Geology and Geophysics of Talumopatu Geothermal Manifestation Area of Mootilango District, Gorontalo Regency, Indonesia

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Abstract. The research aims to assess the geothermal potential and provide a better understanding of the geology and geophysics of the area. The study utilizes various methods, including geological mapping, geochemical analysis, and magnetic and electromagnetic data analysis, to gain insights into the subsurface structures and characteristics of the geothermal system. The study area can be divided into three geomorphological units: Alluvial Plain Unit, Near Plains Unit, and Isolated Hill Unit. The study area exhibits a stratigraphy consisting of three primary units: Talumopatu granite units, Talumopatu sandstone units, and alluvial deposit units. The subsurface lithologies of the Talumopatu manifestation area were analyzed using the Wenner – Alpha configuration ERT method, revealing two distinct lithologies. The first lithology consists of sandstones with a resistivity value ranging from 4.2 to 39.0 Ωm and a thickness of 1.25 to 12.4 m, which act as a permeable layer capable of transmitting water. The second lithology is granite with a resistivity value ranging from 118 to 360 Ωm and a thickness of 3.75 to 15.9 m. This information provides valuable insights into the subsurface characteristics of the area, including the presence of permeable layers and the geological composition of the lithologies

1 Introduction

Geothermal energy refers to the energy that is stored as hot water or steam within specific geological conditions deep in the Earth's crust. These conditions involve the presence of faulted layers interconnected with layers containing high-temperature fluids, typically found several kilometers below the surface [1]. Geothermal energy has many advantages, one of which is friendly to the environment compared to other energies and will never run out as long as geological and hydrological conditions can be maintained in balance[2].

Geothermal energy can be identified through observable indicators known as manifestations, which manifest on the Earth's surface. Those manifestations can take various forms, such as hot soil, geysers, fumaroles, hot steam, sintered silica, and hot springs [3]. The presence of hot water in these manifestations can serve as an indication of the existence of a geothermal system beneath the Earth's surface[4].

The geoelectric method is a geophysical method that uses rock resistivity values to determine the physical properties and subsurface conditions. This method uses variations of resistivity values to detect geological structures or underground rock information[5].

The geoelectric method itself has several configurations, each of which has its advantages and disadvantages. Some commonly used configurations are Wenner, Wenner – Alpha, Wenner – Schlumberger, Dipole-dipole, and Pole-pole. This configuration is a basic configuration that is used as a reference for the development of other configurations [6].

This study aims to determine the subsurface geological lithology so that it can describe the subsurface configuration in 2D and determine the zone of fluid flow in the manifestation area of the research area using the Wenner-Alpha configuration Electrical Resistivity Tomography (ERT) method.

2 Method

Administratively, Talumopatu is in Mootilango District, Gorontalo Regency. The area of study is 7.7 km^2, which is about 5.54% of the total area of Mootilango District. The study area is located at coordinates 00° 38' 00" - 00° 42' 00" N and 122° 35' 00" - 122° 40' 00" E as shown in Figure 1.

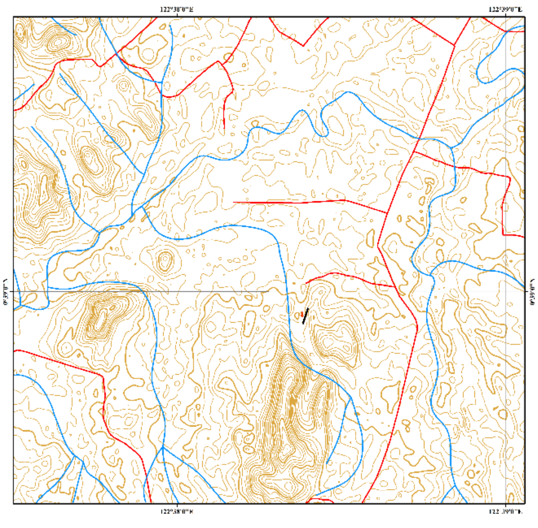

Fig. 1. Talumopatu Geothermal area.

