indonesia is the mineral manganese. Manganese is used in various industries, such as steel, batteries, and chemicals (Sukandarrumidi, 2009) so that Manganese exploration needs to be carried out. Tulungagung Regency, which is located in the Campurdarat Formation, has manganese mineral potential (Badan Geologi Indonesia, 2013). The existence of metal minerals is characterised by specific physical parameters, including magnetic values, chargeability, conductivity, and resistivity. High chargeability values are a characteristic of metallic minerals. The induced polarisation method detects the occurrence of electrical polarisation on the surface of metal minerals under the earth's surface (Syukri, 2020).

Manganese minerals are characterised by resistivity values greater than 10 Ohm-m and chargeability greater than 20 msec. The formation of manganese minerals associated with limestone indicates that the results of the weathering and erosion process of the original rock (Setiarini et al., 2018). The resistivity and chargeability values of manganese minerals, which range from 5 to 50 ohm-meters and have relatively high chargeability values. At the research site, manganese mineralisation is controlled by igneous intrusions (Suyanto & Yatini, 2006). The resistivity and chargeability values are (0-100) Ohm-m and (0-10) ms, (0-100) Ohm-m and > 10 ms, > 100 Ohm-m and > 10 ms, > 100 Ohm-m and (0-10) ms, respectively. The gold mineralisation zone is spread into two areas, namely the western and eastern areas, separated by the Left Paningkaban Shear Fault (Yatini et al., 2019). The andesite igneous rock, rich in Hornblende minerals, breaking through limestone, affects the formation of manganese mineral deposits. manganese deposits in the limestone have a stockwork structure, with the type of manganese deposited being Pirolusite (MnO_2) (Suyanto, 2014). From the results of research using the IP method, it will obtain information about the existence of mineralisation below the surface based on the parameters obtained, the resistivity and chargeability values as a response to the rocks below the surface. The purpose of this study is to provide information on the distribution of manganese minerals and the lithology of the constituent rocks.

Geological Setting

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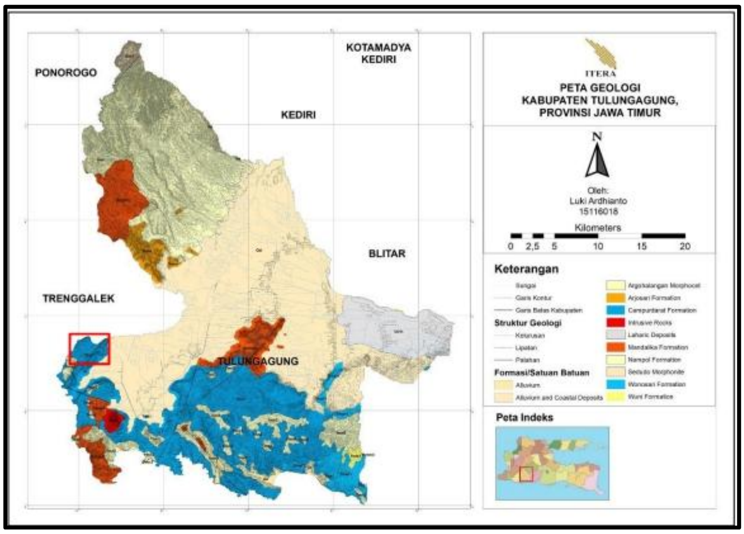

Figure 1. Regional Geological Map of Tulungagung Regency, East Java (Luki Ardhianto, 2020)

According to (Van Bemmelen, 1949), Java Island is regionally divided into five physiographic zones: the Rembang Zone, Randublatung Depression Zone, Kendeng Zone, Solo Zone, and Southern Mountains Zone. The study area is included in the Southern Mountains Zone, located in the southern part of Java Island. It consists of Oligo-Miocene-aged volcanic rocks and carbonate deposits. Based on (Pulunggono et al., 1994). There are several structural patterns in the study area, namely structural patterns with northeast-southwest direction (Meratus direction) formed in the Late Cretaceous-Early Eocene age, structural patterns with north-south direction (Sunda direction) formed in the Early Eocene-Early Oligocene age, and structural patterns with west-east direction (Java direction) formed in the Late Oligocene age by the compression force of the subduction in the southern part of Java Island.

