

## Geochemistry of Geothermal Area in Pohon Batu, West Seram Regency, Moluccas

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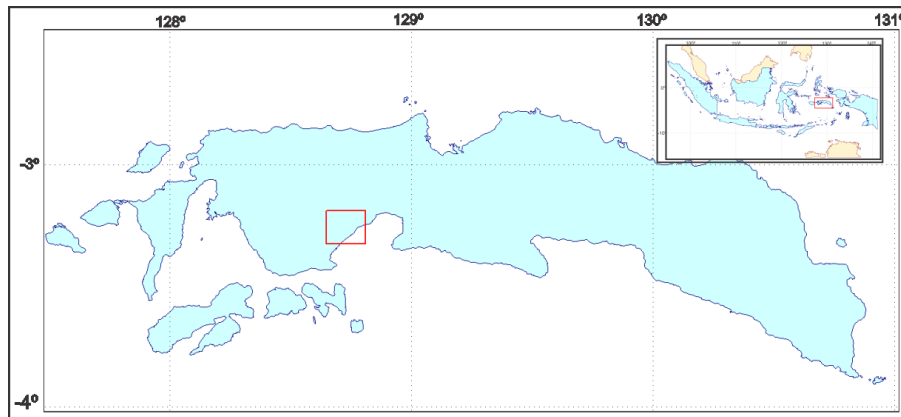
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### ABSTRACT

Indonesia has many geothermal areas which are associated with non-volcanic environment. One of them is Pohon Batu, West Seram Regency, Moluccas. The geothermal manifestations are only Pohon Batu 1-7 hot springs, the temperatures are about 40-60,9°C with neutral pH. Physiographically, it is included Outer Banda arc non volcanic which is consisted of metamorphic rocks in the Permian-Triassic. Pohon Batu has chloride-bicarbonate type of water based on Cl-SO<sub>4</sub>-HCO<sub>3</sub> diagram and plots in partial equilibrium zone based on Na-K-Mg diagram. The temperature of reservoir is about 175-220°C from Na-K geothermometry.

### 1. INTRODUCTION

Geothermal systems in Indonesia are associated with Quaternary volcanism (Sumatera, Java, Bali, Nusa Tenggara, Banda Islands, and North Sulawesi) and non volcanic environment (Kalimantan, most of Sulawesi, Buru island, and Papua). By March 2015, about 324 geothermal locations have been identified with a total potential energy equivalent to 29 GWe (Center for Geological Resources, 2015). Of all these locations, about 70 (25 %) are associated with non-volcanic environment with a total potential of more than 1 GWe. There are about 4 geothermal areas in Seram Island, Indonesia. One of them is Pohon Batu geothermal area which is located at West Seram district, Central Moluccas (Figure 1) or 460951-478870 mE and 9647537- 9632325mN at UTM zone -52. Pohon Batu, is a non volcanic geothermal area. Indonesia non-volcanic geothermal systems have not been utilized as a source of electrical energy, because of the lack of understanding for the non-volcanic geothermal system. This study describes the characteristics of fluids and the conditions of the Pohon Batu non-volcanic geothermal area.



**Figure 1: Map Location of Pohon Batu geothermal area**

### 2. GEOLOGY BACKGROUND

Regionally, based on geology regional of Ambon and Masohi, Moluccas, (Tjokrosapoetra, et al, 1993), Seram, Boano, Kedang, and Manipa island is located at Outer Banda Arc, Seram island incorporated into the Neogen Imbrication zone. Rocks in the investigation area consists of non-volcanic rocks aged Permian (Paleozoic) until Holocene (Figure 2). Pohon Batu regional geology is composed of non-volcanic rocks consisting of metamorphic and sedimentary rocks. The establishment of a geothermal system in the research area is closely related to tectonic activity which is still active today.

The oldest rocks outcrop that can be discovered in the research area is Phyllit with Perm age. The younger lithology is Schist of Perm. The younger lithology is sedimentary rock, Conglomerate with Pliocene –Pleistocene age. The younger than Conglomerate is Limestone with Holocene age. The youngest unit is alluvium.

Geological structure of the research area, generally has northwest-southeast and southwest-northeast orientation. That faults may controlled the occurrence of hot springs in the research area

Geothermal system of Pohon Batu area could be formed by the presence of thermal residue of magma chamber which associated with young plutonic activity. The activity caused igneous intrusion in fracture zone. The intrusive rocks didn't appear to the surface in the research area. The intrusive rocks estimated formed by collision between Seram Island and Australia Plate (Plate Collision) that caused magma flowing upward in the fault zone. The thermal residue formed geothermal activity and forming reservoir in Pohon Batu area.

Geothermal system of Pohon Batu area belong to heat sweep system in plate collision setting in associated with forming of intrusive rocks (Center for Geological Resources, 2014).

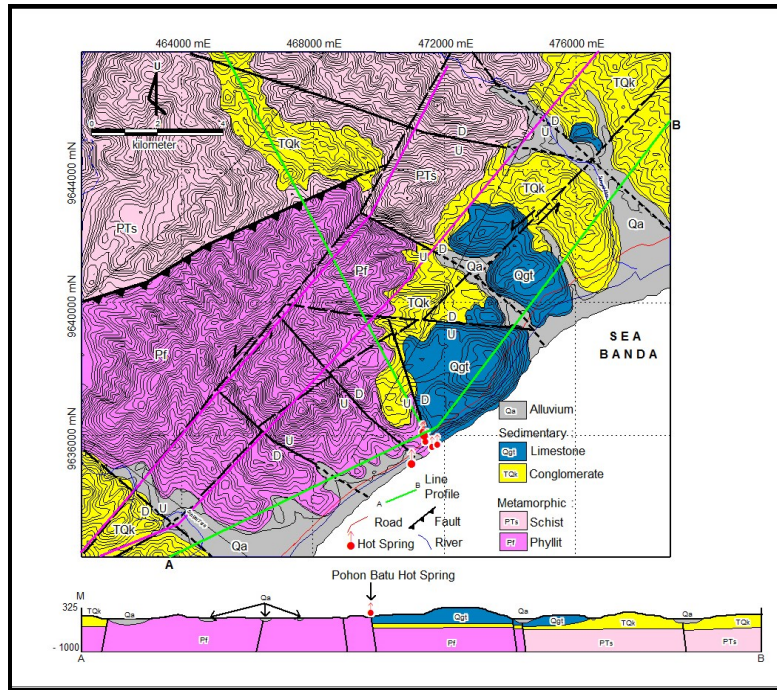


Figure 2: Geological Map of Pohon Batu Geothermal Area (modified from Center for Geological Resources, 2014)

## 2. GEOCHEMISTRY

### 2.1 Thermal Manifestations

#### 1) Hot Spring Pohon Batu-1, 2, and 3

The hot springs are located at Sanahu village, the coordinate is 471645 mT and 9635670 mU, elevation 27 msl. The temperature of hot spring Pohon Batu-1 is about 57,2°C, Pohon Batu-2 is about 59,1°C, and hot spring Pohon Batu-3 is about 50°C (air temperature is 28,2°C), pH 6,13-6,95, electrical conductivity of 7890-9760 μS/cm, flow rate Pohon Batu-1 about 0,5 l/s, and Pohon Batu-2 and 3 about 0,1 l/s. The hot springs are clear, salty, and there are some deposition of iron oxide.

#### 2) Hot Spring Pohon Batu-4

The hot spring Pohon Batu-4 is located at Sanahu village and the coordinate is 471798 mT dan 9635756 mU, elevation of 27 msl. Temperatur of hot spring Pohon Batu-4 is about 57°C (air temperature is 28,2°C), pH 6,34, electrical conductivity of 9040 μS/cm, and flow rate is about 0,1 l/s. The hot springs are clear, salty, and there are some deposition of iron oxide.

#### 3) Hot Spring Pohon Batu-5

The hot spring Pohon Batu-5 is located at Sanahu village and the coordinate is 471455 mT and 9635850 mU elevation of 27 msl. It is appear at Way Popupula river. The temperature of hot springs is about 49,7°C (air temperature is 30,2°C), pH 6,34, electrical conductivity of about 5640 μS/cm, and flow rate is about 0,1 l/s.

