Bulletin of the Geological Society of Malaysia, Volume 68, December 2019, pp. 109 – 115
DOI : https://doi.org/10.7186/bgsm68201910

Integrated geophysical image of the hot spring in Rokan Hulu, Riau, Indonesia

Nur Islami*, Mitri Irianti

Physics Education, FKIP, Universitas Riau. Jl. HR. Soebrantas, Km. 12.5, Pekanbaru, 28293, Indonesia
* Corresponding author email address: nurislami@lecturer.unri.ac.id

Abstract: The first study of the hydrothermal system through the geophysical image in the area of Rokan Hulu hot spring is presented in this paper. The research employed integrated geophysical survey methods which consist of a geomagnetic, geoelectrical resistivity, and very low frequency (VLF) survey. Direct surface resistivity measurement was proposed and used to obtain a correlation of geological conditions with subsurface resistivity values and to correlate with VLF data. The geoelectrical resistivity survey used Wenner configuration, with a minimum electrode distance of 5 m. While the VLF survey was taken at every distance of 6 m. Magnetic surveys were carried out with a spacing of about 0.5 km and covered an area approximately 9 km^2. The results show that there is relatively lower magnetic value zone (about 65 nT) at the hot spring and extends to the southwest. The geoelectrical resistivity shows the possibility of water accumulation with resistivity value less than 150 ohm.m in the zone around the hot spring. While the VLF surveys show more conductive value which indicate the zone of fracture occurs at some places along the low geomagnetic anomaly zones. The surface temperature of the hot spring is 59°C with a constant discharge of about 7 l/s. The hot spring location is connected by fractures to the lower magnetic value zone, which the source of water is coming from the relatively higher elevation of the river surrounding the Rokan intrusion.

Keywords: Geoelectrical resistivity, hot spring, magnetic, VLF, Rokan Hulu

INTRODUCTION

Hot spring often reveals from the ground surface at the area around an active volcano. However, hot spring is not always related to volcanic activity. Some hot springs are found in flat zones, even in areas dominated by sedimentary rocks (Baioumy *et al*., 2015). The presence of hot springs is an indication of the existence of geothermal sources that cause the occurrence of the increase in water temperature. To utilize geothermal resources, it is necessary to explore geothermal systems that exist in the area.

Geophysical surveys are very necessary for investigating the subsurface, because the geophysical surveys are non-destructive, have no environmental impact, fast and relatively cheaper (Telford *et al*., 1990). The one-dimensional or two-dimensional geoelectrical resistivity method has been widely used in various fields of earth investigation. Islami *et al*. (2018a) investigated the presence of potential groundwater in peat area using one-dimensional geoelectrical resistivity. Geoelectrical two-dimensional resistivity method has also been successfully used in the case of seawater intrusion in an aquifer and delineation of leachate plumes (Khaki *et al*., 2016; Baharuddin *et al*., 2013; Zeinab *et al*., 2012; Samsudin *et al*., 2007). The method also has been successfully used for time-lapse nitrate monitoring in shallow groundwater system and also in the investigation of the possibility of heavy metal in the aquifer system (Islami *et al*., 2012; Islami, 2017; Islami *et al*., 2018b). The geoelectrical resistivity method is also very useful for investigating hydrothermal systems (Byrdina *et al*., 2016). The VLF method can also be used to detect the presence of groundwater especially in the zone of rock fracture (Ammar & Kruse, 2016). The VLF method also succeeded to find a zone containing water in the igneous area by combining it with the other geophysical method (Dubba & Ramadass, 2016). The magnetic method which is one of the passive methods in geophysical surveys is also frequently used to investigate the occurrence of metal deposits, especially iron ore. The occurrence of minerals containing magnetic elements causes a high reading effect on the magnetic survey (Shida *et al*., 2019).

The hot spring in Rokan Hulu is located in a remote area of about 180 km from Pekanbaru, the capital of Riau Province, Indonesia. In this area, there is no volcano activity. This hot spring has only been used for the geo-tourism in recent years. There are no subsurface shreds of evidence and investigation of a shallow hydrothermal system presented on the Rokan Hulu hot spring. Until today there are no results of studies published from this hot spring. The purpose of this study is to provide an overview of the subsurface conditions around the hot spring using integrated geomagnetic, VLF and geoelectrical resistivity surveys. The specific goal to be achieved is to confirm the presence of a shallow hydrothermal system and detect its conceivable links with the hydrothermal system. The use of magnetic survey is to detect the possible source of the heat for the hot spring. The VLF survey is to image the possible link of the heat source to the hot spring and the geoelectrical resistivity survey is to image and confirm the possibility hydrothermal system occurrence in the study area. In this study, surface direct resistivity measurement is proposed to improve the resistivity interpretation.

