Indonesian Journal of Geology, Vol. 8 No. 2 June 2013: 89-96

Hotwater Geochemistry for Interpreting The Condition of Geothermal Reservoir, Dieng Plateau Case, Banjarnegara-Wonosobo Regency, Central Java

Geokimia Air Panas untuk Menafsirkan Kondisi Reservoir Panasbumi, Kasus Dataran Tinggi Dieng, Kabupaten Banjarnegara-Wonosobo, Jawa Tengah

Y. Ramadhan[1], K. Channel[1], and N. R. Herdianita[2]

[1]Geological Engineering Programme, Bandung Institute of Technology, Jln. Ganesha 10 Bandung
[2]Research Group of Applied Geology, Bandung Institute of Technology, Jln. Ganesha 10 Bandung

Abstract

The researched area, located in the Dieng Plateau, is included into the Holocene Dieng Volcanic Rock Unit. The regional structure in this area is originated from the major caldera with local fault having orientation of SE - NW. Surface manifestations found in the researched area are hot springs located in Bitingan, Sileri, Siglagah, Pulosari, Kaliputih, and Sikidang. Fumaroles occur in Candradimuka and Pagerkandang and mud pools are located in Sileri and Sikidang craters. Temperatures of the hot springs ranges from 43^o to 61^o C, pH of 6 - 7, and their conductivity are of 38-78 MeV. The type of hotwater is a mixture of bicarbonate, sulfate, and chloride sulfate deriving from condensation of steam. Based on a relative composition of Cl-Li-B, the hot water is originated from four different reservoirs with different rock associations, while their reservoir temperatures vary from 225^o to 300^o C.

Keywords: geochemistry, water type, reservoir, subsurface temperature, Dieng

Abstrak

Daerah penelitan yang terletak di Dataran Tinggi Dieng, termasuk ke dalam Satuan Batuan Gunungapi Dieng berumur Holosen. Daerah penelitian terletak di struktur kaldera dengan sesar penyerta berarah tenggara - barat laut. Manifestasi yang ditemukan di daerah penelitian adalah mata air panas yang berada di Bitingan, Sileri, Siglagah, Pulosari, Kaliputih, dan Sikidang. Fumarola muncul di Candradimuka dan Pagerkandang, serta kolam lumpur hadir di Kawah Sileri dan Kawah Sikidang. Mata air panas mempunyai temperatur 43^o - 61^o C, pH 6 - 7, dan konduktivitas 38 - 78 MeV. Studi geokimia menunjukkan bahwa air panas tersebut terdiri atas bikarbonat, sulfat, dan campuran klorida sulfat yang menandakan berasal dari kondensasi uap air. Berdasarkan kandungan relatif Cl-Li-B, air panas ini diduga berasal dari empat reservoir yang berbeda asosiasi batuannya dengan temperatur reservoir berkisar antara 225^o dan 290^o C.

Kata kunci: *geokimia, tipe air, reservoir, temperatur bawah permukaan, Dieng*

Introduction

Administratively, most of Dieng Plateau is located in Banjarnegara Regency, and the rest is in Wonosobo Regency, Central Java Province, about 26 km in the north of Wonosobo City (Figure 1).

The aim of this research is to find out the characteristics of the surface manifestations for modeling the pattern of their subsurface geothermal fluid flow. The similar studies carried out by Pardyanto (1970) and Condon *et al.* (1996) are used as references and the basic for this further research.

Manuscript received: November 22, 2010, final acceptance: June 11, 2013
Corresponding Author: yuris.ramadhan@yahoo.com/herdianita@gc.itb.ac.id