#### 4) Hot Spring Pohon Batu-6

The hot spring is located at Sanahu village and the coordinate is 471384 mT and 9635974 mU elevation of 27 msl. The hot spring is near the Way Popupula river with continuous bubble. The temperature of hot spring is about 40,5°C (air temperature is about 27,9°C), pH 5,63, electrical conductivity of 3280 μS/cm, and flow rate is about 0,1 liter/detik.

#### 5) Hot Spring Pohon Batu-7

It is located at 471012 mT and 9635165 mU elevation of 27 msl. It is appear at the edge of Pohon Batu beach along about 30 m and appears when the sea is receding. The temperature is about 60,9°C (air temperature is 27,9°C), pH 6,79, electrical conductivity of 3730 μS/cm. The hot spring is already contaminated with sea water at the surface.

## 2.2 Classification of the Fluids

12 samples were taken during the research consisting 8 samples of hot springs and warm springs, 3 samples of cold water, and 1 sample of sea water. The chemical analysis of the water samples is shown on Table 1. The results of hot spring analysis was dominated by chloride ion (1190-1365 mg/l), Na (1069-1246 mg/l), HCO<sub>3</sub> (865-975 mg/l), K (90-110 mg/l), dan SO<sub>4</sub> (216-283 mg/l).

In Figure.3 from the Cl-SO<sub>4</sub>-HCO<sub>3</sub> diagram (Figure 3), Pohon Batu 1, 2, 3, 4, 5, 5a, and 6 hot springs were Chloride-Bicarbonate type with neutral pH. For cold waters mostly are bicarbonate type. Pohon Batu 7 hot spring plotted in the chloride type caused by contamination of sea water.

Based on Cl-Li-B diagram (Figure 4), Pohon Batu hot springs are plotted at Cl Zone. It could be an indication that the hot springs come from magmatism process. Pohon Batu 1-6 hot springs contain chloride about 1190-1365 mg/l, has smaller quantity than sea water. It may indicate there is no mixing with sea water.

Cl/B ratio generally used to indicate for common reservoir source (Nicholson, 1993) of fluids. Difference value of Cl/B depend on lithology and B adsorption to clay layer during fluid transport. In Figure 4, there is positive correlation that Pohon Batu hot spring group are from the same reservoir

Based on Na/1000-K/100-Mg<sup>0.5</sup> diagram, Pohon Batu 1-6 hot springs/warm springs fall into the partial equilibrium zone. It is an indication that reaction between fluids and reservoir rocks were mixed with meteoric water. But there is possibility that Pohon Batu fluids Na-K-Feldspar equilibrium was disturbed by other elements which has high concentration in that environment. In other case, Pohon Batu 7 hot spring which contaminated by sea water is in one trendline with sea water.

