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Geochemistry of A Non Volcanic Geothermal Area in Maranda, Poso Regency, Central Sulawesi, Indonesia

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ABSTRACT

Indonesia has many geothermal areas which are associated with non volcanic environment. One of them is Maranda geothermal area, Poso Regency, Central Sulawesi. There are several manifestations such as hot springs, mud pots, and steaming ground in the area. The temperatures of manifestations range from 42°C-100°C. Maranda-6, Maranda-7, steaming ground, and mud pots have highest temperature. The pH of the fluid ranges from 6.4 - 9.5. The thermal features are associated with the youngest magmatic activity (granite intrusion) that occurred in the Plio-Pleistocene. The geological structure controlling the Maranda geothermal area is dominated by north-south trending structures associated with reverse faulting of Poso which is in the west and the pattern structure relative east-west trending as antithetic. The Maranda geothermal system has chloride type of waters based on Cl-SO_4-HCO_3 diagram and plots in partial equilibrium zone on the Na-K-Mg diagram. The temperature of reservoir is from 160°C-180°C based on water 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 December 2013, about 312 geothermal locations have been identified with a total potential energy equivalent to 29 GWe (Center for Geological Resources, 2013). From all these locations, about 70 or 25 % are associated with non-volcanic environment with a total potential of more than 1 GWe. One of the non-volcanic geothermal areas is Maranda on Sulawesi island, Central Sulawesi, Poso Regency and at coordinates 1^{o} 25' 34“ - 1^{o} 13' 24“ S and 120^{o} 31‘ 9” - 120^{o} 41’ 6” E (Figure 1). Geoscientific investigation was conducted at Maranda in 2011. However, geochemistry studies in non-volcanic areas at the exploration stage are still rare. This study describes the characteristics of fluids and the conditions of the Maranda non-volcanic geothermal area.

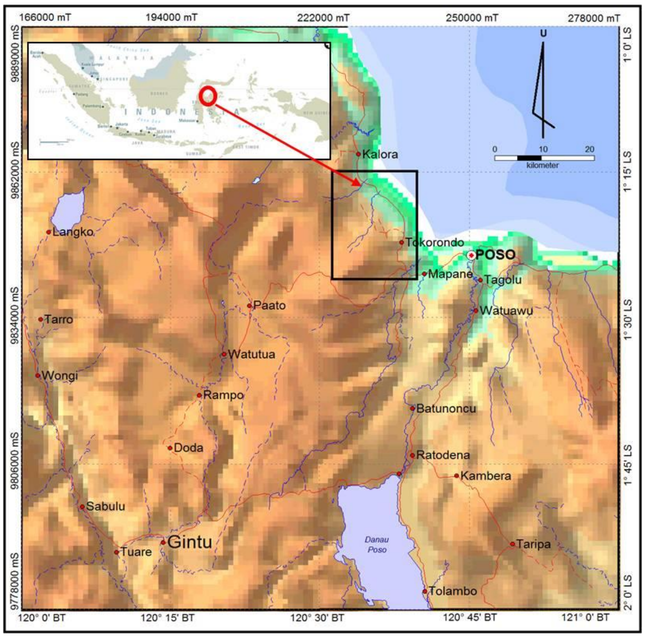

Figure 1: Location of Maranda, Poso, Central Sulawesi

2. GEOLOGICAL SETTING

Sulawesi, located at the triple junction of the Asian, Australian and Pacific plates, is geologically important for unraveling the Cenozoic tectonics of South-East Asia. This island, situated on the active margin of the Asian plate suffered at least four major tectonic events: in the Mid-Cretaceous, Oligo-Miocene, Middle Miocene, and Early Pliocene times (Villeneuve, et al., 2001). Maranda is situated in the metamorphic litho-tectonic terrain associated with tectonic activity between the collision of Eurasian Plate and Block Banda derived from the Indo-Australian Plate in the Oligocene. The geology of Maranda is composed of metamorphic rocks older than Cretaceous, Tertiary volcanic rocks, sedimentary rocks, and surficial sediment (Simandjuntak, 1997).

The tectonic phases caused the formation of a complex of structures in this area. Major reverse fault in this area is the reverse fault, trending nearly north-south, including the Poso and Wekuli faults that separates the West Sulawesi block and East Sulawesi block. The other is a large lateral fault zone Palu-Koro which is trending northwest-southeast.

There are six main units of lithology (Figure 2) in this area: Metamorphic rocks (Km), