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APPLICATION OF MAGNETIC SURVEY TO EXPLORE THE IRON ORE DEPOSITS IN THE NUSAWUNGU COASTAL REGENCY OF CILACAP CENTRAL JAVA

APLIKASI SURVEI MAGNETIK UNTUK MENGEKSPLORASI ENDAPAN BIJI BESI DI KAWASAN PESISIR NUSAWUNGU KABUPATEN CILACAP JAWA TENGAH

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Abstract

The research aiming to explore the iron ore deposits in the Nusawungu coastal Regency of Cilacap has been conducted using the magnetic survey. The acquisition of magnetic data was conducted in April – Mei 2017, covering the area in the ranges of 109.314° – 109.345°E and 7.691° – 7.709°S. The obtained magnetic field strength data were corrected, reduced, and mapped to obtain the contour map of local magnetic anomaly. The modeling process was carried out along the path extending over the map from the positions of 109.314°E and 7.695°S to 109.335°E and 7.699°S, so that some subsurface anomalous objects are obtained. The lithological interpretation was performed to identify the types of subsurface rocks and their formations based on the magnetic susceptibility value of each anomalous objects and supported by the geological information of the research area. Based on the interpretation results, three rocks deposits of alluvium formations were obtained, which are estimated to contain iron ore. The first deposit has a length of 164.85 m, a depth of 0.57 – 8.43 m, and a magnetic susceptibility value of 0.0097 cgs. The second deposit has a length of 376.28 m, a depth of 2.56 – 19.66 m, and a magnetic susceptibility value of 0.0108 cgs. The third deposit has a length of 1,306.26 m, a depth of 3.70 – 58.69 m, and a magnetic susceptibility value of 0.0235 cgs. Out of the whole rocks deposits, the third rock deposit is interpreted to have the most prospective iron ore. This interpretation based on its high magnetic susceptibility value, which indicates the presence of many magnetic minerals (i.e. iron ores) in the rock.

Keywords: *exploration, iron ore, magnetic anomaly, magnetic susceptibility, Nusawungu coastal*

Abstrak

Telah dilakukan penelitian dengan tujuan untuk mengeksplorasi endapan biji besi di kawasan pesisir Nusawungu Kabupaten Cilacap menggunakan metode magnetik. Akuisisi data magnetik dilakukan pada bulan April – Mei 2017 di daerah penelitian yang membentang pada posisi 109,314° – 109,345°BT dan 7,691° – 7,709°LS. Data kuat medan magnetik total yang diperoleh, selanjutnya dikoreksi, direduksi, dan dipetakan sehingga diperoleh peta kontur anomali magnetik lokal. Pemodelan dilakukan di sepanjang *lintasan yang membentang pada peta kontur anomali lokal dari posisi 109,314°BT dan 7,695°LS hingga 109,335°BT dan 7,699°LS sedemikian hingga diperoleh model sebaran benda anomali bawah permukaan. Interpretasi litologi dilakukan untuk mengidentifikasi jenis-jenis batuan dan formasinya berdasarkan nilai suseptibilitas magnetik masing-masing benda anomali yang didukung informasi geologi daerah penelitian. Berdasarkan hasil interpretasi diperoleh tiga endapan batuan dari formasi alluvium yang diestimasi mengandung biji besi. Endapan pertama memiliki panjang 164,85 m, kedalaman 0,57 – 8,43 m, dan nilai suseptibilitas magnetik 0,0097 cgs. Endapan kedua memiliki panjang 376,28 m, kedalaman 2,56 – 19,66 m, dan nilai suseptibilitas magnetik 0,0108 cgs. Adapun endapan ketiga memiliki panjang 1.306,26 m, kedalaman 3,70 – 58,69 m, dan nilai suseptibilitas magnetik 0,0235 cgs. Dari keseluruhan endapan batuan tersebut, endapan batuan ketiga diinterpretasi paling prospek mengandung biji besi. Hal ini didasarkan atas nilai suseptibilitas magnetiknya yang cukup tinggi yang mengindikasikan banyaknya kandungan mineral magnetik (khususnya biji besi) di dalamnya.*