**Table 1: Water Result Analysis in Pohon Batu Area**

Sampel, (mg/l)	pH	EC	Tempera ture (°C)	SiO <sub>2</sub>	B	Al <sup>3+</sup>	Fe <sup>3+</sup>	Ca <sup>2+</sup>	Mg <sup>2+</sup>	Na <sup>+</sup>	K <sup>+</sup>	Li <sup>+</sup>	As <sup>3+</sup>	NH <sub>4</sub> <sup>+</sup>	F <sup>-</sup>	Cl <sup>-</sup>	SO <sub>4</sub> <sup>2-</sup>	HCO <sub>3</sub>	CO <sub>3</sub> <sup>=</sup>	ion balance
Hot Spring Pohon Batu-1	6.48	8800	57.2	82.81	12.98	0.03	2.07	34.42	17.44	1246.96	108.7	4.98	0.5	28	1.35	1365.42	279.82	975.13	0	1.83
Hot Spring Pohon Batu-2	6.13	9760	59.1	83.06	13.82	0.02	1.4	33.64	15.92	1244.32	110.75	5	< 0.01	28	1.4	1365.42	283.11	874.46	0	2.93
Hot Spring Pohon Batu-3	6.95	7890	50	77.59	14.48	0.03	3.7	32.98	15.29	1069.02	90.52	4.35	0.5	26	1.05	1190.77	216.9	877.09	0	1.38
Hot Spring Pohon Batu-4	6.34	9040	57	60.11	11.98	0.03	3.76	38.31	17.18	1217.86	98.45	4.89	0.5	25	0.85	1306.45	278.17	865.38	0	3.60
Hot Spring Pohon Batu-5	6.04	5640	49.7	55.53	8.14	0.03	6.07	8.71	4	742.63	57.65	3.43	1	18	1.02	823.14	214.8	480.99	0	1.07
Hot Spring Pohon Batu-5a	6.04	5640	46.6	54.07	7.53	0.02	6.41	8.32	3.71	687.37	54.67	3.16	1	18	0.92	739.48	178.64	430.18	0	3.32
Hot Spring Pohon Batu-6	5.63	3280	40.5	46.21	4.61	0.06	9.99	5.14	2.84	478.31	41.54	2.14	0.5	15.1	0.73	538.06	151.11	279.05	0	2.40
Hot Spring Pohon Batu-7	6.79	3730	60.9	20.1	6.34	0.03	0.15	390.3	842.15	7987.5	326.6	1.08	< 0.01	10.3	1.24	13019.14	2013.06	260.28	0	3.69
Cold Water Pohon Batu-2	5.79	1261	34.4	26.26	1.96	0.01	0.03	2.93	2.54	201.51	12.25	1.01	< 0.01	3.8	0.19	207.49	49.45	152.56	0	2.08
Sea Water Pohon Batu	7.85	47800	-	2.27	3.84	0.04	0.22	476.5	787.9	10649.8	440.47	0.1	< 0.01	5.4	2.75	17831.5	2567.76	146.82	0	0.39
Cold Water Pohon Batu-1	3.82	130.4	25.8	46.12	0.02	0.34	7.16	0.46	1.68	1.86	2.72	0.01	< 0.01	2.1	0.08	1.9	45.32	0	0	-8.05
River Water Nari Kecil	6.24	91	23.4	18.11	0.02	0.01	0.09	3.31	2.21	1.82	1.07	0.01	< 0.01	0.5	0.03	1.47	4.11	21.89	0	0.16

