JOURNAL OF APPLIED GEOSPATIAL INFORMATION

Vol 5 No 2 2021

http://jurnal.polibatam.ac.id/index.php/JAGI
ISSN Online: 2579-360

Identification of Subsurface Rock Structure of Non-Volcanic Geothermal Systems Based on Gravity Anomalies (Terak Village, Central Bangka Regency)

Reza Firdaus[1], Siska Oktaviyani [1], Putri Hardianti[1], Tri Kusmita[1], Anisa Indriawati[1]
[1] Department of Physics, Faculty of Engineering, University of Bangka Belitung, Bangka 33172, Indonesia.
*Corresponding author e-mail: siskaokt@yahoo.com

Received: September 29, 2021
Accepted: December 01 , 2021
Published: December 02, 2021

Abstract

Geothermal manifestations on Bangka Island are find in the villages of Terak, Pemali, Sungailiat/Pelawan, Dendang, Permis, and Nyelanding. Based on the geological and geochemical survey, manifestation of hot spring in Terak Village, Central Bangka Regency showed a normal fault, horizontal fault structure with northeast-southwest and northwest-southeast trend, and the hot spring is bicarbonate type and immature water. This study is to find out about subsurface rock structure using geophysical method e.g. gravity method. The data used was topographic data and free air anomalies. The data was processed with Bouguer Correction and Terrain Correction to obtain the Complete Bouguer Anomaly (CBA) values. The residual and regional anomaly was separated using upward continuation method, subsurface layer was investigated using 2D forward modeling. The results of the study showed that the subsurface rock structure of the non-volcanic geothermal system in Terak Village consists of caprock in the form of Sandstone (2.28 – 2.49 gr/cm3) at a depth of 0 km – 1.44 km, reservoir rock in the form of Granite rock (2.28 – 2.49 gr/cm3) .77 – 2.78 gr/cm3) at a depth of 0 km – 1.8 km, and the basement rock is Diorite (2.87 – 2.99 gr/cm3) at a depth of 0 – 2 km.

Keywords: *Complete Bouguer Anomaly* (CBA), geothermal non volcanic, gravity method, residual anomaly

1. INTRODUCTION

Geothermal is one of the alternative energy's sources to generate electricity which has the potential to reduce the use of fossil energy sources such as oil and coal (Anggraini, Siregar, & Singarimbun, 2019). Geothermal manifestations in Indonesia that have been identified are 331 points spread from Sabang to Merauke with potential resources of 11,073 MW and reserves of 17,506 MW (ESDM, 2017). This shows that there is a large potential for geothermal energy to be developed in order to optimally utilize it as a source of electricity generation. Generally, geothermal sources are identical to the presence of volcanoes, but some geothermal system is non volcanic type e.g. geothermal system at Bangka Island (Anggraini, Siregar, & Singarimbun, 2019). Geothermal system at Bangka Island was associated with radiogenic processes. Radiogenic geothermal systems came from decay radioactive elements such as Thorium (Th), Potassium (K), and Uranium (U) in Granite rocks. Geothermal manifestations on Bangka Island were found in the villages of Terak, Pemali, Sungailiat/Pelawan, Dendang, Permis, and Nyelanding (ESDM, 2017).

Several studies on non-volcanic geothermal sources that have been carried out on Bangka Island was identification of geological structures (Pitulima & Siregar, 2016; Setiawan & Adithya, 2015), constituent rock elements (Anggraini, Siregar, & Singarimbun, 2019; Siregar, Dewi, & Ngatijo, 2021; Widyaningrum & Kurniawan, 2019), geothermal structures (Siregar & Kurniawan, 2018), and hotspring flows (Purwoto, Rezky, & Simarmata, 2015; Putri & Harianja, 2021). Manifestation of hot springs in Terak Village, Central Bangka Regency in the form of geological and geochemical surveys (ESDM, 2017). Based on a geological survey, Terak Village is composed of metamorphic rocks of Permo-Carbon age, old plutonic igneous rocks in the form of Triassic-aged granite, surface deposits, and alluvium deposits. The domination structure is a normal fault, horizontal fault structure with a northeast-southwest and northwest-southeast direction (ESDM, 2017). Based on the geochemical survey showed 3 hot spring which is bicarbonate type and immature water. Estimated reservoir temperature using a silica geothermometer is around 90°C, hot water temperature is 55°C - 61.8°C, air temperature is 34.6°C, discharge is 0.2 liters/second, pH is 4.89, clear water, and no odor (ESDM, 2017). However, a geophysical survey has not been carried out to determine the subsurface condition of the non-volcanic geothermal area of Terak Village. Therefore, this research was conducted using geophysical survey methods, one of which is the gravity method which aims to determine the structure of non-volcanic geothermal subsurface rock layers in Terak Village.