The research area depicted in Figures 1 and 2 falls within the Campurdarat Formation. Quoted from (Samodra, 1992). This formation consists of crystalline limestone with inserts of carbonate mudstone. The crystalline limestone is light to dark grey in colour, compact, solid, and fossilised. It is partly exhumed and lithified. The hollow limestone exposed in Sukoharjo contains manganese. The thickness of this rock ranges from 10 - 50 m. Limestone in this formation contains many corals, algae, molluscs, echinoid spines, and foraminifera. The depositional environment of these rocks is a shallow sea associated with reefs. The limestones of this unit are similar to limestone lenses in the range of clastic rocks and volcanic rocks of the Jaten Formation, Wuni Formation and Nampol Formation.

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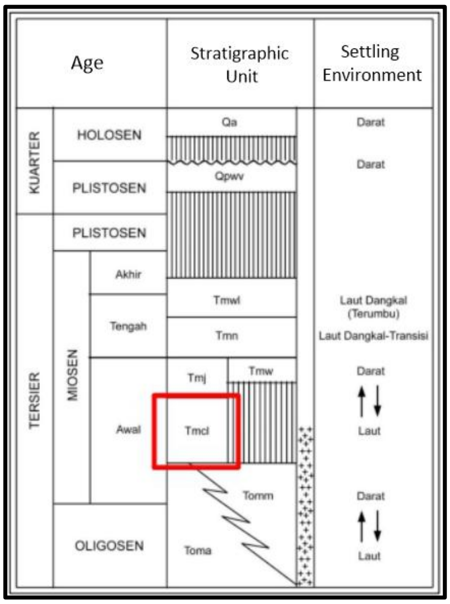

Figure 2. Stratigraphy of the Study Area (Samodra, 1992)

Manganese is one of the most abundant elements in the earth's crust (Chatterjee, 2007). Generally, some rocks contain 0.16% manganese (Rampacek, 1981) where these rocks act as bedrock. These rocks include limestone, sandstone and shale, rijang stone, and jasper. According (Harjanto & Danisworo, 2013). Manganese is one of the 12 largest elements in the Earth's crust. About 300 types of manganese minerals are known, but 13 types are often found in commercial ore deposits. Pyrolusite and psilomelan are common minerals that form the main manganese ore deposits. Manganese deposits are divided into five types: hydrothermal deposits, sedimentary deposits, deposits associated with submarine lava flows, metamorphic deposits, and lateritic deposits and residual accumulations.

METHODS

The research area is administratively located in Tulungagung Regency, East Java. The research used the dipole-dipole configuration IP method on 10 research lines. Measurements were carried out with a spacing of 10 meters on lines N1 - N8, a spacing of 20 meters on lines N9 & N10, and a length of 100 meters on line N2, 110 meters on line N3, 200 meters on line N1, lines N4 - N8, and 260 m on line N9 & N10.

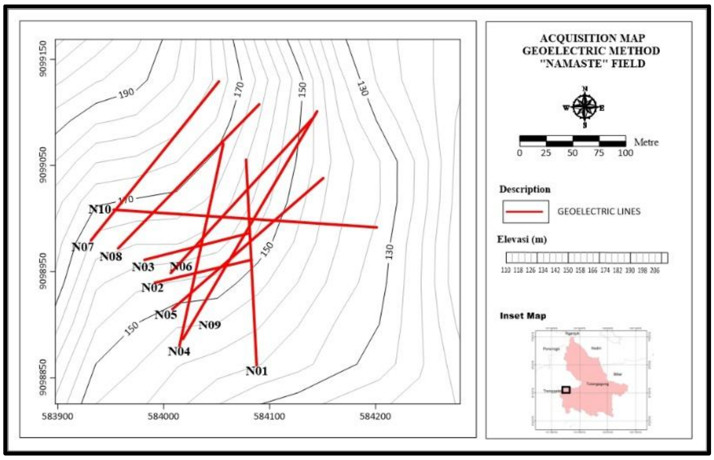

Figure 3. Research Acquisition Design "Namaste" Field

The equipment used in the research, in the form of the Syscal Jr Resistivitymeter main unit, is used as the main tool in conducting geoelectric measurements that measure the response of subsurface resistivity and chargeability values. Supporting equipment includes electrodes, batteries, connector cables, Cu2So4 solution,

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meter, hammer, geological compass, GPS (Global Positioning System), and HT (Handy Talky). The data inversion process was performed using the Res2DInv software to obtain 2D inversion cross-sections. Supporting software used to produce other outputs includes CorelDraw software for creating lithological cross sections, Rockwork software for creating 3D models, Oasis software for the slicing process, Surfer software for stacking on sliced maps, and Leapfrog software for the imaging process in the form of 2D cross-section correlation.

