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# IDENTIFICATION OF IRON MINERALIZATION ZONES USING FORWARD GEOMAGNETIC MODELING METHODS IN PELAIHARI – TANAH LAUT REGENCY

# *IDENTIFIKASI ZONA MINERALISASI BESI MENGGUNAKAN METODE PEMODELAN GEOMAGNETIK MAJU DI KABUPATEN PELAIHARI – TANAH LAUT*

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**Abstract.** Accuracy in identifying the distribution zone of iron ore mineral resources in the Pelaihari area, Tanah Laut Regency, is very important for exploration activities. This study aims to identify the presence of iron ore using magnetic data based on Analytical Signal maps from residual processing and modeling 2D subsurface results to see iron ore mineralization zones. The magnetic method used in this study is a geophysical exploration technique based on measurements of variations in magnetic anomaly intensity in rocks caused by the Earth's magnetic field. Magnetic data underwent magnetic correction, daily correction, and correction according to the International Geomagnetic Reference Field (IGRF) standard to determine the Total Magnetic Intensity (TMI). Based on the results of the study, iron ore mineralization zones were identified at a depth of approximately 10–40 m from the surface with a high susceptibility value of around 0.2 SI. The high residual anomaly response and Analytic Signal values between 23.4–36.0 nT/m indicate a shallow magnetic source localized by ultramafic rocks as the bedrock with a susceptibility value of approximately 0.097 SI at a depth of up to ±150 m, forming a prominent upward bulge. These characteristics indicate significant potential for laterite mineralization.

***Abstrak.*** *Keakuratan dalam mengidentifikasi zona distribusi sumber daya mineral bijih besi di daerah Pelaihari, Kabupaten Tanah Laut, sangat penting untuk kegiatan eksplorasi. Studi ini bertujuan untuk mengidentifikasi keberadaan bijih besi menggunakan data magnetik berdasarkan peta Sinyal Analitik dari pengolahan residual dan pemodelan hasil bawah permukaan 2D untuk melihat zona mineralisasi bijih besi.*

*Metode magnetik yang digunakan dalam penelitian ini adalah teknik eksplorasi geofisika berdasarkan pengukuran variasi intensitas anomali magnetik pada batuan yang disebabkan oleh medan magnet Bumi. Data magnetik telah dilakukan koreksi magnetik, koreksi harian, dan koreksi sesuai standar Medan Referensi Geomagnetik Internasional (IGRF) untuk menentukan Intensitas Magnetik Total (TMI). Berdasarkan hasil penelitian, zona mineralisasi bijih besi diidentifikasi pada kedalaman sekitar 10–40 m dari permukaan dengan nilai suseptibilitas tinggi sekitar 0,2 SI. Respons anomali residual yang tinggi dan nilai Sinyal Analitik antara 23,4–36,0 nT/m menunjukkan sumber magnetik dangkal yang terlokalisasi oleh batuan ultramafik sebagai batuan dasar dengan nilai suseptibilitas sekitar 0,097 SI pada kedalaman hingga ±150 m, membentuk tonjolan ke atas yang menonjol. Karakteristik ini menunjukkan potensi yang signifikan untuk mineralisasi laterit.*



## 1. INTRODUCTION

Indonesia has a fluctuating distribution of iron ore mineral resources, with an upward trend in iron ore reserve data during the 2018-2022 period (Badan Geologi, 2022). One of the iron ore mineral exploitation locations is in South Kalimantan, concentrated in Panggung Village, Pelaihari District, Tanah Laut Regency. In terms of physiography, this area is located at the southwestern end of the Meratus Mountains, the southern part of the Barito Valley, and the Asam-Asam Sub-valley which is between the Sunda Shelf and Meratus Mountains in the west, melange belts and ophiolites in the east with transgression-regression cycles and other local geological events (Pratama et al., 2020). According to Ferial et al. (2019), South Kalimantan is rich in mineral resources, including iron ore. Exploration and investigation using geological methods in Tanah Laut Regency have identified iron ore deposits that show significant potential for iron ore distribution and formation (Tresnadi, 2009).

Iron ore mineral distribution research to identify and model using geomagnetic methods in Pelaihari area, Tanah Laut Regency, was previously conducted by (Arif & Lepong, 2016), who identified three iron ore prospective zones. This study successfully provided an overview of the prospective areas but did not reveal the subsurface geometry in detail. In the same region, identified five primary iron ore mineral distribution locations based on magnetic anomalies and mapping of iron ore distribution results from regional horizontal derivative filtering (Syaripudin et al., 2021). This study used 3D magnetic anomaly modeling to show the distribution of iron ore minerals on a regional scale. However, the limitation of low-resolution data resulted in unclear anomaly boundaries and geological structures, which may be due to the inhomogeneous nature of the site, which consists of loosely consolidated subsurface layers (Alao et al., 2024).

Pelaihari sub-district is one of the areas with potential iron ore mineral reserves in Tanah Laut Regency, a research area where almost 60 percent of the area has sedimentary distribution in the form of quaternary-aged alluvium, and is a bedrock complex consisting of Jura-aged bancuh, ultramafic, schist, and phyllite rocks (Supriyana et al., 2022). This study was conducted to identify the presence of iron ore using magnetic data based on analytical signal maps from residue processing and subsurface 2D modeling results, and supported by secondary data from PT Geosketsa Tierra Nusantara. However, in contrast to previous studies, this research in Pelaihari Sub-district, Desa Panggung aims to characterize subsurface geological conditions at a local scale using detailed geomagnetic measurements taken every 50m, which were previously mapped regionally as alluvial deposits (Qa). This study successfully identified ultramafic intrusion domes and contact zones that serve as the main centers of iron ore mineralization at depths of 10-40 m, with shallow bedrock or intermediate layers (Pancasari et al., 2021; Rahmatillah et al., 2023).

The high-resolution geomagnetic method used in this study proves that the combination of geophysical analysis with magnetic calculation and 2D modeling can overcome the limitations of regional geological maps and provide new information on the potential for primary iron ore mineralization beneath alluvial deposits (Qa), which was not revealed in previous studies. Identification of iron ore mineral distribution prospects using magnetic data based on a combination of analysis with polar reduction, spectral analysis, analytical signals, and 2D modeling can be a solution to interpret the distribution of iron ore minerals, providing useful, accurate, and more effective and efficient information. This is supported by relatively simple, easy, and fast field operations (Rachmawiana et al., 2013). To get optimal results in identifying the mineralization potential of iron ore or metamorphic rocks in knowing the detailed composition, physical and chemical properties, sample analysis is needed in the laboratory (Asrafil et al., 2025).

## 2. LITERATURE REVIEW

The research location is in Panggung Village, Pelaihari Subdistrict, Tanah Laut Regency, South Kalimantan Province. A regional geological map of the research area is shown in **Figure 1**.

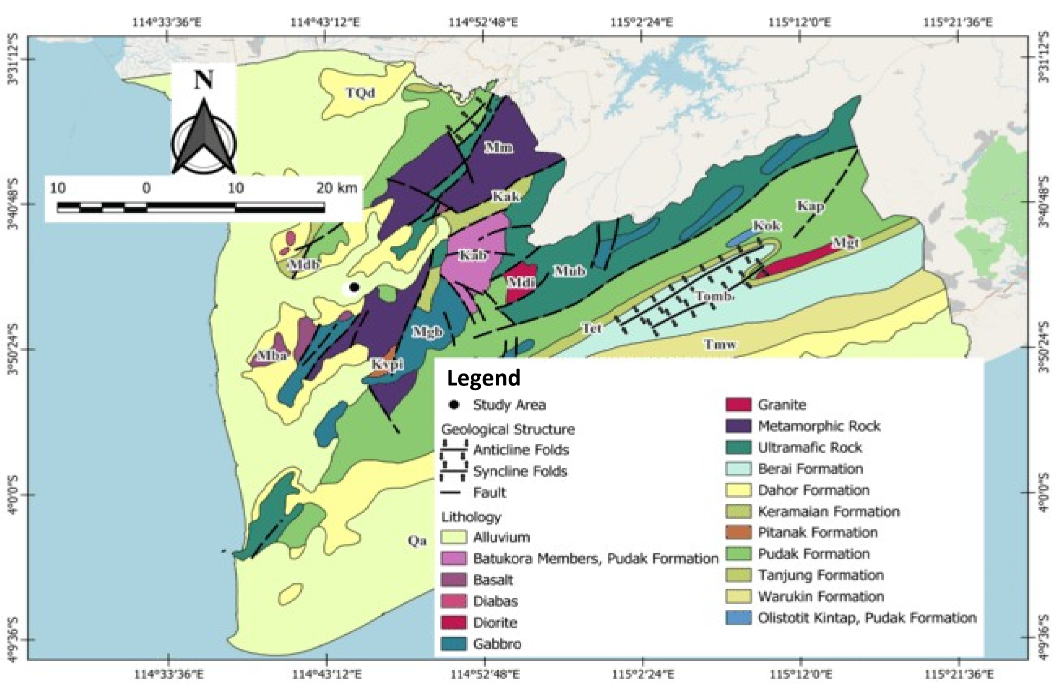


**Figure 1.** Regional Geological Map (Map Modified from Sikumbang & Heryanto, 1994).

Based on the regional geological map of Banjarmasin Sheet (Sikumbang & Heryanto, 1994), the research area is dominated by alluvial deposits. The rock formations found in the study area include alluvial deposits (Qa), which are Quaternary deposits consisting of loose materials such as gravel, silt, sand, and clay that are genetically classified as primary deposits with varying sizes found in Tanah Laut Regency, South Kalimantan (Tresnadi, 2009). However, the study area also contains the Pudak Formation, which includes primary iron ore deposits in other igneous rocks (Supriyana et al., 2022), as observed during field magnetic field measurements.

