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Identification of the distribution of golf mineral carrier rocks using the geomagnetic method in Pujut Lombok

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Abstract

Lombok Island is one of Indonesia's regions that has high gold potential. It is based on a number of intrusive rocks, quartz veins, and faults in this area. The purpose of this study was to determine the distribution and potential of rocks containing gold in Pujut, Central Lombok. The method used is geomagnetic. The results showed that the moderate geomagnetic anomaly was the response of the gold mineral host rock scattered in the center of the study area. The 2D inversion model shows that the rock layers in the study area consist of sandstone, claystone, tuff, tuff breccia, basalt, cracks, intrusions, and faults. This type of rock is thought to be a carrier of gold minerals, except for clay, basalt and breccia. The depth of the gold-bearing rock layer is 0 m to 230 m from the ground surface, with a volume of 1.22x109 m3 in an area of 12 km2. In the future it is necessary to drill and analyze the gold content.

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1. INTRODUCTION

The Lombok Island has various metallic minerals that have obtained exploration and exploitation permits, such as iron ore, iron sand, manganese, lead, copper, and gold. The gold potential in the Lombok area is quite significant by looking at intrusive rock outcrops, quartz veins, and faults, as well as geological data that is suspected to be a carrier of gold minerals. One area with geological information above is Pujut District, Central Lombok Regency. According to the Mining and Energy Office of the Province of NTB (2019), Pujut District is an area that has the prospect of gold mineralization [1]. This is following the reality that many residents are doing small-scale mining, which is traditionally done.

Geologically, Pujut District is generally formed from the Pengulung Formation. The existence of the Pengulung Formation indicates the potential for gold-bearing rock minerals in the area. It is characterized by faults, quartz veins, and intrusions at the site [2]. According to [3; 4] barren host rock the main rock formations are: magnetite, hematite + sulfide, and other minerals such as quartz, feldspar, calcite, mica, chlorite, pyroxene, amphibole, etc.

The mineral formation is related to the rise of hydrothermal fluid solutions to the surface through cracks or fractures in rock structures, which undergo differentiation and deposition processes. Minerals that carry gold elements in nature are always associated with sulfide minerals, namely Pyrite (FeS_2), Chalcopyrite ($CuFeS_2$), Troilite (FeS), and Pyrrhotite ($Fe_{1-x}S$). These sulfide minerals are found in Breccia, Tufa, Basalt, and Dacite rocks, especially in the Pengulung Formation [5].

One of the geophysical methods that can be used to estimate the presence of rocks associated with gold above is the geomagnetic method. The use of the geomagnetic method is based on the differences in the magnetic properties of each stone. The presence of these magnetic minerals will give different magnetic susceptibility values to each rock. This difference is influenced by the physical characteristics of the rock [6]. Therefore, a study was conducted to determine the subsurface rock layers containing a gold, map, and determine the depth and volume of gold-bearing rocks in Pujut District, Central Lombok.

2. MATERIALS AND METHOD

2.1 Geomagnetic Data

Gold mineralization (Au) is associated with quartz veins, faults, and intrusions in the survey area, which may or may not be associated with fractures. This indicates the need to study the structural setting for this type of ore search as it aids in the planning of geophysical surveys. Gold mineralization around Pujut District was traced with measurement dimensions of 4000 m x 3250 m with a distance between measurement points of 250 m and a distance between tracks of 250 m along the N-S to E-W direction.

At each station, five readings were recorded for the magnetic survey (GSM-19T v7.0 proton precession magnetometer) to improve accuracy, and the average of the readings was used in preparing the anomaly map. Base stations for magnetic surveys are installed outside the survey area. Data measurements were carried out using two sets of GSM-19T v7.0 with an accuracy of 0.1 nT. one device remains at the base station to overcome drift and diurnal corrections. Another tool (mobile) measures at each measuring point along all paths (field station). All magnetic data that has been recorded in the survey area, the elevation of each station for data acquisition was obtained using the instrument at all stations with an accuracy of less than 10 cm. Before taking measurements, both tools are set in advance by equating the time, which includes day and hour.