Kata Kunci: *eksplorasi, biji besi, anomali magnetik, suseptibilitas magnetik, pesisir Nusawungu*
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I. INTRODUCTION

The Coastal area of Nusawungu District is one area in the Cilacap Regency, which is supposed to potentially contain iron ore. The total of iron ore reserves in this coast and its surrounding area is estimated about 744,678.85 tons and includes reserves that have not been exploited. Based on the results of research that has been done, the iron ore in this area have a magnetization degree of about 12.2% and iron content (Fe) is more than 53% [1].

Iron ore can be extracted from sand deposits containing significant amount of iron minerals. The deposits can be formed due to the interaction process of climate, water surface, and seawater waves with the original rocks containing iron minerals. Generally, iron sand is composed of magnetite minerals (Fe_3O_4), and small amounts of minerals such as silica, titanium, vanadium, manganese, and calcium. For black iron sand, generally the dominant minerals in it are magnetite (Fe_3O_4), hematite (Fe_2O_3), limonite ($Fe_2O_3.nH_2O$), and siderite ($FeCO_3$) [2].

For the exploration of the iron ore distribution, the geophysical surveys can be applied. One method in the geophysical survey that can be used for this purpose is the magnetic method. The magnetic method is based on the variation of magnetic field value measured on the earth surface due to the inhomogeneous distribution of magnetized rocks and minerals in the subsurface. The basic principle of this method is to utilize the measured magnetic field value on the earth surface to model the distribution of subsurface anomalous bodies based on their magnetic susceptibility values. Therefore, this method is suitable for the exploration of iron sand because iron minerals are very easily magnetized and their magnetic susceptibility are generally large [3,4].

The subsurface magnetic object like the iron ore can be considered as a source of magnetic anomaly. Magnetic anomaly is defined as the magnetic field generated by the distribution of magnetized mineral or rock in the subsurface. According to Telford *et.al*. (1990), a volume composed of magnetic material can be viewed as a magnetic dipole. The magnetization that occurs depends on the magnetic induction received when it is in the earth's magnetic field [5]. Based on Figure 1, the magnetic potential for the entire volume of the magnetized object can be formulated as:

$$V(\vec{r}_0) = -C_m\, M \frac{\partial}{\partial \alpha} \int \left[\frac{dV}{|\vec{r}_0 - \vec{r}|} \right] \qquad (1)$$

where M is the magnetic dipole moment per unit volume and C_m is a constant. Then the total magnetic induction of the objects can be formulated as:

$$\vec{B}(\vec{r}_0) = C_m\, \nabla \int_V \vec{M}(\vec{r}) \bullet \nabla \left[\frac{1}{|\vec{r}_0 - \vec{r}|} \right] dV \qquad (2)$$

The magnetic induction, called the magnetic anomaly, along with the main magnetic field of the earth (B_0) are at each measuring point on the earth's surface. Based on this fact, the value of total magnetic field measured in the apparatus consists of the earth's main magnetic field and the magnetic anomaly. But in reality, the external magnetic field (B_D) from the earth's atmosphere cannot be ignored either. Therefore, the measurable magnetic field value isexpressed as:

$$\vec{B}_T = \vec{B}(\vec{r}_0) + \vec{B}_0 + \vec{B}_D \qquad (3)$$

B_D is an external magnetic noise, which must be removed [6].

