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Utilizing of Geophysical Methods for Geothermal Exploration at Guru Kinayan Village, Tanah Karo Regency

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Abstract: Guru Kinayan, located at the foothills of mount Sinabung in Karo regency, is characterized by several geothermal manifestations, highlighting the necessity of studying its geothermal potential. This research aims to assess the geothermal prospects of the area through 2-D electrical resistivity, geomagnetic surveys, and (XRD) methods. To acquire 2-D resistivity data, a Wenner Schlumberger array with a 5-meter electrode spacing was utilized, and the data were processed using Res2Dinv. Geomagnetic surveys were conducted using a PPM, with the results analyzed using Mag2dc and Surfer 13 to determine susceptibility results. The analysis of rock composition was performed using XRD. The 2-D resistivity results indicated resistivity values ranging from 1 to 1250 Ωm. Values between 1 and 20 Ωm indicated as alluvium, indicating a reservoir for geothermal, while resistivity values >1000 indicates as limestone, which indicated as a heat conductor. The magnetic residual map shows geomagnetic values (20 to 380 nT), suggesting a geothermal source, and the susceptibility values ranging (0.0013 x 10^3 to 0.0088 x 10^3) indicates the presence of igneous rocks, specifically andesite lava and pyroclastic rocks. The XRD results show arsenopirit and quartz in the geothermal area. Based on the integrated results, the study area has significant geothermal potential.

Keywords: Geophysics; Geothermal; Guru Kinayan; Karo; XRD

Introduction

Despite significant potential energy resources, including fossil fuels, coal, and geothermal energy from volcanic activity (Asrillah et al., 2014), North Sumatra, a key energy region in Indonesia, lacks comprehensive geothermal exploration. While surveys have been conducted in areas like Sibayak and Sorik Marapi (Febriadin et al., 2020; Laksono et al., 2023), they have not fully integrated geophysical, and XRD methods. To fully assess the geothermal potential of North Sumatra, additional surveys are necessary.

To comprehensively identify geothermal potential areas, integrating geophysical, and XRD methods is crucial (Larasati et al., 2023; Nursanto et al., 2022). Geophysical investigations employ 2-D resistivity and geomagnetic surveys. Resistivity assesses geothermal prospects (Loke, 2000; Zakaria et al., 2016), while geomagnetic surveys determine depth and surface structure (Maulidan et al., 2022). Geomagnetic anomalies, indicative of lower magnetization in geothermal rocks, can pinpoint potential reservoir zones and heatsources (Oladele et al., 2022). XRD analysis identifies rock types. The combination of geophysical

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methods offers a more comprehensive understanding of the subsurface geology and geothermal characteristics of the area. Consequently, this research will serve as a reference, demonstrating the substantial geothermal potential of North Sumatra, particularly in the Guru Kinayan area, and underscoring the need for further exploration and development.

Method

2-D resistivity was carried out with a multi-electrode resistivity meter system. Such surveys use several electrodes usually ranging from 25 electrodes to 100 electrodes located in a straight line with a constant distance. A computer system is used to select the active electrode for each size. The Wenner Schlumberger array was used for this survey. Wenner Schlumberger methods was selected because it possesses high resolution and the capability to delineate geological structures, which can assist in determining the location and geothermal potential (Loke & Barker, 1996; Saputra et al., 2020).

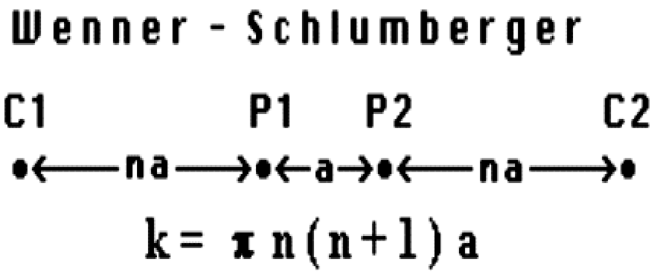

Figure 1. Wenner Schlumberger array

Variations in electrical resistivity in rocks can indicate changes in composition, layers, or levels of contaminants. The resistivity of these rocks is primarily influenced by the degree of fracturing. Highly fractured rocks will exhibit lower resistivity values, while rocks with harder compositions will show higher resistivity values. Table 1 presents the resistivity values for different rock and soil types (Griffiths & Barker, 1993).

