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Magnetic Anomaly to Revealed of Iron Sand Distribution on Jolosutro Beach, East Java, Indonesia

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***Abstract*— *This study aims to investigate the distribution of iron sand at Jolosutro Beach located in Ringinsari Village, Wates Sub-district, Blitar Regency, East Java. The presence of iron sand at the sampling site was predicted to have originated from the placer deposit that was concentrated along Ringinrejo River and then weathered and formed sediment throughout Ringinrejo River and Jolosutro Beach. A magnetic method was employed in this study by measuring the natural magnetic field of the surrounding stones. Data acquisition was accomplished using a Proton Procession Magnetometer (PPM), Geometrics type G-856. As many as 784 measurement points were obtained from an area of 2,500 × 3,000 meters, with a distance of 100 meters between points. The interpretation was carried out according to parameters of magnetic susceptibility and regional geological information from the sampling sites to disclose the distribution of iron sand on Jolosutro Beach. Based on magnetic data acquisition, there were three subsurface structure models consisting of soil and sandstone as the first layer, followed by andesite rock as the second layer and volcanic rock as the third layer. This study found that iron sand was evenly distributed throughout the entire study area. Moreover, the southern part of the study area has the highest anomaly value, with a range of 217.6 nT to 441.5 nT.*

***Keywords*— *Magnetic method, Jolosutro Beach, iron sand, susceptibility.*

I. Introduction

Indonesia is one of the countries that are rich in natural resources, including minerals, oil, and gas [1]. Indonesia's mining sector is one of the important sectors that the government relies on, especially to contribute to foreign exchange. This sector is required to be able to optimize and manage Indonesia's natural resources, especially mineral resources. One of the mineral deposits that are beneficial and well known to have high economic value is iron ore [2]. The nature of these iron deposits is mostly stand-alone, but they are also often found to be associated with other metal minerals [3]. Iron ore is derived from volcanic rock, andesite, and basalt that contain iron [10]. Volcanic materials were then deported to the coast through the river; they ended in the ocean, got eroded, then deported to the shore and deposited [4].

Iron sand has been recorded to be distributed widely in Indonesia, from the western part of Sumatra to Sulawesi. Java Island itself is known for holding a great potential of iron sand, particularly in the southern part of Java [1]. One of the regions located in East Java is indicated to have iron ore, namely Ringinrejo Village, Wates Sub-district, Blitar Regency [5]. Iron mining conducted by a company in this region has revealed the potential it has. Moreover, the geological map of Blitar that falls under Mandalika formation (Tomm) consisting of andesite-basalt, latit, porphyry, rhyolite, dacite, and alluvium (Qa) supports previously reported results [6].

Exploitation and production of iron ore in Ringinrejo Village were once carried out by a company by referring to Law No. 32/2004, Law No. 4/2009, Government Regulation No. 38/2007, Regulation of State Minister of Environment No. 11/2006, Spatial Planning Regulation (Rencana Tata Ruang Wilayah–RTRW) of Blitar Regency of 2004–2014 and 2009–2028. However, the establishment of Regional Regulation No. 5/2009, which assigns Jolosutro Beach as a tourism region, has triggered a strong rejection of mining activities. Damage on the beach environment due to mining activities has reduced the number of fishes caught by fishermen and the income of traders and increased beach erosion [9]. These issues may occur due to previous nonoptimal exploration. Therefore, it is necessary for one to conduct a preliminary study to investigate the distribution of iron ore using magnetic methods based on the measurement of the natural magnetic field. The magnetic method is one of the geophysical methods used to obtain images of the earth's surface based upon its magnetic properties [7]. This method utilizes the earth's magnetic properties to illustrate the contour maps of subsurface susceptibility distribution [14]. The value of magnetic field intensity is used to categorize rocks based on their magnetic properties, which then could be used to determine the distribution of iron sand as iron ore is easily magnetized, and its magnetic susceptibility is relatively large [3, 8]. Therefore, the geological objective of this study was to find the magnitude of the magnetic anomaly, the subsurface structure, and the distribution of iron ore. Furthermore, the collected data were used to investigate the prospective area for iron ore.

