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Travertine Deposits Indicated of a Medium Enthalpy for a Geothermal Reservoir Beneath Dolok Marawa Area, Simalungun, North Sumatera Province - Indonesia

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ABSTRACT

The Dolok Marawa geothermal area is located on the northern part of Sumatera Island, North Sumatera Province. The geothermal manifestation here is reflected by hot springs in an elevation between + 330-370 m asl, along the northwest-southeast trending faults (N 320-330º E). Geothermal manifestations here are covered by volcanic, and sedimentary rocks, and also underlain by Miosen limestone basement. The surface temperature varies between 36.4-66.5º C and has neutral pH (6.57-7, 63). The surface deposit includes travertine deposits of carbonate sinter in an area nearby hot springs.

According to the geochemical fluids analyzed, the Partulatula, Panggaruan and Lakparan hot waters have a high concentration of chloride, the Tinggi Raja, Balakbak, and Bahoan hot waters are situated in the border between chloride and bicarbonate waters, and the Bahbotala hot water is a bicarbonate waters. All hot waters are immature waters.

The estimation of water temperature in the fluid reservoir beneath the area is 180º C (medium enthalpy). An abundant volume of travertine deposits in a nearby surface manifestation characterizes this reservoir. The travertine is also indicative of lime stone basement rocks beneath the area. Than lime stone is strongly disolved by hot fluids at temperature below 180° C

The hydrogen and oxygen isotope ratios of thermal spring waters (^{18}O Vs Deuterium) for the Tinggi Raja hot spring show that fluids have depleted ^{18}O content and lie on the meteoric water line (MWL), but for the Bahoan, Balakbak and Lakparan hot springs, waters are enriched in ^{18}O content. This means tthat the hot fluids are presumably derived directly from a medium enthalpy geothermal reservoir beneath the area with a temperature of about 180º C.

1. INTRODUCTION

Geothermal energy has long been used for thermal heat, for bathing and cooking, and in the 20^{th} Century, for generating of electrical energy. The majority of geothermal systems in the world that have the potential to be developed for their energy are hosted by volcanic rocks in arc tectonic settings. Most Indonesian geothermal areas are of this type, for example the geothermal areas in Sumatera, Java, East Nusatenggara, Sulawesi and Halmahera Island.

Indonesia's geothermal energy has a potential of about 27 GWe, however only 1050 MWe have been utilized for electricity, which is less than 3% of the total National geothermal energy potential capacity. The Indonesian government is still promoting the contracting of small-scale geothermal power stations in many remote islands through The Rural Electrification Program. Utilizing of direct geothermal energy has not been successfully developed significantly yet. Until this time, it has had very limited use and it is still waiting for continued development.

Dolok Marawa is on a part of the Sunda arc, which consists of Upper Cenozoic volcanic rocks. The volcanic rocks are dominantly of intermediate calc-alkaline composition and are unconformably underlain by sedimentary limestone of Tertiary Miosen age, which is exposed in the middle of the survey area.

The study area is located in the Dolok Marawa village, Simalungun Distric, North Sumatera Province. It lies between 98º44'46''-98º52'02'' E longitude and 3º5'49''-3º12'03'' S latitude (Figure 1).

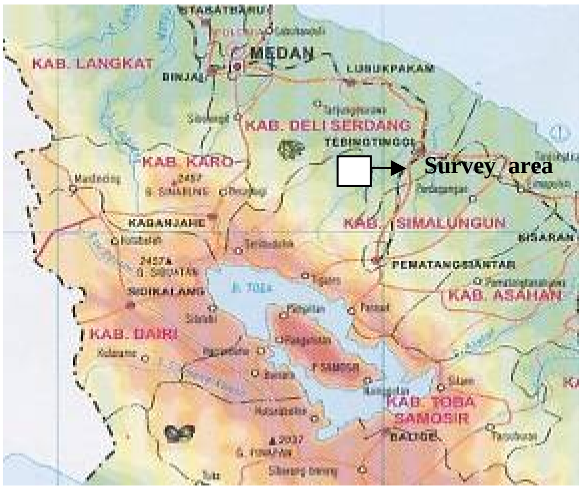

Figure 1: The study area

Geothermal manifestations mostly occur in the middle of the survey area. They contain hot springs and sinter carbonate of the travertine deposits There are some geothermal manifestations in the area that presumably indicate the presence of a medium enthalpy geothermal reservoir beneath the surface manifestations. The utiliziation of geothermal energy by developing a small scale geothermal power plant might support and stablize energy demand and economic growth for local people and local goverment.

