Rock porosity estimation research using refraction seismic waves in Bora Village, Sigi Regency

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Abstract. Rock Porosity Estimation Research Using Refraction Seismic Waves in Bora Village, Sigi Regency has been conducted. The purpose of this study was to determine the distribution of porosity of shallow subsurface rocks at geothermal locations. Data is collected on 6 different trajectories using ES-3000 to get a picture of subsurface waves. The data processing method uses Seisimager software to get a cross-section of the wave velocity and Rockwork software to get a cross-section of the porosity of subsurface rocks. The results showed different rock porosity values for each trajectory. Rock porosity values obtained at track 1 to track 6 are in the range of 27.1% to 30.5%. All trajectories are on a special porosity scale which means they have a large porosity volume as a place to store fluid.

1. Introduction

Porosity is a pore cavity that is usually found in sedimentary rocks. Based on the origin of the formation of porosity consists of 2 types, namely primary porosity and secondary porosity. Rocks with porosity are one of the characteristics of geothermal reservoir rocks [1]. Geothermal is generally found in rock fractures, where the rock consists of cracks and cavities or pores which are often called rock porosity [2]. Geothermal is generally found in rock fractures, where the rock consists of fractures and cavities or pores which are often called rock porosity [2].

The existence of the geothermal system in Indonesia is characterized by the presence of geothermal manifestations that appear to the surface in the form of gas, silica deposits, hot springs, and so on. One of the areas in Indonesia that have geothermal reserves in the province of Central Sulawesi. This area has geothermal potential which is scattered in various places, one of them is in the village of Bora, Sigi Regency. This is evidenced by the manifestations that appear to the earth's surface in the form of hot springs. One of the characteristics of geothermal rock is that it has porosity. To determine the distribution of rock porosity that can store geothermal, an investigation can be carried out using the geophysical method. The geophysical method is a method that utilizes information in the form of physical quantities on the surface to determine the subsurface image.

According to [3], the field porosity can be estimated visually by using a visual aid. This determination is semi-quantitative and a scale is used as shown in Table 1. The table shows the scale of determining whether or not the quality of the rock porosity value of a reservoir is good.

According to (4), porosity (ф) is the ratio of the pore volume of the rock to the total volume of all rocks. This ratio is usually expressed in a percent:
Ф = \frac{pore\ volume}{overall\ volume\ of\ rock} \times 100 \tag{1}

Table 1. Relationship between Value of Porosity and Scale

| Value of Porosity (%) | Scale       |
|-----------------------|-------------|
| 0 ± 5                 | Negligible  |
| 5 ± 10                | Poor        |
| 10 ± 15               | Fair        |
| 15 ± 20               | Good        |
| 20 ± 25               | Very Good   |
| > 25                  | Excellent   |

A pore is a space in a rock that is always filled with fluids, such as fresh / saltwater, air, or natural gas [4]. Effective porosity is when the parts of the pores in the rock are connected. The effective porosity is usually smaller than the total pore cavity which usually ranges from 10% to 15%. The effective porosity is stated as follows

Ф = \frac{Continuous\ pore\ volume}{overall\ volume\ of\ rock} \times 100 \tag{2}

The effective porosity is defined as a fraction of the interconnected nonsolid volume allowing flow through the rock and is described as a percentage (%) [5]. The porosity of sandstone is produced from geological processes that affect the sedimentation process. These processes can be divided into 2 groups, namely the process at the time of deposition and the process after deposition. Control at the time of deposition concerns the texture of the sandstones (grain size and sorting), while the post-deposition process which affects porosity is caused by physical and chemical influences, which are a function of temperature, effective pressure and time [4].

The physical properties of rocks will be significantly affected by porosity and micro-cracks at low pressure [6]. In general, if a magmatic or metaphoric rock contains pores, cracks, or fractures, it will have a lower velocity than the same rock in its intact state. The relationship of pore velocity \(V_p\) (km/s) to porosity \(\Phi_c\) (%) can empirically be given as

\[ V_p = 7.121 - 0.227 \Phi_c \tag{3} \]

on pressure 10 MPa

\[ V_p = 8.227 - 0.253 \Phi_c \tag{4} \]

on pressure 100 Mpa

The relationship between velocity and pressure is generally inversely proportional, that is, in the high-pressure region, the change in velocity is smaller than in the low-pressure region. Changes in velocity during pressure load will have a partially irreversible trajectory of the line of change or known as velocity hysteresis in the low-pressure region. This is due to the micro-crack closure process that cannot be returned to its original state [6].

The seismic refraction method is used in shallow layers, as a way of determining the depth of the bedrock and does not require large energy sources or complete equipment. The energy source is very easy, for example, a hammer is struck on an anvil placed on the ground. The speed of impact is determined by the inertia of the hammer. Sometimes the energy is also obtained from something changed by the operator, for example, the height of the foundation boards from the ground, or from the size of the explosion. Sources like this are also used in the seismic reflection method survey [7].
2. Materials and methods
The research was conducted at the geothermal location, Bora Village, Sigi District, Central Sulawesi Province using the Seismic Refraction method (see Figure 1). This method uses equipment in the form of Es-3000, 12 Geophone detectors, connecting cables (trigger, extension, connector), a current source (battery), hammer, foundation board, roll meter (100 meters), Global Positioning System (GPS), geology maps of Pasangkayu. Measurements were made on 6 different tracks, each track having a length of 33 meters with an interval for each geophone of 3 meters. In general, the method used in this research is the travel time of the wave propagation.