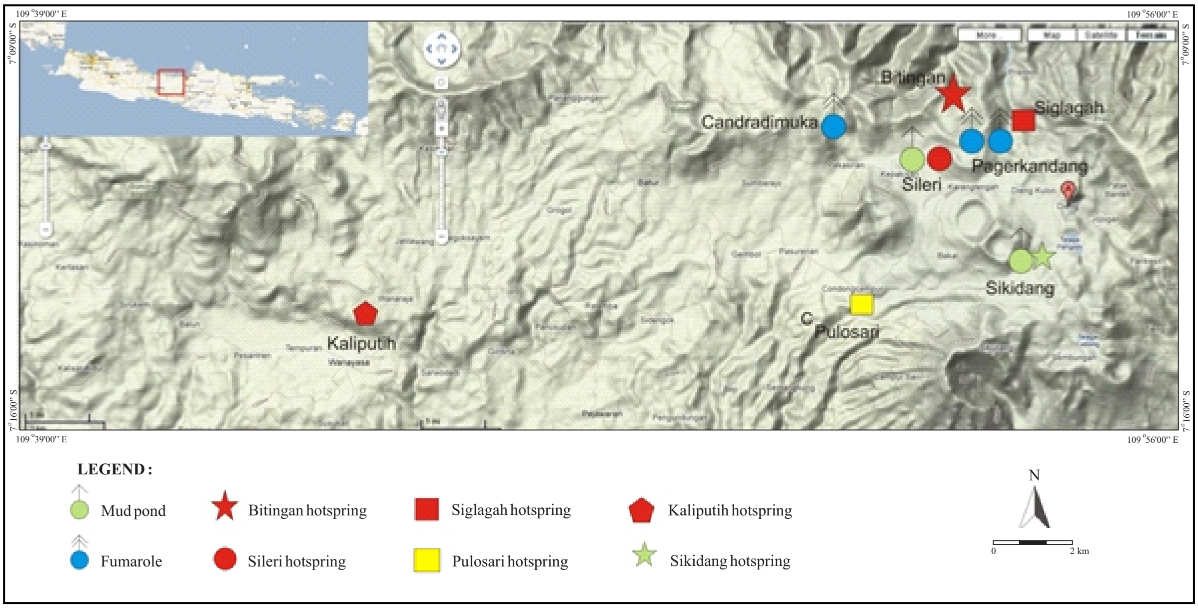

Figure 1. Locality map of the studied area and surface manifestation (image from http://maps.google.com, December 2009).

Methodology

Methods used in this study include field work, water sampling, laboratory analysis, and interpretation. The water sampling followed the guidance of Nicholson's (1993) and Standar Nasional Indonesia (2004). Chemical analyses were applied to six hot water samples including pH when the temperature was 25°C, sixteen main anion analysis elements Cl^-, SO_4^{2-}, and HCO_3^-, and cation like Ca^{2+}, Na^+, K^+, and Mg^{2+}. The analyses were also applied to neutral elements like SiO_2, NH_3, and F, as well as contaminant elements commonly found in geothermal system like As^{3+} and B. Data conformity has been evaluated using ion equilibrium. Furthermore, water sample was also analyzed to find out the content of oxygen isotope-18 ($\delta^{18}O$) and H^{-2} or deuterium (δD) based on mass spectrometer (MS).

Research Results and Discussion

Geological Condition

According to Van Bemmelen (1949) physiographically the researched area is included into the South Serayu Zone which is a southern mountain depression. Generally, the studied area is mountainous and a plateau, having steep to medium steep slopes. The stratigraphy of this area according to Condon *et al*. (1996) is included into the Dieng Volcanic Rock Unit consisting of andesite lava unit and quartz andesite, as well as volcaniclastic rock. The rock silica content decreases from young to old unit. The regional structure of the studied area has a caldera form with local fault trending southeast - northwest.

Surface Manifestation

Based on the observation in the field, there are eleven geothermal manifestations identified consisting of six hotsprings, three fumaroles, and two mud ponds (Figure 1).

Hotwater Chemical Composition

Measurements in the field and laboratory analyses upon six hotwater samples resulted in the temperature, pH, value of the hardness of the water ($CaCO_3$) and sixteen elements as shown in Tables 1 and 2, as well as deuterium isotope analysis (δD) and oxygen-18 ($\delta^{18}O$) as shown in Table 2.