To obtain an overview of subsurface conditions, measurements can be used using the Induced Polarisation (IP) method. The IP method detects the occurrence of electrical polarisation on the surface of metal minerals under the earth's surface (Syukri, 2020). The principle of the IP method is to flow current into the subsurface with a current electrode and capture or measure the potential with a potential electrode. When the current is cut off, the voltage or potential should be zero, but there is a time lag to zero. By using the IP method, measuring this time lag is referred to as the induced polarisation effect, where the medium is a rock.

$$M = \frac{1}{Vp}\int_{t1}^{t2} Vs\ (t)\ dt \tag{1}$$

With M: chargeability (msec), t_1 and t_2: integration limits (seconds), Vs(t): secondary voltage (Volts), Vp: primary voltage (Volts).

Using the resistivity method, the earth is assumed to be layered, with each layer having a different resistivity value. The apparent resistivity is the resistivity of a fictitious homogeneous medium equivalent to the layered subsurface medium. For example, a medium consisting of two layers with different resistivities (ρ1 and ρ2) is considered a homogeneous single-layer medium with one apparent resistivity ρ_a.

$$\rho_a = k\frac{V}{I} \tag{2}$$

With ρ_a: apparent resistivity (Ohm-m), k: geometry factor, ΔV: potential (Volt), I: current (Ampere).

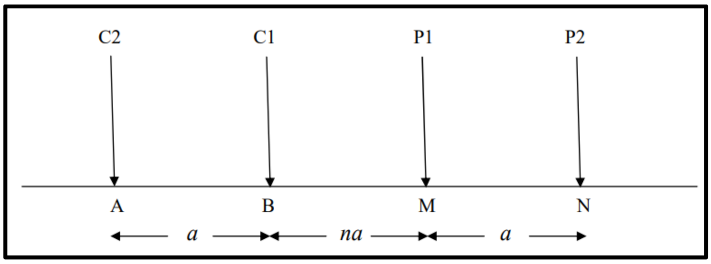

Figure 4. Dipole-dipole configuration electrode array (Reynolds, 2011)

The dipole-dipole configuration generally follows the same basic principle as other configurations, namely by injecting current into the ground to measure the potential difference. The difference between the Dipole-Dipole configuration and other configurations lies in the arrangement of electrodes that adjust to the measurement conditions in the field and the depth of lithology at the subsurface. The dipole - Dipole configuration factor is formulated as follows:

$$k = \pi(n+1)(n+2)n.r \tag{3}$$

k is the geometric factor, a is the electrode spacing, and n is the multiplier number.

RESULTS AND DISCUSSION

The resistivity value obtained in the research area has a value range of 5 Ohm-m to 2500 Ohm-m, while the chargeability value ranges from 1 msec to 295 msec. The study results show that the highest resistivity value is greater than 2500 Ohm-m, and the highest chargeability values are in the range of greater than 295 msec. While the lowest resistivity is in the range of 5 Ohm-m, the lowest chargeability of 1 msec. Based on the resistivity and chargeability values obtained, the value can be categorised into 3 parts on the resistivity and chargeability values, namely the low, medium and high value categories. The division of these categories is as in Table 1 and Table 2

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Table 1. Classification of resistivity and chargeability

No	Classification	Resistivity (Ohm-m)	Chargeability (msec)
1	Low	<100	<100
2	Medium	100 - 2000	100 - 253
3	High	>2000	>253

Table 1. Interpretation of subsurface lithology

No	Resistivity (Ohm-m)	Chargeability (msec)	Interpretation
1	Low	Low	Carbonate mudstone
		Medium - High	Carbonate mudstone contains manganese
2	Medium	Low	Limestone
		Medium - High	Limestone contains manganese (Mn)
3	High	Low	Igneous rock
		Medium - High	Igneous rock contains manganese (Mn)

Resistivity and Chargeability Inversion Model.

