VOL. 11, NO. 7, APRIL 2016 ISSN 1819-6608
ARPN Journal of Engineering and Applied Sciences

www.arpnjournals.com

RADON AND THORON MAPPING TO DELINEATE THE LOCAL-FAULT IN THE WAY RATAI GEOTHERMAL FIELD LAMPUNG INDONESIA

Nandi Haerudin[1], Karyanto[1] and Yudi Kuntoro[2]
[1]Department of Geophysical Engineering, Faculty of Engineering, University of Lampung, Indonesia
[2]Research and Development Center for Oil and Gas "LEMIGAS", Indonesia
E-Mail: nandi.haerudin@eng.unila.ac.id

ABSTRACT

The Survey in the area of geothermal Way Ratai Lampung has been conducted to measure the concentration of Radon and Thoron. The Radon detector RAD 7 used to get field data. The measurement points are 70 stations. These were taken with 200 m - 400 m spacing stations which cover an area of 10 km^2. Study area covered four hot spring geothermal manifestations namely Bambu Kuning, Padok, Margodadi and Way Asin. The aim of this study is to determine the local fault based on the profile of Radon concentration. The observation data were taken in 15 minutes for each station measurement to obtain the value of the Radon concentration accurately. After the Radon concentration values are obtained, it made a contour map. The peaks of contour were connected by a line to get the delineation of the local fault. The result showed three lineament anomalies through geothermal manifestations that indicating as the local fault, namely F1, F2, and F3. The first delineation fault (F1) connected Bambu Kuning and Margodadi hot springs in the northwest to southeast direction. The second (F2) connected Padok and Way Asin hot springs in the southwest to northeast directions. The third (F3) passed Margodadi hot spring in the same direction with F2. Based on the Radon to Thoron ratio, F1 and F2 were suggested as the fault that extends to depth. Both are suggested as the conduit of geothermal fluid.

Keywords: radon measurement, delineation, high permeability, fault.

INTRODUCTION

Indonesia is the country with the largest geothermal reserves in the world. This country has approximately 29.163 GW or 40% of the world's geothermal reserves. More than 200 geothermal systems with significant active surface manifestations occur throughout Indonesia [1]. The geothermal system in Indonesia is generally a volcanic hydrothermal system in the area of high elevation or high terrain occurs with Quaternary volcanism [2,3].

The Pesawaran volcano is located in the southern part of Sumatera Island, Indonesia. Its area is cut by Sesar Menanga. The direction of Sesar Menanga is parallel with the major structure of Sumatra, i.e. Semangko Fault, trending northwest-southeast. (Figure-1), Way Ratai geothermal field located in the southern part of The Pesawaran volcano and is an undeveloped geothermal prospect.

The study area is located in Padang Cermin Sub-District of Pesawaran District, Lampung Province, Indonesia. It is approximately 40 km southwest of Bandar Lampung, the city of Lampung Province. The Way Ratai geothermal field is identified by five manifestations in the form of hot springs. Table-1 showed characteristics of manifestation. Temperature geothermal reservoir estimated 275° C - 350° C. Based on geological observations, in this area was found a few outcrops of rock that have undergone a change. Most hot springs produce precipitated silica sinter. Deployment of broad manifestation is identified by the discovery of stone and vegetation suffered liquefaction degeneration [4].

A research in the geothermal Way Ratai has conducted to map the sources of hot water by using Mise-A-La-Masse [5]. This study, carried out measurements at two local craters namely Magrodadi A and Margodadi B which has a lower elevation. From the results obtained that hot water from the crater Margodadi A is not connected to the crater Margodadi B underneath. This is corroborated by the results of imaging subsurface geothermal area Way Ratai with two-dimensional resistivity method [6]. Then a study about temperature slope vertically and horizontally was conducted in 2013 [7].