2. TECTONIC SETTING

The tectonics of the Indonesian Island arc are the result of the interaction of the Eurasian, Pasific, Philippines and Indian-Australian plates (Katili, 1973) (Figure 2). Most of Indonesian island arc displays micro-continental arc volcanism associated with an oceanic trench subduction zone (Cas and Wright, 1987).

The arc could be divided into four arcs, such as the Sunda arc in the western part, the Banda arc in the estern part, and two small arcs situated to the north Banda arc (the Sangihe-North Sulawesi and Halmahera arcs).

The volcanism and geothermal prospects form a part of the Sunda arc. The evolution of volcanic arcs occured from pre – to mid Tertiary associated with the collision of Australian continent (Audly – Charles, 1975). This event might have caused active volcansim and associated geothermal activity, and resulted in complicated differentiation in the tectonic setting from west to east along the arc island.

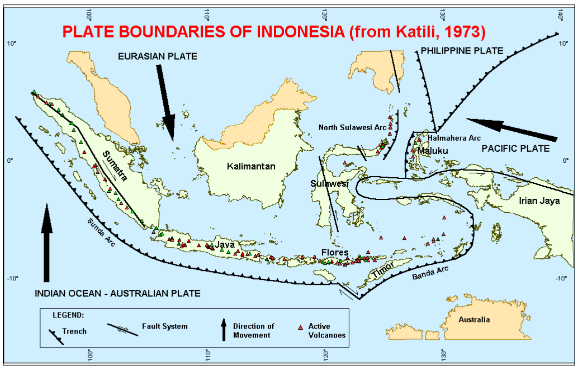

Figure 2: Tectonic of the Indonesian archipellago (Katili, 1973)

3. GEOLOGICAL FRAME WORK

The Indonesian archipelago exists in the volcanic arc as a ring fire belt. It extends about 4,300 km from Weh Island and Sumatera Island in the west through to Bacan Island, Halmahera Island and Kai Island in the east and also to Buru Island in the north. Along that entire island some active and inactive volcanoes exhibit geothermal manifestations. It's globally a geothermal energy in Indonesia Island. Geothermal activity is associated with magma stores beneath volcanic cones and indicates a heat source for geothermal energy.

Stratigraphically the area consists of seven rock units. The rocks are, in succesion from oldest to the youngest: Tertiary Bahbotala limestone (Tgb), Quaternary andesite lava of Mt. Sipapagus (Qls), Quaternary piroxen - andesite lava of Mt. Bahtopu (Qlb), Quaternary pyroclastic flow of Toba (Qat), Quaternary pyroclastic fall of Toba (Qjt), Travertine deposits (Otr) and Aluvium (Qa) (Figure 3).

The geological structure in the area is indicated by topographical lineaments, volcanic cones, triangular facet, fault scarf, joints, off-set rocks, brecciation, some hot springs in geothermal manifestations and a spread of travertine deposits.

Seven hot springs temperature between 36,4-66,5^{0} C, neutral pH, and spread carbonate sinter deposit (travertine) is exposed here along the NE-SW (N 320-325° E) trending Tinggi Raja and Bahbotala faults (Figure 3).