Table 1. Resistivity Value of Rocks and Soil

Material	Resistivity (Ωm)
Alluvium	10 - 800
Sand	60 - 1000
Clay	1 - 100
Sandstone	8 - 4×10^3
Limestone	50 - 4×10^3
Granite	5×10^3 - 1×10^6

The purpose of the magnetic survey is to identify the subsurface geology based on the anomaly of the earth's magnetic field due to the magnetic properties of the underlying rock and the magnetic susceptibility caused by the different magnetic values of the object. Table 2 shows the general magnetic values in common rocks and ores (Telford et al., 2004). The magnetic properties of highly magnetic rocks tend to vary widely and their magnetization is not directly proportional to the applied field.

Table 2. Susceptibility Value of Some Rocks and Minerals

Types of Rocks	Susceptibility (10^3 SI)	Average Interval
Dolomite	0 - 0.9	0.1
Limestones	0 - 3	0.3
Sandstone	0 - 20	0.4
Quartzite	3 - 17	-
Granite	0 - 50	2.5
Rhyolite	0.2 - 35	-
Andesit	-	160
Calcite	-0.001 - (-0.01)	-
Arsenopirit	-	3
Basalt	0.2 - 175	70

The working principle of XRD consist of three main parts, namely the X-ray tube, the object being studied, and the X-ray detector. X-rays are generated in the X-ray tube containing the cathode heating the filament, thereby generating electrons. The difference in voltage causes the acceleration of the electrons to shoot at the object. When an electron has a high energy level and hit the other electrons in the object and produces X-rays. The object and detector rotate to capture and record the intensity of the X-ray reflection. The detector records and processes X-ray signals and processes them in graphic form (Bunaciu et al., 2015).

Result and Discussion

This area is located in an active tectonic zone, characterized by numerous faults and fractures beneath the ground surface. The presence of various rock types indicates that the Guru Kinayan Village area is significantly influenced by the volcanic activity of Mount Sinabung.

Generally, the geology of Guru Kinayan is dominated by tertiary and quaternary volcanic rocks. Volcanic rocks such as basalt, andesite, dacite, and rhyolite are commonly found in this area (Figure 2).

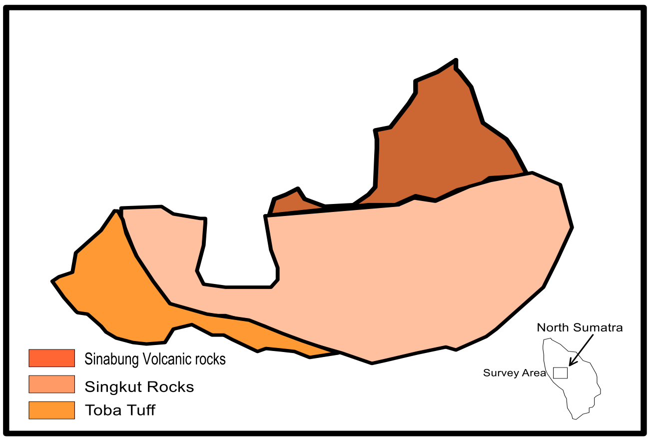

Figure 2. Geological map of Guru Kinayan geothermal area (Barber et al., 2005)

The 2-D resistivity line located in foothill Sinabung montain (Figure 3).

Figure 3. Guru Kinayan survey area

The 2-D resistivity method was carried out in 3 lines as shown in Figure 4. All lines are used Wenner Schlumberger configuration obtained 225 data with 150 meter length and 5 meters electrode spacing.