The study area is the manifestation of the hot spring area of Terak Village, Simpang Katis District, Central Bangka Regency, Bangka Belitung Islands Province with 10 km x 10 km survey area (Figure 1).

Figure 1. Data Acquisition Design

2. METHODS

The data used in this study was topographic and free air anomalies data with 49 points spread survey in order grid. The data was accesed on Topex's website: https://topex.ucsd.edu/cgi-bin/get_data.cgi. The equipment used in this study was listed in Table 1 below.

Table 1. Equipments used in research

Equipments	Function
Google Earth Pro	Making design survey area
Microsoft Excel	Calculate the value of Bouguer Correction and Complete Bouguer Anomaly
Global Mapper 20 (64-bit)	Cut SRTM DEM data for Terrain Correction
Oasis Montaj Viewer v.8.0	Calculates Terrain Correction values, create CBA contour maps, residual and regional anomalies, and 2D modeling (forward modeling)

Free air and topographic anomaly data corrected using Bouguer and Terrain corrections to obtain Complete Bouguer Anomaly (CBA) values. The regional and residual anomaly was separated using upward continuation method. Subsurface rock structure from geothermal system was investigated from 2-dimensional forward modeling along with the conceptual model of radiogenic geothermal (Anderson & Lund, 1979) and geological maps (Margono, Supandjono, & E, 1995).

Bouguer Correction

Bouguer Correction is a correction made to eliminate the effect of gravity caused by the difference elevation between the observation points and datum (mean sea level, msl). Bouguer Correction assumes the rock density value is located between the observation points and msl. In a large horizontal field. The rock density value is uniform (Bouguer density, ρ). Bouguer correction was formulated by eq. 1 (Telford, Geldart, & Sheriff, 1990):

$$BC = 2\,\pi\,G\,\rho\,h \qquad [1]$$

$$BC = 0{,}04193\,\rho\,h$$

where:
BC : Bouguer Correction (*mGal*);
ρ : Bouguer Density (gr/cm^3);
G : Gravitational Constant ($6{,}67 \times 10^{-11} Nm^2/kg^2$);
h : Elevation (*m*).

Terrain Corrections

Terrain correction used to remove the mass effect from the topography around the observation point. The irregularities of the topography e.g. hills and valleys will affect the gravity value measurements in the observation point. Terrain correction was formulated by eq. 2 (Telford, Geldart, & Sheriff, 1990):

$$TC = 2\pi G\rho R \qquad [2]$$

where:
TC : Terrain Correction (mGal);
G : Gravitational Constant (6.67×10^{-11} Nm^2/kg^2);
ρ : Density of Mass (gr/cm^3);
R : Earth Radius (km).

Complete Bouguer Anomaly (CBA)

Complete Bouguer Anomaly (CBA) is an anomaly caused by lateral rock density variations in Earth's crust in the reference field (the geoid field). In this study gravity anomaly obtained from the satellite data, follow the formulation in eq. 3 (Telford, Geldart, & Sheriff, 1990):

$$CBA = FAA - BC + TC \qquad [3]$$

where:
BC : Bouguer Correction (mGal);
FAA : Free Air Anomaly (mGal);
TC : Terrain Correction (mGal).

Regional and Residual Anomalies

CBA value is contain regional anomalies, residual anomalies, and noise. From overlapping anomaly values it's difficult to interpret. So, it is necessary to separate the anomalies. Regional and residual anomaly was separated using upward continuation process. It is to reduce data to flat field. In this process, it applied spectral analysis using (Fourier Transformation and Gaussian Filtering) (Karunianto, Haryanto, Hikmatullah, & Laesanpura, 2017).

3. RESULTS AND DISCUSSION

Gravity Anomaly

Figure 2 represented CBA value in Terak geothermal system. CBA values in this area was 25.7 – 31.8 mGal red to light contour represented moderate – high anomaliess (28.1 – 31.8 mGal).