STUDY AREA

This research was conducted at the location of the hot spring in Rokan Hulu Regency, Indonesia. The hot spring is positioned on longitude 100.270317° East and latitude 0.830121° North (Figure 1). The hot spring is located 80 m above sea level (a.s.l.). The lithology of the research area consisted of the Sihapas formation containing clean quartz sandstones, carbonaceous shale, siltstones, and conglomerate. In addition to the Sihapas formation, the research area is also part of the Tesisa formation consisting of calcareous to carbonaceous siltstones, silty sandstone, and shale. A cassiterite-bearing intrusion of pegmatites, granites, and granodiorites with zones of cataclasis, which are aged around the Jurassic zone are found about 2 km from the hot spring to the south-east direction. This intrusion is part of the Rokan Intrusion (Rock *et al*., 1983). The hot spring is located on the edge of the relatively small hills. Some outcrops of metasediment rocks are encountered around the hot spring. A small lake is found 2 km to the southeast of the hot spring. During a 4 months observation, the temperature of the water surface at hot spring is stable at 59° C. The water is getting out from the surface with a constant discharge of about 7 l/s. This hot spring is located on the outskirts of a hill that runs along the Sumatera Island. The height of the hill peak is 1123 m with a distance of 15.1 km from the hot spring.

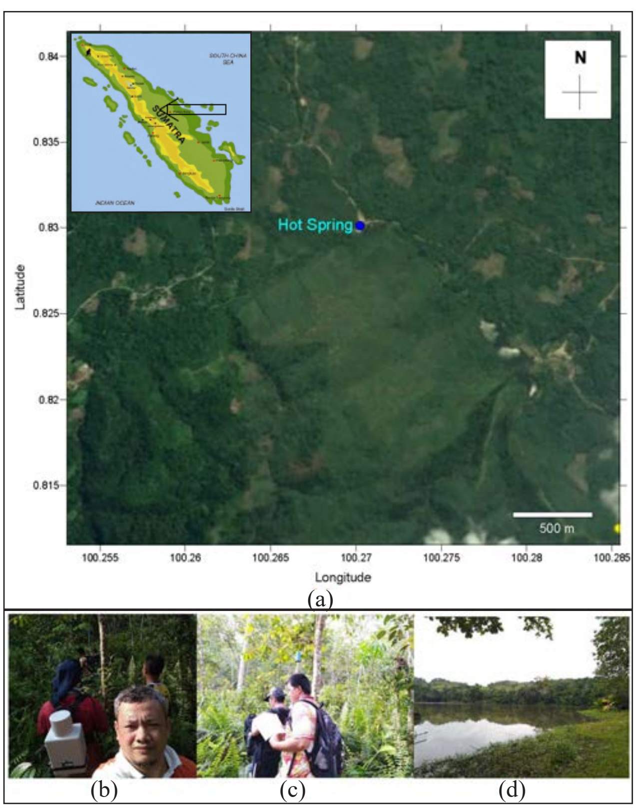

Figure 1: Map of the study area obtained from Google Earth (a). The survey sites are situated in thick secondary forest condition (b and c), and small lake at 2 km to the south-eastern (d).

METHODOLOGY

In this study, integrated geophysical surveys have been used to obtain the subsurface image of hydrothermal system of the hot spring. The survey was commenced with the magnetic survey, followed by geoelectrical resistivity survey, and lastly was Very Low Frequency (VLF) survey. The survey location and the elevation contour map are shown in the Figure 2.

Magnetic survey

In this study, a magnetic survey has been carried out using a PPM Magnetometer Geotron G5 with accuracy readings up to 0.1 nT. The reading station was divided into the base station and mobile station. Because the magnetic survey tool is only one set, the data obtained in the field both at the base and mobile station used the same magnetic equipment. At the base station, the magnetic data was recorded every four hours, due to the field being quite heavy with thick secondary forest conditions. The distance of each station was estimated to be about 500 m and spread in all directions in the study area. A total of 26 stations including base station have been surveyed and took four days long for all data acquisition.