Knowing the Pudak Formation that is buried below the surface to identify the distribution of iron ore can use geomagnetic methods in identifying differences in the susceptibility of subsurface rocks that are influenced by the physical characteristics of the rock, the magnitude of the intensity value and the direction of induction of the total magnetic field that works when the rock begins to be magnetized (Nurfalaq et al., 2020). As for the interpretation of magnetic anomalies, it usually includes the shape, depth, and magnetic properties of the anomaly source, it is necessary to do inversion modeling on magnetic data. Forward modeling is used through the calculation of a theoretical response in the form of a magnetic field curve caused by a magnetic anomaly source assuming its shape, volume and susceptibility (Setyawati et al., 2021). Forward modeling itself is an indirect method of modeling anomalous data or estimating the magnetic susceptibility value of subsurface rocks by first modeling anomalous objects (Deniyatno, 2010; Shabrina et al., 2023).

## 3. RESEARCH METHODS

### *3.1. Data and Research Location*

This Study Uses Secondary Geophysical Data In The Form Of Magnetic Data Obtained From PT Geosketsa Tierrra Nusantara. The Primary Data Was Collected From Measurements Taken At 113 Points In Panggung Village, Pelaihari Subdistrict, Tanah Laut Regency, With A Spacing Of 50 M Between Points And A Research Area Of 497 M × 728 M. The Area Is Suspected To Have More Complex Magnetic Anomalies, Requiring Denser Measurements To Clearly Read The Anomaly Patterns And Obtain More Accurate Modeling Results. The Yellow Dots In The Sub-Area Indicate The Detailed Grid For The Zone That Is The Main Focus Of The Survey. Geographically, The Study Area Is Located At Coordinates UTMX MIN 1586991.85 - UTMX MAX 1587829.21 And UTMY MIN 9576374.89 – UTMY MAX 9576942.79 (**Figure 2**).

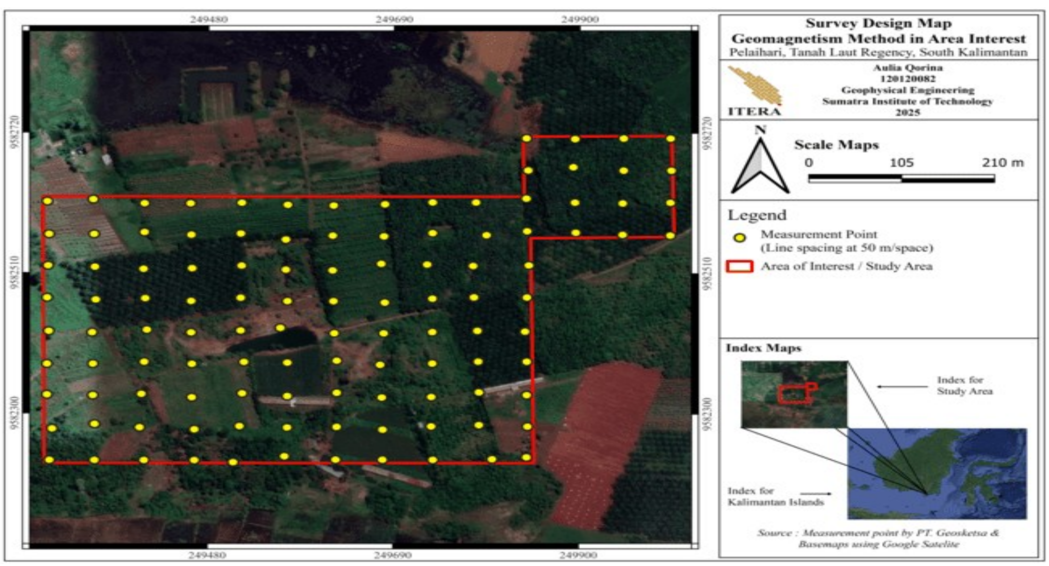


**Figure 2.** Acquisition Design Map.

### *3.2. Magnetic Method*

The magnetic method applied in this study is based on the concept that rocks beneath the surface have different magnetic properties, resulting in variations in magnetic field values. Magnetic data must undergo magnetic correction, diurnal correction, and International Geomagnetic Reference Field (IGRF) standard correction to obtain the Total Magnetic Intensity (TMI) value. Next, a pole reduction process is performed using the Fourier transformation to create a Reduce to Pole (RTP) map. Separation of residual anomalies using a Gaussian filter to separate local signals from the reduced magnetic data can more clearly identify the location of iron ore. Analytic Signal actions are required to strengthen anomalies from the residual map with Geosoft Oasis Montaj.