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2.1 Data acquisition

This research collects surface and subsurface data. Surface data collection uses the 1:10000 scale geological mapping method which includes geomorphological and lithological data collection. Retrieval of subsurface data using the Electrical Resistivity Tomography (ERT) of Wenner – Alpha configuration. The data obtained is in the form of potential difference (ΔV) and current (I). subsurface data collection is conducted by injecting electric current into the ground using 4 electrodes, of which 2 electrodes are current injections and 2 electrodes are potential difference measurements where the distance between the electrodes is the same according to the geometric factor formula [7–9].

$$K=2\pi a \quad (1)$$

Where K = geometry factor and a = distance between electrodes

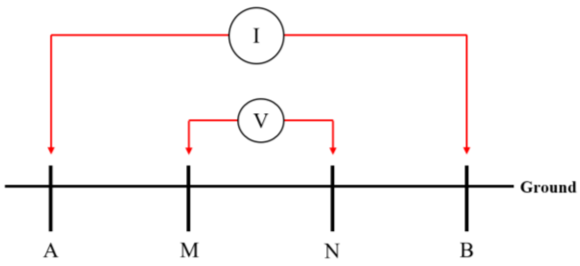

Fig. 2. Wenner-Alpha array showing configuration of Electrodes. Current I flow from Higher current (A) to Lower Current (B). While V related to potential drops between Higher voltage (M) and lower voltage (N).

Moreover, by substituting the configuration value (K) obtained from equation (1) into equation (2), the potential difference (ΔV) and current strength (I) can be used to calculate the apparent resistivity (ρ_a). It is important to note that apparent resistivity (ρ_a) is not an actual resistivity value but rather a combination of resistivity values from different types of rocks. This mixture occurs due to both lateral and vertical variations in the subsurface, encompassing the complexities of the underlying geological formations. The apparent resistivity value given by the following equation.

$$\rho_a = K\frac{\Delta V}{I} \quad (2)$$

Where ρ_a is apparent resistivity, K is geometry factor, ΔV is potential difference value (volts), I is electric current strength (amperes).

Furthermore, the apparent resistivity value (ρ_a) and other calculation results processed using the RES2DINV program to obtain subsurface cross-sections in the form of rock layer distribution in a 2-D (2-dimensional) model. Subsequently, the results obtained from the 2-D model are compared and correlated with lithology data collected during geological investigations. This correlation allows for the modeling of the underground rock types in the study area. By integrating the geophysical data with lithological information, it becomes possible to identify fluid flow zones within the study area [10]. This approach enables a better understanding of the subsurface characteristics, facilitating the assessment of potential fluid movement and distribution in the geological formations being studied. The resistivity value of bedrock is shown in table 1.

Table. 1. Subsurface resistivity values from Telford (Telford, 1990).

Resistivity (Ωm)	**Materials**
200 – 10000	Granit
$1.7 \times 10^2 – 45 \times 10^4$	Andésite
200 – 100000	Basalt
500 – 10000	Limestone
200 – 8000	Sand stone
1 – 1000	Sand
1 – 100	Clay
100 – 600	Gravel
0	Air
0.5 – 300	Ground water
0.2	Salt water

3 Results and Discussion

3.1 Geology of the Study area

The geomorphological study of the study area conducted based on direct and indirect observations. Indirect observations made on topographic maps in the form of observations of contour density, flow patterns and observations of colours, patterns, and textures in SRTM (Shuttle Radar Topography Mission) images. Direct observation conducted by observing the morphology in the field.

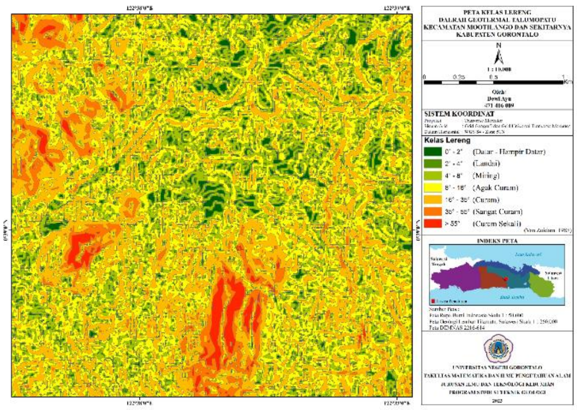

Fig. 3. Slope class map of the study area.

The research area consists of hills and lowlands. The elevation in the study area is 0 – 150 meters above sea level with the lowest points scattered in the north and east, while high elevations spread in the northwest and south.

The slope of the slopes in the study area is flat to very steep [11]. The study area varies from flat (<2°) with distribution throughout the area and is dominantly located in the north to east of the study location.