The magnetic data were then processed by carrying out IGRF (International Geomagnetism Reference Field) and diurnal magnetic corrections. The IGRF correction aimed to reduce the magnetic data from the main magnetic field of the earth. The diurnal correction was referred to data obtained from the base station. The diurnal magnetic correction is to reduce the external effect of the magnetic field in the research area (William *et al*., 2013).

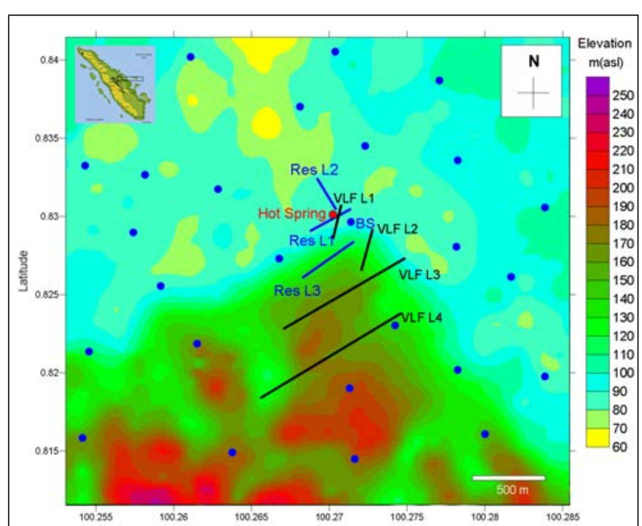

Figure 2: Topography map and location of the magnetic survey (blue circle), resistivity survey (blue line) and VLF survey (black line).

Geoelectrical resistivity survey

Geoelectrical resistivity surveys were carried out to obtain a higher resolution subsurface data to illustrate the existence of a zone of rock fracture as a waterway to the hot spring. Besides, a resistivity survey was also conducted to understand the possibility of a zone of accumulation of water below the surface around the hot spring. Geoelectrical resistivity method involves a direct current injection. The current is injected and measured between two current electrodes, then a voltage measurement between two potential electrodes is measured to compute the apparent resistivity of the subsurface medium. Resolution and depth of penetration of the geoelectrical resistivity survey depend on the distance of electrodes, type of configurations as well as measurement accuracy. Furthermore, the geometrical of configurations is certain criteria to influence signal strength, lateral sensitivity or penetration depth (Telford *et al*., 1990).

The Wenner configuration with 5 m electrodes spacing was employed. For each survey path, the splitting is done up to 16 times the electrode extension (n = 16). The survey was carried out using a homemade resistivity meter that had been tested for its precision and accuracy with a comparison of the Abem Terrameter SAS 4000 resistivity meter. The raw data obtained from field measurements were formatted to the Res2DInv software requirement for the resistivity inversion modelling purposes.

Besides the 2D geoelectrical resistivity survey, in this research, some direct resistivity measurements with small electrode spacing (5 cm) were also conducted to obtain the true resistivity value of certain earth material. As reported by Telford *et al*. (1990), the apparent resistivity will be the true resistivity value by assuming the material is homogenous within the small electrode spacing. The true resistivity value was calculated using the Wenner equation as given in equation (1)

$$\rho = 2\pi a \, \Delta V / i \qquad (1)$$

Where ρ is resistivity (ohm.m), a is electrode spacing (m), ΔV is voltage different and i is current (ampere).

The target of the direct resistivity measurements was the outcrop, wet soil, dry soil, and fully saturated hot spring soil. These true resistivity soils were used as the guidance for the 2D resistivity interpretation.

VLF survey

The VLF method is commonly known in geophysical exploration to look for conductive zones and nonconductive zones, mainly due to rock fracture. The use of the VLF method is very popular when the research zone consists of hilly zones, hard rock, forests and difficult to access. This is because VLF provides easy data acquisition that is relatively easier compared to the geoelectrical resistivity method that requires a long stretch of cable (Telford *et al*., 1990).

The comprehensive and detailed theory of VLF method can be found in some literatures, among them are given in Bozzo *et al*., (1994). VLF uses the principle of electromagnetic (EM) radiation that is produced at a frequency of 15 to 30 kHz. In this method, a transmitter station is needed to produce the electromagnetic wave. This transmitter station is located in various places on the earth for certain purposes by a country. For long distances from the transmitter station, the field of EM propagation is considered to be a planar wave. The EM consists of two electric field components (Ex and Ey), where Ex is parallel to the propagation direction x and Ey is vertical, and a magnetic component Hy will be produced which is horizontal and perpendicular to the propagation direction.