### *3.3. Diurnal Correction*

Daily corrections adjust for differences in the Earth's magnetic field caused by solar radiation and variations in time during a day (Wardinski et al., 2020). This correction process is carried out by recording changes in the magnetic field at the base station during the measurement period, which begins and ends with the Diurnal Correction equation, namely:

$$a = \frac{R_{n+1} - R_n}{\Delta t} \quad (1)$$

H_b=(ΔT) . a+B$H_b = (\Delta T)\,.\,a + B$ (2)

With,

| | | |
|---|---|---|
| $a$ | = | Multiplier factor |
| $R_{n+1}$ | = | Reading the device at position (n+1) |
| $R_n$ | = | Reading the device at position (n+1) |
| $\Delta t$ | = | Observation interval |
| $H_b$ | = | Value at base station (H_base) |
| $\Delta T$ | = | The closest time difference between the base and the rover |
| $B$ | = | Reading value at base station |

Therefore,

$$H_{vh} = H_{Rbase\ to-n} - H_{Rbase\ beginning} \quad (3)$$

### *3.4. IGRF Correction*

The International Geomagnetic Reference Field (IGRF) correction aims to reduce or eliminate the effects of the Earth's main magnetic field, which changes slowly every year. The standardization of the Earth's main magnetic field values through the IGRF is updated periodically every five years. The IGRF values are obtained using the BMKG (Meteorology, Climatology, and Geophysics Agency) calculator.

### *3.5. Total Magnetic Intensity*

Simply put, magnetic field anomalies are differences between the total magnetic field of the Earth and the previously corrected magnetic field (Sharma, 1997). This is explained in the following equation:

$$\Delta H = H_{obs} - H_{IGRF} \pm H_{vh} \quad (4)$$

### *3.6. Reduction to the Pole*

Reduction to the Pole (RTP) is a frequency domain processing technique used to correct magnetic anomaly asymmetries caused by the inclination and declination of the Earth's magnetic field. This process produces anomalies that resemble measurement conditions at the magnetic pole, where the anomaly peak is located directly above its source (Hinze et al., 2013).

### *3.7. Spectral Analysis*

Spectral analysis is a Fourier transform process (Blakely, 1996), used to convert data from the spatial domain to the frequency domain using the following equation:

$$\ln A = \ln B - 2d|k| = \ln B - 4\pi df \quad (5)$$

Where ln $B$ is the intercept and $2d$ or $4\pi d$ is the gradient of the line *ln A* with respect to $k$, so that the depth of the anomaly source can be calculated using the following formula (Hinze et al., 2013):

$$d = \frac{s}{4\pi} \quad (6)$$

$d$ is the depth of the anomaly, and $s$ is the slope value. Frequency is defined as $f = 1/\lambda$, where $\lambda$ is the wavelength, while the wave number $k$ is formulated as $k = 2\pi f = 2\pi/\lambda$.

$$(k) = \frac{|inclination|}{2} Or\ d(f) \frac{|inclination|}{4\mu} \quad (7)$$

### *3.8. Analytic Signal*

Analytical signals are the sum of the first-order derivatives of the vertical and horizontal gradients of the total magnetic field. Analytical signals are highly sensitive to anomaly boundaries, making them very helpful in interpretation for determining geological structures or boundary zones using gravity and magnetic data (MacLeod et al., 1993). The analytical signal results in the highest amplitude, which is typically located directly above the center of the magnetic anomaly (Nasuti & Nasuti, 2018). Analytical signals can be mathematically expressed in the following equation:

$$AS = \sqrt{\left(\frac{\partial T}{\partial x}\right)^2 + \left(\frac{\partial T}{\partial y}\right)^2 + \left(\frac{\partial T}{\partial z}\right)^2} \qquad (8)$$

Where ∂T denotes the total magnetic intensity (nT), ∂x is the first-order derivative with respect to the horizontal component (x-axis), ∂y is the first-order derivative of the horizontal component with respect to the y-axis, and ∂z is the first-order derivative of the vertical component (z-axis) with respect to depth.