4. GEOCHEMICAL OF HOT SPRING FLUIDS

The chemistry data of hot springs is shown in Table 1. The ternary diagram of Cl-SO_4-HCO_3 for Partulatula, Panggaruan and Lakparan hot springs show that the hot springs are classified into the chloride hot water type, while

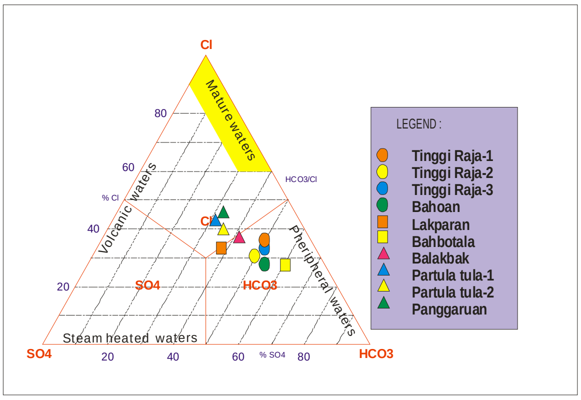

Figure 4: Ternary diagram Cl-SO4-HCO3 of thermal spring waters

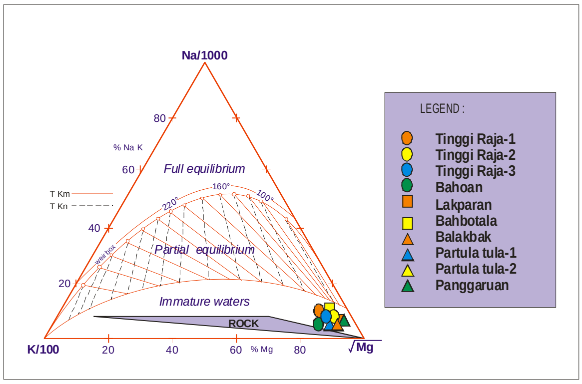

Figure 5: Ternary diagram Na-K-Mg of thermal spring waters

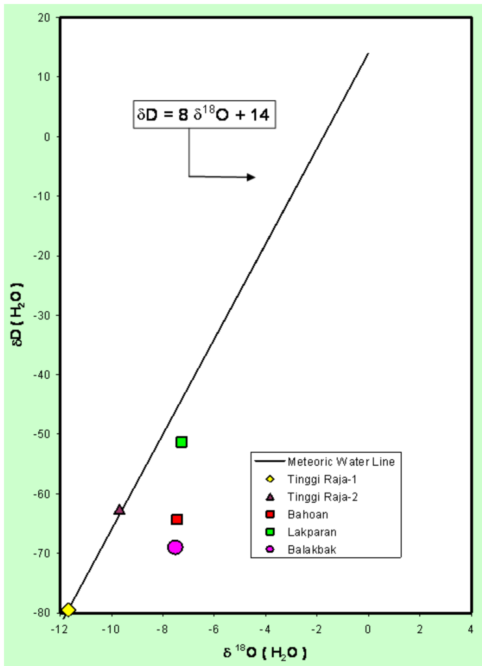

Figure 6: The relationship between hydrogen and oxygen isotope ratio of thermal spring waters Dolok Marawa, North Sumatera

the Tinggi Raja Balakbak and Bahoan hot springs lie in the border line between chloride and bicarbonate. The Bahbotala hot spring is in a bicarbonate type field (Figure 4). As the ternary diagram of Na/1000-K/100-√Mg thermal spring waters from Dolok Marawa shows, all these hot water samples are of the immature type (Figure 5).

The isotopic diagram of ^{18}O and deuterium is used to determine whether there has been depletion or enrichment of ^{18}O content due to magma degassing (Craig, 1961; Zainal Abidin, 1989) and is used for analyzing this area. The data from five samples are shown in Table 2. The relationship between the hydrogen and oxygen isotopic ratio of thermal spring waters in Dolok Marawa, shows that the Bahoan, Balakbak and Lakparan hot springs are enriched in ^{18}O content. This means that hot fluids are presumably derived from a geothermal reservoir beneath the area. The Tinggi Raja hot spring is depleted in ^{18}O content and its position is along the meteoric water line (MWL, Figure 6). This means that the Tinggi Raja hot spring is presumably contaminated by meteoric water.

