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Identification of Iron Ore Deposit in Sub-Surface using Resistivity and Induced Polarization Methods at Sarakaman, Sebuku Island, South Kalimantan

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Abstract. Iron is the second most abundant metal on earth. Sebuku Island is one of the areas in Indonesia that has potential for laterite iron ore. This study aims to detect the presence of mineralized zones and estimate the volume of iron ore. Therefore, geophysical research was carried out using the resistivity method and the Induced Polarization methods with the Wenner-Schlumberger configuration. The research was carried out in 4 paths along 475 m with a space between the electrodes of 5 meters. Based on modeling, 20 iron ore deposits were found in the study area on all trajectories characterized by high chargeability values ranging from 251,55 – 810,55 ms which correlated with low resistivity values of 4,02 – 124,41 m. Then it was found that the direction of the distribution of iron ore deposits in the study area was north-south and there was no continuous zone of iron ore deposits due to the long distance of the path. The amount of deposits of iron ore in the study area in an area of ±39 hectares is approximated to be around 1.807.614 m3 with total reserves of iron ore deposits of 7.230.456 tons.

Keywords: *Induced Polarization (IP), Iron Ore, Resistivity, Sebuku, Wenner-Schlumberger.*
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INTRODUCTION

Based on data from the Geological Agency as of the end of 2014, the largest iron ore reserves in Indonesia were in South Kalimantan Province, amounting to 480.698.847 tons [1]. Geophysics is a science that plays an important role in interpreting the distribution of iron ore minerals and other metal ores under the earth's surface, one of which is using the geoelectrical resistivity method and Induced Polarization (IP) method which is the development of the resistivity geoelectric method.

Iron (Fe) is the second most abundant metal on earth. Rock with iron or iron deposits is known as iron ore. The character of iron deposits can be in the form of metal

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deposits that stand alone but are often associated with other metal minerals [2]. Iron ore deposits can occur either initially or laterally. Magmatic, contact metasomatic, and hydrothermal processes can all contribute to the formation of the iron ore primary deposit. Additionally, secondary deposits are caused by the processes of weathering, transportation, and sedimentation [3]. Economical deposits are generally magnetite, hematite, limonite, and siderite [4]. Resistivity method is one of the geophysical methods used to investigate subsurface conditions. Work principle of the resistivity method is to flow an electric current into the earth through two current electrodes, then measure the potential distribution formed through two potential electrodes [5]. Geoelectric measurements are carried out by injecting electric current (I) into the earth through two current electrodes, As indicated in Fig. 1, the potential difference (V) that arises between C1 and C2 is then measured using P1 and P2, two potential electrodes. Equation may be used to derive resistivity value from the collected readings. [6].

$$\rho_a = K\frac{V}{I} \tag{1}$$

where K is a geometric variable that relies on how the four electrodes are arranged. the Wenner-Schlumberger configuration is defined as the ratio of distance between the C1-P1 electrodes (or C2-P2) to the space between the P1-P2 electrodes. This configuration has a set of constant spacing criteria. [12]. The geometric factors of this configuration are:

$$K = \pi n\,(n+1)a \tag{2}$$

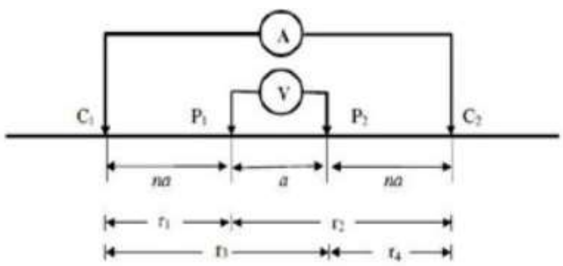

Figure 1. Wenner-Schlumberger Configuration Electrode Arrangement [6].