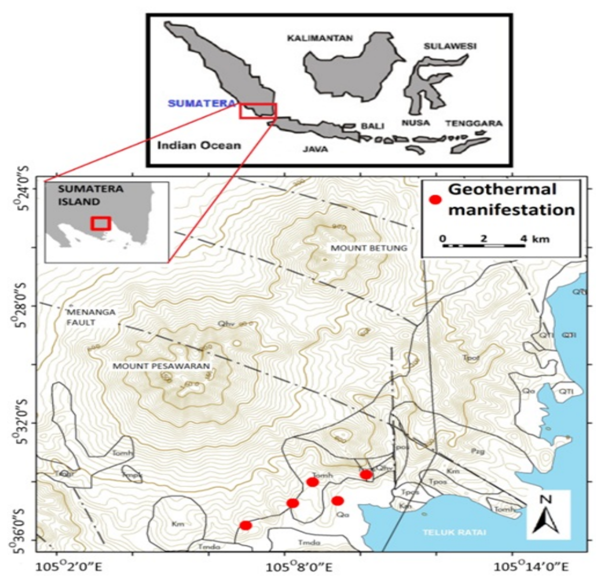

Figure-1. Regional geological map of Gunung Pesawaran Ratai

Based on the result, horizontal temperature mapping, the high temperature about 61° C spread

VOL. 11, NO. 7, APRIL 2016 ISSN 1819-6608
ARPN Journal of Engineering and Applied Sciences

www.arpnjournals.com

throughout on the center of the study area, generally adjacent to the geothermal manifestations. Based on the map of vertical temperature slope, it could be concluded that temperature is getting bigger proportional to the depth. This is an initial indication that the vertical temperature slope is positive and predicted as geothermal prospect area.

Tabel-1. Characteristic of Manifestation in Way Ratai.

Hot spring's location	Temperature (° C)	Elevation (m)	type
Margodadi	98	15 m	Chloride
Way Asin	85	92 m	Chloride
Bambu Kuning	90	91 m	Chloride
Padok	96	22 m	Chloride
Kali Tiga	85	65 m	Chloride

The geothermal manifestations were controlled by structures that were formed in the high permeability zone i.e. fault or fracture. The fracture serves as a channel of geothermal fluid migrating from its source in the reservoir up to the surface which appears to be manifestations of geothermal. Sometimes the fault is buried under an overburden layer. In the study area, no local fault that control of geothermal manifestations is described in the Geology regional map. The faults could be buried by an overburden layer. A detailed description of the fault (local and regional fault) is very important in the geothermal exploration for the success of drilling.

Based on this problem, the aim of this study is to determine the high permeability zone and local fault that controls the appearance of the manifestation in the Way Ratai geothermal by analysis of concentration Radon in soil gas. No study in the Way Ratai geothermal was reported in an international and track-able journal. It is also to be a consideration to write this paper.

METHOD

We used Radon Survey in this study. Radon Survey in geothermal area is a Geochemistry tool [8]. The Elements Radon has three isotopes that often occur in nature, i.e. 222-Rn (radon), 220-Rn (Thoron) and 219-Rn (Action). Radon has a half-life time of 3825 days, Thoron has a half-life of 54.5 seconds, and action has a half-life of 4 seconds. This survey measured only Radon and Thoron.

The Radon and Thoron concentration was measured with Alpha detector RAD 7 from Durridge. First, the probe is inserted into the soil to a minimum depth of 70 cm, to avoid the influence of the atmospheric effect such as humidity, temperature, and wind. Soil gas under the surface was sucked to the detector electrically, replacing the air in the detection cell. Before reaching the detector, soil gas is filtered and passed into the desiccant tube so that water vapor and other particles do not come inside. The Radon concentration was measured by an alpha scintillation Radon counter when the soil gas trough a scintillation chamber and calculated it in 15 minutes.

The Radon and Thoron concentrations are classified into three categories, namely low, high, and anomaly based on the statistical approach using the geometric mean and standard deviation parameters [9]. Geometric mean (r) reads at the 50th percentile, and standard deviation (σ) described the distribution of data. Low values of Radon concentration regard as a background value, while the Radon anomaly value is used to delineate the fault lineament.