Another measurement in this research is the susceptibility measurement of rock samples, which are taken from rock outcrops in each trajectory of the study area. This measurement was carried out using the SM-20 Susceptibility Meter. The purpose of this test is to determine the real value of the rock sample susceptibility in the field, which is then used to interpret the magnetic field measured with the PPM (Proton Precision Magnetometer) tool.

The primary purpose of applying geophysical methods is to estimate subsurface models based on observational data. Diurnal correction is implemented to remove the temporal variations in the strength of the Earth's main magnetic field in the magnetic survey. Further processing of this geophysical data set and preparation of anomaly maps have been carried out. The measured magnetic data resulted from both regional (deep structure) and residual (shallow surface body) coarse effects[7]. Thus, regional (longer wavelength) and residual (shorter wavelength) separations are required depending on the need for qualitative interpretation of the underlying geological model of the rock formation. Regional fields can be defined with an upward continuation. Therefore a residual map of the total magnetic intensity (TMI) of the magnetic data has been obtained by subtracting the regional trend (obtained from an upward continuation to a height of 1000 m) from each of the observed TMIs.

Further processing of this geophysical data set is the compilation of anomaly maps. Data generated from regional (deep structure) and residual (shallow surface body) effects. Thus, the separation of the region (longer wavelength) and residual (shorter wavelength). In this study, qualitative and quantitative interpretations of geological models that form local rock formations are carried out. Regional fields can be defined with an upward continuation. Next, the residual anomaly was obtained by subtracting the regional trend from each of the observed TMIs.

International Geomagnetic Reference Field (IGRF) corrections have been introduced on the TMI map to get IGRF corrected magnetic anomaly map. The reduction to pole (RTP) technique makes the observed total magnetic field independent of the geomagnetic inclination[8]. It eliminates the spurious distortion of a magnetic anomaly due to the effect of the inclination of the geomagnetic field. RTP transformation is beneficial in minimizing the polarity effects introduced in observed magnetic data [8]. Therefore, we used (RTP) filter to the IGRF corrected magnetic anomaly map to get IGRF corrected RTP map.

One of the modeling methods in geophysics is Inverse Modeling. Inversion modeling is a process/mechanism of model modification to better match calculation data and observational data. Inversion modeling is the opposite of forwarding modeling because, in inversion modeling, the model parameters are obtained directly from the measurement data. In contrast, the forward modeling parameters are obtained from the calculation results. Inversion modeling is often referred to as data matching because the model parameters are sought that produce a response that matches the observed data. The suitability between the model response and observational data is generally an objective function that must be minimized [9].

One of the modeling methods in geophysics is Inverse Modeling. Inverse modeling is the process/mechanism of modifying the model to better fit the calculation data and observational data. Inverse modeling is the opposite of forward modeling because, in inverse modeling, model parameters are obtained directly from measurement data. On the contrary, forward modeling parameters are obtained from calculation results. Inverse modeling is often referred to as data fitting because it seeks model parameters that produce responses consistent with the observed data. The agreement between the model response and observational data is typically an objective function that needs to be minimized. Inverse modeling is modeling data by applying mathematical and statistical techniques to recover information about the physical properties of the subsurface (Geomagnetic, Magnetic Susceptibility, Density, Electrical Conductivity, etc.) from observed geophysical data. The softwares used are Oasis Montaj, Global Mapper, Grav2dc and Mag2dc [9].

The Factors influencing magnetic data in this survey are [10]:

a. Daily corrections (diurnal corrections) are corrections made to the measured magnetic data to eliminate the influence of external magnetic fields or daily variations. Daily correction is the deviation of the earth's magnetic field value due to differences in time and the effects of solar radiation in one day. The intended time must refer to or correspond to the measurement time of the magnetic field data at each point (measurement station) to be corrected, which is formulated by:

$$\overrightarrow{\Delta H} = \vec{H}_{obs} - \vec{H}_{IGRF} \pm \vec{H}_{VH}$$

$$\vec{H}_{VH} = \vec{H}_{Bi} - \vec{H}_{BO}$$

where $\vec{H}_{VH}$is the daily magnetic field correction, $\vec{H}_{Bi}$is the magnetic field measurement value at the i-time at the measuring station with i = 1, 2, 3, 4,…… n, and $\vec{H}_{B0}$ is the first measurement value at the base station.