Induced Polarization (IP)

When a current is introduced and then cut off, the phenomenon of induced polarization takes place. The ions in the granite pores will be dispersed from a stable location to an unstable position when the current is injected. When the current is stopped, the potential difference should instantly be zero, however in some media, since the medium acts like a capacitor and stores electrical energy, the potential difference does not immediately become zero. Overvoltage decay is the gradual approach of the measured potential to zero. Chargeability is the ratio of the voltage when the current is shut off to the voltage when the current is injected [7].

$$M = \frac{1}{Vp}\int_{t1}^{t2} Vs\ (t_1) \tag{5}$$

Result of polarization effect can be caused by membrane polarization and electrode polarization. Membrane polarization is caused by the narrowing of the pores due to the presence of very large negatively charged clay particles causing positive ions in the electrolyte fluid to be attracted towards the negatively charged clay particles. This process creates positive clouds (membranes) on side of rock pores. While the electrode polarization is caused by the presence of metallic minerals in the rock that block the flow of current when passing through the rock so that a chemical reaction will occur at the metal mineral boundary area which causes an extra potential or overvoltage [7].

Regional Geology

Sebuku Island is part of the regional geological map sheet Kotabaru, South Kalimantan, where the rock units found in the area consist of ultramafic rocks (Mub), Haruyan Formation (Kvh), Pitap Formation (Ksp), Tanjung Formation (Tet), and alluvium (Qa) deposits [8].

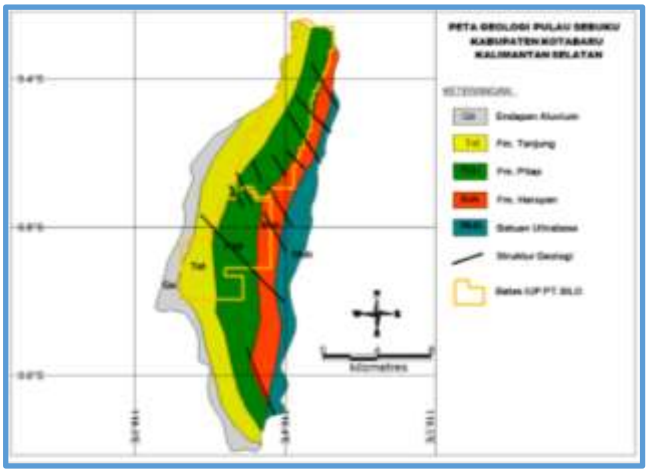

Figure 2. Geology Map of Sebuku Island [9].

Sebuku Island has 3 phases of iron oxide with significant Fe content, namely magnetite, hematite, and goethite. In the research area, the resource that has the potential to contain a lot of Fe is laterite deposits. Laterite deposits are deposits produced by the weathering process of bedrock. In the Serakaman area, generally under lateritic iron ore deposits, there are ultramafic rocks of the type of dunite and harzburgite, so it can be assumed that in this Serakaman area, the bedrock is dominated by ultramafic rocks. The characteristics of iron ore found in the Sebuku Area are as follows, lateritic iron ore deposits, blackish brown-reddish in color, fine sand size-lumps, rather hard, massive, sometimes in the form of lenses and laminates, spreading in a lateral direction almost north-south, the average thickness is approximately 5 m; types of iron ore are dominated by hematite and goethite, in some places there is magnetite; the presence of lateritic iron ore deposits are generally scattered in highland areas on the top soil [9].

METHODS

The research using Sarakaman, Sebuku Island, South Kalimantan using resistivity and IP data with the Wenner-Schulmberger configuration data from Center for Mineral Resources Development Technology (PTPSM-BPPT). In This study consists of 4 tracks, each of which is 475 m long with a space between the electrodes of 5 m and distance between the tracks, namely the L-01 track to the L-02 track along ±138 m, the L-02 track to the L-03 track. along ±160 m and the L-03 track to the L-04 track ±150 m.