II. Regional Geology of the Research Area

The research area was located on Wates Sub-district, Blitar Regency, East Java. Wates Sub-district is stretched from the east to the south ends of Blitar Regency, where Malang Regency is at the east border and the Indian Ocean at the southern border. Hence, the geography and demographics of Wates Sub-district comprise mountains and the coastal area, including Jolosutro Beach [5]. Wates Sub-district is located at coordinates $112^0 17'5''$E-$112^0 23'1''$E and $8^0 13'44''$S-$8^0 20'55''$S. Based on the geological condition, Wates Sub-district consists of Mandalika formation, Campurdarat, Wonosari, and alluvium. Mandalika formation was revealed as the oldest formation in this region that originated from the late Oligocene to middle Miocene and consisted of andesitic-

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basaltic lava, trachyte, dacite, and andesitic breccia. In addition, Mandalika formation also contains a tuff that consists of andesitic tuff, liparite (rhyolite), and breccia that were predicted to contribute to the formation of iron sand at Jolosutro Beach [6].

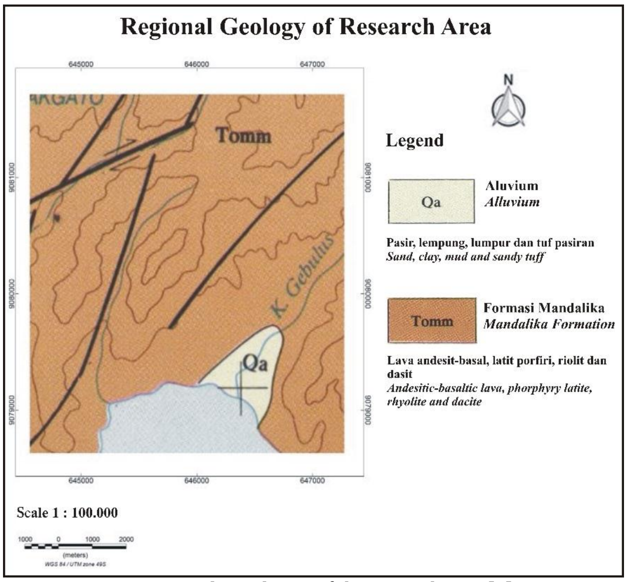

Fig. 1. Geological map of the research area [6]

III. MATERIAL AND METHODS

Magnetic data acquisition was conducted in November 2019 on Jolosutro Beach. The research area was located in Ringinsari Village, Wates Sub-district, Blitar Regency, East Java Province. Magnetic data collection was carried out at an area of 3,000 × 2,500 m that covered the Jolosutro coastal area (Figure 1). The distance between sampling points was ±100 m depending on the field conditions. Data collected included magnetic field intensity, latitude and longitude, altitude, and time. Magnetic field intensity was measured using a Proton Procession Magnetometer (PPM), Geometrics type G-856. Meanwhile, other data, such as latitude, longitude, and altitude, were collected using GPS, and time was recorded by checking the clock. Data collection was carried out using the looping method. There were 784 sampling points selected in this study from the estimated 806 points. The reduction of sampling points was due to difficulty in reaching locations of the targeted points, such as locations above cliffs without any access road.

Magnetic data were processed by using the results of magnetic data acquisition. Data obtained from the field indicated a magnetic anomaly that was influenced by locations inside and outside of the earth. Therefore, a correction was required for further processing through both diurnal correction and correction of the International Geomagnetic Reference Field (IGRF) [7]. A correction was conducted by subtracting the value of magnetic intensity at the base station from the value of the magnetic field intensity of the sampling points. In addition, the transformation was also carried out through an upward continuation and reduction to pole [11]. Upward continuation aims to delete or reduce the effect of residual anomalies that are still present in the data and to find the effects of residual anomalies. The magnitude of magnetic anomalies consisted of two overlapping components: regional and residual component anomalies. The magnetic anomaly data, as the survey target, have always been superposed with other magnetic field anomalies that were originated from a deep and broad source under the surface called the regional anomaly. Interpretation of magnetic anomalies could be carried out when the effect of regional anomaly has been reduced or deleted from the total of magnetic anomalies. By contrast, the residual anomaly obtained from the previous stage was then transformed using reduction to pole. The underlying reason for this transformation is differences in the values of inclination and declination from each region. Therefore, the transformation may try to change a magnetic field from sampling points to a magnetic field from the north pole [8].