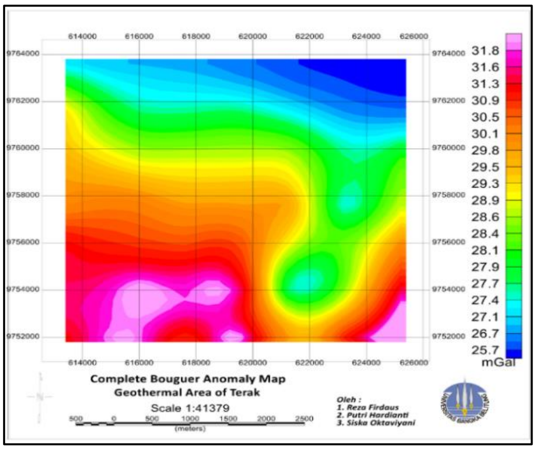

Figure 2. Complete Bouguer Anomaly (CBA) Contour Map.

The high anomalies value caused by the constituent rocks with high rock density, massive, the presence of mafic intrusion of igneous rock that penetrates to the surface, and indicated by silicate deposition from hydrothermal activity (Huenges, 2010). In this study it's caused by the constituent rocks which a high density, e.g. granite or igneous rock (Putri & Harianja, 2021). It has supported by geological condition in the area with the dominated by Sandstone, Granite, Diorite, etc (Margono, Supandjono, & E, 1995). Low anomaly is shown in light green to blue contour (28.0 - 25.7 mGal). Low anomaly value caused by the constituent rocks with lower density, higher porosity, and felsic igneous rock intrusion that penetrates to the surface, fault or fracture zones, and also minerals alteration due to hot water circulation (Huenges, 2010). In this area of hot water manifestation (mineral alteration), fractures such as those found in the north-south part, intrusive of granite rocks from Klabat Granite as Late Triassic age which have less density, and a fault or fracture structure (Putri & Harianja, 2021).

The low anomaly was associated with reservoirs rock. The high anomaly was associated with basement rock (Putri, Nanda, Rizal, Idroes, & N, 2019). Using CBA data, regional & residual anomaly was obtained by perform Fourier Transformation and Gaussian Filtering (Karunianto, Haryanto, Hikmatullah, & Laesanpura, 2017).

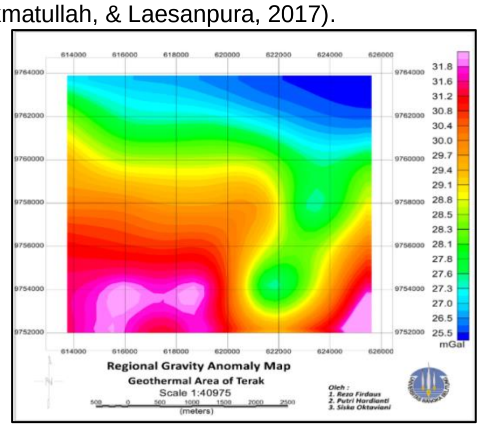

Figure 3. Distribution of Regional Anomalies

Regional anomalies caused by a high homogenity and large rocks from the deepest of subsurface (Mishra, 2009). Figure 3 represented regional anomalies distribution (25.5 – 31.8 mGal). Red to light contour represented moderate to high anomalies from north to south (28.5 – 31.8 mGal). The high anomaly value caused by uncontinuity rock with high density and thickness (Mishra, 2009). It has supported by geological condition in the area which dominated by igneous rock e.g Granite, Diorite, Granodiorit, etc (Margono, Supandjono, & E, 1995). Low anomaly shown in light green to blue contour (25.5 – 28.4 mGal). It was caused by the presence of fractures in the north-south and northwest-southeast. (Huenges, 2010).

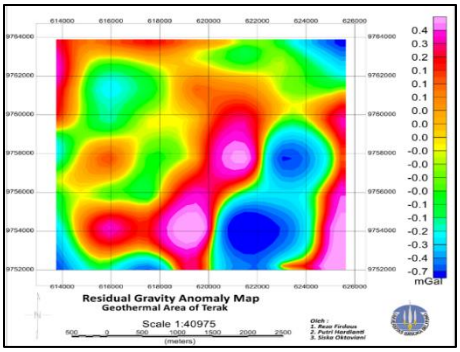

Figure 4. Distribution of Residual Anomalies

Residual anomalies caused by near surface rocks that. So it's can represent the geological structure subsurface (Mishra, 2009). Figure 4 represented residual anomalies values distribution (-0.7 to 0.4 mGal). Red to light contour represented moderate to high anomalies (0.0 – 0.4 mGal). The high anomalies was found in the southern caused by rocks has a high density at Triassic-old Tanjung Genting Formation (Putri & Harianja, 2021). Low anomaly shown in light green to blue contour (-0.1 to 0.0 mGal). It was caused by sedimentary has a low density. The low anomalies it's also granite intrusion from formation Klabat Granite which has characteristics various rocks whith a faults or fractures in the rock layers of the area (Putri & Harianja, 2021).

