

## RESEARCH ARTICLE

# Interpretation of 2D-Subsurface Resistivity Data in The Iron Ore Prospect Area of Eastern Binangun Coastal, Regency of Cilacap, Central Jawa

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## Abstract

Interpretation of 2D-subsurface rock resistivity data has been carried out in the iron ore prospect area of Eastern Binangun Coastal in Cilacap Regency, Central Java. The background of this research is the potential for abundant iron sand in this area that prospects to be exploited. The research was conducted using a magnetic method in 2017 to map the distribution patterns of the local magnetic anomalies that were interpreted to originate from the distribution of iron ore in the subsurface. In 2018, the research continued using the 2D-resistivity method to find out the lithology section in the subsurface of research area. 2D-resistivity data acquisition is carried out on four tracks consisting of Bng-01 to Bng-04. The resistivity data modeling have produced the true resistivity value for each track in the form of the subsurface resistivity section, which including the Bng-01 track is 2.27 – 44.1  $\Omega\text{m}$ ; the Bng-02 track is 4.5 – 58.6  $\Omega\text{m}$ ; the Bng-03 track is 6.37 – 63.4  $\Omega\text{m}$ ; and the Bng-04 track of 4.98 – 83.3  $\Omega\text{m}$ . After interpretation process, some models of subsurface rocks lithology section is obtained under the four trajectories. The rocks acquired from interpretation process consists of sand which inserted with gravel (> 58.6  $\Omega\text{m}$ ); sand containing iron ore grains (28.2 – 83.3  $\Omega\text{m}$ ), clayey sand (11.1 – 32.9  $\Omega\text{m}$ ), sandy clay (4.98 – 13.5  $\Omega\text{m}$ ), and fine sand which intruded by saltwater (<6.49  $\Omega\text{m}$ ). Sand containing iron ore grains is main part of the coastal aquifer so that exploitation of iron sand has the potential to reduce aquifer function in storing and flowing of groundwater and causing of abrasion in the Eastern Binangun Coastal area rivers.

**Keywords:** 2D-resistivity data, Iron ore, Subsurface lithology section, Binangun Coastal

## 1. Introduction

### 1.1 Research Background

One of the natural resources found in the south coast of Java Island in Indonesia is iron sand. Iron sand is a rock fragment measuring between gravel and silt or 0,0625 – 2 millimeter on the Wentworth-Udden scale (a scale which distinguishes sedimentary rocks based on their size). Based on the information from the Oregon Department of Geology and Mineral Industries (Dole, 2006), iron sand consists of opaque mineral mix with non-metallic minerals, such as feldspar, calcite, biotite, amphibole, tourmaline, pyroxene, and others. While the iron ore minerals consist of magnetite, titaniferous magnetite, ilmenite, limonite, and hematite. Titaniferous magnetite is an important part, which is a change from magnetite and ilmenite. Especially the iron ore minerals come from the basaltic and the andesitic volcanic rocks.

Regency of Cilacap, that located at the south coast of Java Island has abundant natural resources of iron sand. One of them is The Eastern Binangun Coastal. This area is located in the eastern of Cilacap City with a distance is about 35 km. The iron ore reserves in this

area have not been officially exploited. According to [The Cilacap Regency Official Website \(2013\)](#), the total area which prospect of iron ore is more than 500 hectares, with a magnetism degree of 12.20% and iron (Fe) content of more than 53%. The coastal area which prospect contains iron ore stretches from the Village of Welahan Wetan District of Binangun to the Village of Jetis District of Nusawungu with reserve is about 744,678.85 tons. The dominant iron ore mineral in the Binangun Coastal is magnetite (Fe<sub>3</sub>O<sub>4</sub>) ([Jatmika et al., 2012](#)).

Geologically, the research area is composed of the alluvium formation and coastal sediments ([Asikin et al., 1992](#)). The alluvium deposits that occupy the northern of the research area consist of silt, clay, sand, gravel, gluttony; and rocks material resulted from erosion of Karangbolong Ancient Volcano that deposited through the flow of several rivers into the research area ([Asikin et al., 1992](#)). While the coastal deposits that occupy the southern part of research area consist of very loose sand that shows the impression of layering where iron sand resource is found ([Herman, 2005](#)), based on the results of research which performed by [Sehah et al. \(2017\)](#), the sediment rock was obtained. These rocks

are interpreted as sand containing iron ore inserted with clay, silt, and gravel from the alluvium formation with depth of 1.709 – 11.966 meters. The magnetic susceptibility value of these rocks is estimated about 0.0093 cgs unit.