In general, magnetic data interpretation could be conducted in two ways: qualitative and quantitative [12]. The qualitative interpretation was based on the contours of the magnetic field anomaly originated from the magnetized objects under the earth's surface. Meanwhile, quantitative interpretation was carried out by constructing a model from residual anomalies. The purpose of magnetic data interpretation is to determine the shape/model and the depth of the objects causing anomalies through mathematical modeling. Modeling was carried out using forward modeling to create a closed polygon and changing its parameters and shapes through a trial-and-error method to find a match between the anomalous data curve from the measurement results and the modeling curve with a small error.

IV. RESULT AND DISCUSSION

IV.1 Total Magnetic Field Anomaly

The total magnetic field anomaly represented the subsurface geological conditions influenced by the shallow source anomalies and deep source anomalies. The highest value of the total magnetic intensity of the study area was 441.5 nT, and the lowest value was −207.4 nT (Figure 2). Positive and negative values indicate the magnitude of magnetic anomalies in the research area and the presence of either positive or negative closure. This positive and negative closure pair indicated that the magnetic field anomaly is a dipole or bipole [3]. According to the range of magnetic anomalies, the research area was categorized into three groups: low, medium, and high anomalies. The low magnetic anomaly was detected in the east and southeast of the study area and presented in dark blue to light blue with a range of −207.4 nT to −58.1 nT. The low anomaly probably consisted of beach and river sediments. River sediment is predicted to be originated from Wonosari River located in the eastern part of the research area. Wonosari River flows from Mount Geblug to the east, expands to the south, and ends at Jolosutro Beach. Contrarily, beach sediment is predicted to be originated from waves of seawater that are continuously heading toward the coast. These sediments generally consisted of sand and mud.

Romandah Kusuma Nur Febriana, Adi Susilo, and Wiyono, "Magnetic Anomaly to Revealed of Iron Sand Distribution on Jolosutro Beach, East Java, Indonesia," *International Research Journal of Advanced Engineering and Science*, Volume 5, Issue 3, pp. 133-137, 2020.

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Medium anomalies were indicated with green to orange colors and ranged from −48.8 nT to 203.6 nT, and they were spread in the western part of the research area. Meanwhile, high anomalies were indicated with red to pink colors and ranged from 217.6 nT to 441.5 nT, and they were spread in the southern part of the research area. Both medium and high anomalies were predicted to be consisting of volcanic rocks and pyroclastic deposits containing andesite. These rocks might be derived from Mount Futkhoria as it had a fairly high magnetic mineral content.

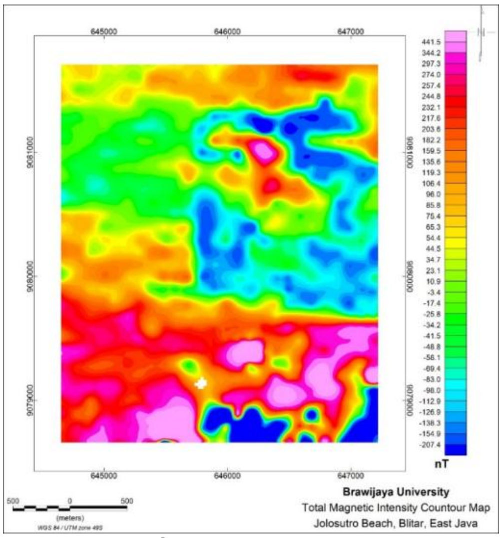

Fig. 2. Total magnetic intensity contour map

IV.2 Separation of Regional and Residual Anomalies

The magnetic anomalies that have gone through upward continuation consisted of regional and residual anomalies [13]. Regional anomalies were associated with general geological conditions in the research area characterized by a low-frequency anomaly. By contrast, residual anomalies were associated with local geological conditions that have been deviated from its regional conditions, and that generally occurred at shallow depths.