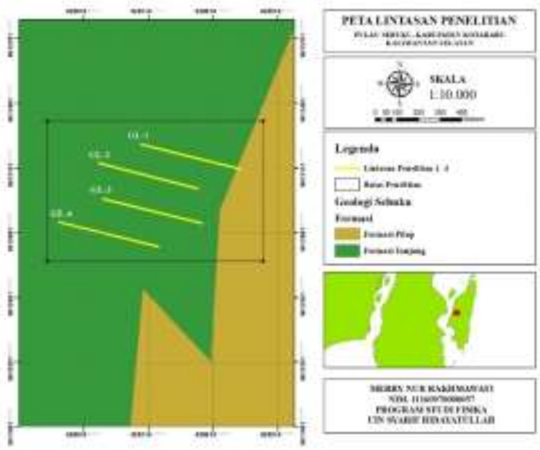

Figure 3. Resistivity and Induced Polarization (IP) Survey Design Map in Sarakaman Area, Sebuku Island, South Kalimantan [9].

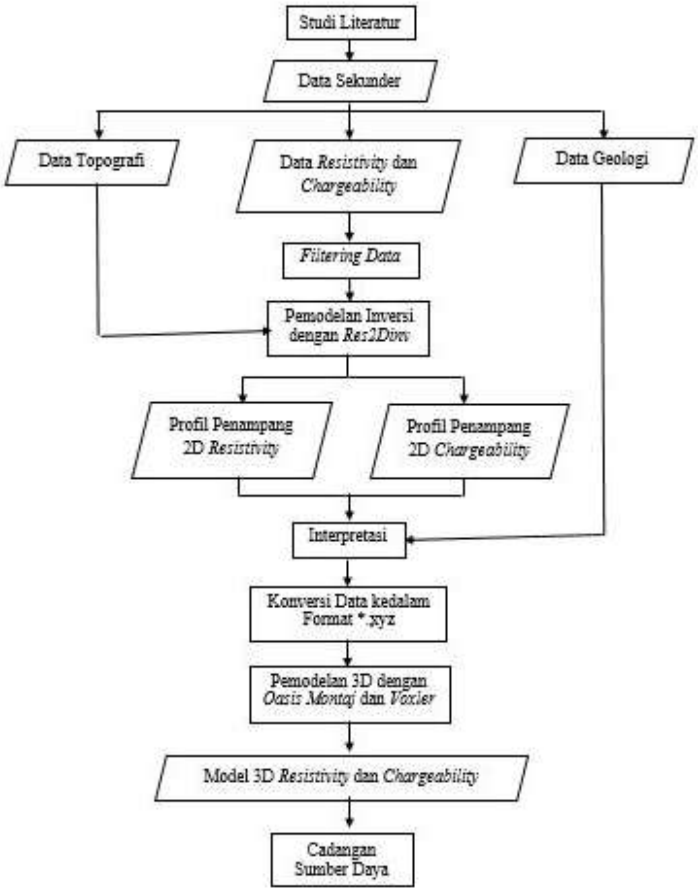

Figure 4. Research Flow Chart

The data obtained is processed and interpretated in 2-Dimensional IP data is carried out by looking at the characteristics or trends in resistivity and chargeability values, which are then correlated with existing geological information. Estimation of the presence of iron ore will be directed at a low resistivity value with a high chargeability value. At 3-Dimensional modeling using Geosoft Oasis Montaj software. It is used to show the distribution of iron ore deposits below the surface and to see whether or not there is a continuity zone for iron ore deposits by correlating the chargeability values of the entire track. Furthermore, Voxler software is used for calculating iron ore resources in the research area. This calculation utilizes the Isosurface module which is a representation of the distribution of data values in 3D (actual chargeability). Determination of the volume of iron ore deposits is done by entering the smallest chargeability limit value of isovalue. The following is a research flow chart, showed as:

RESULTS AND DISCUSSION

Results and Discussion of 2D Inversion Modeling

The 2D cross-section of resistivity and chargeability from all inversion models is then correlated with the geological data of the research area, then interpretation can be made to indicate the zone of presence of iron ore deposits on each lines, as follows.