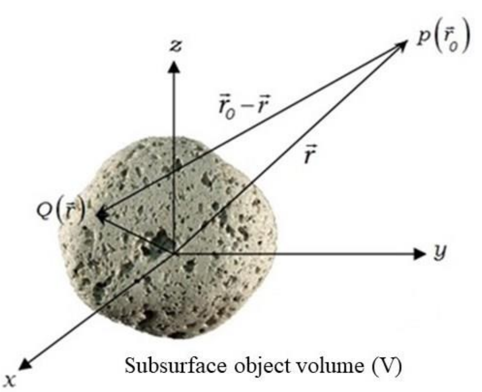

Figure 1. The Magnetic Anomaly of a Magnetized Subsurface Object [5]

II. RESEARCH METHOD

This research was carried out in April – May 2017. The data acquisition was conducted at the western coastal area of Nusawungu district in Cilacap regency, as shown in Figure 2. The processing, modeling, and interpretation of magnetic anomaly data were conducted in the Laboratory of Electronics, Instrumentation, and Geophysics; Faculty of Mathematics and Natural Sciences (FMIPA), Jenderal Soedirman University, Purwokerto.

Figure 2. The Research Location (in the Box Line**)**

Tools and Material

The equipment used in the research are a Proton Precession Magnetometer (PPM) GSM-19T with accuracy of 0.05 nT, a Global Positioning System (GPS), a compass, a recording book and writing tools, a geological map of Banyumas-Cilacap, a topographic map of the research area, a digital camera, and a laptop with excel application, Surfer 7, Fortran, and Mag2DC for Windows software.

Research Procedure

The research procedure consists of data acquisition in the field, data processing in the laboratory, modeling, and interpretation. The obtained data at each measuring point are magnetic field strength, geographical position, elevation, measuring time, and environmental and geological conditions over the surface. To obtain the total magnetic anomaly data, the daily and IGRF corrections are applied. IGRF stands for International Geomagnetic Reference Field, which contains the earth main magnetic field value at all locations on the earth's surface. The daily correction aims to eliminate the external magnetic field variation (B_D), and the IGRF correction aims to remove the earth's main magnetic field value (B_0) from the measured data. Therefore, the total magnetic anomaly data (ΔB) is obtained by the equation:

$$\Delta B = B_T \pm B_D - B_0 \quad (4)$$

The total magnetic anomaly data obtained from equation (4) is still distributed over the topography. They cannot be processed at the next stage if they are not distributed on a horizontal surface. Therefore, the anomaly data must be transformed to the horizontal surface. One method that can be used to transform the anomaly data from the topography surface to the horizontal surface is the Taylor series approximation, which can be expressed as:

$$\Delta B(\lambda, \vartheta, h_0)^{[i+1]} = \Delta B(\lambda, \vartheta, h) - \sum_{n=0}^{\infty} \frac{(h-h_0)^n}{n!} \frac{\partial^n}{\partial z^n} \Delta B(\lambda, \vartheta, h_0)^{[i]} \quad (5)$$

where λ is a longitude, ϑ is a latitude, h is a height of each data over the topography, and h_0 is the average topographic height [7].

Equation (5) needs an initial guess value for $\Delta B(\lambda, \vartheta, h_0)^{[i]}$, in this case $\Delta B(\lambda, \vartheta, h)$, i.e. the anomaly data which is still distributed over the topography, is selected. Therefore, $\Delta B(\lambda, \vartheta, h_0)$, which is an anomalous data distributed over a horizontal surface, can be determined by approximation; i.e. $\Delta B(\lambda, \vartheta, h_0)$ data obtained from the i-iteration process can be used to obtain $\Delta B(\lambda, \vartheta, h_0)$ data on the next iteration (i+1). The iteration process is done sufficiently until convergent values of $\Delta B(\lambda, \vartheta, h_0)$ have been reached [7].

The anomaly data that has been distributed on the horizontal surface need to be corrected from the magnetic effect originating from deep sources, known as the regional anomaly. This is because the research target is a shallow and local object, i.e. the iron ore [8]. The regional anomaly data can be obtained through upward continuation of the magnetic anomaly data up to a certain height, such that the anomaly data range shows very small values, and the contour map shows very smooth pattern and their value tend to be fixed [9]. The upward continuation can be derived from the Green's 2nd identity [7], which can be expressed as:

$$\Delta B(\lambda', \vartheta', h_0 + \Delta h) = \frac{\Delta h}{2\pi} \int_{-\infty}^{\infty}\int_{-\infty}^{\infty} \frac{\Delta B(\lambda, \vartheta, h_0)}{\sqrt{\left((\lambda'-\lambda)^2 + (\vartheta'-\vartheta)^2 + \Delta h^2\right)^{3/2}}} d\lambda\, d\vartheta \quad (6)$$