b. The influence of the earth's main magnetic field. To eliminate the effect of this field, IGRF correction is made to the measured magnetic field data. Earth's main magnetic field changes with time. To uniform the values of the earth's main magnetic field, a standard is made by the IGRF, which is updated every five years, known as the "epoch." Thus, the value of the total magnetic field anomaly or the survey target is:

$$\overline{\Delta H} = \vec{H}_{obs} - \vec{H}_{IGRF} \pm \vec{H}_{VH} \tag{2}$$

with $\overline{\Delta H}$ = total magnetic anomaly, $\vec{H}_{obs}$ = magnetic field measurement at a certain station, $\vec{H}_{IGRF}$ = theoretical magnetic field based on IGRF, $\vec{H}_{VH}$ = daily correction.

c. Magnetic dipole. The total magnetic field anomaly data is still a magnetic dipole at the measurement location. Therefore it is necessary to correct the reduction to the pole. This dipole anomaly is transformed to the earth's magnetic north pole by changing the inclination direction of the anomalous magnetic field to 90˚ as in the earth's magnetic north pole. After being reduced to the poles, the abnormal value will increase because it is a monopole. The anomalous magnetic field is influenced by remanent magnetic fields and induced magnetic fields. If the two magnetic fields are in the same direction, the value of the magnetic anomaly will increase, and vice versa if they are opposite, will be lower.

d. Regional anomalies. The mineral survey is shallow and local. Therefore, it is necessary to separate it from profound and regional abnormalities. One method of separating anomalies is Continuation upwards. The upward continuation method highlights the magnetic anomaly values caused by deep sources and eliminates magnetic anomaly values caused by shallow sources. Thus, the appearance of the magnetic map is no longer dominated by shallow local anomalous features and does not eliminate abnormal regional features. The principle of continuity explains that a potential field value is continuous and can be calculated in a volume at a certain point. In continuous upwards, the value of the potential magnetic field is transformed from a surface plane to a much higher field [9].

2.2. Geological Setting

The research location is in Pujut District, Central Lombok Regency. Determination of the location of the geomagnetic data collection point is done on a grid at intervals of 250 m, and the distance between the tracks is 250 m with a total of 177 points.

Lombok Island consists of various rock formations based on the geological map, namely alluvium, inseparable volcanic rock, Lekopiko Formation, Kalibabak Formation, Selayar Member (Kalipalung Formation), Ekas Formation, Pengulung Formation, Kawangan Formation, and Breakthrough rocks. The Pujut District area comprises the Pengulung Formation, Kalipalung Formation, Ekas Formation, Breakthrough rocks, and several fault estimates. The Pengulung Formation consists of breccia, lava, tuff, and limestone rocks containing sulfide minerals and quartz veins. The Kalipalung Formation consists of alternating limestone breccias and lava, while the Ekas Formation consists of limestone/calcarenite, locally crystalline, and breakthrough rocks consisting of dacite and basalt [2].

Gold-bearing rocks include breccia, lava, tuff, and limestone containing sulfide minerals and quartz veins. This rock type is found in each of the Kalipalung, Pengulung, and Ekas Formations and Breakthrough rocks in the Pujut District. Judging from the natural physical conditions, gold is a mineral formed together with other minerals and as a result of magmatism processes originating from within the magma chamber, then breaking through to the surface in a hydrothermal environment, both weathered and fresh. Gold ore carrier minerals can be distinguished based on metallic and non-metallic (gangue) content in low-sulfide and high-sulfide deposits. These minerals include quartz, adularia, alunite, pyrite, kaolinite, smectite/illite, chlorite, and chalcopyrite [11].

