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Journal of the Earth and Space Physics, Vol. 45, No. 4, Winter 2020, P. 89-98 DOI: 10.22059/jesphys.2020.267095.1007048 Geothermal Potential Assesment of Way Ratai Area Based on Thermal Conductivity Measurement to Measure Thermal Properties of Rocks Karyanto1,2*, Haerudin, N.2, Mulyasari, R.3, Suharno4 and Manurung, P.5 1. Ph.D. Student, Doctoral Program of Mathematics and Natural Science, Faculty of Mathematics and Natural Science, University of Lampung, Lampung, Indonesia 2. Associate Professor, Department of Geophysical Engineering, Faculty of Engineering, University of Lampung, Lampung, Indonesia 3. Lecturer, Department of Geophysical Engineering, Faculty of Engineering, University of Lampung, Lampung, Indonesia 4. Professor, Department of Geophysical Engineering, Faculty of Engineering, University of Lampung, Lampung, Indonesia 5. Professor, Department of Physics, Faculty of Mathematics and Natural Science, University of Lampung, Lampung, Indonesia (Received: 27 Oct 2018, Accepted: 21 Jan 2020) Abstract Thermal conductivity measurements have been used for the Way Ratai geothermal prospect area. The thermal conductivity method is used to evaluate the ability of a rock to deliver heat by conduction. In the area, many surface manifestations are scattered in various regions, where hot springs dominate these various manifestations. The thermal conductivity mapping of rocks is carried out around geothermal manifestations by making a hole as deep as 1 m to insert the stick of conductivity meter. The result of thermal conductivity measurement method is data of k (thermal conductivity), Rt (thermal resistivity), and T (temperature). The measured value of conductivity data in the geothermal field is valued between 0.056 and 0.664 W/mK, thermal resistivity between 1.344 and 17.527 mK/W, and the temperature between 22.7 and 52.6°C. The difference in the value of thermal conductivity rock is influenced by several factors: existing geological structures in the field such as normal faults and lineaments, presence of alteration, and the manifestation zone of hot water or hot vapor that caused by fumaroles. Keywords:

Thermal Conductivity, Temperature, Geothermal, Geology, Way Ratai. 1. Introduction Conductivity or thermal conductivity (k) is an intensive property of material that shows its ability to conduct heat. 3 Thermal conductivity is an important physical property for predicting heat flow and corresponding subsurface temperatures (Haenel et al., 1988; Rühaak et al., 2015; Rühaak, 2015; Blázquez et al., 2018). Meanwhile, each rock has a different conductivity value that depends on the rock structure. Conductivity, resistivity, and temperature of rocks are important data in a geothermal system. Conductivity is used to deliver heat that passes through rocks from heat source rocks through impermeable rock layers to the surface. Thermal conductivity describes how well the heat is conducted through a material (Gua et al., 2017; Blázquez et al., 2018). While resistivity data is 2 used as a comparison of conductivity data that has been produced. In addition, the temperature is usually a linear function of conductivity data when the rock has a high conductivity value, which has a consequence of high or temperature value of the rock. Karyanto (2002) was conducted a study in Way Ratai geothermal area to map the hot springs using the Mise-A-La-Masse method. The result stated that hot water from hot water well A was not connected to hot water well B underneath. This is indicated by isopotential contour between well B and well A that is not connected. However, the contour itself is closer to the center of hot water well A, which indicates that the hot water comes from the well itself. Then in 2003, Karyanto carried out a subsurface imaging process in Way Ratai geothermal area using a 2-dimensional resistivity method. 2 The results showed that hot water wells, which are one of the surface manifestations from a geothermally active