### *3.9. Forward Modeling*

Forward modeling aims to visualize subsurface anomalies in the study area. This modeling is usually done using a 2D projection approach in the form of a square or other shape to represent the subsurface geological conditions of the observation area (Nugroho et al., 2018). This method is carried out through trial and error by repeatedly adjusting the model parameters until the calculation error value approaches the observed data (Grandis, 2009). The modeling equation can be written as follows (Won & Bevis, 1987):

$$\Delta H_z = 2kH_0 \left(\sin I \frac{\partial Z}{\partial z} + \sin\beta \cos I \frac{\partial Z}{\partial x}\right) \qquad (9)$$

and,

$$\Delta H_x = 2kH_0 \left(\sin I \frac{\partial X}{\partial z} + \sin\beta \cos I \frac{\partial X}{\partial x}\right) \qquad (10)$$

Once ΔH_z and ΔH_x are known, the total anomaly ΔH can be calculated using the following equation:

$$\Delta H = \Delta H_z \sin I + \Delta H_x \sin\beta \cos I \qquad (11)$$

This process produces calculation data, which is then compared with observation data by calculating the Root Mean Square (RMS) error using the following equation:

$$RMSE = \sqrt{\frac{1}{N}\sum_{i=1}^{N}(T_i^{cal} - T_i^{obs})^2} \qquad (12)$$

## 4. RESULTS AND DISCUSSION

### *4.1. Total Magnetic Intensity Map*

The total magnetic intensity (TMI) map depicts the distribution of magnetic anomalies after daily corrections and IGRF corrections have been made to eliminate the effects of magnetic fields originating from within and outside the Earth. The data analyzed is magnetic intensity data from the research area. The Total Magnetic Intensity map is presented in **Figure 3**.

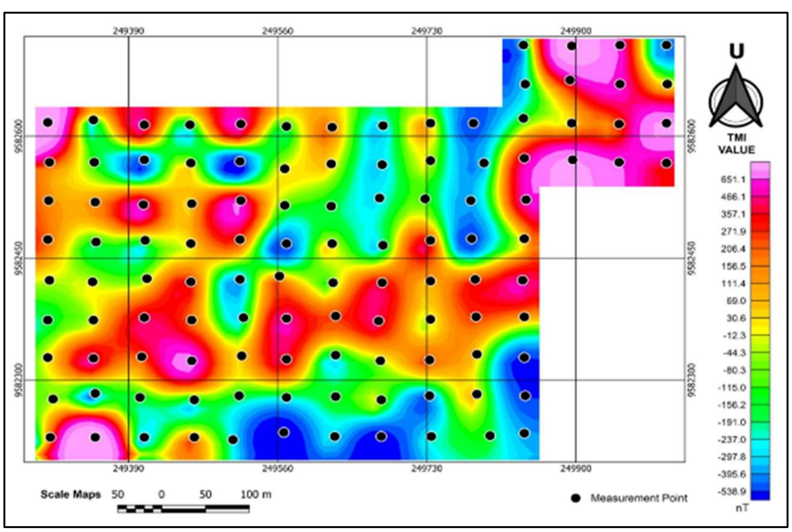


**Figure 3.** Total Magnetic Intensity Map.

Based on the color scale in **Figure 3** above, the distribution of magnetic anomaly values shows variations from high to low. Based on the image displayed, the total magnetic intensity values range from -538.9 nT to 651.1 nT. Low anomalies in TMI data have a value range between -538.9 nT and -12.3. Moderate anomalies are in the value range of approximately 30.6 nT to 206.4 nT. Meanwhile, high anomalies are in the value range of approximately 271.9 nT to 651.1 nT.

The Total Magnetic Intensity Map shows anomalies that are still dipolar in nature, marked by scattered pairs of positive and negative closures. This pattern is the result of various anomaly sources that are still mixed between shallow sources and deeper sources. Therefore, an RTP process is needed to obtain a clearer picture of the rock magnetic pattern.

### *4.2. Reduction Map to the Pole*

The Reduce to Pole (RTP) filter process is performed on magnetic field anomaly data. The Reduction to Pole map is presented in **Figure 4**.