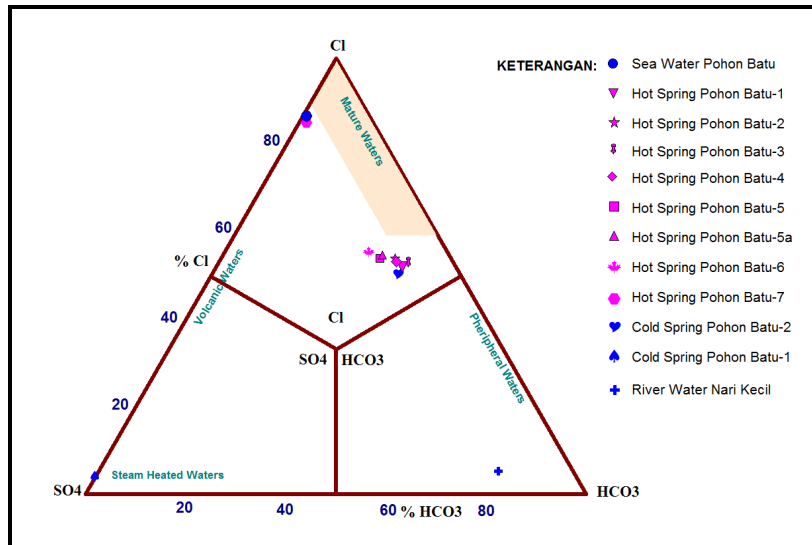


Figure 3: Cl-SO<sub>4</sub>-HCO<sub>3</sub> Ternary Diagram

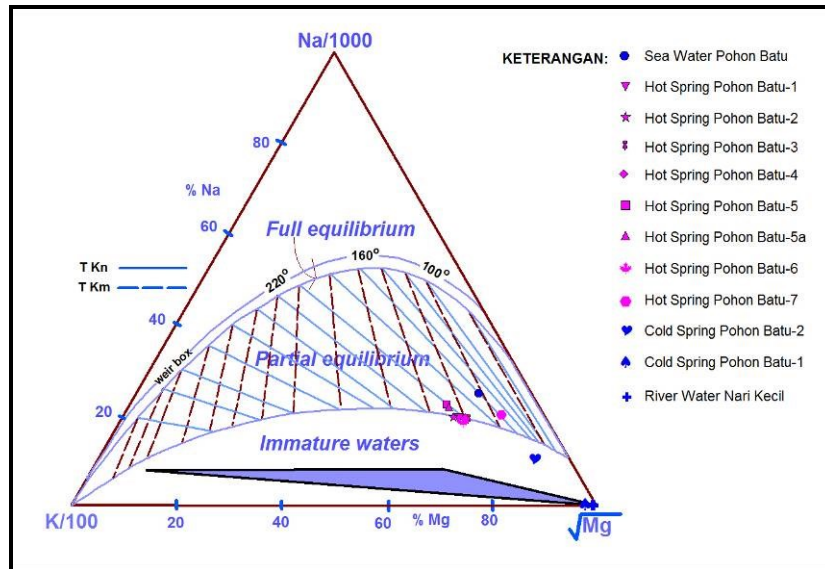


Figure 4: Na-K-Mg Ternary Diagram

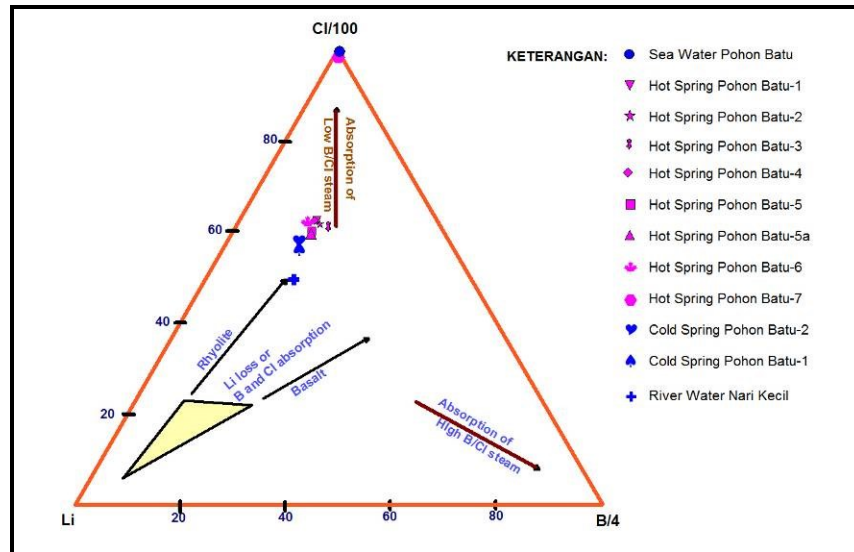


Figure 5: Cl-Li-B Ternary Diagram

2.3 Geothermometry

The prediction of reservoir temperature is calculated with eight different geothermometer equations (Tabel 2). The calculation result that shown in Table 2, the temperature of reservoir about 170-220 °C (intermediate enthalphy). Since the temperature of manifestations relative low to medium, the silica geothermometers seems not to realistic.

Table 1: Geothermometry in Pohon Batu Area

Sample	Quartz cond	Quartz adiabatic	Na-K-Ca	Na-K-Ca Mg corr	Na/K Fournier	Na/K Truesdell	Na/K (Giggenbach)	K/Mg (Giggenbach)
Pohon Batu-1 Hotspring	127	124	206	-31	205	173	222	123
Pohon Batu-2 Hotspring	127	124	207	-16	207	175	223	125
Pohon Batu-3 Hotspring	124	121	201	-31	203	170	219	120
Pohon Batu-4 Hotspring	111	110	200	-32	199	166	216	121
Pohon Batu-5 Hotspring	107	107	202	55	196	162	213	127
Pohon Batu-5a Hotspring	106	106	202	58	198	164	215	126
Pohon Batu-6 Hotspring	99	99	205	52	205	173	221	122

2.4 Isotope

Stable water isotope data plot in global meteoric water line and local meteoric water line which approached by local groundwater samples, and the formula is  $\delta D = 8.22 \delta^{18}O + 13.97$  (Figure 6.). It could be an indication that it is meteoric water origin. Several isotope of hot springs (Pohon Batu 5, 5a, and 6) near to local meteoric water line, it could be an indication that the contributions of deep fluids is minor, but for hot spring Pohon Batu 1, 2, 3, and 4 are more positive than local waters, this could be an indication that geothermal fluids has been enriched with  $^{18}O$  because of rock-water reactions at depth (Nicholson, 1993). Pohon Batu 7 hotspring was appropriate with its environment which contaminated by sea water.