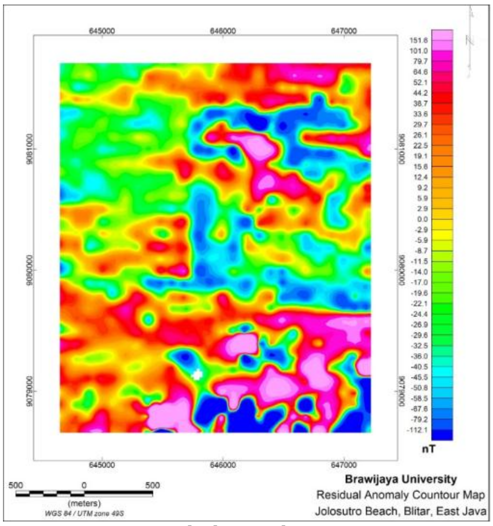

Fig. 3. Residual anomaly contour map

The results of the residual anomaly indicated that the lowest residual anomaly was −112.1 nT, and the highest residual anomaly was 151.6 nT (Figure 3). The pattern of a residual anomaly contour map is relatively similar to that of the total magnetic anomaly contour map. The target of this research was a residual anomaly. The residual anomaly indicated the subsurface rock structure in accordance with actual conditions in the field. A high value of the magnetic anomaly indicated high and positive magnetic susceptibility of rocks in the research area (rocks that are magnetic). The medium magnetic anomaly indicated medium and positive magnetic susceptibility of rocks. Meanwhile, the low magnetic anomaly indicated low and negative magnetic susceptibility of rocks (rocks that are nonmagnetic).

IV.3 Reduction to Pole

The residual anomaly contour map was basically sufficient to represent the condition of a magnetic anomaly in the research area (Figure 3); however, it was considered to be less valid if interpretation was performed qualitatively. During magnetic data processing, reduction to the pole is required to change the direction of magnetization to the vertical direction, so that the magnetic anomaly would be able to instigate the object's position that was responsible for it [15]. This process might result in a magnetic anomaly that was monopole [15]. A reduction to the pole was carried out on residual anomaly data (Figure 4). This study recorded that the research area has an inclination value of −32.9616° and a declination value of 0.9171°. Reduction to the pole was carried out by transforming the inclination value to 90° and the declination value to 0°, as the magnetic pole indicates that the directions of the earth's magnetic field and induction magnetic are downward.

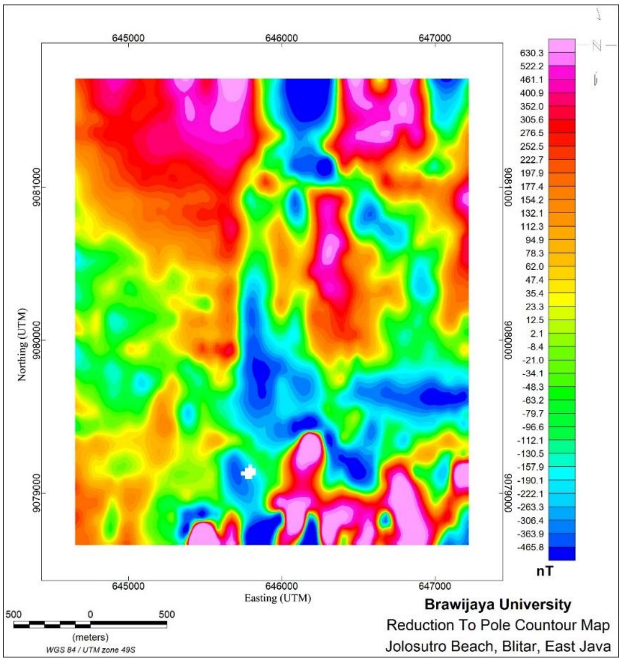

Fig. 4. Reduction to the pole contour map

Romandah Kusuma Nur Febriana, Adi Susilo, and Wiyono, "Magnetic Anomaly to Revealed of Iron Sand Distribution on Jolosutro Beach, East Java, Indonesia," *International Research Journal of Advanced Engineering and Science*, Volume 5, Issue 3, pp. 133-137, 2020.