3. RESULTS AND DISCUSSION

3.1. Qualitative Interpretation

3.1.1 Total magnetic anomaly

The total magnetic anomaly (Figure 1) combines regional and residual magnetic anomalies. The total magnetic anomaly obtained is reduced to the poles to localize the area with the maximum or minimum magnetic field intensity above the object causing the anomaly. Low anomalies (-290.7 nT to 33.3 nT) are marked with dark blue to light green colors that spread in the study area's northern, central, and eastern parts. This low anomaly is probably due to the rock in the region having low magnetite minerals. Furthermore, the anomaly of the moderate magnetic field (41.9 nT to 172.8 nT) is shown in yellow to orange, which is visible in the west and south of the study area. It is suspected that the rocks in the area have moderate magnetite minerals [8]. High anomaly (186.3 nT to 639.4 nT) marked by red to pink color which spreads from the west and south of the study area. The high anomaly indicates the rock has a high magnetite mineral. The contour map of the total magnetic anomaly is shown in Figure 1.

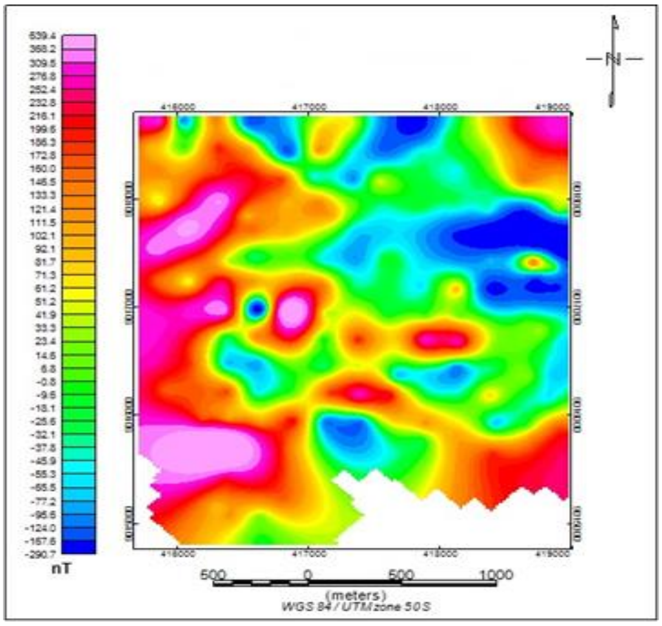

Figure 1. Contour Map of Total Magnetic Anomaly

3.1.2 Pole Reduction

The value of the total magnetic anomaly obtained is still influenced by the earth's two magnetic poles (dipole). This isn't easy to analyze. For this reason, the reduction is carried out to the poles to change the two magnetic poles (dipole) of the earth into one pole (monopole) of the planet, namely the earth's magnetic north pole. Low anomaly groups are located in the middle, north, and south of the study area with anomaly values of -633.7 to -40.1 nT. Medium anomaly groups are located in the west, south, and northeast of the study area, with anomaly values ranging from -27.5 to 191.4 nT. The high anomaly group is located in the westernmost, southernmost, and easternmost part of the study area, with anomalous values ranging from 228.4 to 709.2 nT. The value of the magnetic anomaly reduced to the poles can be seen in Figure 2.

3.1.3 Upward Continuation

The magnetic anomaly value that has been reduced to the poles is still a mixed value of regional and residual magnetic anomaly. The information on the deep and shallow subsurface is still unclear. Thus, separating the anomaly using the upward continuation method is necessary. This process will produce regional magnetic anomalies using programs Mag2dc. The upward continuation process in this study was carried out from a height of 100 m to 1100 m from the total magnetic anomaly data. In this study, changes in the value of the anomaly are seen to be constant at an altitude of 1000 m to 1100 m, so that the anomaly in the upward continuation is chosen for the anomaly with an altitude of 1000 m as the regional anomaly value. Selection of too high an altitude can eliminate shallow and local anomalies that are the main targets of research surveys. Regional magnetic anomaly values are not the survey's target in this study. Thus, a reduction is made between the total magnetic anomaly value that has been reduced to the poles with the regional magnetic anomaly value, and the residual magnetic anomaly value is the target in this study. Residual magnetic anomaly is the effect/response of shallow magnetic anomaly, characterized by small magnetic anomaly contours. This residual anomaly is modeled. The residual anomaly map indicates a complex structure/strata, where the contour pattern has positive and negative anomaly values (Figure 3).