The contour maps of concentration Radon, Thoron, and 'Radon to Thoron ratio', were created using Kriging interpolation to determine the location of anomalies. They are usually characterized by peaks of closed contours. These peaks are connected by a line to get the local fault trends. The Radon concentration and the ratio Radon to Thoron is compared and analyzed.

RESULT AND DISCUSSION

A total of 70 measurement points was taken with spacious 200 m - 400 m which covers an area of 10 km^2. Station measurement covered for four geothermal manifestations namely Bambu Kuning, Padok, Margodadi and Way Asin hot spring (Figure-2). No station carried out in the Kali Tiga hot spring. The nearest station is about 150 m distance. Anomalous of radon concentrations (<12 803 Bq/m^3) was founded around manifestation Bambu Kuning, Padok, Margodadi and Asin Way. There are the anomalous areas which are distant of manifestation in the northwest and southwest of the study area.

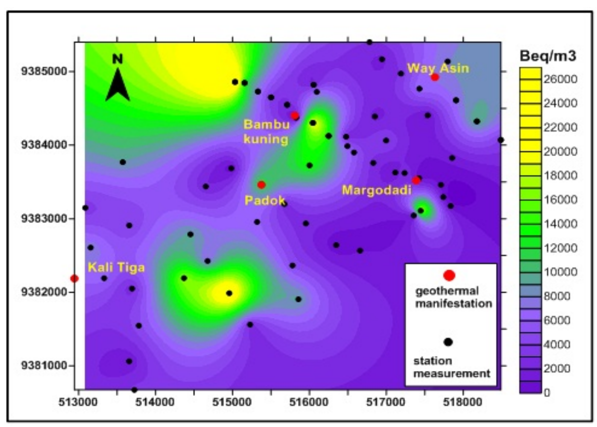

Figure-2. Contour map of Radon concentration and distribution of station measurement in the Way Ratai geothermal field.

Soil gas classification data listed in the Table 2. The results of Radon (Rn) concentration values are from 267 Bq/m^3 to 25700 Bq/m^3 and Thoron (Tn) values are from 100 Bq/m3 to 59000 Bq/m^3. Low concentration values are less than 6378 Bq/m^3 for Radon and less than 14685 Bq/m^3 for Thoron. This value is considered as the value of the background. The anomalous values are more than 12806 Bq/m^3 for Radon and more than 30211 Bq/m^3

ARPN Journal of Engineering and Applied Sciences

www.arpnjournals.com

for Thoron. The Thoron maximum value is greater than the Radon maximum value. This showed that the top layer is a rock that has a high porosity and permeability in the form alluvium and Tuff. This value is greater than a Radon survey in the nearest geothermal area i.e Rajabasa. The results of Radon measurements in the Rajabasa geothermal area are from 311 Bq/m^3 until 17750 Bq/m^3, while Thoron are from 0 Bq/m^3 until 8133 Bq/m^3 [10].

To characterize the study area, the spatial distribution of soil gas data was interpreted using contour maps. The observation data are presented on contour maps with Kriging method provided by Surfer 10. In the contour map of Radon concentrations, there are three lines that connected Radon anomaly. The first (F1) is trending from northwest to southeast through Bambu Kuning and Margodadi hot spring, the second (F2) is trending from southwest - northeast connect three manifestations that are Kali Tiga, Padok and Way Asin hot spring, and the third is trending from southwest - northeast through Margodadi hot spring (Figure-3). The local fault F1 is parallel to the Sesar Menanga regional fault.

Table-2. Soil gas classification for observation data.