IV.4 *Quantitative Interpretation*

Quantitative interpretation (Figure 5) was carried out by creating an incision on a magnetic anomaly. The incision was determined based on the results of the qualitative interpretation that has been obtained previously (see residual anomaly contour map and reduction to pole contour map). In addition, the determination of incision also depended on the geological conditions indicated by the Blitar geological map made by M. Z. Sjarifudin and S. Hamidi in 1992. The geological map explained that the acquisition points used in a recent study were dominated by volcano rocks that mostly belonged to Mandalika formation. There were three overlapping incisions (Figure 5), namely A-A' incision, B-B' incision, and C-C' incision. Quantitative interpretation intends to determine the shape/model and depth of anomalous objects or geological structures through mathematical modeling.

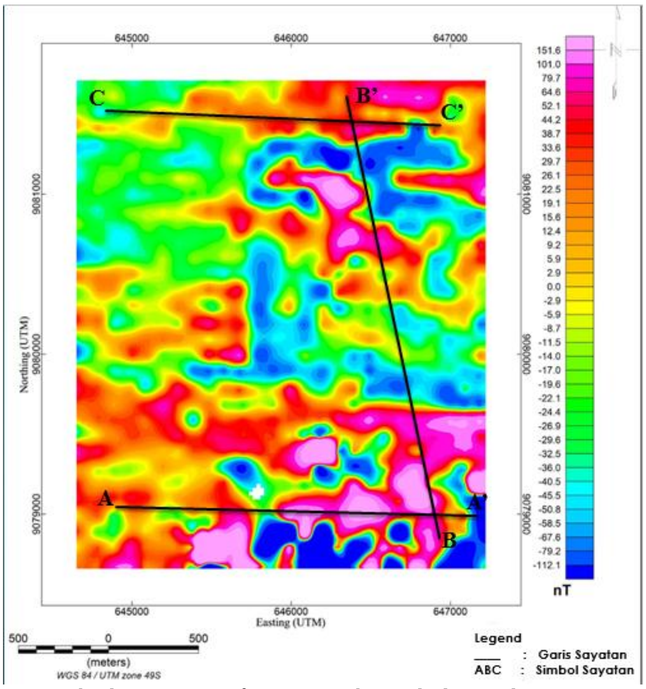

Fig. 5. The determination of incision on the residual anomaly contour map

The results of subsurface modeling on each incision are presented in Figures 6, 7, and 8. There were three putative layers on each incision. The A-A' incision cut from positive to negative closures at each end that went from southwest to southeast, with a length of 2,365 m, and three bodies with RMS of 5.33% were formed on this incision (Figure 6). The incision on the B-B' track cut from positive to negative closures at each end that went from southeast to north, with a length of 2,850 m. The modeling of the B-B' incision formed three bodies with RMS of 20.79% (Figure 7).

The C-C' incision cut from positive to positive closures at each end that went from southeast to north, with a length of 2,000 m. The results of modeling on the C-C' incision formed three bodies with RMS of 8.37% (Figure 8).