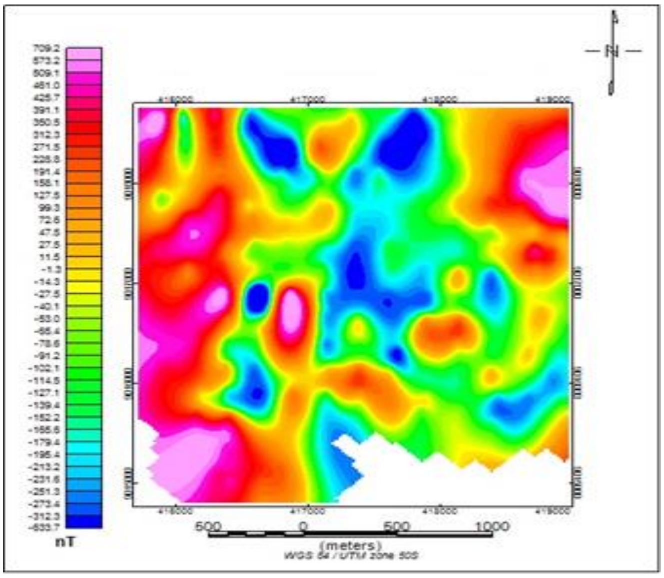

Figure 2. Contour Map of Magnetic Anomaly Induced to The Pole

The residual anomaly contour map (Figure 3) has a magnetic anomaly range from -767.9 nT to 689.1 nT. A light blue indicates low residual anomaly to light green color with a value range of -767.9 nT to -98.5 nT. This low anomaly seems to dominate the northern and central parts of the study area. This anomaly is related to sandstones and claystone in the study area with low magnetite minerals and is flanked by moderate residual anomalies. Moderate anomalies are marked with a yellow to orange color, or anomaly values are -86.5 nT to 107.0 nT. Anomalies are scattered in the study area's east, south, and west. They are suspected to be related to tuff and breccia rocks that have moderate magnetite minerals.

In the study area, it is suspected that there are faults flanked by low and medium anomalies that stretch from north to south. In addition, there are also indications of breakthrough rock with a slight anomaly of high closure. High residual anomalies are marked with red to pink colors found in the study area's western, southern, and northeastern ends. High anomalous values between 132.1 nT to 689.1 nT are thought to be related to the presence of basalt rocks that have high magnetite minerals.

Moderate anomaly in this research area characterizes weak geological conditions, confining zones, and functioning as a place for hot (hydrothermal) fluids to escape. Geologically, the moderate anomaly that spreads in the study area is interpreted as a response to the tuff rock containing gold mineralization. This follows the geological map made by [2]. This interpretation is based on the susceptibility measurements of rock samples from the site and reference susceptibility tables.

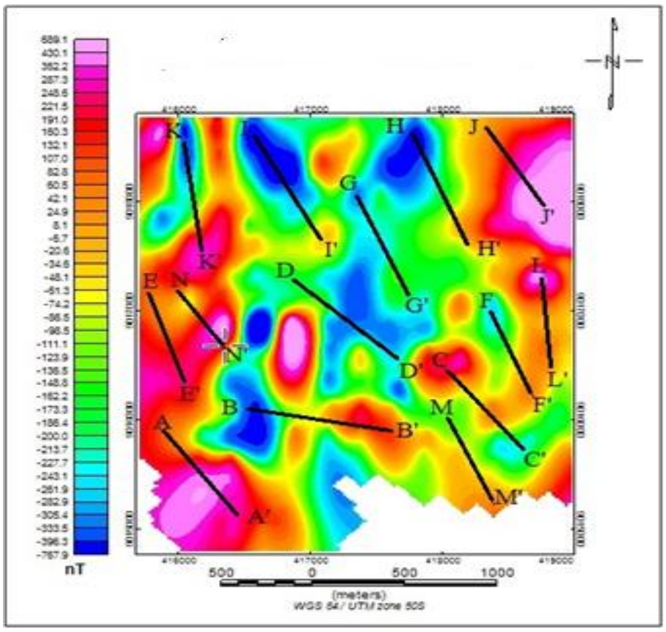

Figure 3. Contour Map of Magnetic Residual Anomaly with Incision

3.2. Quantitative Interpretation

3.2.1 Rock Sample Susceptibility Measurement

The results of the susceptibility measurement of rock samples can be used as supporting data in making subsurface structural models and determining rock types. The results of this measurement can be seen in Table 1.