The coastal aquifer is the groundwater sources that potential in the Eastern Binangun Coastal area, such as for drinking, bathing, and other necessities of human life. The coastal aquifers are an important water source to meet the needs of freshwater, especially in areas that develop along the coast (M'koumfida et al., 2018). Many areas on the coast which many populations, causing increased demand for freshwater. Also, in this area usually there is the interface zone as a barrier between saltwater and freshwater (Supriyadi et.al, 2017). Therefore, this area around the coastal requires a special attention and management to overcome it. Moreover, this area is the prospect of iron ore which potential to be exploited.

## 1.2. Basic Theory

To determine the characteristics of coastal aquifers in the iron ore prospect area, the geophysical research is carried out. The method used in this research is the 2D-resistivity. The 2D-resistivity method is one of methods in the geoelectric survey which used to research subsurface conditions by studying the nature of electricity in the subsurface rocks. Generally, the resistivity method is used for shallow exploration, that is around 300 – 500 meters (Nurhidayat, 2016). The resistivity method can be used for exploration in several fields, such to interpret subsurface stratigraphical structure, distribution of mineral deposits, accumulation of petroleum in the shallow reservoir layer, groundwater aquifers, geothermal reservoirs, and fluid contact between oil and water (Hersir, 2015).

This research aims to obtain the 2D-resistivity cross section in the subsurface of Eastern Binangun Coastal area based on the resistivity data from the acquisition. The subsurface resistivity profile that obtained is interpreted to obtain the subsurface rocks lithological profile in this area including the coastal aquifer and iron sand deposits so that its physical characteristics can be evaluated early. The 2D-resistivity method is suitable for this purpose because its working principles are based on the changes of the subsurface rocks resistivity values in two dimension, which easy to detect (Kumar et.al., 2015)

Data acquisition technique in the 2D-resistivity can be done by injecting the DC electric current into the rock of the earth's crust through two current electrodes;  $C_1$  and  $C_2$ . The DC electric current which injected will spread evenly to all rocks medium as shown in Fig. 1. The electrical polarization that occurs in the subsurface rock is measured by two voltage potential electrodes, namely  $P_1$  and  $P_2$ . After the current and voltage values are measured, then the apparent resistivity value of the subsurface rock can be calculated using a simple equation (Telford et.al., 1990).

$$\rho_a = K \frac{\Delta V}{I} \quad (1)$$

where  $\rho_a$  is the apparent resistivity,  $K$  is the geometrical factor,  $\Delta V$  is the voltage (mV) and  $I$  is the current (mA). The calculated resistivity is generally expressed in Ohm-meters ( $\Omega m$ ).

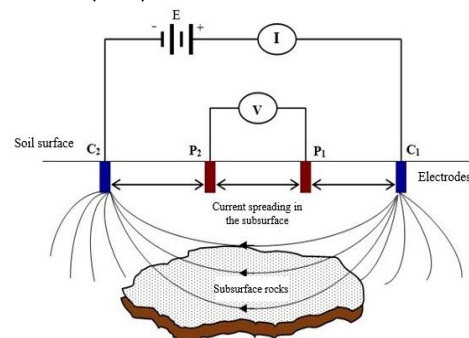


Fig. 1. The scheme of geo-electrical resistivity data acquisition

The geometrical factor in the equation (2) will give a certain value for a used electrode spacing. And for Wenner configuration, all inter-electrode spacing are equal to a constant value, i.e.  $a$ . Thus, the geometrical factor can be written as

$$K = \frac{2\pi}{\left(\frac{1}{C_1 P_1} - \frac{1}{P_1 C_2}\right) - \left(\frac{1}{C_1 P_2} - \frac{1}{P_2 C_2}\right)} = 2\pi a \quad (2)$$

The advantage of the Wenner configuration is that the accuracy of voltage readings on  $P_1, P_2$  electrodes is better because the  $P_1, P_2$  electrodes are relatively close to the  $C_1, C_2$  electrodes as if using the multimeter measuring instrument with a relatively smaller impedance.