Characteristics of The Hotwaters

Of six hotwater samples studied, generally their temperature is between 44° - 65°C, pH in the

Table 1. Characteristics of Surface Manifestation

No.	Location	Sample No	Date of Sampling	Coordinate		T°C	pH	Conductivity (MeV)	Debit (l/dt)	Manifestation type and Description
				S	E					
1	Bitingan	Bit-06	8 Juni 2009	7°11’06.6”	109°53’24.8”	59	6.77	48.5	0.47	Consisting of five hotsprings, coming out of cracks, no bubbles, colourless, odourless, tasteless, no surface deposit
2	Sileri	Slr-01	8 Juni 2009	7°11’42.3”	109°53’0.48”	65	6.30	71.5	0.07	Hotspring coming out of cracks, no bubbles, colourless, odourless, tasteless, no surface deposit
3	Siglagah	Pgd-07	8 Juni 2009	7°11’27.18”	109°54’3.54”	61	7.09	35.0	0.01	Hotspring formed through depression system, no bubbles, colourless, odourless, tasteless, no surface deposit
4	Pulosari	Pul-01	8 Juni 2009	7°13’36.54”	109°52’21.6”	44	6.14	78.8	n/a	Hotwater pond, 1.05 m^2 large, coming out of cracks, there are bubbles, a bit sulphur smell, a bit surface deposit
5	Kaliputih	Klp-01	8 Juni 2009	7°13’54.48”	109°43’49.68”	43	6.57	54.8	n/a	Hotwater pond, 12.5 m^2 large, coming out of cracks, there are bubbles, a bit sulphur smell, there is sulphur deposit around the pond
6	Sikidang	Skd-09	9 Juni 2009	7°13’11.6”	109°54’21.72”	61	6.20	50.6	n/a	Hotspring, coming out of cracks, no bubbles, sulphur smell and a bit muddy, there is surface deposit
7	Sipandu	Pgd-06	9 Juni 2009	7°11’28.5”	109°53’59.1”	94*	n/a	n/a	n/a	Fumaroles, white smokes, thundering sound, no bubbles
8	Pager Kandang	Pgd-14	9 Juni 2009	7°11’47.9”	109°53’26.5”	93*	n/a	n/a	n/a	Fumaroles, white smokes, thundering sound, no bubbles, a bit sulphur smell, there is sulphur deposit
9	Candradimuka	n/a	9 Juni 2009	7°11’10.6”	109°51’25.3”	94*	n/a	n/a	n/a	Fumaroles, white smokes, thundering sound, there are bubbles, strong sulphur smell, there is sulphur deposit
10	Sileri	n/a	9 Juni 2009	7°11’42.3”	109°53’00	70	n/a	n/a	n/a	Mud pond, muddy water, strong sulphur smell, there are bubbles, white smokes, there is sulphur deposit, the area about 100 m^2
11	Sikidang	n/a	9 Juni 2009	7°13’09.4”	109°54’53.2”	88	n/a	n/a	n/a	Mud pond, muddy water, strong sulphur smell, there are bubbles, white smokes, there is sulphur deposit, about 25 m^2 in broad

Table 2. Water Geochemical Analysis (in mg/kg), Isotope Deuterium (δD), and Oxygen-18 ($\delta^{18}O$) in ‰

No	Location	pH (lab .25 0 c)	DHL (uS/cm)	$CaCO_3$	Ca^{2+}	Mg^{2+}	Cl^-	F	SO_4^{2-}	Na^+	K^+	Fe	Mn	B	NH_4	SiO_2	HCO_3^-	$CO_{2\,total}$	As^{3+}	Li^+	δD	$\delta^{18}O$	Ion Balance (%)
1	Bitingan	7.99	693	124	11.28	23.38	17.96	1.39	59.50	71.30	28.20	0.01	0.07	1.38	0.83	38.94	243.30	0.00	0.01	0.03	-46.97 ± 0.3	-7.62 ± 0.2	5
2	Sileri	8.37	849	277	13.69	58.97	69.22	1.15	76.80	61.69	21.30	0.12	0.50	3.84	1.94	41.09	231.90	0.00	0.01	0.05	-49.37 ± 0.8	-6.98 ± 0.4	9
3	Siglagah	8.27	283	106	14.50	17.04	7.42	1.17	28.70	17.43	21.10	0.34	0.40	0.32	0.04	44.06	118.36	0.00	0.09	0.00	-49.57 ± 1.0	-7.59 ± 0.5	11
4	Pulosari	4.54	1218	358	19.33	63.35	289.0	5.96	214.0	76.23	52.00	0.68	0.86	0.87	0.95	46.34	21.74	1.73	1.73	0.02	-46.97 ± 0.2	-6.47 ± 0.2	9
5	Kaliputih	8.36	2790	527	4.03	125.50	484.50	1.20	11.10	321.30	41.50	0.08	0.05	1.19	0.005	46.34	634.09	0.00	0.00	0.88	-30.87 ± 0.4	-5.03 ± 0.1	3
6	Sikidang	3.88	1832	351	43.50	58.94	27.48	6.82	862.00	203.40	51.60	11.44	0.61	0.69	5.27	58.68	0.00	5.19	0.01	0.01	-38.97 ± 0.9	-2.46 ± 0.4	4