2D Subsurface Model

2D subsurface model obtained by applying fourth cross section (A, B, C, and D) from distribution of residual anomaly (Figure 5). The length of cross section A and D are 7.13 km and 1.66 km from the northwest to the southeast. Meanwhile, cross section B and C are 6.13 km and 6.32 km from the northeast to the southwest. 2D subsurface model was carried out using approximated by Linier Equation (forward modeling).

Geothermal system model was refers to using conceptual model radiogenic geothermal system (Anderson & Lund, 1979) and geological map of North Bangka (Margono, Supandjono, & E, 1995). Geological condition was dominated by Alluvium, Sandstone, Granite, Grano Diorite, Diorite, and Quartz Diorite from Granite Klabat, Kompleks Pemali, and Tanjunggenting Formation (Margono, Supandjono, & E, 1995).

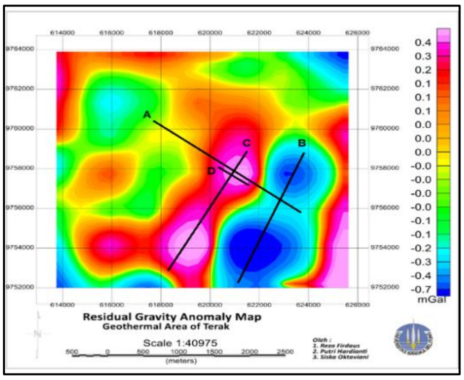

Figure 5. Path of Cross Section A, B, C, D

Figure 6 shown 2D model from cross section with high to low anomaly (Cross section A). In this figure First layer of rock has a density value 2.28 - 2.44 gr/cm^3. It was interpreted as Sandstone with an average thickness of 0.25 km found along 2.63 km from the southeast with a depth of 0.4 km. In this cross section, a There is Granite (2.79 gr/cm^3) at the surface with average thickness of 0.9 km along 3.8 km (from 0.3 km – 4.5 km) alongate from the northwest to the southeast. The other layer was Diorite (2.87 - 2.99 gr/cm^3) with an average thickness of 0.3 km. Diorite rock is find in the surface along 0 km – 0.3 km from northwest to southeast. Then the the last layer has a density of 2.41 gr/cm^3 (Sandstone) at a depth of 1.3 km – 2 km with an average thickness of 0.55 km.

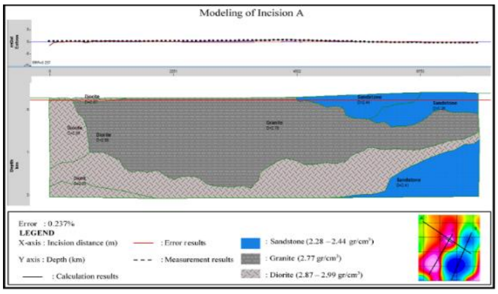

Figure 6. 2D Geothermal Modeling of Terak Village Cross Section A

Figure 7 shown 2D model from cross section with low anomaly (Cross section B). This figure shown 4 layers of rock on subsurface of geothermal system. The first layer was Sandstone (2.39-2.49 gr/cm) with average thickness of 0.35 km (from 0 km - 0.4 km). The second layer was Granite (2.77 gr/cm^3) with an average thickness of 0.9 km at a depth of 0.3 km -1.4 km. The third layer has a density value of 2.85 gr/cm^3 was interpreted as Diorite with an average thickness of 0.6 km (from 1.3 km – 2 km). Then the last layer with an average thickness of 0.15 km (1.8 km to 2 km) was interpreted as Sandstone (2.39 – 2.43 gr/cm^3).