Then, the obtained anomaly data is taken from the total magnetic anomaly data distributed over the horizontal surface in equation (5), so as to obtain the local magnetic anomaly data as the following equation:

$$\Delta B_{Lokal} = \Delta B(\lambda, \vartheta, h_0) - \Delta B(\lambda', \vartheta', h_0 + \Delta h) \quad (7)$$

The modeling of anomalous objects has been performed using the Mag2DC for Windows software, i.e. by matching the model of anomaly curves against the observed anomaly curve derived from local magnetic anomaly data. After the two curves are matched, a number of objects, assumed to be the subsurface rocks of the research area, are thus be obtained [10].

III. RESULTS AND DISCUSSION

Results of Acquisition and Processing of Magnetic Field Data

The acquisition of magnetic data has been done in the field at 144 location points scattered over 109.314° – 109.345°E and 7.691° – 7.709°S. The total magnetic field strength obtained from it is 44297.50 – 46960.12 nT, resulting in a contour map shown in Figure 3.

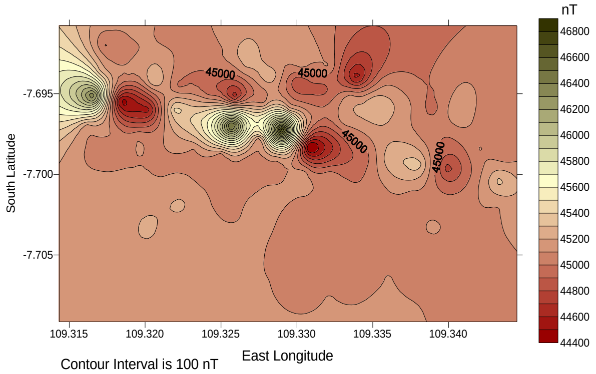

Figure 3. The Contour Map of the Total Magnetic Field Strength in the Research Area

To obtain the total magnetic anomaly data, the daily and IGRF corrections are applied according to equation (4). The IGRF value for the research area is 44998.5 nT [11]. After the corrections are done, the total magnetic anomaly data distributed on the topographic surface have values of -694.32–1961.62 nT, with corresponding contour map shown in Figure 4.

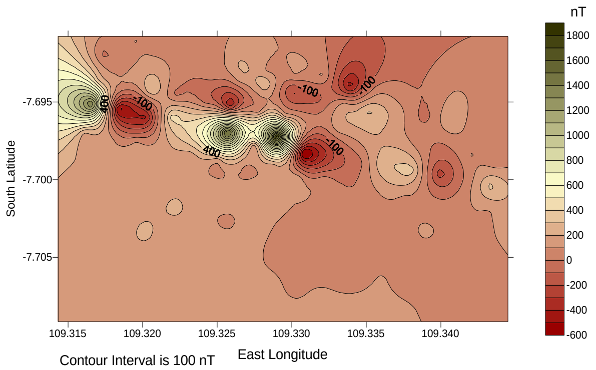

Figure 4. The Contour Map of the Total Magnetic Anomaly that Distributed on the Topography

Next, the magnetic anomaly data must be transformed from the topographic surface to a horizontal surface, as in equation (5). The height of the horizontal surface is taken as the average topographic height, i.e. 24.82 meters, to speed up the iteration process in reaching convergence [7]. The magnetic anomaly data on the horizontal surface are obtained to have the value of -589.62 – 1823.61 nT, with its contour map shown in Figure 5. Comparing the result to the previous magnetic anomaly value range, it can be inferred that convergence has been reached, implying that it has been placed on a horizontal surface [12].