The subsurface rocks as a medium also have different resistivity properties according to its type. Therefore, by utilizing the differences in the resistivity properties of the rocks, then it can be seen how the subsurface geological conditions. In this research, the 2D-resistivity method has used to investigate and interpret the subsurface geological structures. The variation in rocks resistivity depends on the types of rocks and minerals, porosity, fluid content in the pores of the rock (can be in the form of petroleum, gas, or water), and others (Saad et.al., 2012)

## 2. Research Method

The acquisition of 2D-resistivity data using Wenner configuration has been carried out in Eastern Binangun Coastal area Regency of Cilacap, as shown in Fig. 2. Data processing, data modeling, and interpretation were carried out in the Geophysical Laboratory; Faculty of Mathematics and Natural Sciences, Jenderal Soedirman University, Purwokerto, Central Java. This research has been conducted for six months; from March to August 2018. The main equipment that used is Resistivity meter with NRD-300 type, which equipped with supporting components. Also, the other equipment also used, such the global positioning system (GPS), the geological maps, the google earth applications, and others.

The research begins with the determination of the location of trajectory for 2D-resistivity data acquisition.



Fig. 2. The research location; The Eastern Nusawungu Coastal in Cilacap Regency

First, the entire of electrodes is positioned on the left of the trajectory with the same distance, that is equal to  $a$ . Next, be measured some variable, i.e. current ( $I$ ), voltage ( $\Delta V$ ), and distance between electrodes ( $a$ ). Moreover, then all electrodes are moved to the right as far as  $a$ , where  $C_1$  is moved to  $P_1$ ,  $P_1$  is transferred to  $P_2$ , and  $P_2$  is moved to  $C_2$ , then those physical variables are measured again. The measurements are carried out continuously until the entire of research area can be covered. To obtain the 2D-resistivity section under a particular trajectory, the resistivity data acquisition on a trajectory is repeated up to  $n$  times of measurements; where each the repeating, the distance between electrodes is always widened to  $2a$ ,  $3a$ ,  $4a$ ,  $5a$ ,  $6a$  and so on, as shown in Fig. 3 (Saad, 2012). But the electrode movement distance to the right is made fixed, that is equal to  $a$ .

The obtained resistivity data from the acquisition on each track, then processed and modeled in inversion. The obtained result is the 2D-resistivity cross section of subsurface rock. Based on the geological information of the research area and the supporting of research data, then be conducted interpretation to the 2D-resistivity cross-section, so obtained the subsurface lithological profile of the research area. Based on this subsurface lithological profile, iron sand deposits and their exploitation effects on the research area can be interpreted, especially for the coastal aquifers.

### 3. Result and Discussion

The 2D-resistivity data acquisition with the Wenner configuration has been conducted over four trajectories which placed in the iron ore prospect area, based on the local magnetic anomaly map from the research by Sehad et al. (2017). The position of each trajectory is

shown in Fig. 4. The data which obtained in the field for each trajectory consists of electric current ( $I$ ), voltage ( $\Delta V$ ), and distance between electrodes ( $a$ ). Based on these data, the geometrical factor ( $K_{Wen}$ ) and the apparent resistivity ( $\rho_a$ ) values for each array can be calculated. Then the datum point value for each  $n$  of measurement can be determined based on the distance value between electrodes in the Wenner configuration.

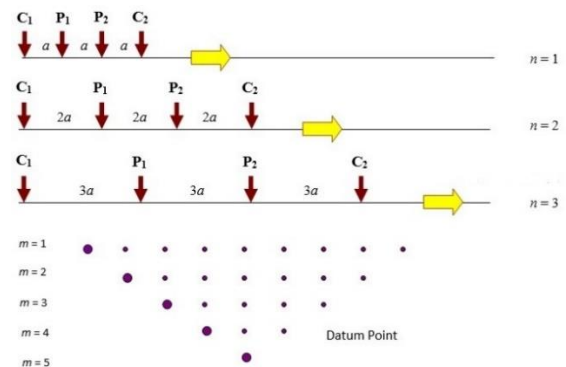


Fig. 3. The resistivity data acquisition technique uses the Wenner configuration.