Figure 4. Guru Kinayan survey lines

Line 1 Guru Kinayan (Figure 5) at a distance of 45 to 85 m (depth of 1 to 13 m) and also at a distance of 100 m to 150 m (depth of 1 m to 20 m) shows a resistivity value between 1 to 20 Ωm indicated as clay which is a reservoir of geothermal hot water. Whereas the resistivity > 1000 Ωm indicates as limestone and it can be a heat conductor from the heat source.

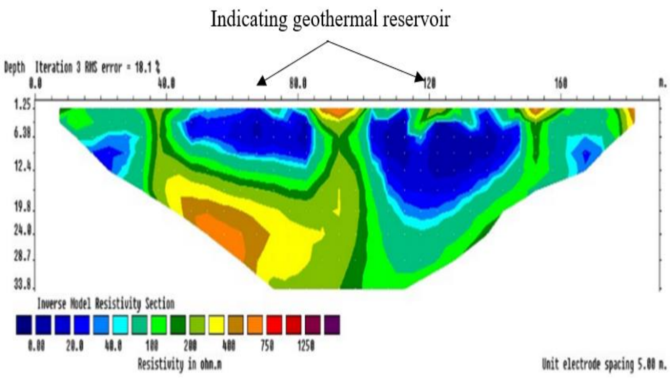

Figure 5. Line 1 Guru Kinayan

Line 2 Guru Kinayan (Figure 6) indicates a potential clay zone, which could be a geothermal reservoir with a resistivity of 1-20 Ωm at a depth of 12 to 24 meters. Conversely, resistivity values more than 200 Ωm are indicative of limestone, which could serve as a heat conductor from the heat source.

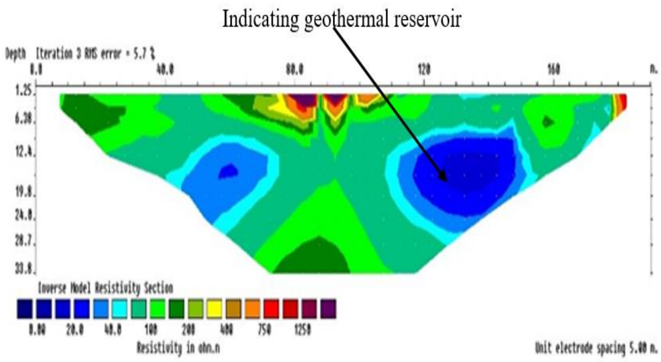

Figure 6. Line 2 Gurukinayan

Line 3 Guru Kinayan (Figure 7) indicates a potential clay zone, which could be a geothermal reservoir with a relatively uniform resistivity of 1-20 Ωm throughout the area. In contrast, higher resistivity values exceeding 200 Ωm, indicative of limestone, are localized within specific parts of the area and could serve as a heat conductor from the heat source.

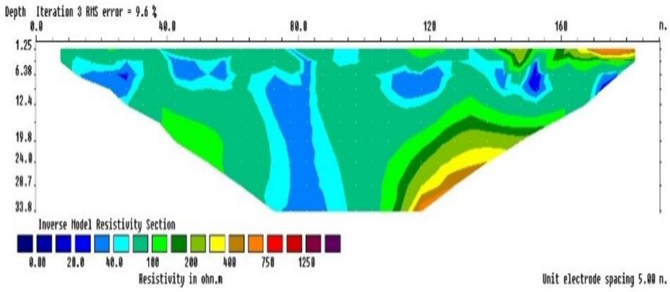

Figure 7. Line 3 Guru Kinayan

2-D resistivity value in Guru Kinayan area is divided according to the resistance value as set out in the table 4 below.