![Figure 1. Map Location Research](image)

Wave propagation travel time data is measured data obtained from the data acquisition process; then data processing is carried out, starting from the picking process using the Pickwin program to obtain the wave propagation travel time curve. This data is correlated with the height data at the location and is used as input data in the Plotrefa program to obtain a 2-D refractive seismic wave velocity profile and a structural profile of subsurface rock layers. Furthermore, the seismic refractive wave propagation velocity inversion is carried out and processed using the Rockwork program to obtain a subsurface rock porosity distribution profile. Furthermore, the process of analysis and interpretation of the profiles obtained is carried out.

3. Results and discussion
From the measurements made, the seismic refraction recording data were obtained which showed a graph of the relationship between the time of wave propagation and the distance between the recorded geophones. The results of processing the refractive seismic wave data obtained a cross-sectional profile of 2D seismic wave velocity at track 1 to track 6 with varying values, namely 389 m / s - 858 m / s, 178 m / s - 530 m / s, respectively. 201 m / s - 660 m / s, 340 m / s - 688 m / s, 314 m / s - 816 m / s, and 388 m / s - 950 m / s as shown from Figures 2 to Figure 7. The highest wave speed is on line 6 which is 858 m / s and the lowest value is on line 2 with a speed of 950 m / s. Based on this value, it shows that the wave speed will increase with increasing depth. Because the wave velocity values obtained are only around 178 m / s to 950 m / s, only one lithological layer is obtained, namely dry sand.

Each path has a velocity value that varies with the lowest value found at the surface of the soil and it increases with increasing depth, this proves the basic assumption that the rock in the sub-surface medium becomes more compact as the depth increases. It also affects the porosity of the rock, the higher the
porosity value contained in rock material, the lower the rock cohesiveness so that the lower the speed of wave propagation in the rock and vice versa.

Figure 2. Cross section of wave velocity p traverse at track 1

Figure 3. Cross section of wave velocity p traverse at track 2

Figure 4. Cross section of wave velocity p traverse at track 3

Figure 5. Cross section of wave velocity p traverse at track 4

Figure 6. Cross section of wave velocity p traverse at track 5
Due to the small value of the wave velocity obtained, only one lithological layer is obtained, namely dry sand. It is based on the P wave velocity data on the sub-surface material in Table 2.

Table 2. Wave velocity in subsurface material

| Rock               | Velocity (m/s) |
|--------------------|----------------|
| Dry sand           | 200 - 1000     |
| Sand (water-saturated) | 1500 - 2000   |
| Sand (unsaturated) | 1000 - 1500    |
| Clay               | 1000 - 2500    |
| Sandy clay         | 1500 - 2500    |
| Permafrost         | 3500 - 4000    |

The cross-sectional profile of rock porosity describes the distribution of rock porosity values that are below the ground surface at each measurement track. The value of rock porosity is obtained using Equation 3. Based on the cross-section of the distribution of rock porosity on track 1 - track 6 as shown from Figure 8 to Figure 13, The lowest range of porosity values obtained at track 1, 2, 3, 4, 5, and 6 are 27.5% - 29.6%, 29.0% - 30.5%, 28.4% - 30.4%, 28.3% - 29.8%, 27.7% - 29.9%, and 27.1% - 29.6%, respectively. The lowest rock porosity value was on track 2 of 27.1%, while the highest porosity value was on track 6 of 30.5%.
From the results of data interpretation, it can be seen that the subsurface geological conditions for each track are in accordance with the geological conditions of the Bora area. Where based on the geological conditions Bora Village is in the Pakuli Formation which consists of sandstone and conglomerates. While the value of rock porosity varies, this is because the weathering of rocks that occurs in each layer is also different depending on the weathering factors that influence it. The highest porosity value was on line 2 at 30.5% and the lowest rock porosity value was on line 6 at 27.1%. It may be due to the rock structure at that location [8].

All tracks are on an excellent scale which means they have a large pore volume. It allows subsurface rocks to have large deposits of geothermal fluid. It is possible that the fluid that is below the surface can appear as a new hot spring manifestation if there is a fracture as a way out of the fluid to the surface.
the past, the spring manifestation first appeared around the 2 way but then disappeared and reappeared in the present hot spring manifestation site. The current Bora hot springs used to have only a small volume, but due to the special scale rock pores as a storage area for fluid under the surface, the volume of hot springs is getting bigger.

4. Conclusion
The highest wave velocity value is on line 6, namely 950 m / s, and the lowest wave velocity value is on line 2 with a speed of 178 m / s. For all measured passes, the layer structure is obtained which is a layer of dry sand. The highest rock porosity value is on track 2, which is around 30.5%, while the lowest value for rock porosity is on track 6, which is around 27.1%. Based on the data obtained, it shows that all trajectories are on an excellent scale, which means that on line 1 to line 6 it has a large potential for storage of geothermal fluid and can be discharged at any time if it has the way to escape to the surface.

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