The T-VLF equipment produced by IRIS manufacture France was used to collect the VLF data in this study. There were four lines of VLF surveys collected in the study area. Data collection was carried out for every 6 meters with a total length of 2800 m for all the survey line. The VLF survey was concentrated at the zone between the low magnetic anomaly and the hot spring.

RESULTS AND DISCUSSION

The magnetic result

Magnetic method was used to define the magnetic anomaly in the study area. The magnetic field anomaly is expected and produced by the magnetic properties of the earth materials below the surface. After the IGRF correction, the magnetic data was corrected with diurnal correction. Figure 3 shows the diurnal magnetic data observed at the base station. Within four days of data observation, the highest magnetic data occur at around 17:54 p.m. (the second day). The lowest data happened at around 11:00 a.m. (the first day). The data observation was commenced at 7:00 a.m. and finished at 18:00 p.m. every day. These data was used to perform the diurnal correction of the moving reading data.

After performing the IGRF and diurnal correction, the recorded magnetic data in the field is expected truly coming from the target in subsurface. Figure 4 shows the contoured magnetic data that is plotted in the real latitude and longitude where the data observed. Some corrections have applied on the magnetic data and plotted in the map.

In Figure 4, the polar contour pattern such as anomaly of positive and negative polar does not appear, it is due to the research area is relatively small, which is less than 9 km^2. The contour magnetic map in Figure 4 shows the highest value of 130 nT and the lowest of 65 nT. The variation magnetic value in the study area is not too big.

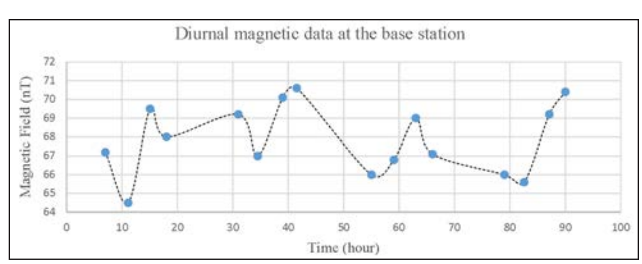

Figure 3: Diurnal magnetic data at the base station observed from 7:00 a.m. on the first day.

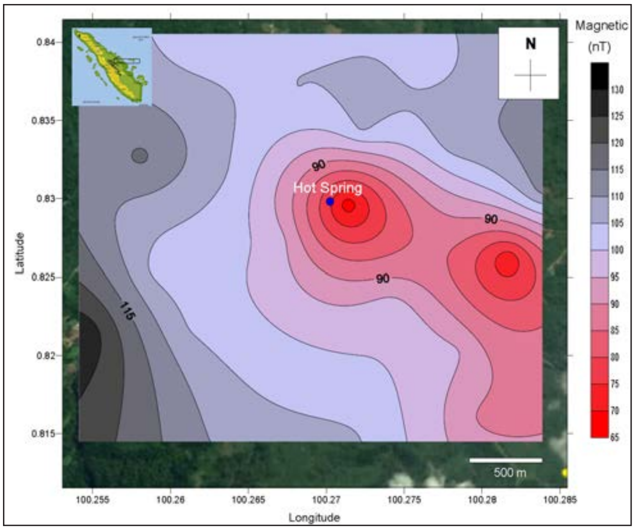

Figure 4: The magnetic distribution data in the study area.

This indicates that the earth material below the surface is not great in their magnetic property.

In Figure 4, generally, relatively low magnetic field is detected at the zone of the hot spring location. This zone of the low magnetic field is extended towards the southeast. Base on this map, the lower magnetic field reading can be seen at two reading locations, at the base station and 1 km to the southeast. Although it is not certain that these locations are the source of the heat, however, the low magnetic field zone is an indication of the relatively higher temperature zones. In this area, the potential source of the heat is possible from magma intrusion. It is also correlated to the finding that there was igneous rock intrusion found at the southeast direction from the hot spring. The increasing of temperature will decrease the magnetic property of the rock, so that the rock will tend to be lower magnetic field if it is compared to the surrounding rock (Telford *et al*., 1990). Mohammadzadeh & Kazemi (2017) also found that lower magnetic value at the surrounding area of the hot spring in Iran. Hence, the presence of hot spring is very possible produced by pathway of rock fracture. The hydrothermal uses this pathway from the relatively higher elevation to the hot spring zone with lower elevation.