Line L-01

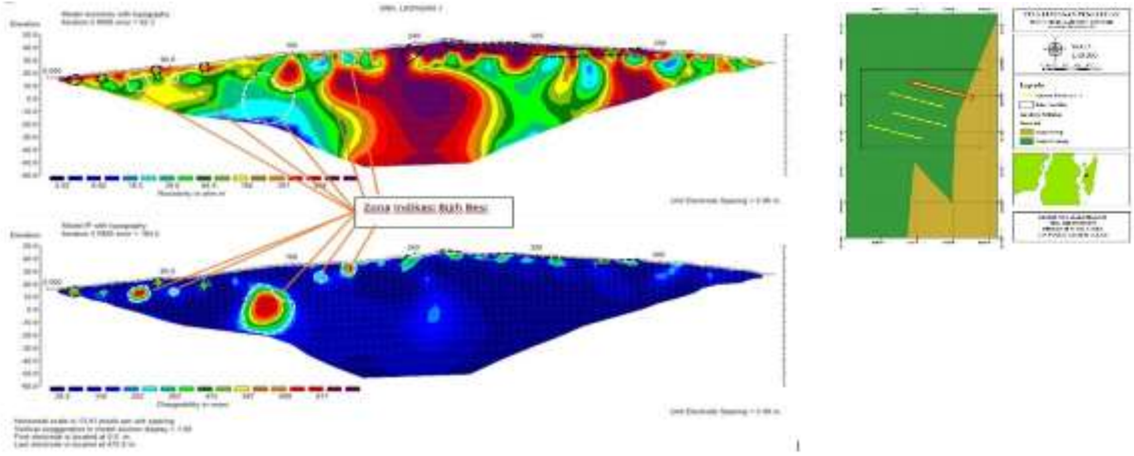

Figure 5. Inversion Model and Interpretation of Resistivity and Chargeability Sections on the Line L-01.

Based on analysis of the image (Fig. 5), the resistivity value obtained on the line L-01 is between 8,26 – 1.226,76 m while the chargeability value is between 27,95 – 810,55 ms. In the 2-Dimensional section of Induced Polarization (IP) data, the chargeability value contrasts with a value range of 251,55 to 810,55 ms, which correlates with a resistivity value range of 8,62 – 124,41 m which is interpreted as iron ore deposits. So it can be seen that on the line L-01 there are 5 iron ore deposits which are marked with white dotted lines.

Table 1. Distribution of Iron Ore Deposits on the Line L-01.

Depth (mdpl)	Length (m)	Resistivity (Ohm m)	Chargeability (ms)	Description
20 – 10	15 – 20	124,41 – 1.226,76	251,55 – 698,75	Anomaly
15 – 10	35 – 40	39,62 – 266,78	251,55 – 363,35	Anomaly
20 – 5	55 – 70	58,01 – 124,41	251,55 – 810,55	Iron Ore
25 – 20	70 – 75	124,41 – 390,66	251,55 – 642,95	Anomaly
10 – 5	80 – 85	84,95 – 124,41	251,55 – 363,35	Iron Ore
20 – 15	100 – 105	124,41 – 390,66	251,55 – 586, 95	Anomaly
20 – (-20)	125 – 160	8,62 – 124,41	251,55 – 810,55	Iron Ore
25 – 20	175 – 180	8,62 – 27,05	251,55 – 363,35	Iron Ore
35 – 25	190 – 200	12,62 – 58,01	251,55 – 754,65	Iron Ore
40 – 25	230 – 245	124,41 – 1.226,76	251,55 – 475,15	Anomaly