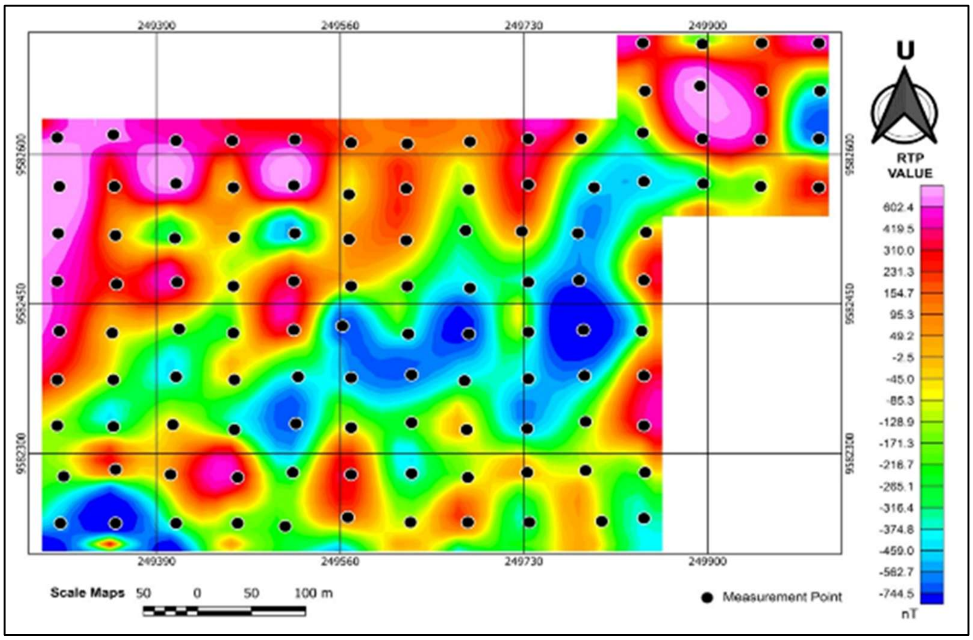


**Figure 4.** Reduction Map to the Pole.

This process is intended to eliminate the influence of magnetic inclination angles while minimizing interpretation errors due to magnetic field anomalies that directly indicate the position of objects by standardizing the poles through adjustment of the inclination and declination angles in the study area from -23 and 0.7° to 90° and 0°. This reduction to the pole process is recommended in the interpretation stage. However, the data obtained from this process still has limitations, namely being affected by the presence of mixed deep and shallow anomalies.

**Figure 4** above shows the distribution of magnetic anomalies after reduction to the poles. This process results in a change in the range of values, with variations from -744.5 nT to 602.4 nT. Low anomalies range from -744.5 nT to -85.3 nT. Moderate anomalies range from -45.0 nT to 154.7 nT. High anomalies range from 231.3 nT to 602.4 nT.

### *4.3. Spectral Analysis*

Spectral analysis is used to estimate regional depth, residuals, and noise. Spectral analysis is a process that converts a signal into a Fourier transform, used to transform a signal from the time domain to the frequency domain. **Figure 5** shows that the regional anomaly has an estimated depth of 260.6737 meters, and the residual anomaly is at a depth of 214.2566 meters, obtained based on equation 6.

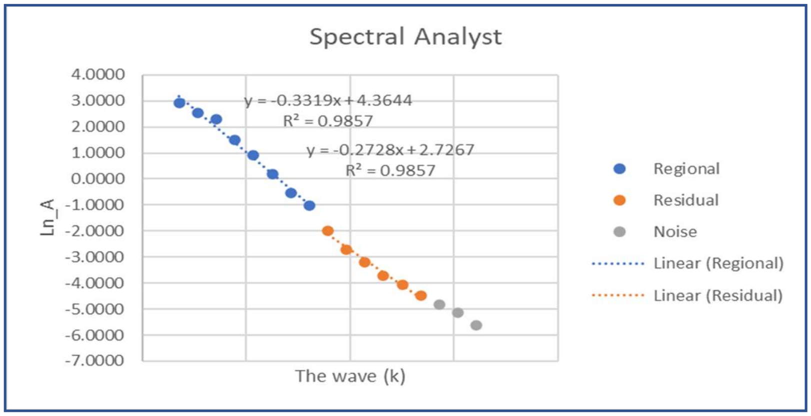


**Figure 5.** Spectral Analysis.

### *4.4. Analytic Signal Map*

**Figure 6** shows the results of the Analytic Signal map, which reinforces the anomaly effect of the residual map to identify the presence of iron ore.

Iron ore is located in high anomalies, with values ranging from 23.4 nT/m to 36.0 nT/m, as shown by the analytical signal map in the study area, which corresponds to the observations made by PT. Geosketsa Tierra Nusantara in January 2018. This indicates that the prospect zone with the maximum analytical signal value shows the possibility of laterite iron ore deposits with a fairly large anomaly size. Low anomalies in the analytical signal map results indicate the presence of alluvial deposits (surface) or sedimentary rocks with low mineral content relative to magnetic levels. This is supported by the geological map of the study area.