The geoelectrical resistivity result

Table 1 is the resistivity data obtained from measurements directly above the surface using a 5 cm electrode spacing. Thus the measurement obtained is the actual resistivity value because it is assumed within a range of 5 cm that the measured material is homogeneous (Telford *et al*., 1990). Table 1 shows that relative dry soil has an average resistivity of 518.3 ohm.m. Meanwhile, when filled with water, soil resistivity decreases dramatically to 87.6 ohm.m. Fresh sediment has an average resistivity of 3374.1 ohm.m. Whereas when it is wet it will become 1647.2 ohm.m. From this data, it can be seen that the possibility of fracture zones resistivity that have the potential for water path way is ranging from 30.8-162.3 ohm.m.

Table 1: Material and true resistivity of direct measurement of the samples.

Material	Number of samples	Resistivity Range (Ωm)	Average Resistivity (Ωm)
Relative dry soil	12	305.9 – 918.6	518.3
Water-saturated Soil	8	30.8 – 162.3	87.6
Fresh metasediment	12	2380.2 – 4453.3	3374.1
Wet metasediment	12	1382.2-3871.6	1647.2

Figure 5 is modelling results of the geoelectrical resistivity survey. The survey line Res L1 is located south of the hot spring (see map in Figure 2) with the survey direction from Northeast to Southwest. While the survey line Res L2 is at the north side of the hot spring and leads to the southeast. The survey line Res L3 is located south of the hot spring and is parallel to survey line Res L1. As seen on the magnetic map (Figure 4), it appears that the zone with a low magnetic value is located to the southeast of the hot spring. Thus the position of Res L1 and L3 is between the hot spring and the low magnetic zone.

In the Res L1 resistivity model, the resistivity varies from around 40 ohm.m (deep blue) to more than 3000 ohm.m (dark red). There is a zone of low resistivity at a depth of 70 m a.s.l., it can be interpreted as a zone of water presence. Whereas in other zones on the Res L1, a relatively high resistivity value is observed. This zone is interpreted as a solid rock zone without the presence of water or crack zone. In the Res L2 model, the zone that has a low resistivity of around 120 ohm.m (light blue) is found on the surface and located to the end of the Res L1. This zone is a wet soil zone because it is near the water pool in the hot spring. While below the surface, there is no indication of the presence of water. Almost all resistivity in the Res L2 has a value of more than 500 ohm.m. The Res L2 is dominated by resistivity value of more than 2000 ohm.m which indicates the presence without crack or fractured zone. The Res L3 is located 300 m southward from the hot spring position. At Res L3, the dominant resistivity is above 2000 ohm.m, but at the base of this path, there is a zone of water presence that is at a depth of 100 m a.s.l. It is very clear that this low resistivity zone is a water pathway from the same zone as appeared in the Res L1.

The VLF result

A total of four VLF survey lines was conducted on the hill just after the hot spring. Line 1 was adjusted perpendicular with the resistivity Res L1. While the other three lines were conducted further to the southward. Figure 6 shows the VLF data. The conductive zone is represented by the blue colour, while the red colour is representative of more resistive zone. In the VLF Line 1, the conductive zone appears at the depth 20 m below the surface. This conductive zone is exactly at the