The apparent resistivity, the datum point, and distance between electrodes for each  $n$  data in the trajectory are then modeled to result in 2D-subsurface resistivity profile. The 2D-subsurface resistivity profile that generated from modeling for the Bng-01 to Bng-04 trajectories is shown in Fig. 5 to Fig. 8. While its lithological interpretation results are shown in Table 1 to Table 4. The length of each data acquisition trajectory is 200 meters. The obtained results showed that the trend of subsurface rocks resistivity value changed downward; where the value is getting smaller.

The 2D-subsurface resistivity profile which obtained is interpreted so that known the types of its constituent rocks, including iron sand deposits and coastal aquifer. The interpretation results are designed using the Res2Dinv 3.54 software, so that it can obtain the 2D-subsurface lithological profile in the research area as shown in Appendix 1. This design is based on the 2D-resistivity profile and the results of its interpretation. Then, the resistivity values of some objects having similar interpretation are grouped into one type of rock. Example fine sand, sandy clay, clayey sand, sand containing iron ore, and others.

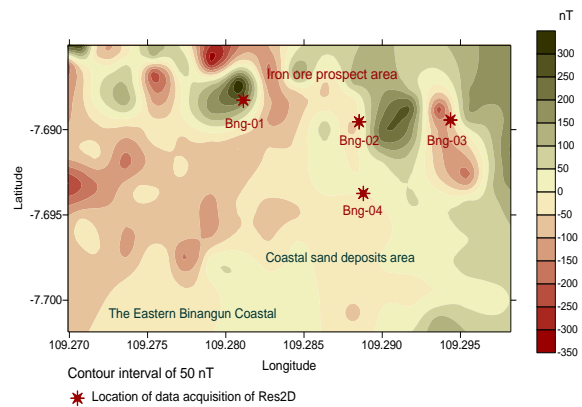


Fig. 4. Location of 2D-resistivity data acquisition on the magnetic anomaly map of Eastern Binangun Coastal area in Cilacap Regency

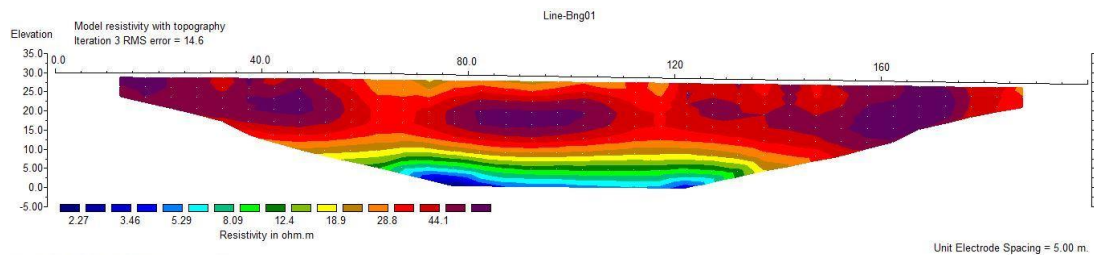


Fig. 5. The 2D-subsurface rocks resistivity profile of modeling results using Res2DInv 3.54 in the Bng-01 trajectory

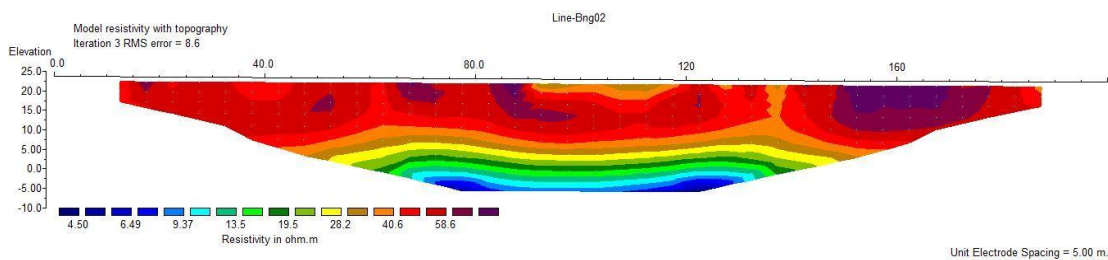


Fig. 6. The 2D-subsurface rocks resistivity profile of modeling results using Res2DInv 3.54 in the Bng-02 trajectory