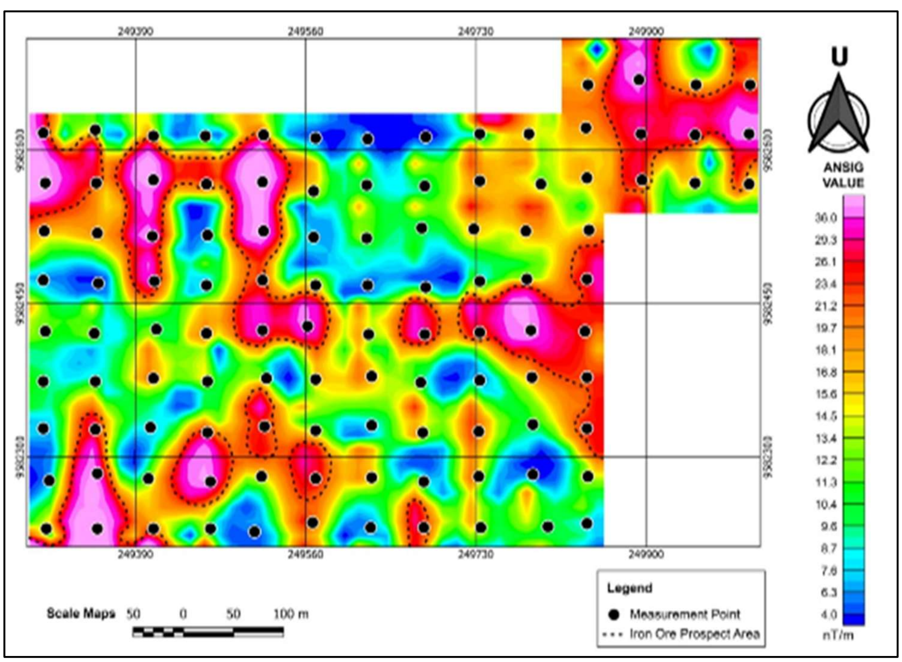


**Figure 6.** Analytic Signal Map.

### *4.5. Residual Separation Map*

The residual map that has been processed with a Gaussian filter shows a more contrasting distribution of anomalies than the RTP map. The Gaussian filter, which applies the Low Pass Filter principle, produces a smoother image and represents the anomaly response in the magnetic data. Residual anomalies, known as shallow anomalies, are obtained by subtracting the RTP map from the regional anomaly map, thereby displaying a more varied anomaly response that reflects the characteristics of shallow anomalies in the magnetic data. Based on these anomaly responses, low anomalies range from -652.1 nT to -322.8 nT, while high anomalies range from 197.7 nT to 464.9 nT.

In **Figure 7**, the presence of iron ore mineralization zones is interpreted using an anomaly enhancement filter. During the signal analysis stage, the anomalies from the residual map are enhanced. The circled area (delineation result) indicates the presence of iron ore from the Analytic Signal map. When viewed on the residual map of the delineation result, there are still low anomalies indicating that the iron ore mineral is exposed by the Pudak formation.

Based on this anomaly pattern, the A–B slicing was determined based on field observations that indicated the presence of iron ore in the zone. The slice line was selected to cross the area with the most contrasting magnetic anomaly variations, so that it could representatively illustrate changes in magnetic residual values in relation to mineralization distribution. In addition, the direction of the slice was determined through discussion to ensure that the cross-section cut through the most significant iron ore prospect, thereby making the subsurface interpretation more accurate and informative.

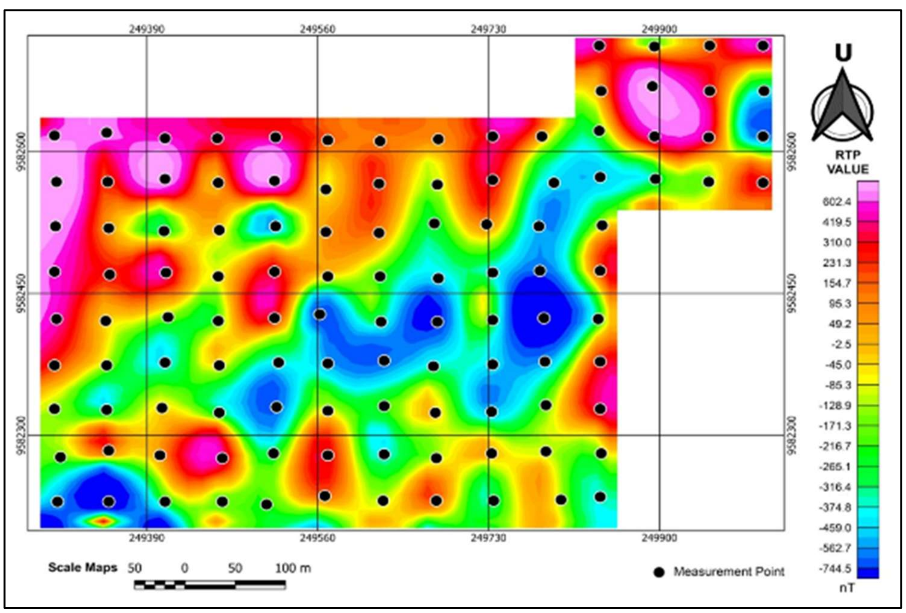


**Figure 7.** Residual Separation Map.

### *4.6. Slice A-B Modeling*

The 2D magnetic modeling on section A–B (**Figure 8**) was carried out with a west-southwest to northeast orientation, following the direction of the dominant magnetic anomaly distribution and iron ore prospect zones in the study area. This orientation was chosen to optimally represent lateral and vertical changes in magnetic response, so that the distribution and geometry of magnetized bodies could be depicted more realistically.