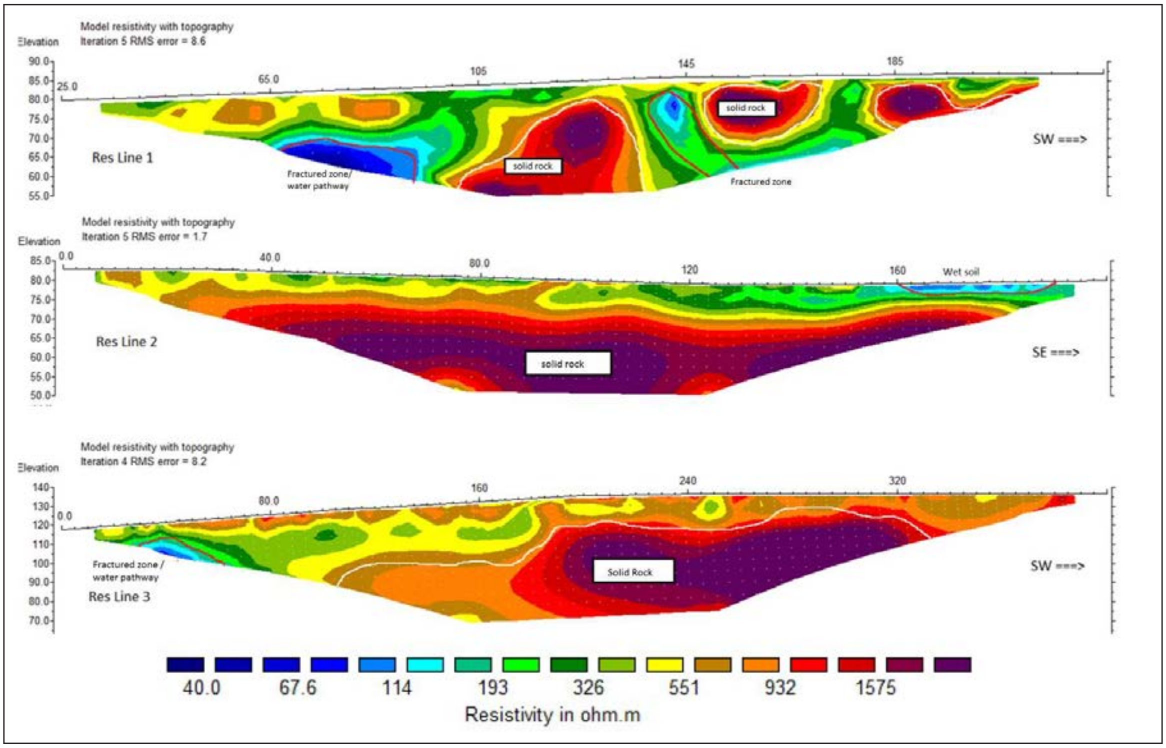

Figure 5: Geoelectrical resistivity model of line Res L1, Res L2 and Res L3.