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area like Way Ratai, indicate that between hot springs A and B are not related to each other. Karyanto et al. (2008) have determined the conductive zone of Way Ratai Lampung with resistivity method. Data that measured from the area are mostly taken from surface manifestations. These data indicate that the distribution pattern of low resistivity anomalies ($\rho a \leq 10$ ohm meters) is at the top of the study area and will increase in line with increasing depth. However, this pattern is mostly continuous and not discrete. Haerudin et al. (2016) mapped Radon and Thoron to delineate local faults. [1] The results show that there are three lineament anomalies that pass geothermal manifestations indicated as local faults, namely F1, F2, and F3. The first fault delineation (F1) connects the Bambu Kuning spring and Margodadi from the northwest to the southeast. The second (F2) connects the Padok hot spring and Way Asin from the southwest to the northeast. The third (F3) passed Margodadi hot spring in the same direction with F2. Based on the ratio of Radon to Thoron, F1 and F2 is a fault that extends to deeper parts. Both are indicated as geothermal fluid flow channels. According to Karyanto and Haerudin (2013), heat is the dominant parameter in geothermal active areas. Therefore, a study that discusses this parameter, [2] is needed to be applied in Way Ratai geothermal area, that is located at coordinates 5.12° - 5.84°S and 104.92° - 105.34°E, Padang Cermin SubDistrict, Pesawaran District, Lampung Province, Indonesia. This geothermal area has several hot water wells on the surface with a relatively high temperature (80°C - 90°C) (Karyanto, 2003). The wells are surface manifestation of a geothermal system that has not been fully explored by researchers. [1] The main purpose of this research is specifically to map the distribution of rock thermal conductivity values, analyze the value of rock thermal conductivity, and determine the factors that affect the rock thermal conductivity value. 2. Theory 2-1. Way Ratai Local Geology The research area is dominated by lithology product of young volcanoes (Qhv), alluvium (Qa), Hulusimpang formation (Tomh), Sabu formation (Tpos), Kantur formation (Tmpk), and Menanga formation (Km). Stratigraphy in this area is composed by rocks of Pre-Tertiary, Tertiary, and Quaternary. Volcano stratigraphy of Way Ratai [4] and surrounding areas are grouped into: 1) Tertiary rocks (bedrock), 2) Old Pre-BetungRatai volcanic rocks, 3) Volcanic rocks resulting from eruptions of Betung and Ratai Volcanic. The complete volcanic structure in the Way Ratai - Lampung Geothermal Field is separated into 40 lithology units, including three surface destruction sediment units (debris, lava and alluvium deposits), one unit Banjarmeger volcanic eruption rock and three volcanic rock units associated with Gebang volcano (Figure 1). In the study area there were three geological structure groups, namely caldera structure, crater structure and fault. Fault structures in the Way Ratai geothermal field and its surroundings are dominated by northwestsoutheast and northeast-southwest faults, which are suspected as normal faults. The mechanism for the formation of normal faults is caused by tention and tends to cause wide open space. Therefore, its presence is considered important because it can support the high permeability of reservoir rock that is the target zone of the geothermal prospect in Way Ratai.

2-2.T Heat tempe in a differ proce when proce heat, small Fig Thermal Con flowing erature part medium w rent medium ess, for exam n a piece of i ess, if the m then the te ler, on the co Geothermal P ure 1. Geologic nductivity process f to a lower t without parti ms is call mple, the pro iron is heated medium is fas emperature g ontrary if a Potential Assesm cal map of the r from a h temperature cle medium led conduc ocess that occ d. In conduc st in conduc gradient will medium is s ment of Way R research area (m highpart m or ction curs ction cting l be slow Ratai Area Bas modification fro in conduct temperature (Isjmiradi, 1 the tempera straight line to Equation = In where T is heat produce sed on Therma om Gafoer et al ting heat increase 1989). Furth ture rise in will be obta (1) (Carslaw temperature ed by the so al ... l., 1993). then the occurs hermore, by the time fu ined that cor w and Jaeger, e (Celsius), ource (probe) 91 spatial rapidly y plotting unction, a rresponds 1959). (1) Q is the) per unit

92 Journal of the Earth and Space Physics, Vol. 45, No. 4, Winter 2020 length (W/m), k is the material thermal conductivity (W / m C), t is time (second), and A is a constant that states the temperature t = 0 (Celsius). Based on the second law of thermodynamics, thermal conductivity can be measured if there is heat transfer from a high temperature to low temperature. With this formula, if a material is given certain heat power, heat transfer will occur. The principle is then applied to the Needle Probe method