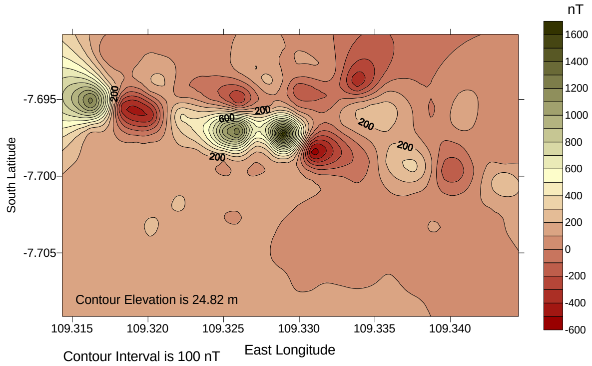

Figure 5. The Contour Map of Total Magnetic Anomaly Distributed on the Horizontal Surface

The target of this research is shallow and local rocks, such as iron sand, requiring that regional magnetic effects be removed (equation (7)). It can be obtained through an upward continuation of the total magnetic anomaly data up to 3250 m above the reference spheroid. This height is chosen because the anomaly data interval between one point to the others around it is very small, and the contour has reached a fixed pattern, as shown in Figure 6.

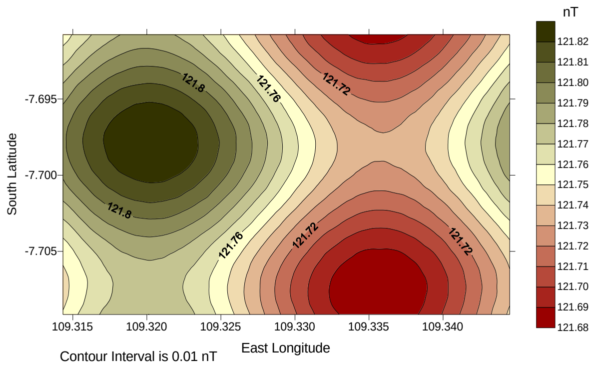

Figure 6. The Contour Map of Regional Magnetic Anomaly in the Research Area

The regional magnetic anomaly data, is then corrected from the total magnetic anomaly data that distributed on the horizontal surface, so as to obtain the local magnetic anomaly data. This local anomaly data is distributed over the average topographic height, i.e. 24.82 meters, and plotted as a contour map shown in

Figure 7. The local magnetic anomaly originates from magnetized minerals and rocks in the crust located near the surface, such as iron ore. The local magnetic anomaly data, is then used as the basis for our modeling [13].

To obtain the distribution and potentiality of iron ore in the research area, modeling process is then carried out. The modeling is done by making a path over the local anomaly contour through some anomaly closure that is prospectively predicted to contain iron ore. The modeling is done on the local magnetic anomaly data along the path where the modeled data is extracted. The path line made over the local anomaly contour map is shown in Figure 7.

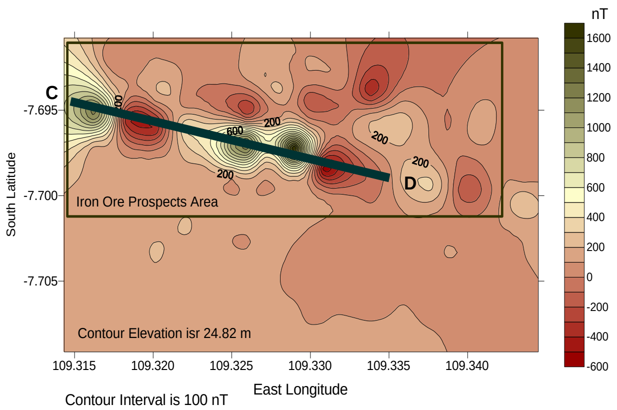

Figure 7. The Contour Map of Local Magnetic Anomaly and the CD Path Used as the Data Source for Modeling

In modeling the subsurface anomaly objects several parameters, shown in the Table 1, are required. It processes magnetic anomaly data taken along CD path extending from 109.3144°E and 7.6945°S up to 109.3352°E and 7.6990°S, with the length of 2354,84 m. The direction of the path is 77.67° N-W. The modeling has been done using the Mag2DC for Windows by matching the curve of the observed local anomaly curve and that of the calculated model. After a match is reached, nine anomalous objects, which can be interpreted as subsurface rocks, are obtained (Figure 8).