3.2 Alluvial Plain Unit

The slope relief is sloping to sloping (2° - 8°) distributed in several places. Slopes with moderately steep to steep slopes (8° - 35°) scattered in the southeast and southwest of the study site. Meanwhile, slopes with very steep slopes (35° - 55°) to very steep (> 55°) located at some parts of the south to northwest of the study location (Figure 4.1).

Analysis of river flow patterns in the study area was determined based on the classification of Twidale (2004) showing sub-parallel flow patterns (Figure 4)[12]. Sub-parallel river flow patterns refer to the patterns of river flow that are primarily influenced by lithology, slope, and elongated contour patterns, rather than being visibly controlled by structural factors. In such cases, the direction and alignment of the rivers are primarily determined by the composition and characteristics of the underlying rocks, the slope of the terrain, and the elongated shapes of the land contours. The absence of discernible structural control suggests that the primary factors shaping the flow patterns are related to the geological and topographic features rather than tectonic influences.

The geomorphology of the study area consists of Alluvial Plains, Almost Plains and Isolated Hills. The naming of the geomorphological units in the study area refers to van Zuidam's classification [11] which divides unit characteristics based on the general relief and slope as well as the genetic description of the morphology formed from endogenous and exogenous processes.

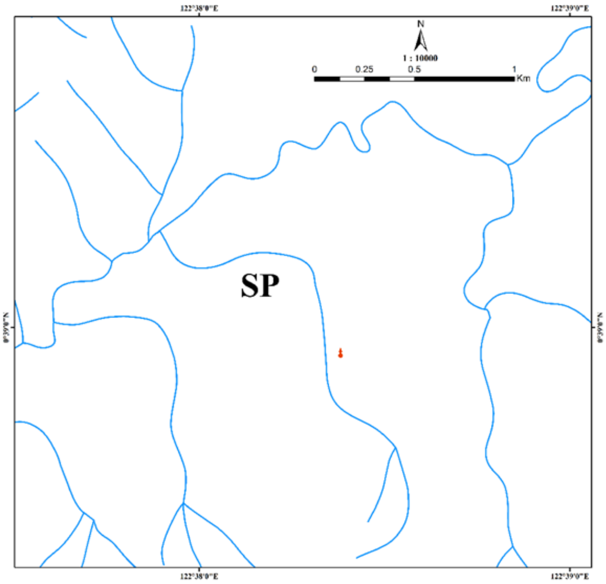

Fig. 4 Map of river flow patterns in the study area

The unit is characterized by a relatively loose contour pattern. This unit has an overall slope of 0° - 8° (flat – oblique) where the unit relief is plain with an elevation of about 0 – 25 mamsl. The constituent rocks of the unit are primarily composed of loose, unconsolidated material of alluvial origin, characterized by sand-sized to crustal-sized particles. These rocks have not undergone significant consolidation or lithification processes. The alluvial deposits typically consist of sediments that have been transported and deposited by water, such as rivers or streams, and are often found in areas with high sedimentation rates or near water bodies. The loose nature of these rocks indicates a lack of cementation or binding agents, resulting in a relatively soft and unconsolidated material.

The river in this unit is an old river stadium with a sub-parallel pattern of river flow. The valleys in this unit have U-shaped valleys. The processes that occur are dominantly lateral erosion and weathering that continues to occur.

Part of this unit's territory has become a settlement for residents. On the Geomorphological Map (Appendix II), this unit is marked in blue (R: 79, G: 129, B: 189). This unit is located in the northeastern part of the study area.

Fig. 5. Appearance of the Alluvial Plain Unit

3.3 Barely Plain Unit

The unit exhibits a tight contour pattern, indicating steep and rapid changes in elevation over a relatively small area. This unit has an overall slope of 8° - 16° (sloping - steep) where the relief of the unit is plain to hilly with an elevation of about ± 25 - 75 mamsl. The unit rock is sandstone.

The river in this unit is in the form of mature - old river stadia with a river flow pattern in the form of a sub-parallel pattern. The valleys in this unit have U - V shaped valleys. The processes that occur are dominantly lateral erosion and weathering that continues to occur.

Part of this unit's territory has become a settlement for local residents. On the Geomorphological Map (Appendix II), this unit is marked in light brown (R: 210, G: 115, B: 36). This unit occupies the eastern part of the study area. Its distribution is relatively east-northwest.