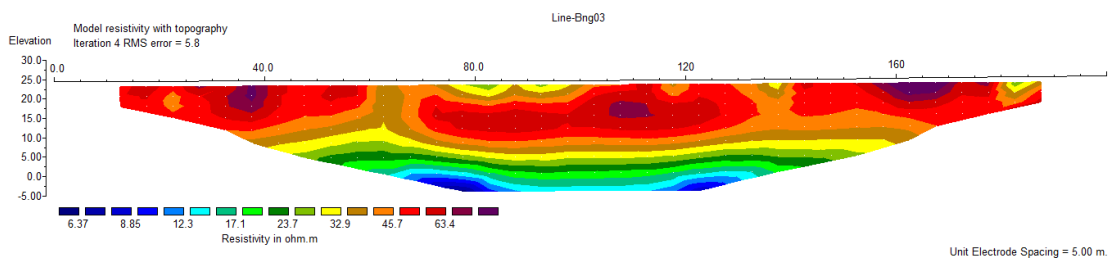


Fig. 7. The 2D-subsurface rocks resistivity profile of modeling results using Res2DInv 3.54 in the Bng-03 trajectory

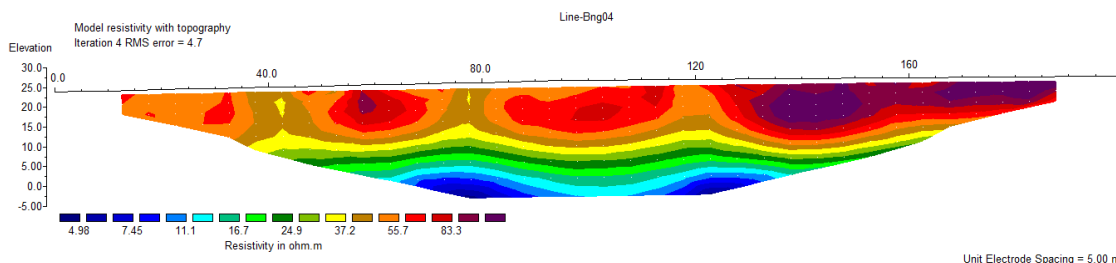


Fig. 8. The 2D-subsurface rocks resistivity profile of modeling results using Res2DInv 3.54 in the Bng-04 trajectory

Table 1. The interpretation results to the 2D-resistivity profile contour of the Bng-01 trajectory.

Resistivity ( $\Omega\text{m}$ )	Interpretation	
	Lithology	Hydrology
< 5.29	Fine Sand	Deep aquifer
5.29 – 12.4	Sandy clay	Semi
12.4 – 28.8	Clayey Sand	impermeable
> 28.8	Sand containing iron ore grains	Semi aquifer Shallow aquifer

The subsurface rock resistivity section in the Bng-01 track shows that the deep aquifer is estimated been intruded by saltwater. This estimation is based on the small resistivity value for the coastal aquifer. According to the literature, the layers that saturated with saltwater and dissolved solids have resistivity values of 8 – 50  $\Omega\text{m}$  (Satriani, 2011). This is also supported by information from the map of Groundwater Potential Indication and Irrigation Area which issued by the Ciptakarya General Directorate (2003). The Iron ore is estimated to be in the sand with a resistivity value of **more than 28.8  $\Omega\text{m}$  and partly distributed up to the surface**. The range of its resistivity values is relatively small and according to the high magnetic anomaly value, which shows a high iron ore content (Saad et.al., 2012).

Table 2. The interpretation results to the 2D-resistivity profile contour of the Bng-02 trajectory.

Resistivity ( $\Omega\text{m}$ )	Interpretation	
	Lithology	Hydrology
< 6.49	Fine Sand	Deep aquifer
6.49 – 13.5	Sandy clay	Semi
13.5 – 28.2	Clayey sand	impermeable
28.2 – 58.6	Sand containing iron ore grains	Semi aquifer Shallow aquifer
> 58.6	Sand inserted with gravel	Non aquifer

Based on the modeling results as shown in Fig. 2, the deep aquifer in the Bng-02 track is interpreted to have also been intruded by saltwater. This is based on the very small resistivity value, that is less than 6.49  $\Omega\text{m}$ . While the shallow aquifers are mostly estimated not to be intruded by salt water, sand that contains iron ore is estimated to be present on the surface of research area.