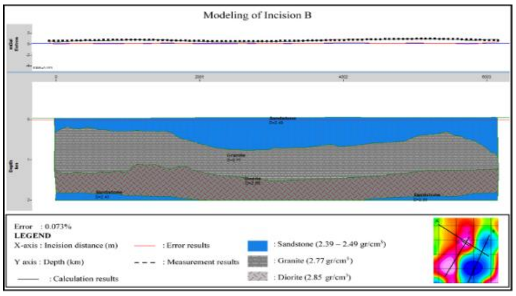

Figure 7. 2D Geothermal Modeling of Terak Village Cross Section C

Figure 8 represented 2D model from cross section with high anomaly (Cross section C). The first layer with density value of 2.49 gr/cm^3 interpreted as Sandstone. It has an average thickness of 0.538 km at a depth of 0 km – 0.5 km. The second layer was interpreted as Granite (2.77 gr/cm^3) at a depth of 0.4 km - 1.8 km with average thickness of 0.844 km. The third layer was Diorite (2.85 gr/cm^3) along depth of 1 km – 2 km (average thickness of 0.441 km). The last layer with density of 2.4 – 2.41 gr/cm^3 at a depth of 1.8 km to 2 km was Sandstone (average thickness 0.237 meters).

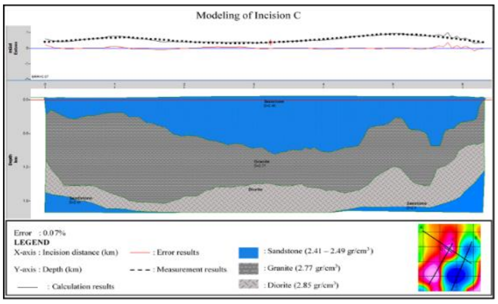

Figure 8. 2D Geothermal Modeling of Terak Village Cross Section C

Figure 9 represented 2D model from cross section with high anomaly (Cross section D). This cross section consists of 4 layers of rock. A rock with density value 2.44 gr/cm^3 as Sandstone with an average thickness of 1 km at a depth of 0 km – 1.44 km. The second layer was Granite (2.77 gr/cm^3) along 0.7 km (0.3 km – 1.7 km). The third layer extends along 0.9 km at a depth of 0.78 km-2 km. was Diorite (2.85 gr/cm^3). Then, the last layer has a density value of 2.44 gr/cm^3 at a depth of 1.9 km to 2.00 km with an average thickness of 0.3 km was Sandstone.

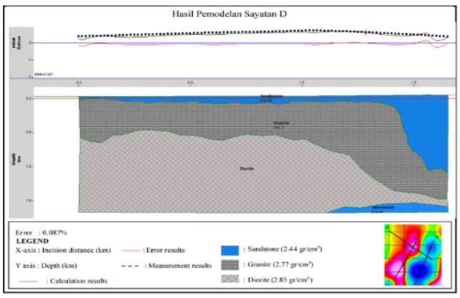

Figure 9. 2D Geothermal Modeling of Terak Village Cross Section D

Geothermal manifestations of Bangka Island are non-volcanic geothermal produce from radiogenic processes. Radiogenic geothermal systems originate from the decay of radioactive substances Thorium (Th), Potassium (K), and Uranium (U) from intrusive Granite rocks (ESDM, 2015). The formation of geothermal systems in several manifestations on Bangka Island is estimated to be associated with large-dimensional plutonic rock bodies e.g. batholiths, Granites, and clabat Granites of late Triassic – early Jurassic age (Purwoto, Rezky, & Simarmata, 2015). Based on the geology of rock formations and the results of interpretation of subsurface rock structures Granite rocks is reservoir source as radioactive carriers which are estimated as heat sources with the dominating characteristic of silica (SiO_2) in the form of quartz and the presence of Sandstone around the Granite (Widyaningrum & Kurniawan, 2019; Anggraini, Siregar, & Singarimbun, 2019; Siregar, Dewi, & Ngatijo, 2021; Pitulima & Siregar, 2016; Setiawan & Adithya, 2015; Siregar & Kurniawan, 2018; Purwoto, Rezky, & Simarmata, 2015; Putri & Harianja, 2021).

Geologically, Terak Village was composed by metamorphic rocks of Permo-Carbon age, old plutonic igneous rocks in the form of Triassic-aged Granite, and surface deposits, as well as alluvial deposits (ESDM, 2017) e. g. Alluvium, Sandstone, Granite, Grano Diorite, Diorite, and Diorite Quartz (Margono, Supandjono, & E, 1995). This model in this study shown the subsurface rock structure of the non-volcanic geothermal system in Terak Village consists of third layers of rock. The first layer as Caprock with a density of 2.28 – 2.49 gr/cm^3. The second layer was Granite as reservoir rock with density 2.77 – 2.78 gr/cm^3. Basement rock was represented by Diorite with a density of 2.87 – 2.99 gr/cm^3).