Fig. 6. Appearance of the Plains Unit

3.4 Isolated Hill Unit

The unit is characterized by a dense contour pattern. This unit has an overall slope of 16° - 55° (steep - very steep) where the unit relief is plains to hills with elevations of around ± 25 - 150 mamsl. The unit constituent rock is Granite.

The river in this unit is a mature river stadium with a sub-parallel pattern of river flow. The valleys in this unit have V-shaped valleys. The processes that occur are moderate – very strong weathering and erosion.

On the Geomorphological Map (Appendix II), this unit is marked in light brown (R: 139, G: 69, B: 19). This unit occupies the south to northwest part of the study area. The spread of this unit scattered in several places.

Fig. 7. Appearance of the Isolated Hill Unit

3.5 Stratigraphy of the area

The stratigraphy of the study area refers to the Indonesian Stratigraphic Code with an unofficial lithostratigraphic naming system (1996), namely the determination of aid units based on lithological characteristics by observing rock types, combinations, uniformity, and other phenomena.
The stratigraphy of the study area is composed of the oldest to the youngest units consisting of Talumopatu granite units, Talumopatu sandstone units, and alluvial deposits.

3.6 Talumopatu Granite Unit

The Talumopatu Granite unit (see Figure 8) occupies 1.43 km² or 14% of the total area of the study area and is spread over several research areas. This unit is marked in pink (R: 239, G: 47, B: 114) on the geological map (Appendix III). This unit is the oldest of all units found in the study area and is related to geothermal occurrences.

The lithological features of this granite include the following megascopic characteristics (see Figure 9): white color, massive structure, high degree of holocrystalline crystallization, phaneritic texture with uniform equigranularity, and the presence of euhedral-subhedral phenocrysts. The observed minerals in the phenocrysts include quartz, plagioclase, orthoclase, and hornblende.

Fig. 8. appearance of Granite outcrops at Talumopatu

Fig. 9. Megascopic Appearance of Granite units

Based on the comparison with the regional geology of the Tilamuta area and its surroundings [13], the age of this unit is determined to be Middle-Late Miocene. It is classified within the Boliyohuto diorite rock formation.

3.7 Talumopatu Sandstone Unit

The Talumopatu Sandstone unit occupies 6.52 km² or 66% of the total area of the study area and distributed over several research areas. The unit appears in yellow (R: 255, G: 255, B: 0) on the geological map (Appendix III). The megascopic characteristics of this granite are yellowish brown in colour, massive structure, grain size 1/8 mm, sub angular – sub rounded, carbonate cement, good sorting. There is claystone characterized by a light-gray colour, grain size of 1/16 mm and not compact.

Fig. 10. Appearance of the Sandstone Outcrop at Talumopatu

Fig. 11. Megascopic appearance of sandstone units

Based on the regional geology of the Tilamuta area and its surroundings [13](Bachri, et al., 1994), the age of this unit is determined to be Pleistocene-Holocene. It belongs to the lake sedimentary rock formations found in the area.

3. 8 Alluvial Deposits

The Alluvial deposit unit occupies 1.96 km² or 20% of the total area of the study area and is spread over several research areas. This unit is marked in gray (R: 178, G: 178, B: 178) on the geological map (Appendix III).

The Lithological characteristics of the unit consists of loose material in the form of gravelly sand that has not experienced compaction, this unit is the youngest unit with a unit age equivalent to Holocene age and includes Alluvium [13].

Fig. 12. Appearance of the Sandstone Outcrops at Talumopatu

3.9 Interpretation of Subsurface Geology

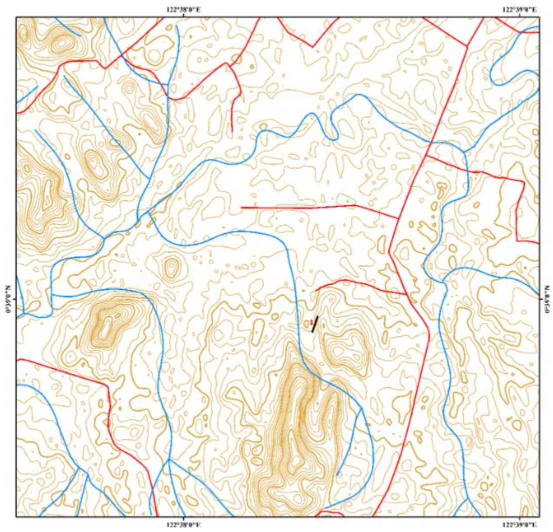

Fig. 13. Electrical Resistivity Tomography (ERT) section of the Talumopatu region.