field is between 6 - 7 (neutral) and the result of laboratory analysis is between 3 - 8 (acids - bases). Measured conductivity ranges from 35 - 78 Mev, and the measured hardness of the water ($CaCO_3$) based on laboratory analysis is between 106 - 527 mg/kg.

Analysis result in Table 2 shows that ionic equilibrium has the value of 4 - 11 %. Ionic equilibrium of lack to 5 % is in Kaliputih, Bitingan, and Sikidang, while the rest is more than 5 %. The analytical result is said to be proper if the ionic equilibrium is lack or more than 5 %. This analytical result is from the hotwater coming out of Kaliputih, Bitingan, and Sikidang. Nevertheless, it does not mean that the result of hotwater analysis having ionic equilibrium of more than 5 % is not proper for interpretation. High ionic equilibrium is also influenced by the type and process undergone by the water (Nicholson, 1993). It is estimated the value of ionic equilibrium of more than 5 % because it is mixed up with meteoric water or surrounding rocks.

Based on diagram Cl-HCO_3-SO_4, hotsprings in the studied area can be classified into several types (Figure 2). Bicarbonate water comes out of hotsprings in Bitingan, Sileri, and Siglagah. These hotsprings were formed in shallow areas as the result of CO_2 gas absorbsion and steam heated water condensation. Sulfate hotwater coming out of Sikidang hotspring shows that it was formed in the shallowest part caused by steam heated water into meteoric water or as the result of H_2S oxidation in oxidation zone forming H_2SO_4. Water mixed with sulfate chloride coming out of Pulosari hotspring is estimated to come from the mix of reservoir water with condensate from the steam, and chloride bicarbonate hotwater coming out at Kaliputih was formed in the condition of mix of meteoric steam heated water.

Hotwater Sources and Reservoirs

Based on diagram Cl-Li-B in Figure 3, it is estimated that hotwater coming out in the studied area is from four different sources or reservoirs. The first reservoir is the one that formed Pulosari hotspring. This hotspring has the comparison of B/Cl of less than 0.01. This shows the influence of a volcanomagmatic process. The second reservoir comes out as Kaliputih hotspring. This hotspring has the comparison of less than 0.02 which shows the influence of a volcanomagmatic process but less

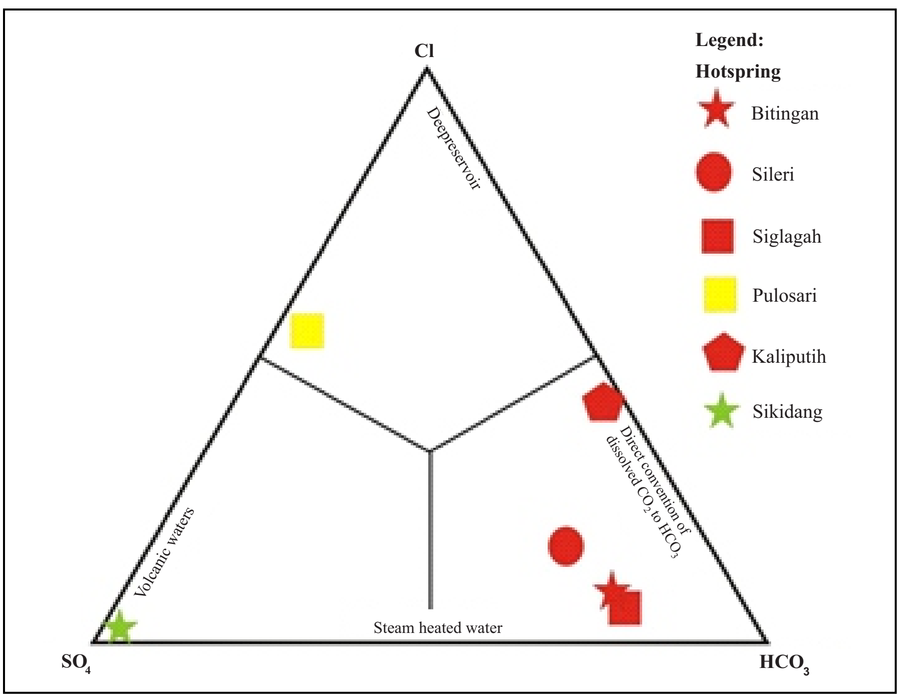

Figure 2 Diagram Cl-HCO_3-SO_4, showing hotwater which generally is of bicarbonate type.