Figure 5 shows a cross-section of line N3 in the 'Namaste' area with an azimuth of N 77°E, a line length of 110 meters, and a southwest-northeast orientation. The inversion results show resistivity values ranging from 5 Ohm-m to 2500 Ohm-m and chargeability values ranging from 1 msec to 295 msec. The resistivity cross-section in Figure 5 (A) shows medium values, interpreted as Campurdarat Formation limestone with a resistivity of 100 Ohm-m to 2000 Ohm-m. Low resistivity values (<100 Ohm-m) are interpreted as the Campurdarat Formation carbonate mudstones. The chargeability cross-section in Figure 5 (B) shows low values (<100 msec), indicating little or no metallic minerals. Medium to high chargeability values (>100 msec) indicate the presence of metallic minerals caused by polarisation in rocks containing metallic minerals, in this case, Manganese (Mn) minerals. Figure 5 (C) shows the lithological cross-section of the interpreted resistivity values.

Based on the analysis of resistivity and chargeability values, the location of manganese minerals can be determined. Manganese minerals at the research site are scattered nodules, with manganese zones located at low resistivity (carbonate mudstone) and medium to high (limestone) with medium to high chargeability. High chargeability values indicate the existence of polarisation in mineral-bearing rocks, on the Namaste line N3. The identified manganese minerals are associated with carbonate mudstones, which are thought to have been initially weathered from fresh limestone. Manganese minerals identified in line N3 are at a distance of 90 - 100 m with a depth reached <20 meters or at an elevation of 165 - 150 meters. The formation of manganese minerals is caused by the deposition of residual magma that passes through limestone gaps, resulting in the formation of manganese nodules. According to (Suyanto, 2014). Manganese deposits in this area are influenced by the intrusion of Hornblende-rich andesitic igneous rocks, with manganese precipitating in hollow limestone to form a stockwork structure featuring manganese pyrolusite (MnO_2).

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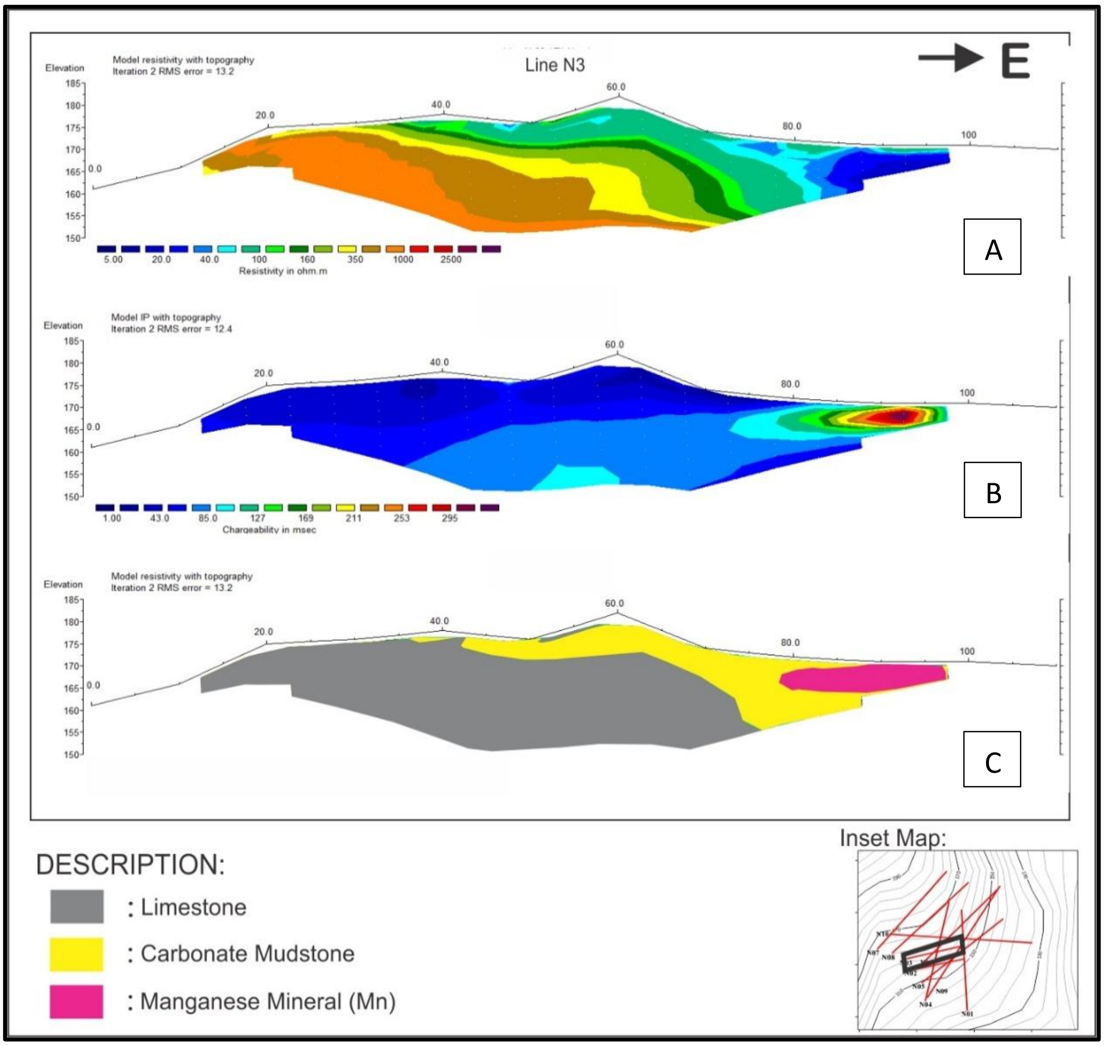