40 – 30	255 - 385	124,41 – 1.226,76	251,55 – 475,15	Anomaly

Line L-02

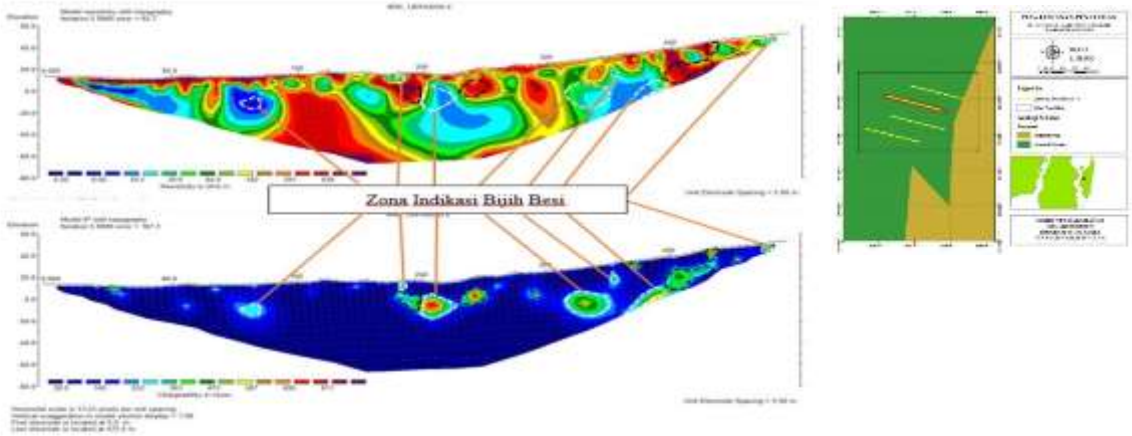

Figure 6. Inversion Model and Interpretation of Resistivity and Chargeability Sections on the Line L-02.

Based on analysis of the image (Fig. 6), the resistivity value obtained on the line L-02 is between 8,62 – 1.226,76 m, while the chargeability value is between 27,95 – 754,65 ms. In the 2-Dimensional section of Induced Polarization (IP) data, the chargeability value contrasts with a value range of 251,55 to 754,65 ms, which is interpreted as an iron ore deposit which is correlated with a resistivity value range of 8,62 – 124,41 m. So it can be seen that on the line L-02 there are 7 iron ore deposits which are marked with white dotted lines.

Table 2. Distribution of Iron Ore Deposits on the Line L-02.

Depth (mdpl)	Length (m)	Resistivity (Ohm.m)	Chargeability (ms)	Description
10 - 5	40 – 45	390,66 – 837,74	251,55 – 586,95	Anomaly
-5 – (-15)	125 – 135	8,62 – 12,62	251,55 – 307,45	Iron Ore
5 – (-10)	220 – 240	390,66 – 1.226,76	251,55 – 531,05	Anomaly
10 – 5	225 – 230	27,05 – 58,01	251,55 – 307,45	Iron Ore
5 – (-15)	240 – 260	12,62 – 124,41	251,55 – 754,65	Iron Ore
10 – (-5)	260 – 280	124,41 – 837,74	251,55 – 754,65	Anomaly
5 – 0	310 – 315	390,66 – 837,74	251,55 – 307,45	Anomaly
0 – (-20)	330 – 355	18,47 – 84,95	251,55 – 586,95	Iron Ore
20 – 10	360 – 365	18,47 – 84,95	251,55 – 363,35	Iron Ore
20 – 15	375 – 380	124,41 – 572,08	251,55 – 586,95	Anomaly
5 – (-15)	365 – 390	12,62 – 84,95	251,55 – 642,85	Iron Ore
20 – 0	395 – 425	124,41 – 1.226,76	251,55 – 475,15	Anomaly
40 – 30	420 – 430	124,41 – 1.226,76	251,55 – 754,65	Anomaly
35 – 30	440 – 445	84,95 – 182,18	251,55 – 307,45	Anomaly
40 – 35	460 – 465	18,47 – 39,62	251,55 – 586,95	Iron Ore