3.2.2 2D Magnetic Anomaly Modeling

2D Magnetic Anomaly Modeling is done by inversion modeling. The data used to make magnetic anomaly modeling is residual magnetic anomaly data by making incisions, as shown in Figure 3. The incisions made on this residual magnetic anomaly map are expected to represent the entire research area to describe the structure/subsurface strata of the research area close to the actual condition.

This modeling requires several inclinations, declinations, IGRF correction, and residual contour grid inputs. This research area has an inclination value of -33.5344o, a declination value of 0.9707o, and an IGRF value of 45031.1 nT. The modeling results can be seen in Figure 4.

In the model (Figure 4), the first layer of sandstone is assumed to be at a depth of 0 meters to 108.23 meters with a susceptibility value of 0.000101 (cgs system). This estimation is supported by measuring the susceptibility value of rock samples on the track, as shown in Table 1. The second layer is a tuff rock at a depth of 108.23 m to 230.64 m with a susceptibility value of 0.001001 (cgs system). The third layer is a breccia with a susceptibility value of 0.001701 (cgs system) at a depth of 230.64 m to 332.91 m. The fourth layer is assumed to be basalt with a susceptibility value of 0.003051 (cgs system), at a depth of 332.91 m to 454.49 m below the local soil surface.

The results of the subsequent subsurface modeling are sections BB', CC', DD', EE', FF', GG', HH', II', JJ', KK', LL', MM', and NN". Susceptibility values and rock layer depth modeled for each cross-sectional model: AA', BB', CC', DD', EE', FF', GG', HH', II', JJ', KK', LL' , MM' and NN' are presented in Table 2.

3.2.3 Analysis of Depth and Volume of Gold Mineral Carrier Rock

The final stage of data interpretation is to determine the depth and volume of each rock in the study area and obtain a 3D model of each rock which can be seen in Figure 5.

Table 1. Results of rock sample susceptibility measurements

No	Susceptibility (x 10^{-3}; cgs)						
	Sample 1	**Sample 2**	**Sample 3**	**Sample 4**	**Sample 5**	**Sample 6**	**Sample 7**
1	0.170	0.334	0.217	0.133	0.161	0.249	0.219
2	0.176	0.336	0.217	0.132	0.158	0.250	0.219
3	0.174	0.344	0.216	0.135	0.159	0.250	0.200
4	0.173	0.325	0.214	0.133	0.162	0.247	0.220
5	0.171	0.320	0.211	0.135	0.158	0.244	0.214
6	0.171	0.342	0.215	0.133	0.161	0.244	0.217
7	0.175	0.335	0.216	0.136	0.162	0.249	0.215
8	0.171	0.338	0.214	0.135	0.162	0.250	0.219
9	0.175	0.336	0.222	0.130	0.158	0.238	0.220
10	0.176	0.332	0.222	0.135	0.161	0.246	0.206
Average	0.173	0.334	0.216	0.134	0.160	0.247	0.215
Standard Deviation	0.002	0.007	0.003	0.002	0.002	0.004	0.007
%Error	0.001	0.002	0.001	0.001	0.001	0.001	0.002