DISCUSSION

The chloride and neutral pH waters in hot springs (Figure 4) suggest thatvthe thermal hot fluids beneath the area are probably derived from a geothermal reservoir. Chloride bicarbonate type fluids mean that the hot fluids have been somewhat contaminated by meteoric water. Bicarbonate type fluids mean that the hot fluids from the geothermal reservoir are dominantly surface waters. The fact that immature water is indicated for all of the hot springs, as shown in Figure 5, suggests that all of the hot springs sampled have been contaminated by surface meteoric water.

The relationship between the hydrogen and oxygen isotope ratio shown in the ^{18}O and deuterium diagram for thermal spring waters from Dolok Marawa (Figure 6), shows that all of the hot springs sample are enriched in ^{18}O, except for the Tinggi Raja hot springs, which are depleted in ^{18}O content. This means that all of the hot fluids are presumably respectively to a magma degassing in the geothermal reservoir beneath the area (Craig, 1961; Zainal Abidin, 1989), except for the Tinggi Raja hot springs which have been contaminated by a meteoric water.

The reservoir estimated beneath Dolok Marawa is below than 180° C. The reservoir site is characterized by a covering of travertine deposits close to surface manifestations. Travertine deposits here are also indicative of limestone in the basement rocks at depth in the area. There it would be disolved by hot water fluids in temperature conditions below 180° C, a medium enthalpy geothermal reservoir (Mahon and Ellis, 1977; Fournier, 1981). The temperature 180° C of hot water fluids is probably representative of a reservoir temperature beneath Dolok Marawa.

CONCLUSION

The tentative model of Dolok Marawa mostly derived from geological and geochemical surveys is shown in Figure 7.

- Cap-rocks or a clay-cap layers overlie a geothermal reservoir and have hot fluids from the reservoir migrating to the surface.
- The reservoir zone (feed zone) is a permeable unit of Tertiery limestone, which is filled by medium enthalpy hot water fluids at about 180° C.
- The conductive rocks are a crystaline basement, which is overlain by a Miosen limestone.
- Convected heat flows with reservoir hot fluids, which migrate to the surface driven by high P and T conditions. The heat-source is suspected to be a magma chamber beneath Mt. Bahtopu.

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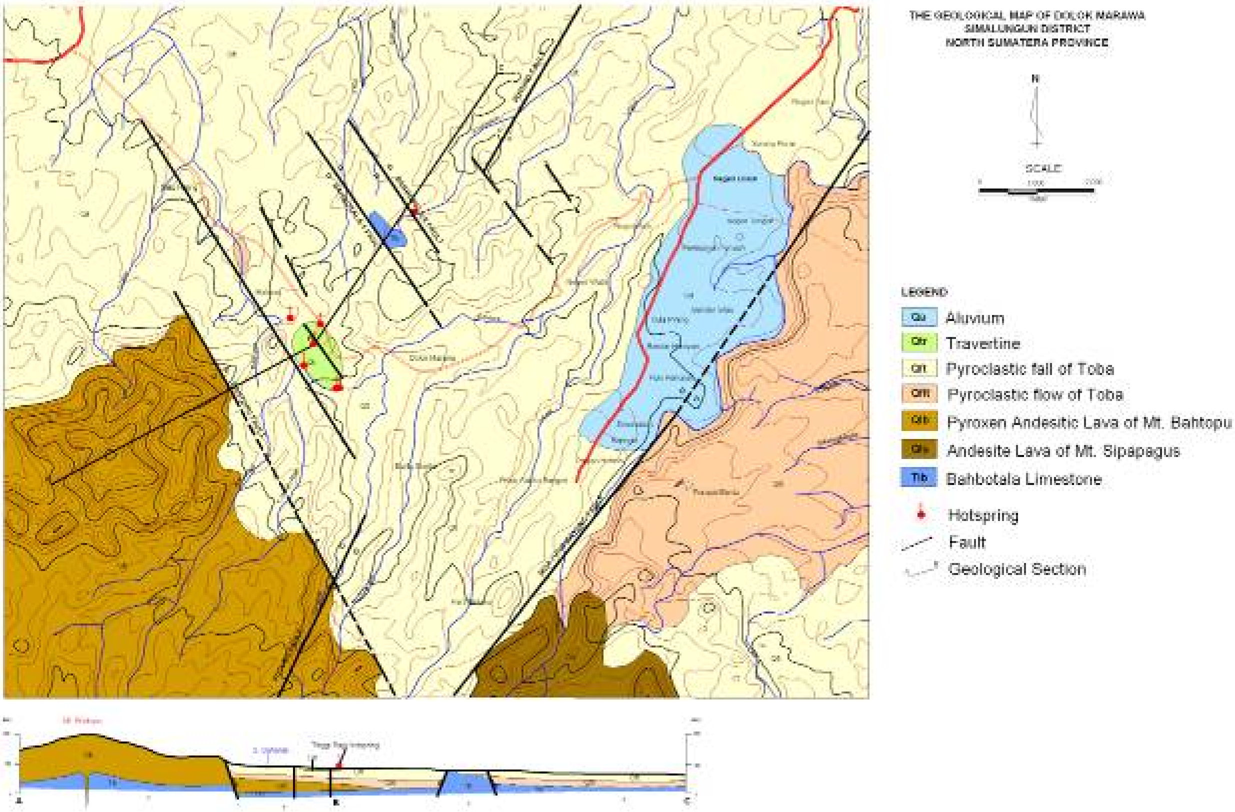