Classification	Radon (Bq/m^3)	Thoron (Bq/m^3)	Radon/ Thoron (Bq/m^3)
Minimum	267	100	0.082
Maximum	25700	59000	4.506
mean (r)	6428	15525	0.695
standar deviation (σ)	6378	14685	0.789
low (C < σ)	< 6378	< 14685	< 0.789
high (σ < C < σ+ r)	6378 – 12806	14685 – 30211	0.789 – 1.484
Anomalies (σ+ r < C < σ+ 2r)	12806 – 19235	30211 – 45736	1.484 – 2.180

*) C = concentration

The values of Radon anomaly indicated high permeability zone where Radon quickly migrates to the surface before decaying into daughter products and it can be calculated by the device of the detector [11,12,13]. The existence of fault supporting gas transportation because it increases the permeability of rock and to be the geothermal fluid channels that migrating to the surface. A velocity of geothermal fluid migrating from the reservoir to surface also depends on other factors, including the level of cracking and porosity of the rock. The level of rock's cracking is the more dominant factor to be a geothermal fluid channel. The peak value of the concentration of radon shows the area of geothermal conduits.

As we discussed in the introduction, geothermal Way Ratai Regions have not the outcrop at the surface that indicate the presence of a fault. Delineation of high radon anomaly in this area proves that the Radon method can detect the buried fault under overburden layer as reported [14].

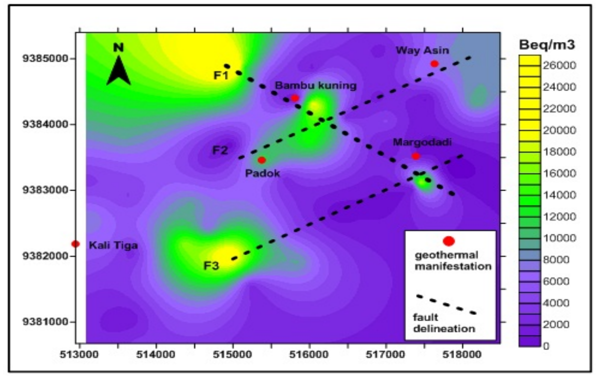

Figure-3. Delineation of local fault based on Radon concentration map.

Thoron contour map illustrated in Figure-4. Thoron has a short half-life of 54.5 s, so that the concentration decreases rapidly when it migrate to the surface. The measurable Thoron values come from the shallow layer. A zone with high Thoron values (> 14 685 Bq/m^3) describes the shallow layer with high porosity. This area is thought to be the area in the form of a thick sedimentary Tuff. This zone is located in the southwestern part of the study area. In other side, Radon has a half-life of 3.825 days and can be transported in a fracture for a considerable distance.

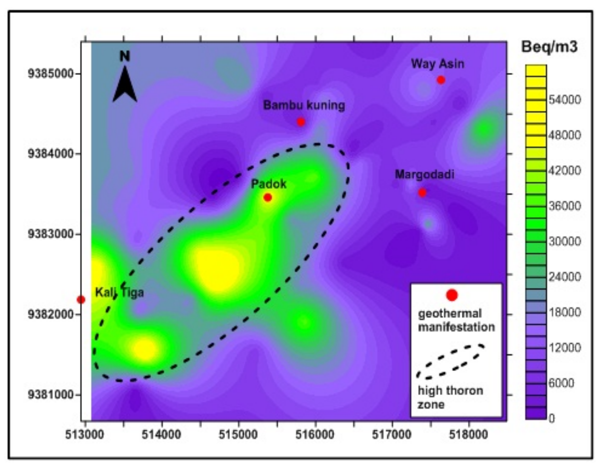

Figure-4. Delineation of high Thoron concentration.

To detect the presence of faults or fracture system that connecting surface to the depth, is used by the anomaly of Radon to Thoron ratio. The Radon from the depth contains less Thoron and has high value of 'Radon to Thoron ratio'.

The Radon concentration map compared with the Radon to Thoron ratio map as shown in Figure 5. The values of anomalous Radon and Radon ratio to Thoron used to determine the local fault that penetrates to the depths. There are two lineaments that determined on this map, namely f1 and f2. Line f1 is similar to F1 and f2 is similar to F2. It's located in a zone bounded by Bambu

VOL. 11, NO. 7, APRIL 2016 ISSN 1819-6608
ARPN Journal of Engineering and Applied Sciences

www.arpnjournals.com

Kuning, Padok, Margodadi and Way Asin hot spring. No line is similar to F3. So, it is interpreted as a shallow fault.