Figure 5. Inversion Modelling Results, a) Resistivity Cross-section, b) Chargeability Cross-section, c) Lithological Interpretation and Identification of Manganese Mineral Deposits Zone

Correlation Inversion Model

The interpretation of the correlation is based on the information presented in Tables 1 and 2. High resistivity values (>2500 Ohm-m) are depicted in purple and interpreted as breakthrough rocks. Medium resistivity values (100-2000 Ohm-m) are interpreted as carbonate mudstone of the Campurdarat Formation, while low resistivity values (<100 Ohm-m) are indicative of This Formation. The correlation results in Figure 6 show that the line is composed of limestone at the bottom and carbonate mudstone at the top, both parts of the Campurdarat Formation. The surface tends to have low resistivity values, indicating carbonate mudstone lithology. The lower part of the cross-section is characterised by medium to high resistivity, indicating the presence of limestone.

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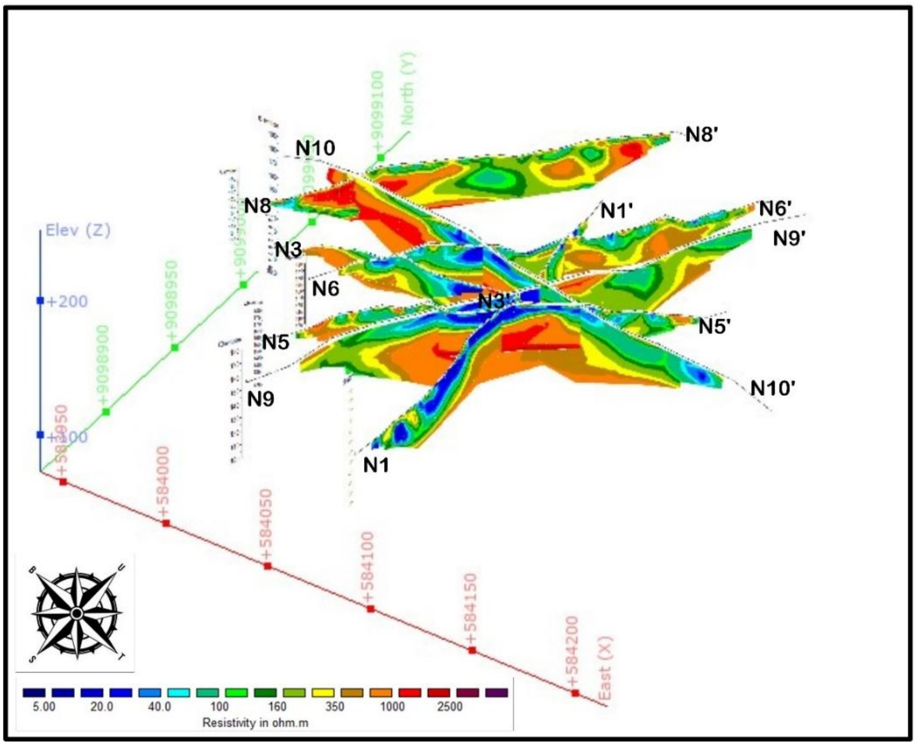