Figure 3. The geological map of the Dolok Marawa area.

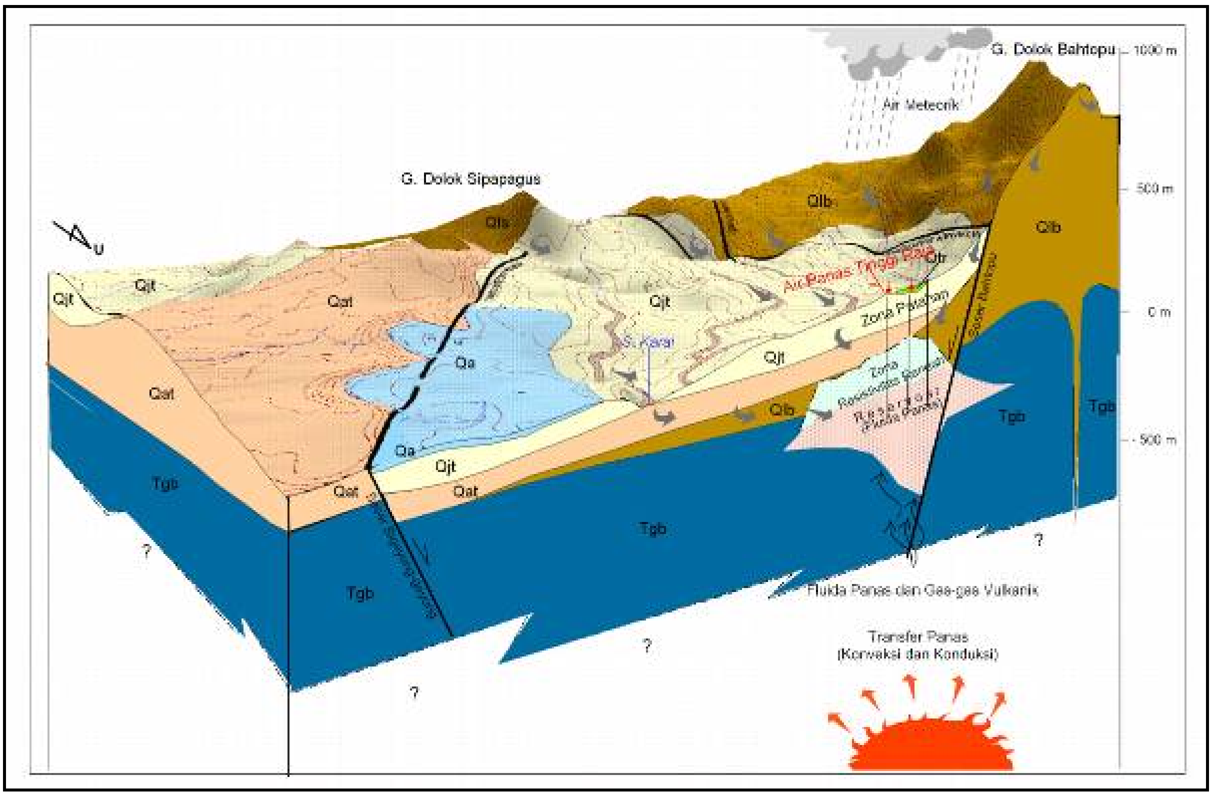

Figure 7: The tentative model of the Dolok Marawa geothermal area

Table 1. Hot Water Analyses in Dolok Marawa.

Constituent	Units	TR 1	TR 2	TR 3	BHN	LKP	BHB	BLB	PR 1	PR 2	PG
Elevation	m asl	428	432	433	433	433	395	396	395	395	400
Hot spring Temperature	^oC	64.8	65.6	61.9	63.0	49.2	37.4	63.8	60.0	63.2	63.1
Air Temperature	^oC	26.9	27.2	29.3	27.6	32.0	26.7	27.0	26.8	27.2	26.2
Flow rate	lt/second	20	20	5	20	10	5	20	20	20	5
pH	-	6.64	6.59	6.62	6.57	6.64	6.62	6.74	7.63	6.55	6.48
Na	ppm	124.84	124.84	124.84	124.84	80.54	52.35	120.81	153.03	144.97	153.03
K	ppm	34.00	34.00	34.00	34.00	30.00	16.00	32.00	42.00	40.00	42.00
Li	ppm	0.72	0.72	0.76	0.74	0.62	0.68	0.59	0.80	0.75	0.82
Ca	ppm	208.09	209.76	200.03	210.04	254.79	86.30	217.70	109.50	125.40	142.10
Mg	ppm	55.10	58.00	58.80	57.20	50.70	17.40	55.10	40.70	37.50	39.40
Fe	ppm	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
CO_3	ppm	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
As	ppm	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