Figure-6 showed fault lineaments located on a geological map. The lineament F1 is parallel with Menanga regional fault (sesar Menanga), but F2 is perpendicular to it. The lineament F1 is suspected as the main fault that controlled the geothermal system of Way Ratai. To strengthen these results, it needs to calculate the length and direction of topographic lineament using the Ross diagram. To researchers who want to continue this study, we list data of measurements of Radon and Thoron in the Way Ratai geothermal field in Table-3.

CONCLUSIONS

The Radon concentration map shown three lineament anomalies that indicating as the local fault. The first (F1) is trending from northwest to southeast trough Bambu Kuning and Margodadi hot spring, the second (F2) is trending from southwest - northeast connect three manifestations that are Kali Tiga, Padok and Way Asin hot spring, and the third (F3) is trending from southwest - northeast through Margodadi hot spring. Based on the contour map of Radon and Thoron concentration ratio, the fault which is being main channel fluid from reservoir migrated to surface located in a zone bounded by Bambu Kuning, Padok, Margodadi and Way Asin hot spring.

Table-2(a). Results of measurements of radon and thoron in the geothermal area Way Ratai.

No.	Station	Longitude	Latitude	Elevation (m)	Radon (Bq/m^3)	Thoron (Bq/m^3)	Rn/Tn
1	BK 1	515826	9384375	97	609	2320	0.263
2	BK 2	515710	9384549	107	2823	5120	0.551
3	BK 3	515500	9384650	141	3610	7530	0.479
4	BK 4	515331	9384731	151	7580	3430	2.210
5	BK 5	515157	9384847	182	12300	19400	0.634
6	BK 6	515033	9384860	233	25700	22300	1.152
7	BK 7	516055	9384822	132	1660	8290	0.200
8	BK 8	516045	9384304	116	20700	20600	1.005
9	BK 9	516249	9384126	108	13500	12600	1.071
10	WA 1	517906	9384611	77	7090	3030	2.340
11	WA 2	518177	9384324	68	10100	33400	0.302
12	WA 3	518489	9384072	28	3870	14000	0.276
13	WA 4	517430	9384768	60	6900	18700	0.369
14	WA 5	517798	9385139	107	7930	11300	0.702
15	WA 6	517189	9384974	91	3140	13200	0.238
16	WA 7	516943	9385169	132	1710	7070	0.242
17	WA 8	516781	9385402	210	3020	3670	0.823
18	PD 1	515857	9381906	43	9330	37900	0.246
19	PD 2	515779	9382365	43	4640	19700	0.236
20	KT 1	513724	9380673	30	3330	2760	1.207
21	KT 2	513656	9381063	25	1050	233	4.506
22	KT 3	513782	9381547	36	4730	57900	0.082
23	KT 4	513694	9382051	57	2270	14600	0.155
24	KT 5	513331	9382192	76	6470	42000	0.154
25	KT 6	513155	9382608	113	7820	49900	0.157
26	KT 7	513086	9383149	145	3370	21500	0.157
27	PD 3	515376	9383472	62	12200	50700	0.241
28	PD 4	514985	9383686	205	267	464	0.575
29	PD 5	514652	9383439	91	2020	1030	1.961
30	PD 6	515675	9383200	76	2480	20800	0.119
31	PD 7	515320	9382957	53	6310	39100	0.161
32	PD 8	515954	9382936	56	2550	20700	0.123
33	PD 9	516347	9382642	53	267	2970	0.090
34	PD 10	516658	9382567	58	998	3180	0.314
35	RT 1	515228	9381562	27	2500	8990	0.278

VOL. 11, NO. 7, APRIL 2016 ISSN 1819-6608
ARPN Journal of Engineering and Applied Sciences

www.arpnjournals.com

Table-2(b). Results of measurements of radon and thoron in the geothermal area Way Ratai (continued).