(principle of the tool used), which is one of the practical methods for measuring a thermal conductivity of a material with a working system as follows: a probe that has been flowed with certain heat is inserted into material to be measured, which then causes a difference in temperature between the probe and the material causes heat transfer, which will be detected by a sensor inside the probe. The heat energy [4] formed in the needle probe comes from electrical energy, by flowing electric current into the heating wire. [9] Electric current in a wire is defined as the amount of charge that passes through the wire each time the unit is at a certain point. Therefore, the current (I) [1] is defined as: = (2) where q denotes the amount of charge (C) that passes through the conductor at a location during a certain time interval which expressed by t (seconds) and I states the electric current (A). If q that moves past the potential difference (V) is qV, then the power (P), [2] which is the speed of energy transfer, is (Fraden, 1996): = (3) With P, the power (Watts) and V represent the potential difference produced (Volts). The charge that flows every second is an electric current, with: =

(4) The heat that produced in a heating coil occurs because there are many collisions between moving electrons and atoms in the wire. At each collision, energy from the electrons is [1] transferred to the atom that collides with them, which causes the kinetic energy of the atom to increase, therefore, the wire's temperature increase (Fraden, 1996). This increased heat energy can be transferred as heat with conduction properties onto the needle probe. Most of the geothermal reservoirs are found in volcanic rocks with the main flows through fractures. As found in oil fields, the important rock properties that determines the geothermal reservoir rock properties are porosity, permeability and, rock density. Meanwhile, several other important parameters are [20] specific heat and thermal conductivity (Saptadji, 2002). [15] Thermal conductivity is the thermal property of an object that leads to transfer of heat in a unit of time through a certain cross-sectional area driven by a difference in temperature (Jangam and Mujumdar, 2010). [2] The value of thermal conductivity of rocks of determines the potential of the geothermal reservoir as geothermal energy source (Endovani, 2016). According to Raina (1993), the conductivity value of rocks

is around 0.05 W/m° C to 3.0 W/m °C. While thermal resistivity is the thermal property of an object to inhibit the flow of heat in a unit of time through a certain cross-sectional area caused by a temperature difference. The relationship between 18 thermal conductivity and resistivity can be expressed as Equation (5): = (5)

where k is thermal conductivity and Rt is thermal resistivity. 2-3. Data and Methods Tools and materials used in this study are: 1:500,000 scale Geothermal Working Area map, SRTM DEM map, regional geological map (Gafoer 4 et al., 2003), local geological map (Gafoer et al., 2003), GPS garmin map 78s, CT Drill, Main unit MAE v.A5000T, Probe CTS45, CT measurements & Stationery form, Laptop with Global Mapper v.13, Surfer v.12, ArcMap v.10.0, Map Source v.240, and Microsoft Excel v.2007 software. Research using rock thermal conductivity 1 method was conducted in Way Ratai geothermal field using primary data with 122 measurement points with seven manifestations of hot water and scattered in eight sub-districts of Way Ratai region. The observational results in this study included conductivity maps that overlaid with local