Figure 6. Correlation of Resistivity Cross-section of Namaste Field research area line N1, N3, N5, N6, N8, N9, and N10

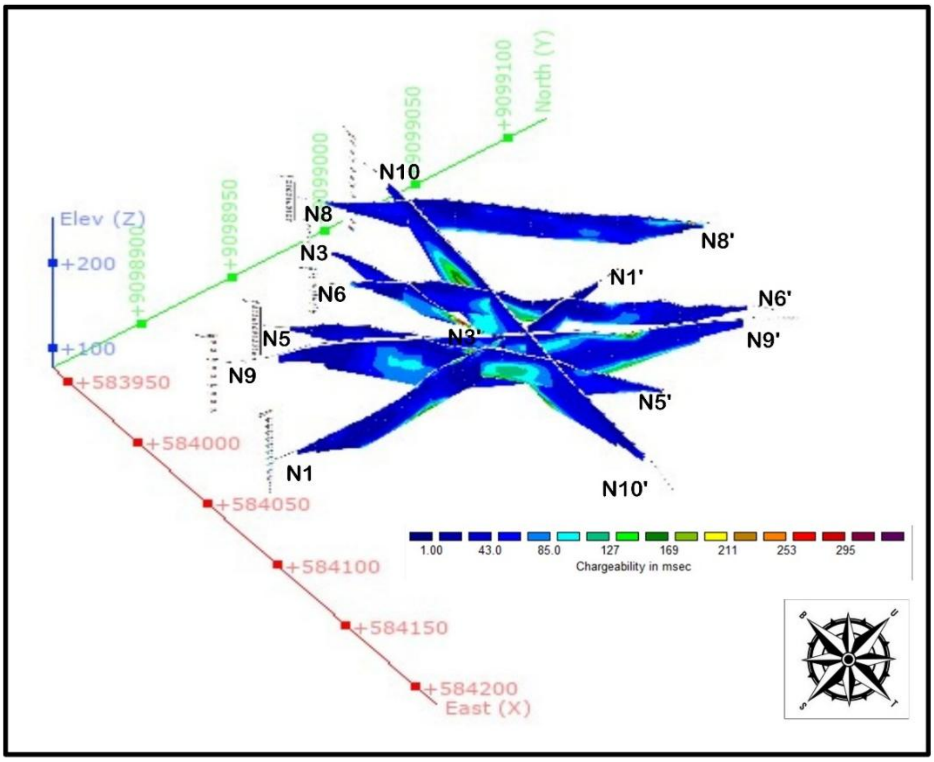

Figure 7. Correlation of Chargeability Cross Section of Namaste Field research area on line N1, N3, N5, N6, N8, N9, and N10

Figure 7 shows the distribution of chargeability values, divided into two categories: low (<100 msec) and medium-high (>100 msec). Low chargeability dominates, indicating the presence of zones without metallic minerals. The high chargeability in certain areas of the lines indicates zones of manganese mineral occurrence. Manganese minerals are unevenly distributed over the surface area. Lines N1, N3, N5, N6, N8, N9 and N10 have medium-high chargeability spots identified as manganese minerals, especially in the eastern area of the study. This manganese is formed from the deposition of residual magma that flows through limestone crevices,

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forming nodules. The formation of manganese deposits is influenced by the intrusion of Hornblende-rich andesitic igneous rocks, which precipitate in limestone with a stockwork structure and a manganese pyrolusite (MnO2) type (Suyanto, 2014).