The interval of rocks resistivity values in this trajectory is 6.49 – 58.6  $\Omega\text{m}$ . The rocks with relatively high resistivity values (more than 58.6  $\Omega\text{m}$ ) are not dominant and only localized in the north. The rocks are interpreted as sand inserted with gravel, but estimated contains small amounts of iron ore.

Table 3. The interpretation results to the 2D-resistivity profile contour of the Bng-03 trajectory.

Resistivity ( $\Omega\text{m}$ )	Interpretation	
	Lithology	Hydrology
< 6.37	Fine sand	Deep aquifer
6.37 – 12.3	Sandy clay	Semi
12.3 – 32.9	Clayey Sand	impermeable
32.9 – 63.4	Sand containing iron ore grains	Semi aquifer Shallow aquifer
> 63.4	Sand inserted with gravel	Non aquifer

The results of modeling on the 2D-resistivity profile in the Bng-03 track is similar to the Bng-02 track, both its resistivity value and its interpretation result. Then, in this trajectory, there is also sand deposite which interpreted to contain iron ore grains. The range of rock resistivity values in the Bng-03 track is relatively higher than Bng-02 track, which is 6.37 – 63.4  $\Omega\text{m}$ . Rocks with a higher resistivity value (more than 63.4  $\Omega\text{m}$ ) are very few, only localized at three places. Those rocks are interpreted as sand that inserted with gravel and may to still contain small amounts of iron ore. The rocks may contribute as one of the negative anomalous sources in the magnetic anomaly map, as shown in Fig. 4. This is related to low iron ore mineral content in it.

Table 4. The interpretation results to the 2D-resistivity profile contour of the Bng-04 trajectory.

Resistivity ( $\Omega\text{m}$ )	Interpretation	
	Lithology	Hydrology
< 4.98	Fine sand	Deep aquifer
4.98 – 11.1	Sandy clay	Semi
11.1 – 24.9	Clayey sand	impermeable
24.9 – 83.3	Sand containing iron ore grains	Semi aquifer Shallow aquifer
> 83.3	Sand inserted with gravel	Non aquifer

The range of resistivity values for the Bng-04 track is the highest, which is 4.98 – 83.3  $\Omega\text{m}$ . Sand inserted with gravel (located at the upper right on Fig. 8) is thought to contribute to this. In addition, this trajectory is relatively far from the magnetic anomalies closures center as shown in Fig. 4, so the iron sand deposits in this research area are not expected to be much, such as previous trajectories. This also produces high resistivity value in this area. In general, the results of lithological interpretation on the Bng-04 track is same as the others tracks. This is related to the changes of the subsurface resistivity values which almost same in the all research areas. It indicates that the research area has the same subsurface rock stratigraphy.

Based on the results of 2D resistivity data modeling on trajectories throughout the research area, it is known that the research area is dominated by rocks which have relatively small resistivity values (<100  $\Omega\text{m}$ ). The rocks are defined as sedimentary rock, especially the alluvium and coastal deposite. Sedimentary rocks generally have low resistivity values because it has high water content and greater porosity than igneous and metamorphic rocks. This is consistent with the geological information that the dominant rocks in the research area are coastal deposits and alluvium, where iron ore resource is found (Herman, 2005). According to some residents, the iron sand can be observed clearly when they dig wells with an average depth of about 5 meters. In some locations, iron sand is often found on the surface of research area as shown in Fig. 9. Most of the iron ore grains have been mixed with sand, gravel and surface soil. Because of enough prospects, in this area iron ore mining was carried out by the local company. But this business was stopped, because it was opposed by the community



Fig. 9. Iron ore grains are found on the surface of the research area in the Eastern Binangun Coastal

The fact that shallow aquifers in the research area are not intruded by saltwater is supported by the results of testing the electrical conductivity of water samples.