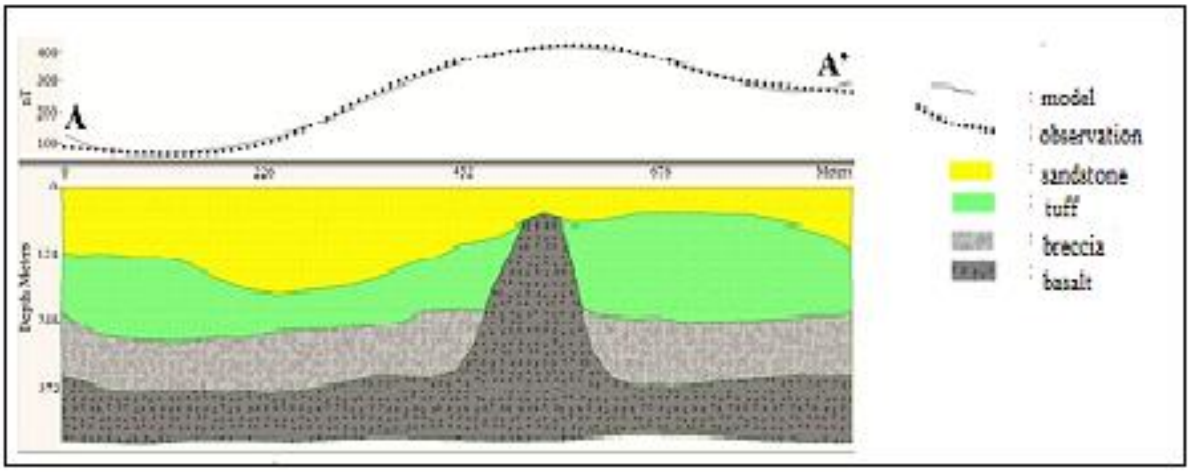

Figure 4. AA' Intersectional model

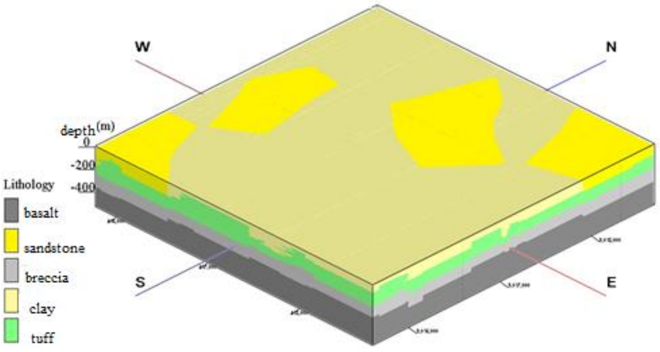

Figure 5. 3D Cross-Sectional Model for Each Rock Layer Using Mag2dc Programs

Figure 5 represents a 3D visualization for each rock layer based on the depth and type of rock. These results are obtained from the 2D results from the previous one. Based on the data processing results, the rocks in the first layer are sandstone and clay with a volume of 184,765,000 m3 and 623,831,000 m3, respectively, with an average depth of 0 – 108.23 m, for the second layer, tuff with a volume of 1,220 is obtained. 150,000 m3 with an average depth of 108.23 – 230.64 m, for the third layer obtained breccia stone with a volume of 1,042,463,000 m3 with an average depth of 230.64 – 332.91 m, and for the fourth layer obtained basalt with volume 1,749,919,000 m3 with an average depth of 332.91 – 454.49 m. Based on geological data, rocks containing gold mineralization are found in the second layer, namely tuff rock (Figure 6), with green color.