To interpret the types of subsurface rocks indicated as anomalous objects the magnetic susceptibility value of the average rock in the research area is estimated earlier based on the local geological information. The average rocks in this area are estimated as silt, clay, sand, and gravel containing iron ore grains from the alluvium formation. Therefore, their magnetic susceptibility value is assumed to be equal to 0.0080 cgs [14]. The magnetic susceptibility value of each modeled anomalous object (χ) can be obtained by adding up the magnetic susceptibility value of the average rocks and the magnetic susceptibility contrast value of each object ($\Delta\chi$), as shown in Table 2.

Table 1. The Modeling Parameter of Magnetic Anomaly in the Research Area

Modeling Parameter	Value
The value of the earth's main magnetic field (IGRF)	44999.00 nT
The inclination angle	-32.4162°
The declination angle	0.8505°
The strike length of the model object	100.00 meter
Number of modeled anomaly objects	10
The magnetic susceptibility contrast interval	-0.0032 – 0.0103 cgs unit
The depth interval of anomalous objects	1.709 – 204.274 m

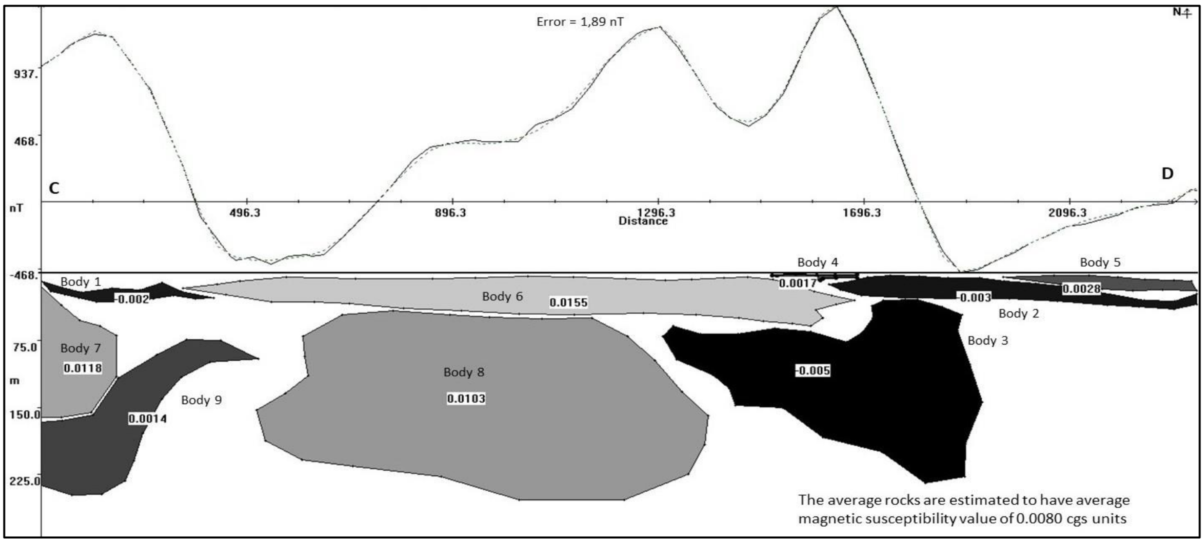

Figure 8. The Results of Modeling using Mag2DC for WINDOWS Software to Magnetic Anomaly Data on CD Path and it′s Interpretations

The results of modeling and interpretation to the anomalous objects show three subsurface objects under CD path that can be interpreted as iron sand deposit, inserted by sand, silt, and clay from the alluvium formations. The first object has a length of about 164.85 m, a depth of 0.57 – 8.43 m, and the magnetic susceptibility value of about 0.0097 cgs. The second object has a length of about 376.28 m, a depth of 2.56 – 19.66 m, and the magnetic susceptibility value of about 0.0108 cgs. And the third object has a length of about 1306.26 m, a depth of 3.70 – 58.69 m, and the magnetic susceptibility value of about 0.0235 cgs. Of all the objects, the third object is interpreted to contain the most iron ore because it has the largest magnetic susceptibility value. This shows the presense of magnetic minerals in these rocks, particularly iron minerals [15].