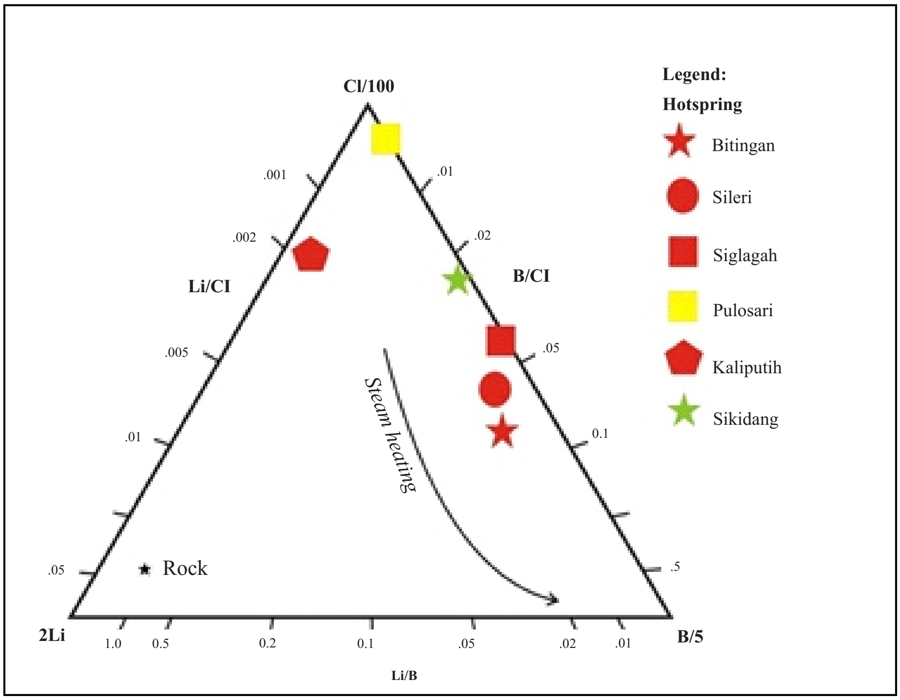

Figure 3. Diagram Cl-Li-B showing four different hotwater reservoirs.