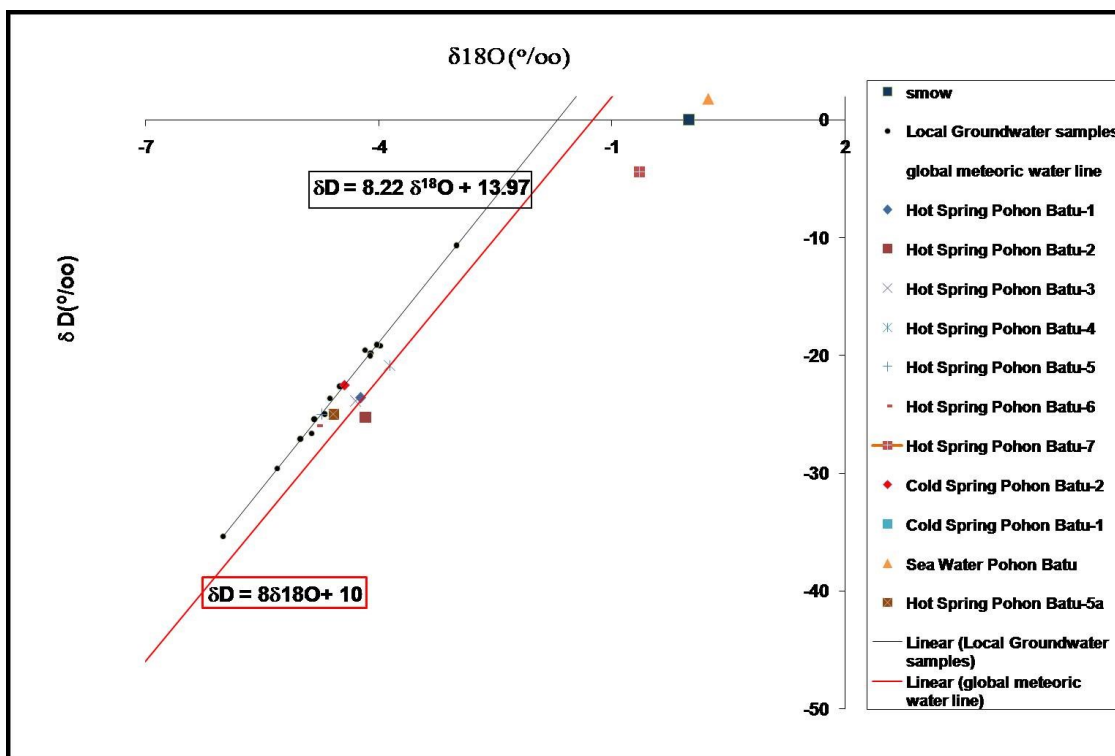


Figure 6: Water Isotopes Diagram

### 2.5 Gas

Gases in geothermal discharges usually are  $\text{CO}_2$ ,  $\text{H}_2\text{S}$ ,  $\text{NH}_3$ ,  $\text{N}_2$ ,  $\text{H}_2$ , dan  $\text{CH}_4$ , referred to as the “non condensible gases” (Nicholson, 1993). The equilibrium of  $\text{CO}_2/\text{CH}_4$  varies with temperature and rock type. Based on Norman and Moore diagram (1999), shows that bubble gas Pohon Batu from hot spring Pohon Batu-6 has been mixing or condensing with meteoric water in certain depth.