4. CONCLUSION

Base on the analisysof gravity anomalies, it is known that the subsurface rock structure of the non-volcanic geothermal system in Terak Village is in the form of Sandstone (2.28 – 2.49 gr/cm^3) at a depth of 0 – 1.44 km was estimated as a caprock) Granite rock (2.77 – 2.78 gr/cm^3) at a depth of 0 – 1. 1.8 km was estimated as reservoir rock, and Diorite rock (2.87 – 2.99 gr/cm^3) at a depth of 0 – 2 km was estimated as basement rock.

ACKNOWLEDGEMENT

The authors would like to thank the University of Bangka Belitung for their support of this articel from MBKM research program.

REFERENCES

Anderson, D., & Lund, J. 1979. Direct Utilization Of Geothermal Energy: A Technical Handbook. United States: https://Doi.Org/10.2172/6707209.

Anggraini, M., Siregar, R. N., & Singarimbun, A. 2019. Identification of Radioactive Elements of Nyelanding Granite (South Bangka) Using X-Ray Fluorescence Method. Journal Of Science And Applicative Technology, 1-7.

ESDM. 2015. Non-Volcanic Geothermal System in Sulawesi. Bandung: Center for Geological Resources, Geological Agency of the Ministry of Energy and Mineral Resources.

ESDM. 2017. Indonesia's Geothermal Potential Volume 1. Jakarta: Geothermal Directorate General of New, Renewable Energy and Energy Conservation, Ministry of Energy and Mineral Resources.

Karunianto, A. J., Haryanto, D., Hikmatullah, F., & Laesanpura, A. 2017. Determination of Regional and Residual Gravity Anomalies Using Gaussian Filters in Mamuju, West Sulawesi. Exploration, 89-98.

Margono, U., Supandjono, R., & E, P. 1995. Geological Map of Sheets of South Bangka, Sumatra. Bandung: Center for Geological Research and Development.

Pitulima, J., & Siregar, R. N. 2016. Identification of the Geological Structure of Non-volcanic Hot Springs in Nyelanding Village, South Bangka Using the Geoelectrical Method of Wenner Configuration. Banjarmasin: Proceedings of SNRT (National Seminar on Applied Research).

Purwoto, E., Rezk, Y., & Simarmata, R. S. 2015. Survey of Heat Flow in Permis Geothermal Area, South Bangka Regency, Bangka Belitung Province. Geological Resource Center.

Putri, D. A., & Harianja, A. K. 2021. Identification of Radiogenic Geothermal Prospects Using Landsat-8 and Gravity in Permis Region. Jge (Journal of Exploration Geophysics), 7(1), 52-70.

Putri, D. R., Nanda, M., Rizal, S., Idroes, R., & N, I. 2019. Interpretation of Gravity Satellite Data To Delineate Structural Features Connected To Geothermal Resources At Bur Ni Geureudong Geothermal Field. Iop Publishing, 1-6.

Setiawan, D. L., & Adithya, L. 2015. Geothermal Geology and Geochemistry of Permis Region, South Bangka Regency, Bangka-Belitung Province. Colloquium: Geothermal Research Group, Center for Geological Resources.

Siregar, A. M., Dewi, I. K., & Ngatijo. 2021. Identification of Granite Rocks in Nearby Geothermal Prospects Using Magnetic Methods. Spej (Science And Phsics Education Journal), 4(2), 62-69.

Siregar, R. N., & Kurniawan, W. B. 2018. 2d Interpretation Of Subsurface Hot Spring Geothermal Structure In Nyelanding Village Through Schlumberger Geoelectricity Configuration Method. Scientific Journal of Physical Education-Biruni, 7(1), 81-87.

Telford, W. M., Geldart, L. P., & Sheriff, R. E. 1990. Applied Geophysics (2 Ed.). Cambridge: Cambridge University Press.

Widyaningrum, Y., & Kurniawan, W. B. 2019. Characteristics of Rocks Composing Hot Springs Nyelanding Village, Air Gegas District, South Bangka Regency (An Summary). Bangka: Proceedings of the National Seminar on Research & Community Service.