No.	Station	Longitude	Latitude	Elevation (m)	Radon (Bq/m^3)	Thoron (Bq/m^3)	Rn/Tn
36	RT 2	514453	9382789	69	9450	46100	0.205
37	RT 3	514676	9382426	48	6840	59000	0.116
38	RT 4	514958	9381988	36	24400	23800	1.025
39	MG 14	517446	9383109	91	19200	24400	0.787
40	MG 15	517356	9383044	8	1240	100	0.700
41	MG 16	517855	9383827	7	1580	14700	0.107
42	HB 1	513573	9383770	249	9010	19300	0.467
43	HB 2	513658	9382909	180	3850	12800	0.301
44	HB 3	514369	9382193	100	16800	19100	0.880
45	BK 10	516095	9384725	136	7060	17900	0.394
46	BK 11	516001	9383726	101	13600	38000	0.358
47	MG1	517710	9383461	35	646	2920	0.221
48	MG2	517741	9383295	26	643	1080	0.595
49	MG3	517836	9383174	27	304	100	3.040
50	MG4	517425	9383552	44	304	203	1.498
51	MG5	517237	9383622	50	3220	17500	0.184
52	MG6	517116	9383629	67	883	5210	0.169
53	MG7	516579	9383901	130	5510	15500	0.355
54	MG8	516830	9383760	168	2540	7250	0.350
55	MG9	516494	9383987	109	6190	3500	1.769
56	MG10	516477	9384115	97	2020	2560	0.789
57	MG11	516997	9384064	98	4380	8100	0.541
58	MG12	516851	9384391	116	1610	5630	0.286
59	MG13	517538	9384406	46	750	5150	0.146
60	BK1	515826	9384375	97	609	2320	0.263
61	BK2	515710	9384549	107	2830	5120	0.553
62	BK3	515500	9384650	141	3610	7530	0.479
63	BK4	515331	9384731	151	7580	3430	2.210
64	BK5	515157	9384847	182	12300	19400	0.634
65	BK6	515033	9384860	233	25700	22300	1.152
66	BK7	516055	9384822	132	1660	8290	0.200
67	BK8	516045	9384304	116	20700	20600	1.005
68	BK9	516249	9384126	108	13500	12600	1.071
69	WA1	517906	9384611	77	7090	3030	2.340
70	WA2	518177	9384324	68	10100	33400	0.302
71	WA3	518489	9384072	28	3870	14000	0.276

ARPN Journal of Engineering and Applied Sciences

www.arpnjournals.com

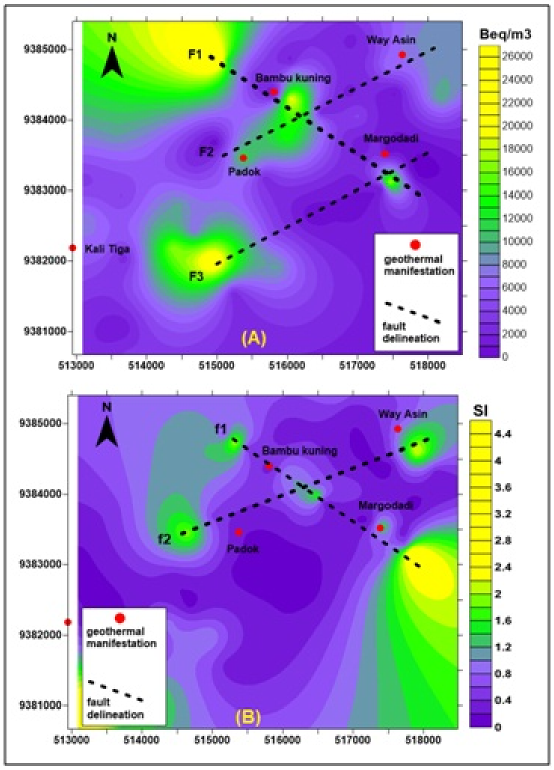

Figure-5. Contour Map of Radon concentration and Radon to Thoron Ratio (F1 = f1; F2 = f2).