NH_4	ppm	0.36	0.00	0.36	0.00	0.00	0.00	0.00	0.36	0.00	0.00
HCO_3	ppm	390.27	408.07	382.64	367.39	314.00	250.43	338.79	283.49	272.05	274.59
Cl	ppm	263.85	263.85	263.85	246.26	289.03	105.54	246.26	334.21	299.03	316.62
SO_4	ppm	114.00	128.00	112.00	97.00	180.00	42.00	152.00	136.00	138.00	124.00
B	ppm	2.28	2.17	2.28	2.38	24.87	23.24	8.91	13.14	3.48	2.80
F	ppm	0.00	0.50	0.00	0.50	1.50	1.50	1.50	1.00	0.50	1.00
SiO_2	ppm	46.31	45.84	46.76	47.92	40.11	47.86	46.76	52.07	48.86	52.75
Conductivity	uhos/cm	1778	1742	1690	1630	1308	683	1704	1632	1420	1598

Legend:

TR 1	:	Tinggi Raja 1 hot spring
TR 2	:	Tinggi Raja 2 hot spring
TR 3	:	Tinggi Raja 3 hot spring
BHN	:	Bahoan hot spring
LKP		Lakparan hot spring
BHB	:	Bahbotala hot spring
BLB	:	Balakbak hot spring
PR 1		Partula 1 hot spring
PR 2		Partula 2 hot spring
PG	:	Panggaruan hot spring

Table 2. The Isotopic Data analyses of ^{18}O and Deuterium for Thermal Spring Waters in Dolok Marawa.

No.	Hot spring samples	^{18}O($^{o}/_{oo}$) SMOW	D($^{o}/_{oo}$) SMOW
1.	Tinggi Raja 1	-11,7	-79,5
2.	Tinggi Raja 2	-9,7	-62,6
3.	Bahoan	-7,5	-64,3
4.	Lakparan	-7,3	-51,3
5.	Balakbak	-7,5	-69,0