Gas (%mol)	Pohon Batu
He	0,035
$\text{H}_2$	2,455
$\text{O}_2$	0,000
Ar	0,705
$\text{N}_2$	49,541
$\text{CH}_4$	3,692
$\text{CO}_2$	28,156

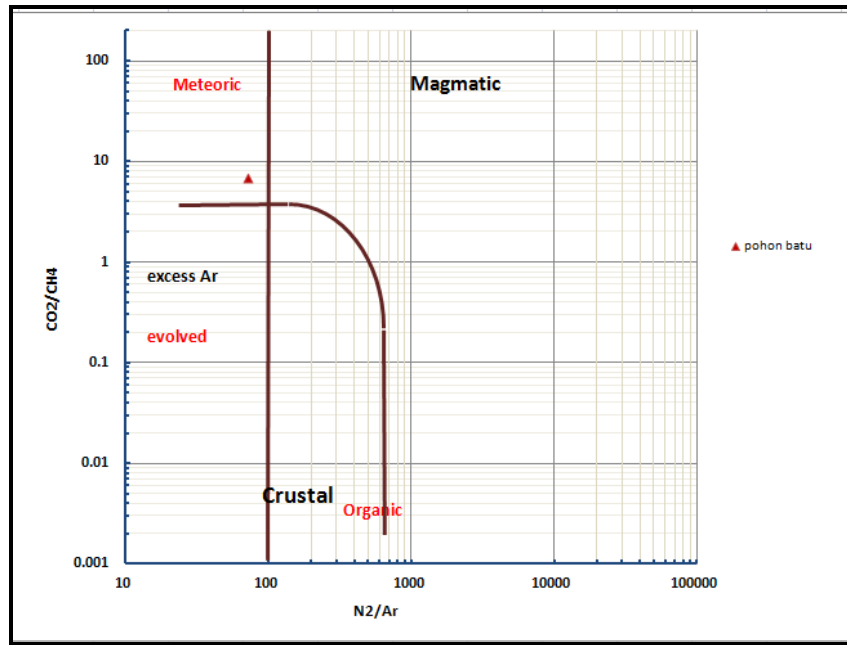


Figure 7. Indicator Origin Fluid Diagram (Norman dan Moore, 1999)

**2.6 Mercury Soil**

Permeable regions and possible upflow could be determined with soil mercury survey (Nicholson, 1993). Concentrations of Hg soil have a range from 2.6 to 20.915 ppb. The anomaly of Hg soil concentrated around hot springs. It could be an indication of an upflow of the Pohon Batu geothermal system, supporting that the type of manifestations is chloride-bicarbonate type, low terrain, and there is no manifestations except the Pohon Batu hot springs.

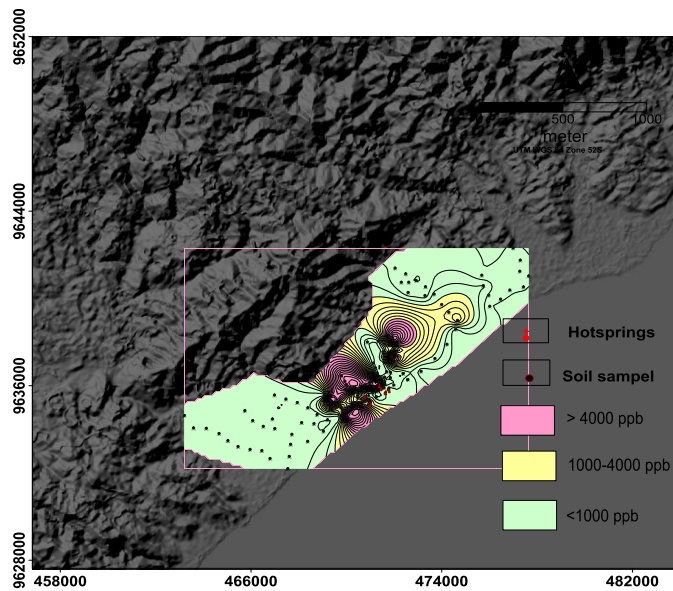


Figure 8. Map of Distribution Soil Hg at Pohon Batu Geothermal Area

**3. CONCEPTUAL MODEL**

Distribution of Pohon Batu hotsprings are along Wai Popupula River with temperature about 40-60 °C. The apperance of the manifestations controlled by oblique fault (normal-dextral) with north-south orientation. The presence of the manifestations may related with plutonic activities in the form as young intrusive rocks which not appear to the surface as heat source and strong tectonic activities as consequence of Pohon Batu location that located in convergent of Australia, Pacific, and Eurasia tectonic plates.