Depth Slicing

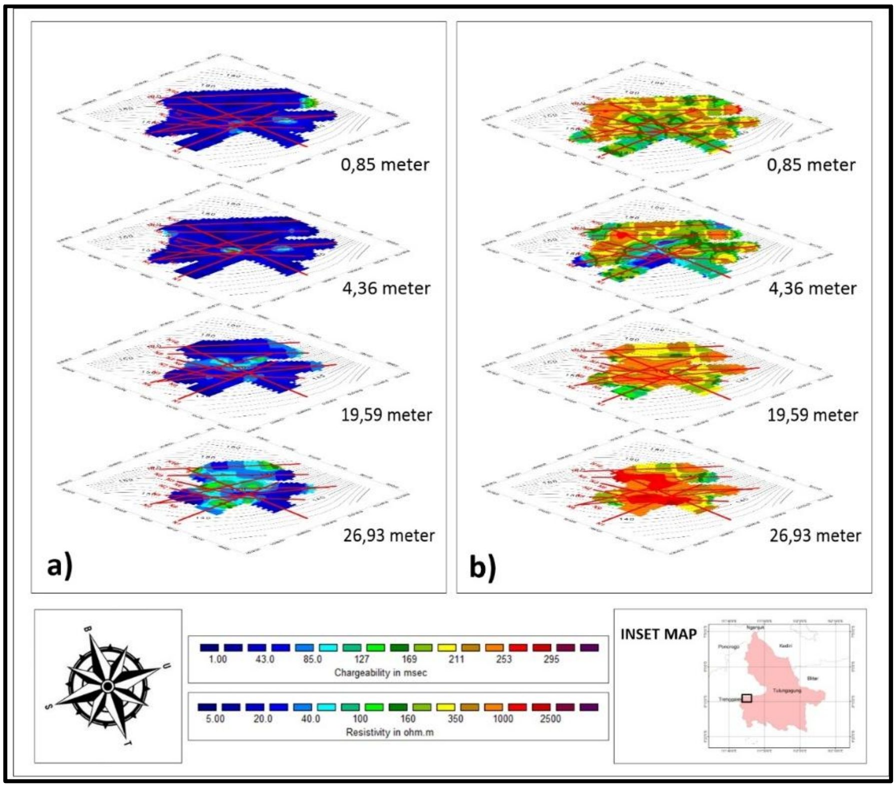

Figure 8. Depth Slicing Map a) slicing of chargeability values at depths of 0.85, 4.36, 19.59, and 26.93 meters and b) slicing of resistivity values at depths of 0.85, 4.36, 19.59, and 26.93 meters

The resistivity depth slicing map in Figure 8 shows that at a depth of -0.85 meters, the resistivity value is dominated by medium to high values, which are interpreted as limestone from the Campurdarat Formation (referring to Tables 1 and 2). At a depth of -4.36 meters in the southeast area, there is a low resistivity value of <100 ohm meters, which is interpreted as carbonate claystone. This suggests that the carbonate claystone is interbedded with the overlying limestone. At a depth of -6.33 meters, the zone of low resistivity values in the southeast indicates reduced insertion of carbonate mudstone in the surrounding limestone. At a depth of -8.5 meters, the zone of low resistivity decreases further, resulting in an area dominated by medium to high resistivity values, interpreted as limestone from the Campurdarat Formation. The resistivity depth slicing maps in Figure 8 for depths of -16.41, -19.59, and -26.93 meters show the dominance of medium to high resistivity values,

The depth slicing map in Figure 8 a) shows the response of targets that have high chargeability values, as indicated by the green response on the map (>100 msec). The high response indicates the identification of the target as a Manganese (Mn) mineral. Depth: -0.85 meters. Medium-high chargeability spots are visible in the north. Depth -4.36 meters in the central part. The depth of -19.59 meters is in the north. A depth of 26.93 meters is in the central area of the map. High chargeability values are caused by polarisation in rocks that contain certain materials, including metal minerals such as manganese. Manganese minerals are thought to be formed from the deposition of residual magma that flows through limestone crevices and forms nodules. According to (Suyanto, 2014), the formation of manganese deposits in the study area was influenced by the intrusion of andesitic igneous rocks rich in Hornblende, with manganese deposited as pyrolusite (MnO2).