Table 2. Resistivity Value and Rock Type

Resistivity Value (Ωm)	Hotwater 1
0 - 20	Clay
100 - 200	Alluvium
200 - 1000	Limestone
> 1000	Andesite rock

All resistivity lines show resistivity values 0 Ωm to 1250 Ωm. It indicates that the area is very likely an alluvium area that stores hot water. This water comesfrom a reservoir located below the surface which then appears on the surface. The resistivity values from 0 to 200 Ωm can be indicates as a hot reservoir. While the resistivity value > 200 Ωm can be indicated as a heat conductor (limestone and andesite rock).

Based on the results of observational data measurements, magnetic field anomalies were obtained and presented as a contour map using Surfer 13 software, as shown in Figure 8.

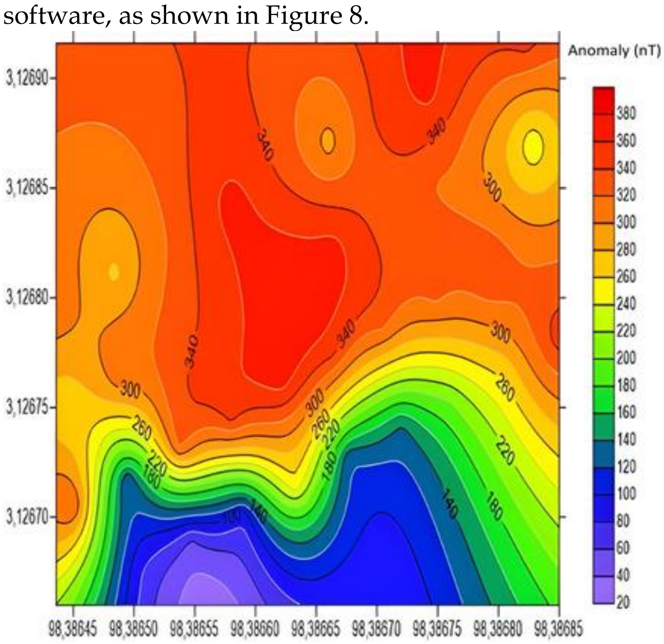

Figure 8. Map of the distribution of earth's magnetic anomalies

Figure 8 shows the magnetic field strength at the research location ranges from 20 nT to 380 nT. Low-intensity magnetic anomalies have a value of around 20 nT to 120 nT, which are visible in the section marked in bold blue. Moderate magnetic anomalies have a value of around 140 nT to 220 nT, as seen in the section marked in green. High magnetic anomalies have a value of around 240 nT to 380 nT, visible in the section marked with yellow to reddish color.

Susceptibility of Geothermal Area

The magnetic susceptibility is a fundamental physical parameter in magnetic investigations, because susceptibility is a measure of the ability of a rock to receive magnetization from the earth's magnetic field. To get a clear picture of the magnetic properties found in the research area, magnetic susceptibility measurements were carried out at each measurement point. The following is an image of the susceptibility contour map shown in Figure 9.