This study obtained results in the form of geoelectric resistivity measurement data with the Wenner – Alpha configuration. The length of the stretch is 100 meters with a point of 0 m located at coordinates N 00° 38' 54" E 122° 38' 23" on the south and a point of 100 m is on coordinates N 00° 38' 57" E 122° 38' 24" on the north, with an electrode spacing of 5 meters and a total of 63 datum points was obtained.
Figure 13 is the result of data processing using RES2DINV software with 15 iterations and an error value of 2.5%, obtained resistivity values that vary between 0.15 Ωm to 360 Ωm.

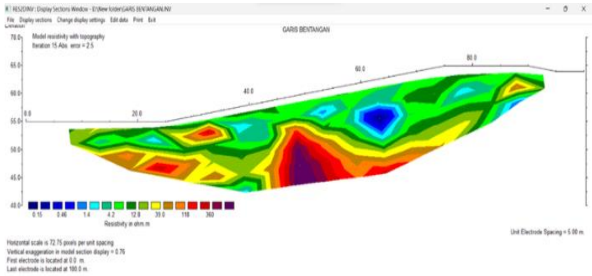

Fig. 14 2D section of the inversion result with topography

The blue color with a resistivity value of 0.15 – 1.4 Ωm indicates groundwater anomalies. Green and yellow colors with a resistivity value of 4.2 – 39.0 Ωm indicate layers of sand and gravel. Brown and red colors with resistivity values of 118 – 360 Ωm indicate granite layers.
The interpretation of the measurement data can be conducted by referring to Telford's table of rock resistivity values (1990) and correlating it with the geological map of the study area. In this case, several materials can be identified. The first material is estimated to be a sandstone unit with a resistivity value ranging from 4.2 to 39.0 Ωm. This unit is distributed across a depth of 1.25 to 12.4 m and spans a distance of 10 to 90 m along the track (as shown in Figure 14). Based on previous research by Triahadin and Setyawan (2014), sandstones are known to have high permeability, allowing water to pass through easily[14]. This characteristic suggests the presence of fluid flow zones within this unit. It is worth noting that this sandstone unit belongs to the Pleistocene-Holocene lake sedimentary rock formation based on the regional geological context.

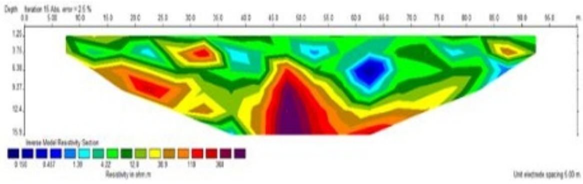

Fig. 15. 2D cross-section of the inversion result without topography

The second material is estimated to be a granite unit which has a resistivity value of 118 – 360 Ωm. This unit is spread over 10 – 60 m with a depth of 3.75 – 15.9 m spread along the track (Figure 4.13). This unit is a rock from the Middle – Late Miocene Boliyohuto diorite rock formation.

Table 2 Lithology of Subsurface Resistivity Values 4.2

Kode	Resistivity (Ωm)	Depth (m)	Lithology
	4.2 – 39.0 Ωm	1.25 – 12.4	Sandstone
	118 – 360 Ωm	3.75 – 15.9	Granite

4 Conclusion

Based on the geological conditions of the research area, it can conclude that 1) Geomorphology of the study area in the form of Alluvial Plain Unit, Near Plains Unit and Isolated Hill Unit. 2) The stratigraphy of the study area follows a chronological sequence from old to young, consisting of Talumopatu granite units, Talumopatu sandstone units, and alluvial deposit units. The Talumopatu granite units are the oldest, characterized by coarse-grained and crystalline granite rocks. Overlying them are the Talumopatu sandstone units, composed of sedimentary sandstone rocks. The youngest units are the alluvial deposits, representing the deposition of unconsolidated materials by water bodies.

While based on 2D subsurface cross-sectional analysis using the Wenner – Alpha configuration ERT method, there are two subsurface lithologies of the Talumopatu manifestation area consisting of sandstones with a resistivity value of 4.2 – 39.0 Ωm with a thickness of 1.25 – 12.4 m which acts as a permeable layer or is able to pass water marked by there is a zone of fluid flow and granite with a resistivity value of 118 – 360 Ωm which has a thickness of 3.75 – 15.9 m.

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