 geological maps, conductivity maps with topographic maps, temperature maps, and resistivity maps. 1 This research was conducted to analyze the four maps and find out the factors that influenced rock thermal conductivity values. The research method consists of several stages: data acquisition, data processing, and data interpretation. In data acquisition, measurements were taken with electrode sensors or probes that were placed 0.5 m under the surface with closed hole conditions. The probe was positioned to make 4 contact with the surface. The probe is inserted into the hole as careful as possible to prevent damage. 1 Data collection was done for 5 minutes. The measurements data were received in the form of Rt (thermal resistivity), k (thermal conductivity), and T (temperature) values. 19 After data acquisition phase, data processing was carried out. Method use for gridding data is Kriging Method. Kriging is a geostatistical method 1 that is used to estimate the value of a point or block as a linear combination from sampled values around the point to be estimated. Kriging value is obtained as a result of the minimum estimation variance by expanding the use of semi-variogram. Kriging estimator can be interpreted as a unit of unbiased variable and the sum of the overall weights. This value [17] is used to estimate the value of thickness, height, grade or other variables. Kriging gives more values to samples with close distance compared to samples that have a longer distance. Continuity and anisotropy conditions are important considerations in the Kriging process. Data geometric shape, estimated variable characters, and the block size are also estimated. [1] This method is able to produce maps with a good appearance that comes from the smoothing effect, where the effect is formed directly on the depiction of contour lines. Data processing produced four maps, which are rock thermal conductivity map with topography (topographic data from DEM SRTM map), rock thermal conductivity map overlaid with local geological conditions, thermal resistivity map, and temperature map [1] of the study area. The last stage is data interpretation, which was done by examining the four data maps. First, a map of the thermal conductivity of rocks overlaid with local geological map. The area that has a high thermal conductivity value is presumed to be in proximity with a manifestation of hot water. The appearance is closely related to geological conditions of faults and lineaments that control the area the temperature distribution. Second, a map of rock thermal conductivity overlaid with topography map. Topographic contours of a region were generally [2] used to determine onsite conditions at the time of data acquisition. Denser topography contour shows higher inclination. Third, data from temperature maps was needed to confirm [3] the thermal conductivity of the rocks in an area: temperature values and thermal conductivity are linear dependent. Higher conductivity value of a point will be shown through high temperature measured, [1] and vice versa. Fourth, resistivity data was used to compare the thermal conductivity value of rock. In theory, it was explained that the conductivity value is inversely proportional to its resistivity value. If the conductivity value of a point shows a high value, then the resistivity value will be low, and vice versa. 4. Results and Discussion Rock thermal conductivity value in Way Ratai geothermal prospect area was [1] affected by several factors: geological structure, the presence of alteration, and hot spring manifestation. In this case, specifically, the existence of alteration affects the value of thermal conductivity. This is because alteration rocks have a good level of conductivity. Alteration rocks contain several types of minerals: alunite, chlorite, hematite, pyrite, magnetite, and silica. These minerals have very good properties and conductivity (Horai, 1971). Then the existence of geothermal manifestations is very influential on the distribution of thermal conductivity values. This was because geothermal manifestations have high temperatures which can affect the value rock thermal conductivity. 4-1. Conductivity - Local Geological Map Based on Figure 2, hot spring appearance in Way Ratai areas 2 related to the geological appearance in the field. Normal faults are the control factors in the study area, which

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96 4-4. The Based o prospect measure 17.527 m as a conducti Thermal function is to de has bee replacem caused b et al., geotherm of temp mineralo solid sta to pota minerals J ermal Resist on Figure 5, t area ments are va mK/W. The comparativ ivity rock va l resistivity n as thermal etermine the en altered. ment of prima by rising ho t 2015). Alt mal area occ perature and ogical compo ate). Tempera assium, calc s the be 7 Journal of the E tivity Map , Way Ratai thermal alued betwee resistivity d ve data f lues. y data has conductivity manifestati Alterations ary phases an t fluids surfa teration in curs due to t d high pres osition of th ature that cau cium, and come clay F Earth and Spa i geotherma resistivity en 1.344 and 2 data was used for therma s the same y data, which ion area tha include the nd the result ace (Suharno Way Rata the influence sure on the he rock (in a used damage magnesium y minerals Figure 5. T Figure 6. Integra ace Physics, Vo al y d d al e h at e s o ai e e a e m s. The resi Fro is m ther ther Hig the also man that them hig hot Fig Fig man tem Lik resi Thermal resistiv ated map of res ol. 13 45, No. 4, W erefore, the a istivity value om the maps made from th rmal cond rmal resistiv gh therma northweste o in most nifestations. t have low m intersect h-temperatur t springs m gure 6. gure 6 shows nifestations mperature th kewise, thes istivity and h vity map. search results. Winter 2020 altered area e. s produced, a he results of ductivity, t vity as shown al conduc ern part of areas that h Likewise thermal re with these re areas, are manifestation s

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 5. Conclusions The difference in values of thermal conductivity of rock 1 is influenced by several factors: existing geological structures in the field such as normal faults and lineaments, the presence of alteration and the manifestation zone of hot water or hot vapor that caused by fumaroles. 2 The existence of geothermal manifestations affect the distribution of thermal conductivity values in the study area.

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