Table 2. Susceptibility Value and Rock Layer Depth

Slice	Susceptibility ($x\ 10^{-3}$ cgs)	Rock	Depth (m)
AA’	0.10	sandstone	0 – 121.84
	1.00	Tuff	121.84 – 270.70
	1.70	breccia	270.70 – 374.20
	3.05	Basalt	374.20 – 462.74
BB’	0.20	Clay	0 – 98.07
	1.10	Tuff	98.07 – 213.36
	1.75	breccia	213.36 – 320.53
	3.05	Basalt	320.53– 440.77
CC’	0.30	Clay	0 – 115.39
	1.15	Tuff	115.39 – 258.92
	1.70	Breccia	258.92– 359.05
	3.05	Basalt	359.05 – 504.92
DD’	0.20	Clay	0 – 110.76
	1.15	Tuff	110.76 – 248.55
	1.60	Breccia	248.55 – 329.06
	3.05	Basalt	329.06 – 509.27
EE’	0.20	Clay	0 – 114.77
	1.10	Tuff	114.77 – 270.20
	1.75	Breccia	270.20 – 342.51
	3.05	Basalt	342.51 – 457.01
FF’	0.25	Clay	0 – 106.68
	1.10	Tuff	106.68 – 212.87
	1.60	Breccia	212.87 – 319.07
	3.00	Basalt	319.07– 429.29
GG’	0.10	sandstone	0 – 123.26
	1.00	Tuff	123.26 – 245.18
	1.60	Breccia	245.18 – 368.53
	2.95	Basalt	368.53 – 500.73
HH’	0.20	Clay	0 – 119.82
	1.15	Tuff	119.82 – 252.27
	1.75	Breccia	252.27 – 363.38
	3.05	Basalt	363.38 – 470.18
II’	0.20	Clay	0 – 126.55
	1.00	Tuff	126.55 – 255.77
	1.70	Breccia	255.77 – 382.05
	3.00	Basalt	382.05 – 514.13
JJ’	0.15	Sandstone	0 – 108.69
	1.15	Tuff	108.69 – 216.95
	1.65	Breccia	216.95 – 325.21
	3.00	Basalt	325.21 – 427.44
KK’	0.20	clay	0 – 117.27
	1.00	Tuff	117.27 – 233.23
	1.65	Breccia	233.23 – 350.60
	2.95	Basalt	350.60 – 478.19
LL’	0.25	Clay	0 – 97.61
	1.20	Tuff	97.61 – 194.57
	1.95	Breccia	194.57 – 290.35
	3.25	Basalt	290.35 – 392.70
MM’	0.20	Clay	0 – 96.243
	1.00	Tuff	96.24 – 191.97
	1.70	Breccia	191.97 – 290.05
	3.00	Basalt	290.05 – 382.91
NN’	0.15	Sandstone	0 – 58.33
	1.10	Tuff	58.33 – 164.37
	1.70	Breccia	164.37 – 246.11
	3.05	Basalt	246.11 – 329.64

From the data processing results, the volume of tuff rock layers is interpreted as rock containing gold minerals. The volume of tuff rock is 1,220,150,000 m3 (25.31%), with the overall volume of the interpretation of the research area being 4,821,128,000 m3. These results were obtained in the Pujut District area with about 12 km2.

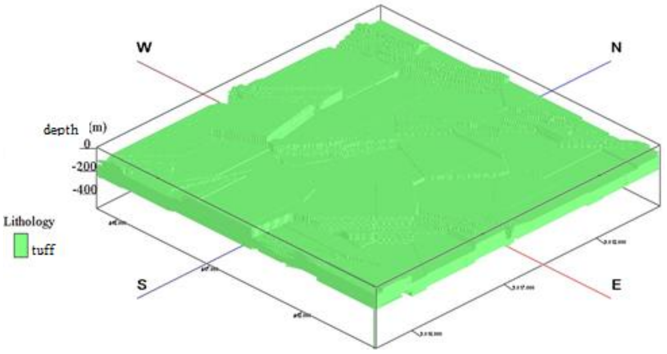

Figure 6. Cross-Sectional 3D Model of Tuff Rock Layers Using Mag2dc Programs

4. CONCLUSION

Based on the results of the qualitative and quantitative interpretation of geomagnetic data in Pujut District, Central Lombok, it can be concluded that: Moderate anomalies are marked with a yellow to orange color, or anomaly values are -86.5 nT to 107.0 nT. The subsurface rock strata of the study area consist of sandstone and claystone layers, tuff rock layers, breccia rock layers, and basalt rock layers. Tuff rock has a susceptibility value between (1.0 – 1.20) x 10-3 (in the SI system). This tuff rock is thought to be a carrier rock for gold minerals. This gold mineral carrier rock is located at a depth of 108.23 m to 230.64 m below the local soil surface. The results of the quantitative interpretation of the 3D model obtained the volume of tuff rock layers as rocks suspected of containing gold as much as 1.22 x 109 m3 spread over an area of 12 km2.

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