Tabel 2. The Results of Interpretation of Rock Types and Their Formation on CD Path

Anomalous Object	Depth (meter)	$\Delta\chi$ (cgs units)	χ (cgs units)	Interpretation of Rock Types and its Formation
Object 1	8.547 – 32.479	-0.0026	0.0066	Alluvium deposit composed of sand, silt, clay, and
Object 2	2.564 – 40.741	-0.0031	0.0051	gravel containing iron ore.
Object 3	29.915 – 235.043	-0.0052	0.0032	Limestone inserts with sandstones from the Halang formation.
Object 4	0.570 – 8.433	0.0017	0.0097	Iron sand coexists with silt and clay from the alluvium
Object 5	2.564 – 19.658	0.0028	0.0108	formation.
Object 6	3.704 – 58.689	0.0155	0.0235	Iron sand (dominant) coexists with silt and clay from the alluvium formations.
Object 7	6.838 – 175.214	0.0118	0.0198	Andesite breccia inserts with sandstones and basal
Object 8	41.880 – 253.846	0.0103	0.0183	lava from the Halang formation.
Object 9	74.359 – 247.863	0.0014	0.0094	Limestone inserts with sandstones from the Halang formation.

The results of interpretation also found iron ore in the other rocks from the alluvium formation, although not dominant. These rocks are interpreted as a mixture of sand, silt, clay, and gravel containing iron ore grain, alternately. This interpretation is based on the magnetic susceptibility values that is relatively large i.e. 0.0066 cgs and 0.001 cgs. The deposits of these two rocks stretch under the CD path at a depth of 2.564 – 40.741 m. Based on the research done by Hikmatyar, the average iron (Fe) content in the iron sand sample taken in the research area from various samples is 11.027% [16].

As much as potentially contain iron ores, the alluvium deposits in the coastal area of Nusawungu district the alluvium deposit such as sand, clay, silt, and gravel also play a significant role in inhibiting the coastal abrasion and the seawater intrusion into the aquifer. Therefore, the rocks of alluvium formations in the coastal area of Nusawungu district must be conserved and should not be damaged and destroyed by the exploitation of iron sand.

IV. CONCLUSION

The exploration of iron ore deposit in the west coastal area of Nusawungu district in Cilacap Regency has been done based on the magnetic survey. Data acquisition has been conducted in April – May 2017 with geographical position of 109.314°-109.345°E and 7.691°-7.709°S. The magnetic field strength data obtained are then processed, corrected, and reduced so as to obtain the local magnetic anomaly data. Modeling of the local magnetic anomaly data was performed on a CD path extending from a position of 109.314°E and 7.695°S to 109.335°E and 7.699°S, resulting in 10 anomalous objects, which can be interpreted as subsurface rocks.

Based on the results of the interpretation, there are three subsurface rocks, which are interpreted as the deposit of iron sand coexisting with sand, silt, and clay from alluvium formation. Those rocks have the magnetic susceptibility values of 0.0097 cgs, 0.0108 cgs, and 0.0235 cgs, respectively. Of all the rocks, the third rock is estimated to contain the most iron ore. This is based on its high magnetic susceptibility value, which indicates the magnetic mineral content in the rock.

To identify the distribution and the potentiality of iron ore in the research area more clearly, it is necessary to apply other methods in the geophysical exploration. The application of the geoelectric method using the Schlumberger configuration is desirable, since it can be used to interpret the depth of iron ore deposits thoroughly. Also, the application of the Wenner configuration can be used to determine the distribution of iron ore deposits more accurately in the lateral and the vertical directions.

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