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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.

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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 us ed 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 conductiv ity 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. 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 va lue 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 used as a comparison of conductivity data th at 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 co nnected to hot water well B underneath. This is indicated by iso- potential 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. The results showed that hot water wells, which are one of the surface manifestations from a geothermally active *Corresponding author: karyanto@eng.unila.ac.id 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 da ta indicate that the distribution pattern of low resistivity anomalies (? a = 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.

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, 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 Sub-District, 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. 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-Ter tiary, Tertiary, and Quaternary. Volcano stratigraphy of Way Ratai and surrounding areas are grouped into: 1) Tertiary rocks (bedrock), 2) Old Pre-Betung- Ratai 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 northwest- southeast 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 temp e in a diffe r proc e whe n proc e heat, smal l Fig T hermal Co n flowing e rature part medium w r ent mediu m e ss, for exa m n a piece of i e ss, if the m then the t e l e r , on the c o Geothermal P ure 1. Geologi c n ductivit y process f to a lower t w ithout parti m s is cal l m ple, the pr o i ron is heate d m edium is fa s e mperature g o ntrary if a P otential Asses m c al map of the r f rom a h t emperature cle mediu m l ed condu c o cess that oc c d .

In condu c s t in condu c g radient wil l medium is s m ent of Way R r esearch area (m h igh- part m or c tion c urs c tion c ting l be s low R atai Area Ba s m odification fr o in conduc t temperature (Isjmiradi, 1 the temper a straight line to Equation = In where T is heat produc e s ed on Therm a o m Gafoer et a l t ing heat increase 1 989). Furt h tu r e rise in will be obta (1) (Carsla w temperatur e e d by the s o a l ... l ., 1993).

then the occurs h ermore, b y the time f u ined that co r w and Jaeger, e (Celsius), o urce (probe) 91 spatial rapidly y plotting u nction, a r responds 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 formed in the needle probe comes from electrical energy, by flowing electric current into the heating wire. 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) 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), which is the speed of energy transfer, is (Fraden, 1996): = (3) With P, the power (Watts) and V represent the potential differen ce 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 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 specific heat and thermal conductivity (Saptadji, 2002). 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).

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 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 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 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 Geothermal Potential Assesment of Way Ratai Area Based on Thermal … 93 geological maps, conductivity maps with topographic maps, temperature maps, and resistivity maps.

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 contact with the surface. The probe is inserted into the hole as careful as possible to prevent damage. 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.

After data acquisition phase, data processing was carried out. Method use for gridding data is Kriging Method. Kriging is a geostatistical method 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 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. 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 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 used to determine on- site conditions at the time of data acquisition. Denser topography contour shows higher inclination. Third, data from temperature maps was needed to confirm 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, 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 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: alun ite, 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 related to the geological appearance in the field. Normal faults are the control factors in the study area, which 94 directed north-w e which h a structur e lava se d flow 1, R Ratai la v Ratai la v Conduc t that hig h several steam d i to the w which i addition of roc k undergo i existenc e thermal alteratio n conduct i manifes t sinter w thermal Further m value i n faults a n J from nort h e st to south - a ve the sam e e s. This stu d d imentary r R atai pyrocl a v a 2, Ratai I v a 7.

t ivity-local h conductivi t hot spring i scharge fro m w ater vapour ncrease the , soil or top s k s weathe r i ng alter a e of alterat i conductiv i n rocks a i vity. In th e t ation a r ea w hich has a conductivit y m ore, there i s n the geol o n d lineamen t J ournal of the E h -east to so u - east, also t h e main direc d y area is c r ocks, Rata i a stic flow 2, l ava 4, Rata geological t y values ar e manifestat i m fumarole s content in conductivi t s oil at this a r r ing that a tion proc e i on affects t i ty. This a re rocks e study are a is dominat e a high infl u y value. s also a high o gical struc t t s.

This is c a Fi g E arth and Sp a u th-west an d h e lineament tions as fau l c omposed o i pyroclasti c Ratai lava 1 i lava 5, an d map show e scattered o n i ons or h o s . This is du e the hot are a t y value. I n r ea is a resu l continuousl y e sses. Th e t he value o is becaus e with goo d a , hot sprin g e d by silic a u ence on it conductivit y t ure such a a used by th e g ure 2.

Condu c a ce Physics, V o d s l t f c , d s n o t e a , n l t y e f e d g a s y s e we a b y val u wh e clo s as w of t Ro c dis t ge o lig h lo w is Ra t lav a for m lav a co n col o co n loc a Ra t roc (R a spr e an d str u c tivity – local g o l. 45, No. 4, W a k zone on hot fluids t h u e. The co n e n the meas u s e to the sw a w ell as on r o t he high con d c ks ther m t ribution tha t o logical co n h t blue to da r w value of ro dominantly t ai lava 1 (R L a 7 (RL7), a n m of Ratai p a deposits (L n ductivity a s o r scale s h n ductivity v a ted at rock t ai lava 5 (R k in the fo a p2).

The or a e ad over se v d the appear a u cture. eological map. W inter 2020 that area t h h us increasin n ductivity v a u rement pro c a mp or in o t o cks contain i d uctive natu r m al cond u t overlaid w i n ditions are r k blue colo r ck thermal c located at L 1), Ratai l a n d there is a p yroclastic f L H) which s well.