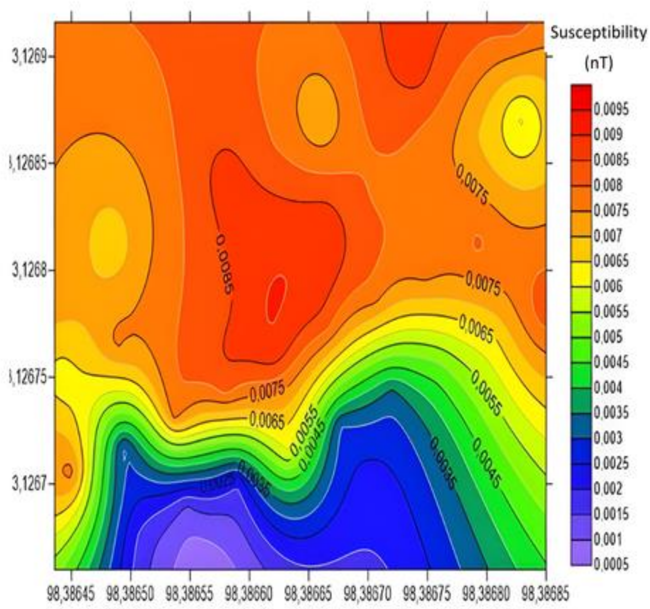

Figure 9. Susceptibility countor map at the research site

Based on the calculation of susceptibility values, it was determined that the Guru Kinayan Village geothermal area has susceptibility values ranging from 0.5×10^{-3} nT to 9.5×10^{-3} nT. These values were used to identify the type of rock beneath the surface in the geothermal area. During geothermal surveys, the focus is on identifying low anomalies, as the demagnetization process caused by hydrothermal alteration can turn rocks minerals into paramagnetic or diamagnetic minerals.

The top layer, characterized by a susceptibility value of $k = 9.5 \times 10^{-3}$ nT, is interpreted as consisting of andesitic lava and pyroclastic rocks. These igneous rocks are the primary constituents of the geothermal system within the study area. Such a geological setting is often a product of volcanic eruptions.

The XRD test in the Guru Kinayan Village area was conducted to compare the results with geophysical survey. The mineral composition of the rock, as shown in Table 3, is mainly Asbecasite and Quartz. The analysis of field survey measurements revealed that the first geothermal system is located in line 1 and line 2 areas.

Table 3. X-Ray Diffraction Result

Point	Mineral Content
1	Asbecasite
2	Quartz

The subsurface pattern of hot springs is investigated by interpreting the 2D electrical resistivity profile. Resistance values shown in 2D electrical resistivity range from A resistivity value of 1-1250 Ωm and are nominated by geothermal reservoir and limestone which are thought to be reservoir heat conductors. Magnetic values show magnetic anomaly values have a value of about 20 nT to 68 nT. High magnetic anomaly is found in the central part from south to north. While low anomalies are found in the southwest and east, especially in the middle and east. Based on the value of the magnetic field anomaly, the study area is dominated by low magnetic field anomaly values. a high anomaly that can be estimated to have a type regarding the approximate type of constituent rock which is thought to be caused by volcanic rocks that have high susceptibility from the Sibayak Formation or Mount Sinabung. The anomalous pattern is thought to be caused by sedimentary rocks. Meanwhile, the XRD results are dominated by gypsum and magnesium, which are one of the main elements that produce geothermal energy.

Conclusion

The study is was done at Guru Kinayan, Village located at the foothills of Mount Sinabung, demonstrates considerable geothermal potential. Utilizing 2-D electrical resistivity, geomagnetic surveys, and X-Ray Diffraction (XRD) methods, the research delineated resistivity values ranging from 1 to 1250 Ωm. Lower resistivity values signify the presence of alluvial deposits, which serve as reservoirs for geothermal hot water, while high resistivity values indicate limestone formations, which function as heat conductors. The geomagnetic survey suggests the existence of potential geothermal sources, and susceptibility values indicate the presence of igneous rocks, particularly andesite lava and pyroclastic materials. These results show the significant geothermal potential of the area.

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Author Contributions

Conceptualization, Kadri, M; methodology, Kadri, M., Tampubolon, T., Hutahaean, J., Muztaza, N. M., & Nawawi, M. N. M.; validation, Kadri, M.., Muztaza, N. M., Nawawi, M. N. M.; formal analysis, Kadri, M., Tampubolon, T; investigation, Kadri, M., Tampubolon, T., Hutahaean, J., Muztaza, N. M., & Nawawi, M. N. M.; resources, Kadri, M., Tampubolon, T., Hutahaean, J., Muztaza, N. M., Nawawi, M. N. M.; data curation, Kadri, M., Tampubolon, T., Hutahaean, J., Muztaza, N. M., & Nawawi, M. N. M.: writing—original draft preparation, Kadri, M; writing—review and editing, Kadri, M., Tampubolon, T., Hutahaean, J., Muztaza, N. M., & Nawawi, M. N. M.

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Conflicts of Interest

The authors declare no conflict of interest in this research.

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