Line L-03

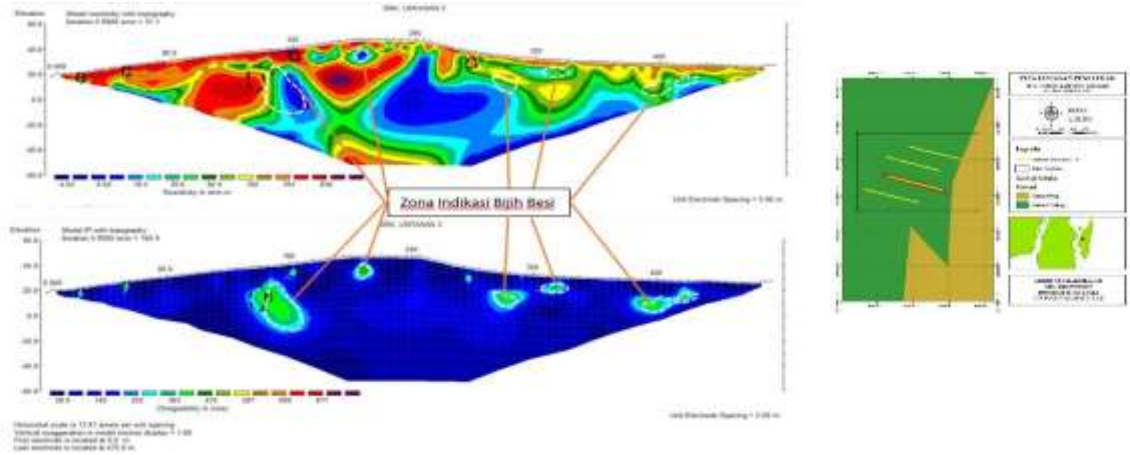

Figure 7. Inversion Model and Interpretation of Resistivity and Chargeability Sections on the Line L-03.

Based on analysis of the image (Fig. 7), the resistivity value obtained on the L-03 path is between 5,88 – 837,34 m while the chargeability value is between 27,95 – 475,15 ms. In the 2-Dimensional section of Induced Polarization (IP) data, the chargeability value contrasts with a value range of 251,55 to 475,15 ms, which is interpreted as an iron ore deposit which is correlated with a resistivity value range of 5,88 – 124,41 m. So it can be seen that on the L-03 line there are 5 iron ore deposits which are marked with white dotted lines.

Table 3. Distribution of Iron Ore Deposits on the Line L-03.

Depth (mdpl)	Length (m)	Resistivity (Ohm.m)	Chargeability (ms)	Description
20 – 15	20 – 25	266,78 – 837,74	251,55 – 363,35	Anomaly
23 – 18	50 – 55	266,78 – 837,74	251,55 – 363,35	Anomaly
20 – 5	125 – 140	124,41 – 572,08	251,55 – 419,25	Anomaly
25 – (-10)	140 – 170	5,88 – 124,41	251,55 – 475,15	Iron Ore
35 – 25	160 – 165	390,66 – 837,34	251,55 – 363,35	Anomaly
40 – 30	200 – 215	5,88 – 27,05	251,55 – 475,15	Iron Ore
20 – 15	275 – 280	124,41 – 182,18	251,55 – 307,45	Anomaly
15 – 5	295 – 310	18,47 – 124,41	251,55 – 419,25	Iron Ore
25 – 15	325 – 340	12,62 – 84,95	251,55 – 363,35	Iron Ore
20 – 0	385 – 425	27,05 – 124,41	251,55 – 419,25	Iron Ore