The h ows the v alue and i lithology: R R L5), and th e rm of two a nge to dar k v en manifest a a nce of the e h a t can be p g the condu c a lue also inc r c ess is carri e t her aqueou s i ng water, b e r e of the wa t u ctivity v i th the area' s highlighte d r scales sho w c onductivity Ratai lith o a va 2 (RL2), rock insert f low 1 (Rap 1 have low t h yellow to medium t h i t is domi n R atai lava 4 (e re is interc a pyroclastic k red color s c a tions of hot e xisting geol o p assed c tivity r eases e d out s areas e cause t er.

v alues s local d with w ing a and it o logy: Ratai in the 1) and h ermal green h ermal n antly (RL4), a lation flows c ale is water o gical 4-2. C Base d geot h cond u 0.05 6 cont o dista n repre the d lines Stee p at n o gentl e at s o Basi c terra i acqu i 4-3. T Figu r meas pros p 52.5 9 C onductivit y d on Figure h ermal pro s u ctivity mea 6 to 0.644 W o ur map, it n ce betwee n sent steep s l d istance be t to each ot h p slopes top o o rth-east an d e slopes top o uth-east an d c ally, topo g i n of the i sition is car r T emperatu r r e 4 sho w urement o f p ect area is 9 ° C. The te Geothermal P y – topo g ra p 3, the valu s pect area surement is v W /mK.

On t is explaine d n topograph i l opes, other w t ween topo g h er represe n o graphy do m d east of the ography do m d south of g raphic map study ar e r ied out. r e Map w s that t h f Way R a value d b e t mperature d P otential Asses m p h y map e of Way R rock the r v alued bet w t he topogra p d that the cl i c contour l w ise, the fa r g raphic co n n t gentle sl o m inantly loc study area m inantly loc the study a is used to v e a when h e temper a a tai geothe r t ween 22.6

8 d ata was use d Figure 3. C Fig u m ent of Way R R atai r mal w een p hic o ser l ines r ther n tour o pes. ated and a ted a rea. v iew d ata a ture r mal 8 to d as C onductivity-t o u re 4. Tempera t R atai Area Ba s supporting values that w on existi n conductivit y From the te m is shown t h scattered i n spring in th e Distribution appear with that shows l predominan t direction of scale show s temperature east, south e study area.

shows high manifestati o obtained te m that the ma p with its te m is directly li n o pography map t ure map. s ed on Therm a data for t w as measur e n g theory, y values a r m perature m h at high-te m n several m e study area. of rock purple, lig h ow rock te m t ly located i n study area.

s the value and is pre d e ast, and so u The orang e rock tempe r o ns of hot m perature a n p of thermal m perature ha s n ear depend e . a l ... t hermal co n e d in the fiel d temperat u r e linear d e easured val u m perature v a m anifestation s temperatur e h t blue to o m perature va l n west and n The green t of the med i d ominantly l o u th directio n e to dark r r ature values spring.

B n alysis, it ca n conductivit y s a relative v e nt on each o 95 n ductivity d . Based u re and e pendent. u e map, it a lues are s of hot e values o ld scales l ue and is n orthwest t o yellow i um rock o cated in n s of the r ed color in seven B ased on n be seen y of rock v alue that o ther. 96 4-4. Th e Based o prospec t measure 17.527 m as a conduct i Therma l function is to d e has be e replace m caused b et al.,

geother m of tem p mineral o solid st a to pot a mineral s J e rmal Resis t o n Figure 5 , t area ments are v a m K/W. The comparati v i vity rock va l resistivit y n as thermal e termine the e n altered. m ent of prim a b y rising ho t 2015). Al t m al area oc c p erature an d o gical comp o a te).

Temper a a ssium, cal c s the b e J ournal of the E t ivit y Map , Way Rata i thermal a lued betwe e resistivity d v e data f lues. y data ha s conductivit y manifestat i Alterations a ry phases a n t fluids surf a t eration in c urs due to t d high pres o sition of t h a ture that ca u c ium, and come cla y F E arth and Sp a i geotherm a resistivit y e n 1.344 an d d ata was use d f o r therm a s the sam e y data, whic h i on area th a include th e n d the result a ce (Suharn o Way Rat a t he influenc e sure on th e h e rock (in a u sed damag e magnesiu m y mineral s Figure 5. T F igure 6. Integr a a ce Physics, V o a l y d d a l e h a t e s o a i e e a e m s .

Th e res i Fr o is m the r the r Hi g the als o ma n tha t the m hig ho t Fi g Fi g ma n te m Li k res i T hermal resisti v a ted map of re s o l. 45, No. 4, W e refore, the a i stivity valu e o m the map s m ade from t h r mal con d r mal resisti v g h therm a northwest e o in most n ifestations. t have low m intersect h-temperatu r t springs m g ure 6. g ure 6 show s n ifestations m perature t h k ewise, thes i stivity and h v ity map. s earch results.

W inter 2020 a ltered area e . s produced, a h e results of d uctivity, t v ity as show n a l condu c e rn part of areas that h Likewis e thermal re with these r e areas, are m anifestatio n s that regio n that tend h an the s u e areas ha v h igher therm has a low t h a n integrate d research ba s t emperature n in Figure 6 .

c tivity is the study h ave hot s p e , for r e sistivity, m o regions. W h in areas tha t n s, as sho w n s that have to be hig h u rrounding v e lower t h al conductiv h ermal d map s ed on and . in area, p rings e gions o st of h ereas t have w n in these h er in area. h ermal ity. Geothermal Potential Assesment of Way Ratai Area Based on Thermal ... 97 5.

Conclusions The difference in values of thermal conductivity of rock 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. The existence of geothermal manifestations affect the distribution of thermal conductivity values in the study area.

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