All water samples are taken from the wells around the resistivity data trajectories. The complete testing results of electrical conductivity of several well water samples can be seen in Table 5. Table 5 shows that well

water sourced from shallow aquifers in this area may not have been intruded by salt water, like the results of hydrological interpretation. According to [Hendrayana \(2002\)](#) the limit of the electrical conductivity value for freshwater is less than 1.500  $\mu\text{Si}$  per cm, so that all well water samples in this coastal area are freshwater. The electrical conductivity in minerals and solutions takes place by the movement of electrons and ions ([Porretta and Bianchi, 2016](#)). The electric conduction in the rocks, in many cases through water contained in the rock pores and along the interface layer of the rock and solution ([Kebede, 2001](#)).

Table 5. The electrical conductivity of several water samples from measurements taken around the trajectories.

Water Samples	Average Electrical Conductivity ( $\mu\text{Si}/\text{cm}$ )	Distance from The Sea (m)
Bng - 01	425,00	1396,69
Bng - 02	456,67	1297,49
Bng - 03	608,99	1305,71
Bng - 04	394,33	654,36

Water samples were taken from 2 – 3 wells for each trajectory.

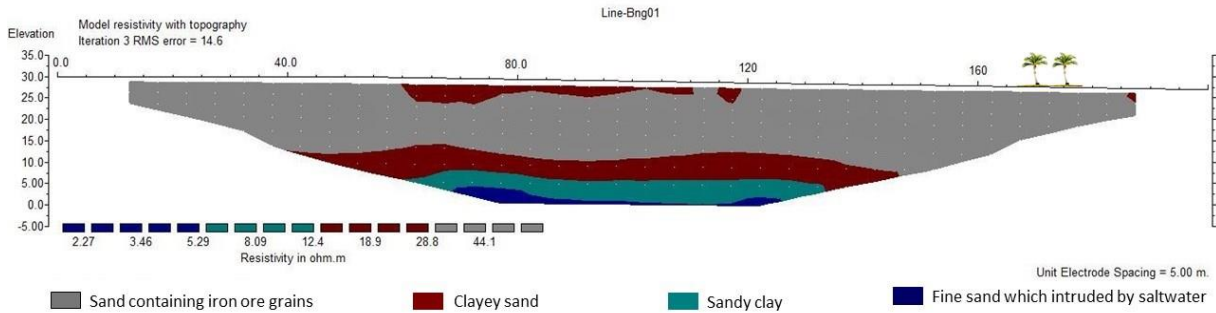


Fig. 10. The subsurface rocks lithological profile of interpretation results using Res2Dinv 3.54 on the Bng-01 trajectory

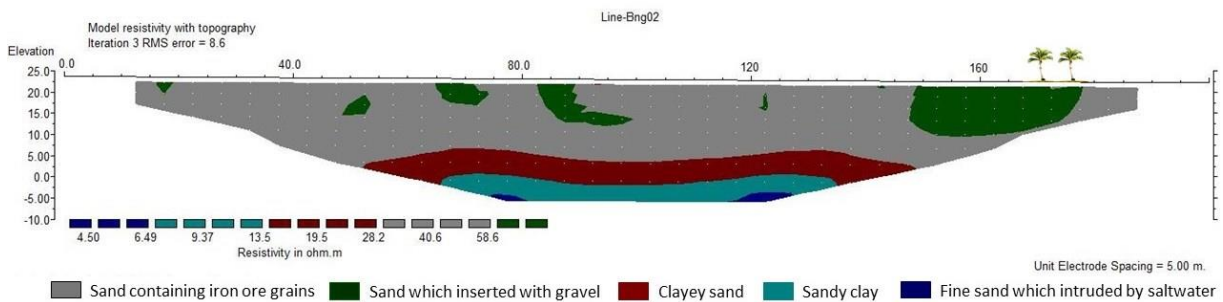


Fig. 11. The subsurface rocks lithological profile of interpretation results using Res2Dinv 3.54 on the Bng-02 trajectory