Line L-04

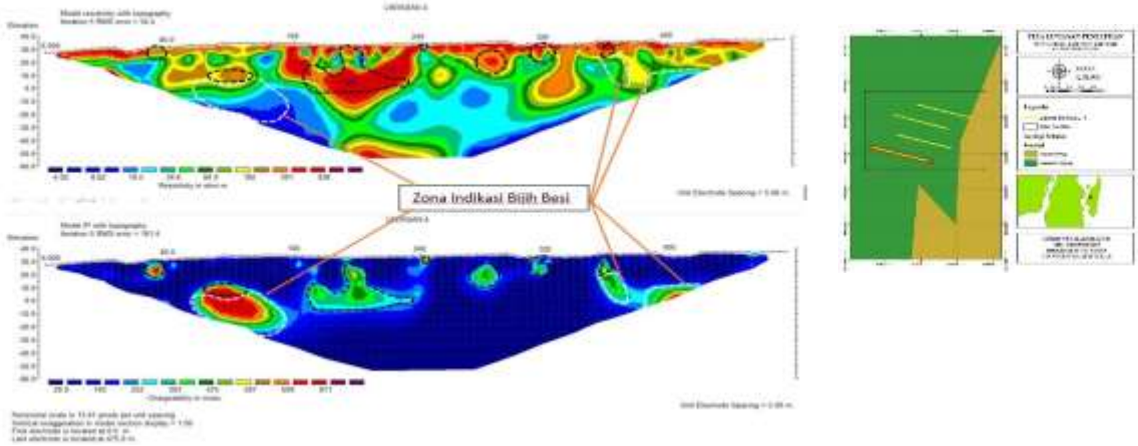

Figure 8. Inversion Model and Interpretation of Resistivity and Chargeability Sections on the Line L-04.

Based on analysis of the image (Fig. 8), the resistivity value obtained on the L-04 path is between 4,02 – 1.226,76 m while the chargeability value is between 27,95 – 810,55 ms. In the 2-Dimensional section of Induced Polarization (IP) data, the chargeability value contrasts with a value range of 251,55 to 810,55 ms, which is interpreted as an iron ore deposit which is correlated with a resistivity value range of 4,02 – 124,41 m. So it can be seen that on the line L-04 there are 3 iron ore deposits which are marked with white dotted lines.

Table 4. Distribution of Iron Ore Deposits on the Line L-04.

Depth (mdpl)	Length (m)	Resistivity (Ohm.m)	Chargeability (ms)	Description
30 – 20	65 – 75	39,62 – 390,66	251,55 – 810,55	Anomaly
5 – (-30)	95 – 155	4,02 – 124,41	251,55 – 810,55	Iron Ore
15 – 5	100 – 130	124,41 – 390,66	251,55 – 810,55	Anomaly
25 – (-5)	165 – 235	39,62 – 1226,76	251,55 – 586,95	Anomaly
35 – 30	240 - 245	124,41 – 390,66	251,55 – 698,75	Anomaly
30 – 10	270 – 290	124,41 – 572,08	251,55 – 531,05	Anomaly
30 – 20	310 – 325	39,62 – 837,34	251,55 – 586,95	Anomaly
30 - 20	350 - 360	182,18 – 387,74	251,55 – 586,95	Anomaly
20 – (-5)	350 – 370	27,05 – 124,41	251,55 – 475,15	Iron Ore
10 – (-10)	385 - 420	12,62 – 124,41	251,55 – 698,75	Iron Ore

Based on tables 1 – 4, it can be seen that there are high resistivity anomalies in line L-01 – L-04 which are resistive, they have values ranging from 124,41 m to 1.226,76 m and are not interpreted as resistivity values. iron ore minerals, because theoretically metal ore minerals including iron ore are conductors which have low resistivity values, especially in massive iron ores, not as fragments in other rock matrices. In conditions where high resistivity values are estimated to occur due to the presence of cavities between fragments and iron ore fragments filled with air. And, generally iron ore in this area is dominated by hematite iron ore.