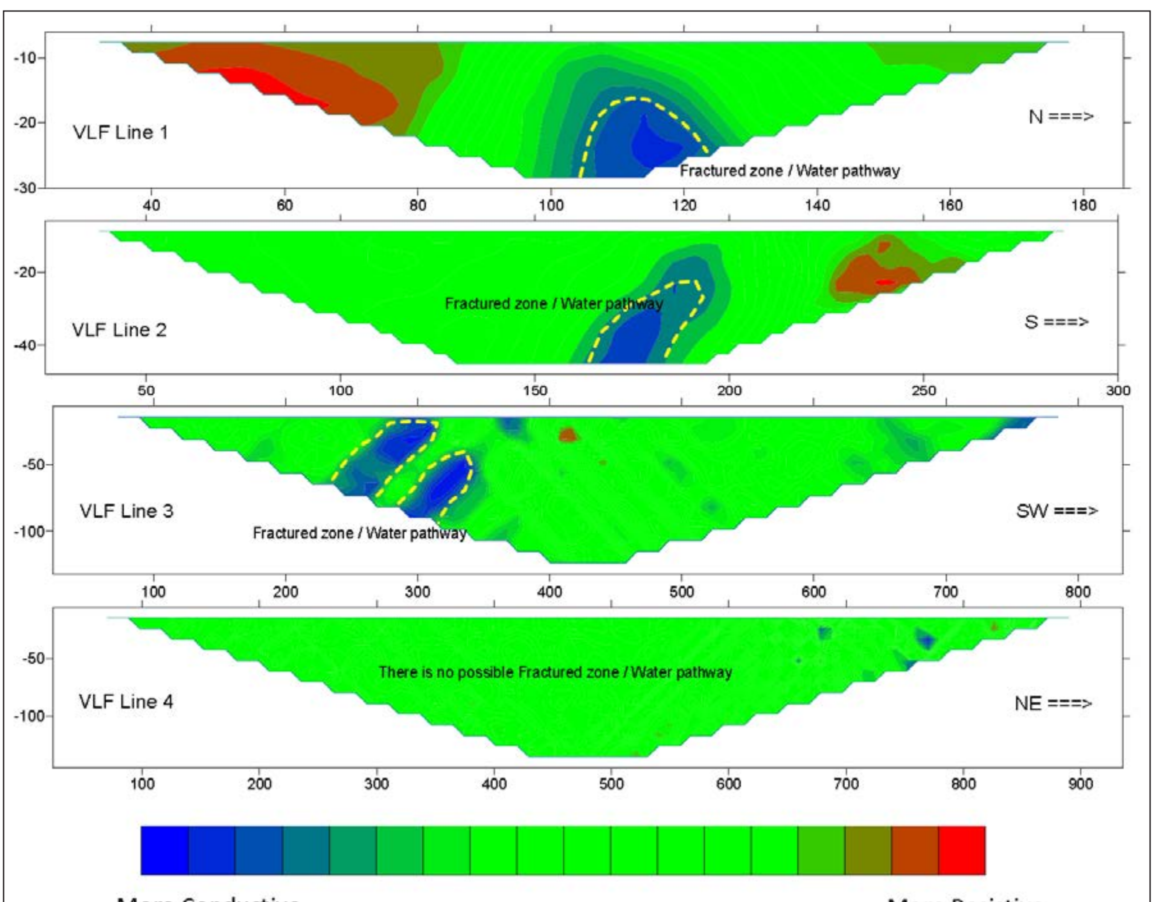

Figure 6: The VLF result.

same position with the low resistivity zone in resistivity Res Line 1. Base on the direct resistivity measurement in Table 1, the low resistivity value is representing the possibility of the wet zone. In the VLF Line 2, the conductive zone appears at the same depth with the VLF Line 1. The conductive zone in the VLF Line 2 is clearly extended from the same conductive zone in VLF Line 1 and lower resistivity zone in Res Line 1. The next survey line is the VLF Line 3. It was conducted with 900 m length. In the VLF Line 3, there are two conductive zones occur from the surface and extended downward. These conductive zones were believed from the same conductive zone in VLF Line 2 and VLF Line 1. However in the VLF Line 4, there is no conductive zone can be observed.

The hydrothermal system revealed on the geophysical image

The magnetic survey data shows that there is a zone that has a relatively low magnetic field that stretches from the hot spring and extends to the southeast. By assuming the rocks distribution in the study area is relatively the same, the low magnetic value must indicate a difference in the characteristics of rock physics. Magnetic property of the rocks will weaken when the rock experience relatively higher temperature. Thus, in this study, it is believed that the low magnetic field in the zone is due to the zone having relatively higher temperature. In the zone between the hot spring and the location of the discovery of Rokan Intrusion, there is a possibility of rock fractures as indicated by the conductive zone in the VLF model. The VLF data obtained indicate the existence of a conductive zone. The possibility of this conductive zone is the passage of fluid from the heat source to the hot spring. From the topographical map shown in Figure 2, it shows that the zone found in the intrusion rocks has a height of about 120 m a.s.l. Whereas the location of the hot spring has an altitude of 80 m a.s.l. Furthermore, around the Rokan intrusion zone, a relatively large river is found stretching from southwest to northeast. It is believed that the source of water in the hot spring is water from this river. From the resistivity data conducted around the hot spring, it can be seen that the zone which has low resistivity is at a depth of 20 m. This low resistivity zone was also found in a number of surveys so that it was seen that this zone of resistivity was connected to the southeast. Based on these geophysical images, it can be clearly seen that the low resistivity obtained from the geoelectrical resistivity data and conductive zone from the VLF data has the same directional trend with the magnetic field weak anomaly data. Thus, all the geophysical image have clearly shown the possibility of the hydrothermal system in the Rokan Hulu hot spring.

CONCLUSION

The Rokan Hulu hot spring has been successfully imaged through the integrated geophysical methods in this research. The magnetic survey shows that the hot spring has a relatively low magnetic field compare to other survey location. The zone of low magnetic field extends to the southeast where the Rokan intrusion is found. The VLF images provide the possibility of the conductive zone which is indicated as the fracture as the water path from the relatively higher elevated river to the hot spring positioned at the relatively lower elevation. While the geoelectrical resistivity image indicated that the hot spring connected to the conductive zone shown in the VLF data. The integrated geophysical methods have provided the hydrothermal image of the Rokan Hulu hot spring.

ACKNOWLEDGMENT

We are very thankful to DIKTI for the research funding through LPPM Universitas Riau. We also thank the field crew in assisting during data acquisition in the field.

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Manuscript received 8 August 2019
Revised manuscript received 22 September 2019
Manuscript accepted 13 October 2019