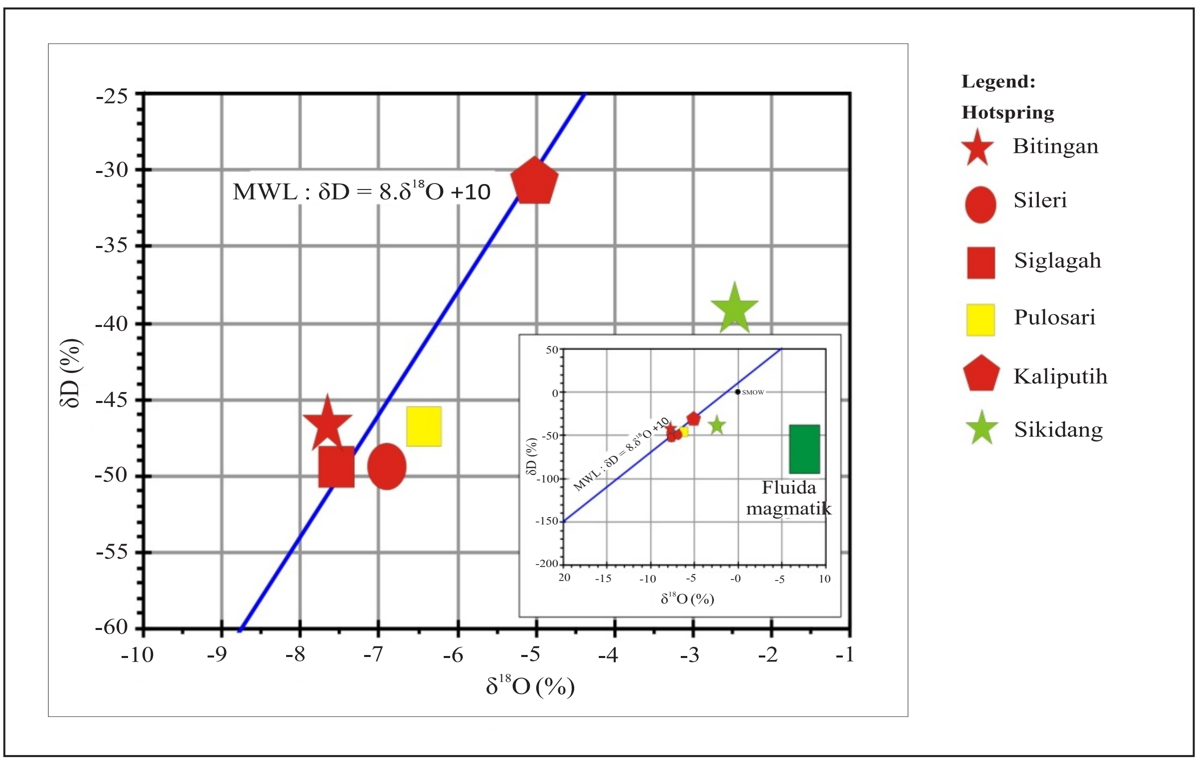

Figure 4. A graph showing the relationship between hotwater stable isotope-18 ($\delta^{18}O$) and δD in the studied area.

dominant than that of Pulosari hotspring. The third reservoir comes out as Bitingan, Sileri, and Siglagah hotsprings that are included into one group. This shows that there is a similarity in steam heating having the comparison of Li/Cl of less than 0.001 and B/Cl between 0.05 and 0.1. The forth reservoir comes out as Sikidang hotspring having the comparison of B/Cl less than 0.03. The hotspring reservoir differences are also in the hydrology pattern and geological unit.

Characteristics of Stable Isotope $\delta^{18}O$ and δD

The relationship graph between stable isotope δD and $\delta^{18}O$ in Figure 4 shows that the content of hotwater isotope δD and $\delta^{18}O$ in the studied area is generally like that of the content of global meteoric water stable isotope. A bit displacement of the content of stable isotope between meteoric water and hotwater shows that geothermal system has interacted with surrounding rocks and has reached an equilibrium (Nicholson, 1993). Figure 4 shows that Kaliputih hotspring has δD and $\delta^{18}O$ of less than those other areas'. This shows that there are different infiltration areas with other hotsprings. Sikidang hotspring which has δD and $\delta^{18}O$ shows that it has been steam heated or evaporation near the surface. This is also shown by the type of Sikidang hotspring which is sulfate water.

Estimated Subsurface Temperature

The estimated subsurface temperatures were calculated using geothermometer method of Na-K-Ca compared with fumarol manifestations available in the studied area. Geothermometer of Na-K-Ca was used to calculate the reservoir temperatures at the studied area, because hotwater in this area has interacted with surrounding rocks and has a high Ca content. The hotwater used for geothermometer calculation is from Pulosari that has a mix type of sulfate chloride with pH value. Based on the geothermometer calculation of Na-K-Ca, hotwater reservoirs in the studied area have a temperature of 295^o C.

As a comparison, manifestation as dry fumarol with dry characteristics and thundering sound is available in Pagerkandang and Sipandu fumaroles. According to Hochstein and Browne (2000) dry fumarol show the geothermal reservoir of $\geq$ 225^o C. Therefore, it can be interpreted that Pagerkandang and Sipandu geothermals have reservoir temperatures of $\geq$ 225^o C. Thus, it can be said that the geothermal temperature of the studied area is above 225^o C, and may be it reaches 300^o C (Figure 5).