Distribution of Subsurface Iron Ore Deposits

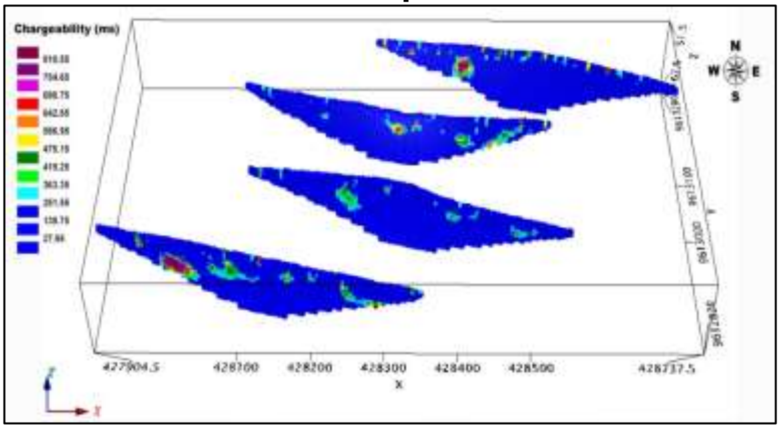

Figure 9. 3D Model from Correlation of Chargeability Inversion Results of All Lines.

Based on the correlation of the IP (chargeability) values in the form of a 3D model (Fig. 9), iron ore deposits are scattered in certain locations in the form of iron ore fragments in a matrix of dunite and harzburgite ultramafic rocks and in the form of iron ore chunks with a north-south direction. And, there is also no continuous zone of iron ore deposits found. This is because the distance between the tracks is quite far, namely the L-01 track to the L-02 track along ±138 m, the L-02 track to the L-03 track ±160 m and the L-03 track to the L-04 track ±150 m.

Calculation of Iron Ore Resources

The volume of the iron ore deposits zone, which has a chargeability value of 251,55 ms in the research region within an area of around ±39 hectares, is estimated to be roughly 1.807.614 m3 based on (Fig.11), the findings of 3D isosurface modeling using Voxler software. The mass estimated reserves of ore deposits in a region of around ±39 hectares are given if the iron ore density is considered to be 4 g/cm3

Mass = volume x density

= 1.807.614 m^3 x 4.000 kg/m^3

= 7.230.456 tons

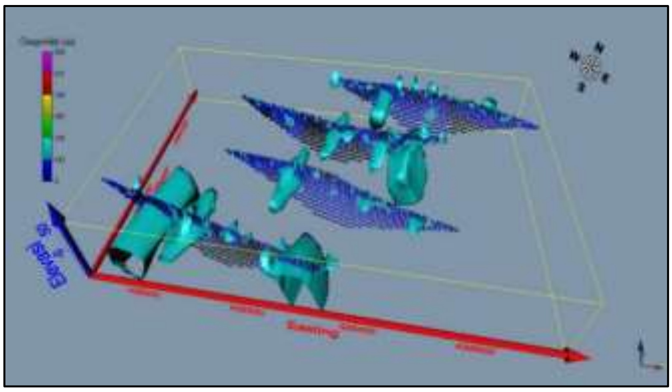

Figure 10. Distribution of Iron Ore Deposits.

CONCLUSIONS

Based on the results and discussion, it can be concluded that the distribution of the resistivity value and the chargeability value below the surface is, the L-01 track with a resistivity value of 4,02 – 1.266,76 m and chargeability value of 27,95 – 810,55 ms. The L-02 track has a resistivity value of 8,62 – 1.226,76 m and a chargeability value of 27,95 – 754,65 ms. The L-03 track has a resistivity value of 5,88 – 837,34 m and a chargeability value of 27,95 – 475,15 ms. The L-04 track has a resistivity value of 4.02 – 1.226,76 m and a chargeability value of 27,95 – 810,55 ms. Iron ore deposits in the study area were found on all tracks, namely at L-01 as many as 5 deposits, L-02 as many as 7 deposits, L-03 as many as 5 deposits, and L-04 as many as 3 deposits based on a low resistivity value of 124,41 m and a high chargeability value of 251,55 ms. The distribution of iron ore deposits in the study area is in a north-south direction and no continuity zone for iron ore deposits is found due to the long distance between the trajectories. The resource of iron ore deposits in the research area with an area of ±39 hectares is 7.230.456 tons which is dominated by hematite iron ore.

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