Tentative geochemistry model in Pohon Batu geothermal area was hypothesized in Figure 9. Since geothermal manifestation only seven hot springs where relative close each others, the type of waters are chloride-bicarbonate type, neutral pH, and located in partial equilibrium zone, stable isotope analysis estimated as interaction between rocks and thermal fluid in the reservoir, relative low terrain at Pohon Batu geothermal area, and support with anomaly of mercury soil at the hot springs, so it could be an indication that the hot spring of Pohon batu is the upflow of the system or margin upflow of the geothermal system. This indication is correlated with the gravity and AMT result that the anomaly of geophisic is just below the Pohon Batu hot springs (Center for Geological Resources, 2015). High sulfate concentration may came from oxidation of H<sub>2</sub>S gases that condensed, also may came from enrichment from oxidation of sulphide minerals.

Based on data that mentioned above, the tentative model of hydrogeochemistry of Pohon Batu can be created (Figure 9)

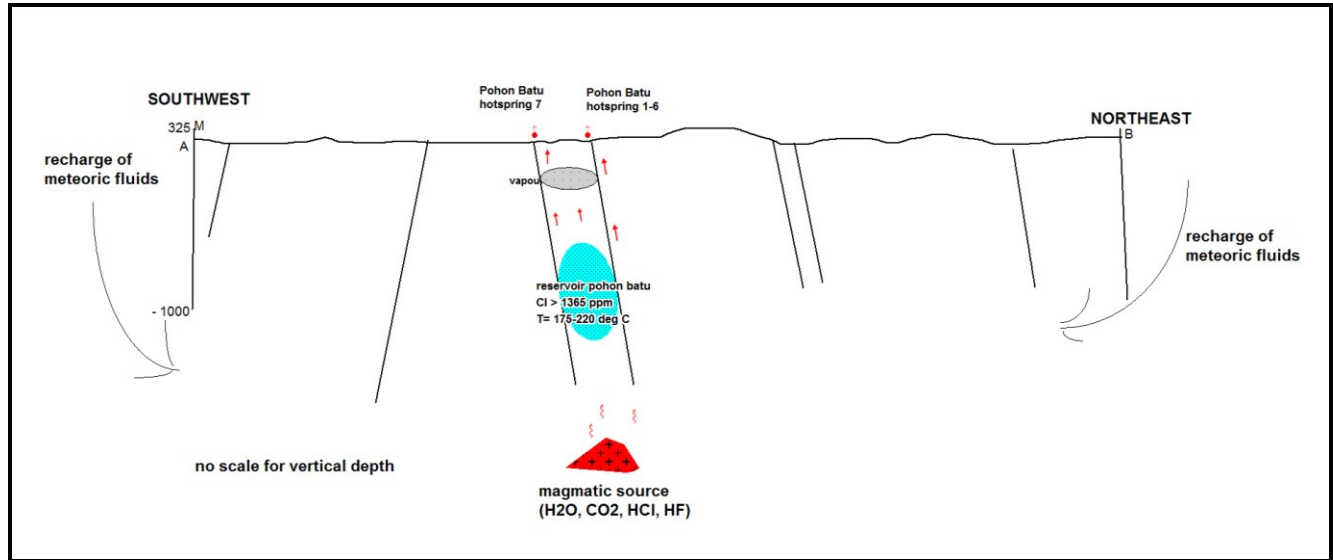


Figure 9. Tentative model of hydrogeochemistry Pohon Batu Geothermal Area

#### 4. CONCLUSION

Geothermal manifestations are only one cluster hot springs Pohon Batu (40-60,9°C and neutral pH). Pohon Batu hot springs are chloride-bicarbonate type and plotted in partial equilibrium. Reservoir temperature was estimated about 175-220 °C that belong to medium temperature. Pohon Batu hot springs could be the upflow zone of the system

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