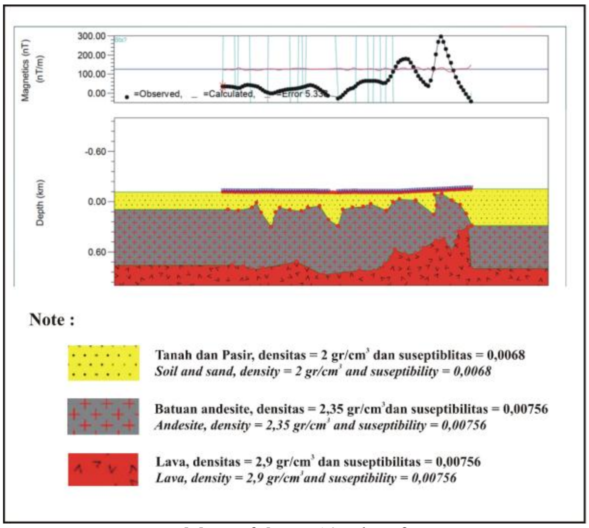

Fig. 6. Modeling of the A-A' subsurface structure

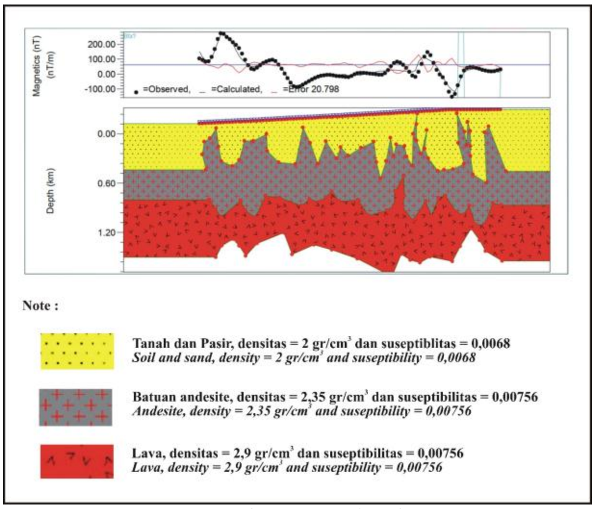

Fig. 7. Modeling of the B-B' subsurface structure

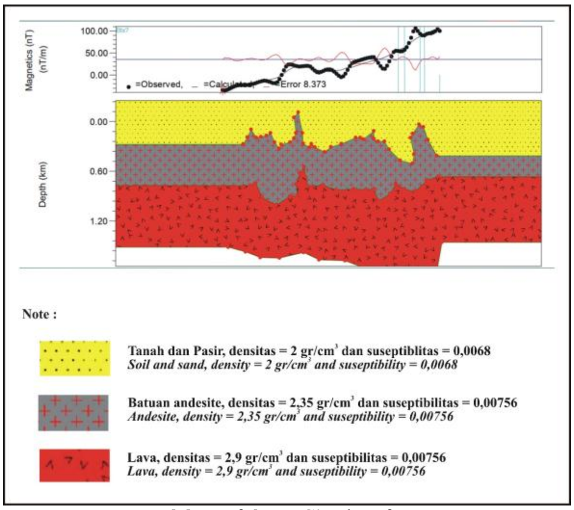

Fig. 8. Modeling of the C-C' subsurface structure

The results of subsurface modeling provided more tangible and comprehensible pictures of subsurface structures. According to subsurface modeling, volcanic rocks dominated the research area. These were in accordance with the information provided on the Blitar geological map, which exhibited that the research area occupies the southern part of Blitar and is composed of igneous rocks, sedimentary rocks, and volcanic rocks. The oldest rocks were known to be andesite, basalt, and latite porphyry that belonged to Mandalika formation (Tomm) and alternated with Tuf Mandalika Formation (Tomt) comprising of dacite and rhyolite (liparite). Those two rocks are predicted to have originated from late Oligocene [6]. The top layer was dominated by groups of soil and sandstone; this was in accordance with the Blitar geological map, where quarterly-holocene alluvium formation (Qa), as the youngest unit, was indicted in the map. Alluvium is originally divided into beach and river sediments. The beach sediment consists of sand and mud [6].

Aside of the availability of the geological map, the research area also covered Futkhoria Mount, comprising of rocks that were gray to blackish gray and weathered to brownish-gray in color. The color index ranged from mesocratic to melanocratic. Rock texture was mostly the size of the afanitic crystal. Therefore, Futkhoria Mount is indicated to consist of igneous rock, specifically basalt-porphyry and andesite-porphyry [6].

V. Conclusion

Magnetic data processing indicated that the research area comprised of three models of subsurface structures in which the first layer consisted of soil and sandstone, the second layer consisted of andesite rocks, and the third layer consisted of volcanic rocks. Iron sand is almost evenly distributed throughout the entire research area. In addition, the southern part of the research area has the highest magnetic anomaly ranging from 217.6 nT to 441.5 nT.

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