The uppermost layer in the model is interpreted as an alluvial deposit (Qa Formation) with a relatively thin thickness of approximately ±1–3 meters and very low susceptibility values. The selection of alluvial lithology as the surface layer is based on the regional geological conditions of the study area, which is dominated by young alluvial deposits. The loose material character of this layer causes its contribution to the magnetic response to be very small and not dominant.

Beneath the alluvial layer, modeling results indicate the presence of a strongly magnetized zone at a depth of ±10–40 meters from the surface, with a susceptibility value of approximately 0.2 SI. This zone is interpreted as a laterite iron ore mineralization zone, which is a direct result of magnetic modeling interpretation in this study. The relatively high susceptibility value indicates the presence of significant amounts of magnetic minerals, which contribute to the high magnetic anomaly on the A–B section.

The presence of lateritic iron ore in the study area is closely related to the intensive chemical weathering of ultramafic parent rocks. Weathering, which is influenced by climatic conditions and groundwater movement, causes iron enrichment through the formation of hematite and goethite minerals, resulting in brown to black lateritic layers. This interpretation is consistent with the characteristics of laterite iron ore deposits formed as a result of weathering and metamorphism of rocks over a long geological time span, as described by Syaripudin et al. (2021).

At the bottom of the model, the presence of ultramafic rocks is interpreted as bedrock, which lies at a depth of up to approximately 150 meters and has a susceptibility value of around 0.097 SI. These rocks form an upward bulge in several segments of the section, indicating the presence of ultramafic rock bodies. The geometry of the bedrock acts as the main controller of the development of lateritic weathering zones and iron ore accumulation above it.

Overall, 2D magnetic modeling of the southwest–northeast section was able to quantitatively describe the subsurface layer structure, the geometry of the magnetized body, and the genetic relationship between ultramafic rocks as parent rocks and lateritic weathering processes that produced iron ore mineralization in the study area.

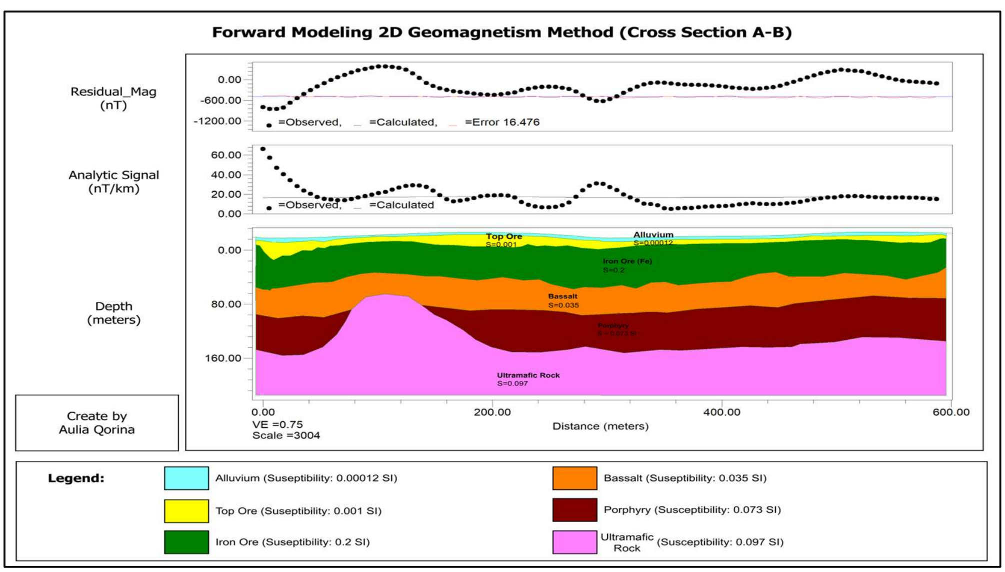


**Figure 8.** Forward Modeling Slice A-B.

## 5. CONCLUSION

The iron ore mineralization zone in the study area was identified at a depth of approximately 10–40 m from the surface with a high susceptibility value of around 0.2 SI, reflecting the presence of a significant amount of strongly magnetized material. The existence of this zone is supported by a high residual anomaly response and an Analytic Signal value ranging from 23.4–36.0 nT/m, indicating a shallow and localized magnetic source.

The correspondence between the residual anomaly pattern and the Analytic Signal peak shows a strong relationship between the magnetic response and the presence of laterite iron ore mineralization zones. The mineralization formation system is controlled by ultramafic rocks as the bedrock with a susceptibility value of approximately 0.097 SI at a depth of up to ±150 m, which forms an upward bulge geometry. This geometry acts as the main controller of intensive chemical weathering and lateritization processes, enabling the accumulation of iron ore at the top of the ultramafic bedrock.

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