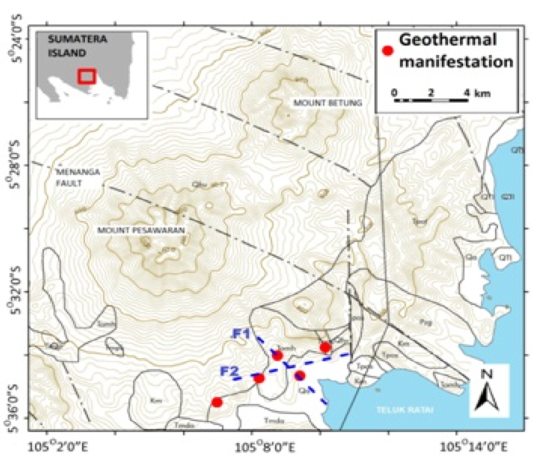

Figure-6. The local fault (blue dash line) that control manifestations of Way Ratai geothermal field.

REFERENCES

[1] Phuong N. K., Harijoko A., Itoi R., and Unoki Y. 2012. Journal of Volcanology and Geothermal Research. 229–230: 23-33.

[2] Sudarman S., Suroto, Pudyastuti K., Aspiyo S. 2000. Geothermal development progress in Indonesia: country update 1995–2000. Proceedings of the WGC 2000, Japan. pp. 455–460.

[3] Hochstein M.P., Sudarman S. 2008. History of geothermal exploration in Indonesia from 1970 to 2000. Geothermics. 37: 220–266.

[4] Suharno, Amukti R., Hidayatika A., and Putroi M. K. 2015. Geothermal Prospect of Padang Cermin Pesawaran Lampung Province, Indonesia. Proceedings World Geothermal Congress 2015, Melbourne, Australia. 19-25 April.

[5] Karyanto. 2002. Mapping Deployment Hot Springs in Region Geothermal Way Ratai, Lampung with Mise-A-La-Masse Method, Jurnal Sains dan Teknologi, FMIPA Unila, 8(2): 81-86.

[6] Karyanto. 2003. Subsurface Imaging Regional The Geothermal Way Ratai Lampung by 2 Dimensional Resistivity Method, Jurnal Sains dan Teknologi, FMIPA Unila, 9(3): 20-26.

[7] Karyanto and Haerudin N. 2013. A Qualitative Interpretation of Surface Temperature on Geothermal Way Ratai Lampung. Seminar Nasional SATEK V 19 – 20 November, Bandar Lampung.

[8] J. E. Gingrich. 1984. Journal of Geochemical Exploration. 21: 19-39.

[9] R.W. Klusman. 1993. Gas and Related Methods for Natural Resource Exploration, England. John Wiley & Son Ltd. pp. 483.

[10] Haerudin, N., Wahyudi and Suryanto, W. 2013. Radon and Thoron Analysis of Soil Gas Survey Case Study of Rajabasa Geothermal Field. AIP Proceeding conference, USA. 1554: 218-221.

[11] Ioannides K., Papachristodoulou C., Stamoulis K., Karamanis D., Pavlides S., Hatzipetros A., and Karakala E. 2003. Applied Radiation and Isotopes. 59 (2-3): 205–213.

[12] Swakon J., Kozak K., Paszkowski M., Gradzin'ski R., Loskiewicz J., Mazur J., Janik M., Bogacz J., Horwacik T., and Olko P. 2004. Journal of Environmental Radioactivity. 78(2): 137 – 149.

[13] Jönsson G. 1995. Radiation Measurements. 25(1-4): 537-546.

[14] Fu C. C., Walia Y. F., and Chen C. H. 2005. Geochemical Journal. 39: 427-439.