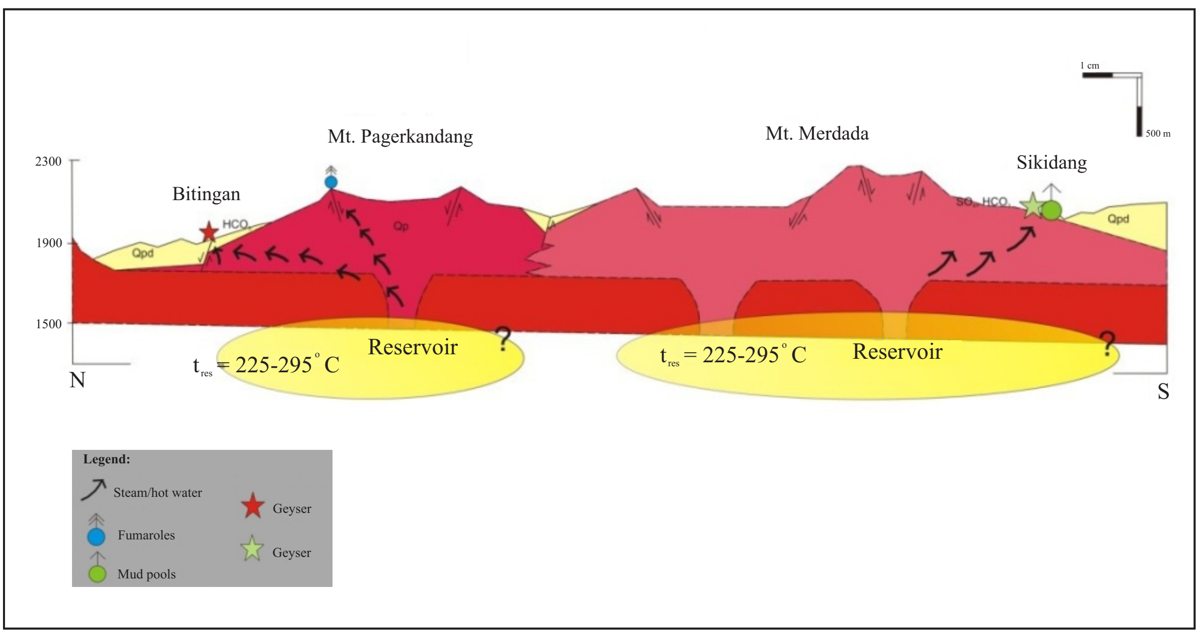

Figure 5. Tentative sketch model of Dieng geothermal trending north - south, the geology is based on Condon *et al*. (1996) and field observation.

Conclusion

The studied area is located in the South Serayu area as a depression of a mountain and a high. It lies at the Dieng caldera depression which generally consists of lava andesite.

Geochemical study shows that in this area there are four reservoirs which can be divided based on hotwater origin. The Bitingan, Sileri, and Siglagah areas are included into bicarbonate hotwater type. Pulosari hotwater is included into chloride sulfate hotwater. Kaliputih is included into chloride bicarbonate hotwater, whilst Sikidang is included into sulfate hotwater. The reservoir of Pulosari and Kaliputih hotsprings is estimated to be influenced by a volcanomagmatic process, but it comes from meteoric water that has undergone heating without mixing with magmatic water based on stable isotope.

Based on the subsurface calculation, the temperatures of studied area are between 225^o - 295^o C.

Sileri and Sikidang is the potential area for a further study, this area is chosen based on the appearance of fumaroles which have high temperature and spring with bicarbonate type showing heated surface water with high surface temperature.

Acknowledgments–This paper was presented on the 39th IAGI Annual Meeting, in Lombok, on 2010. The authors would like to thank the reviewers for their comments improving the quality of this paper.

Refferences

Condon W.H., Pardiyanto L., Ketner K.R., Amin T.C., Gafoer S., and Samodra H. 1996. *Geological Map of Banjarnegara dan Pekalongan Quadrangles, Central Java*. Geological Research and Development Centre, Bandung.

Google map, 2009. http://maps.google.com. [Desember dan Januari 2010].

Nicholson, K.N., 1993. *Geothermal Fluids, Chemistry and Exploration Techniques*. Springer- Verlag, Berlin Heidelberg, 263pp.

Pardyanto, L., 1970. The Geology of the Dieng area Central Java, A report based mainly on photo-interpretation and literature study. *Vulcanology Report*.

Standard Nasional Indonesia, 2004. *Air dan air limbah*. SNI 06-6989.11-2004 Badan Standardisasi Nasional.

Van Bemmelen, R.W., 1949. *The Geology of Indonesia*. Vol.1A. The Hague, Government Printing Office, Jakarta.