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3D Modelling of Manganese (Mn) Mineral Distribution

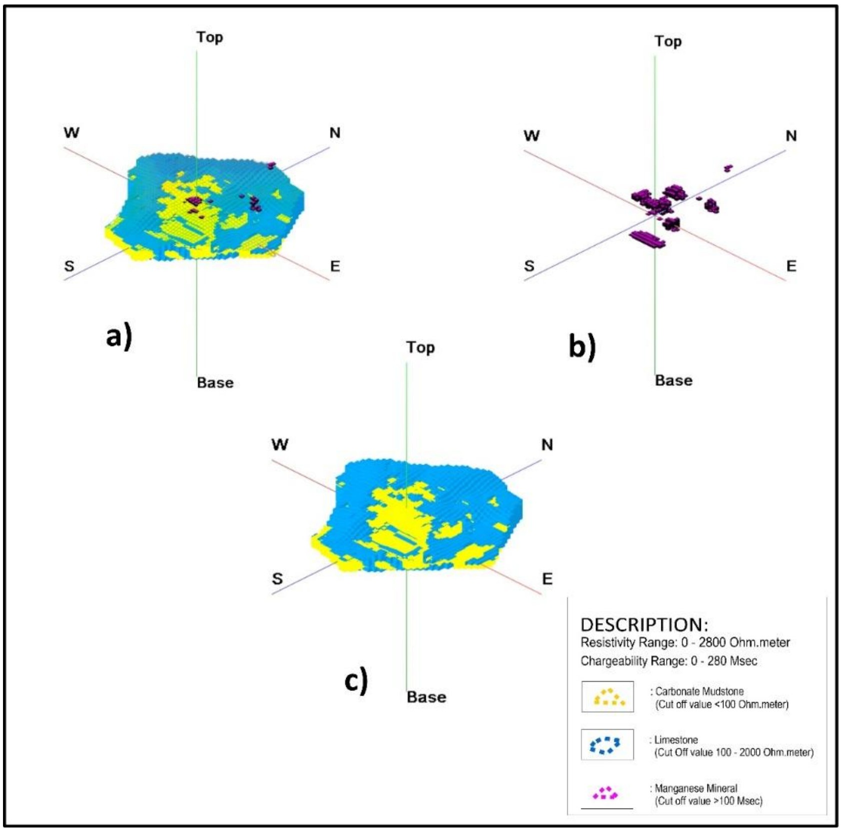

Figure 9. 3D Modelling of Manganese Mineral Distribution a) Overlay of Chargeability Resistivity value, b) Chargeability Model, and c) Resistivity Model in the 'Namaste' Research Area

Figure 9 c) shows the resistivity model with a range of values between 0 - 2800 Ohm-m. Referring to Tables 1 and 2, the range is <100 Ohm-m for carbonate mudstone lithology of the Campurdarat Formation and 100 - 2000 Ohm-m for limestone lithology of the Campurdarat Formation. The research area is characterised by the presence of limestone and carbonate mudstone (Samodra, 1992). Figure 9b) shows the distribution model of chargeability in the study area, with values ranging from 0 to 280 msec. Referring to Tables 1 and 2, values >100 msec are interpreted as manganese minerals, which have moderate to high chargeability values (>100 msec). Figure 9 a) shows the manganese mineral zone estimation model based on overlaid chargeability values. Referring to Tables 1 and 2, the overlay modelling shows the constituent lithology in the form of limestone Campurdarat Formation, which is shown in blue on the model. The lithology of the carbonate mudstone in the Campurdarat Formation is depicted in the model using a yellow colour. In the overlay model, the chargeability value indicating the presence of the target is in the middle of the study, near the surface, and to a depth of less than 27 meters. Manganese minerals are thought to be formed due to the deposition of residual magma that flows through limestone crevices and settles in limestone cavities, forming nodules. According to (Suyanto, 2014), the formation of manganese mineral deposits in the study area was influenced by the intrusion of andesite igneous rocks rich in Hornblende minerals. Manganese deposits are formed from hydrothermal solutions that flow through limestone crevices containing Oolite and precipitate in cavities, forming a stockwork structure with manganese pyrolusite (MnO_2).

CONCLUSION

The lithology in the "Namaste" field area consists of limestone with a resistivity of 100-2000 ohm-m and carbonate mudstone with a resistivity <100 ohm-m, belonging to the Campurdarat Formation. Manganese minerals are found in materials with chargeability >100 msec associated with limestone (100-2000) ohm-m and slightly in carbonate mudstone or weathered limestone (resistivity <100 ohm-m). Manganese distribution is dominant in the central and northern areas, in the form of nodules or boulders near the surface and unevenly distributed. Vertically, manganese is found from the surface to a depth of less than -27 meters.

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