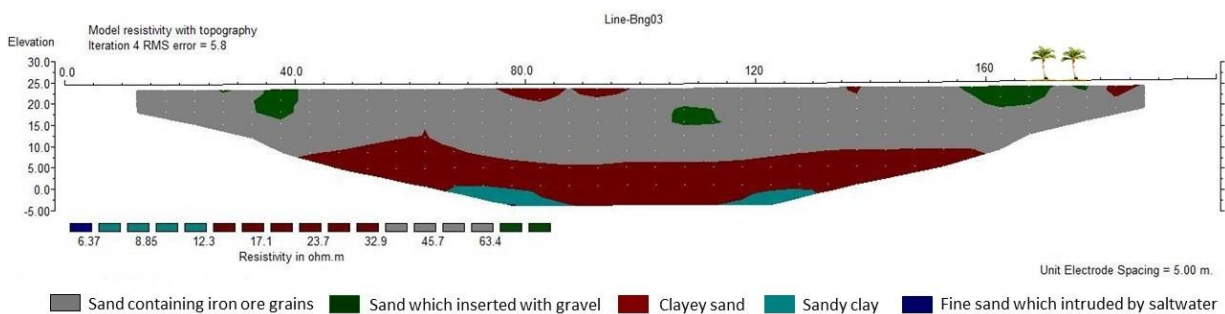


Fig. 12. The subsurface rocks lithological profile of interpretation results using Res2Dinv 3.54 on the Bng-03 trajectory

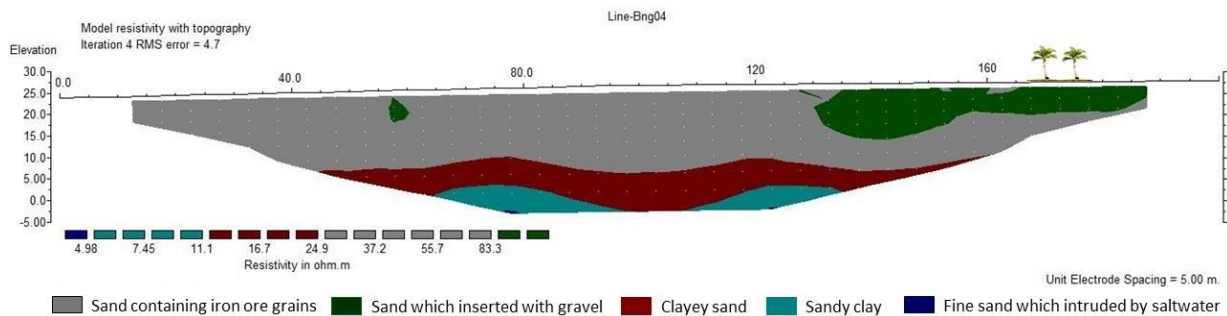


Fig. 13. The subsurface rocks lithological profile of interpretation results using Res2Dinv 3.54 on the Bng-04 trajectory

#### 4. Conclusion

The geoelectric-resistivity survey has been done in the iron ore prospect area of Eastern Binangun Coastal in Cilacap Regency Central Java Indonesia with purpose to interpret the subsurface rock structure. This research was conducted for six months; from March to August 2018. Data acquisition of the 2D-resistivity in the field has been carried out on four tracks consisting of Bng-01 to Bng-04 using the Wenner configuration. Those data trajectories is placed in the iron ore prospect area based on the local magnetic anomaly map of research area.

Based on the results of 2D-resistivity data modeling, the true resistivity value can be obtained for each track in the form of subsurface resistivity cross-section, which includes the Bng-01 track of 2.27 – 44.1  $\Omega\text{m}$ ; the Bng-02 track of 4.5 – 58.6  $\Omega\text{m}$ ; the Bng-03 track of 6.37 – 63.4  $\Omega\text{m}$ ; and the Bng-04 track of 4.98 – 83.3  $\Omega\text{m}$ . After interpretation, then obtained the subsurface lithological profile, consisting of several rocks. Those rocks consists of sand which inserted with gravel (> 58.6  $\Omega\text{m}$ ); sand containing iron ore grains (28.2 – 83.3  $\Omega\text{m}$ ), clayey sand (11.1 – 32.9  $\Omega\text{m}$ ), sandy clay (4.98 – 13.5  $\Omega\text{m}$ ), and fine sand which intruded by saltwater (<6.49  $\Omega\text{m}$ ).

The sand which contains iron ore is main part of the coastal aquifer. The exploitation of iron sand massively causes sand and other subsurface rocks to disappear or decrease. Therefore, this exploitation activity has the potential to reduce the aquifer function in storing and flowing of groundwater. Furthermore, this activity also can trigger the coast abrasion and seawater intrusion into coastal aquifers in the research area.

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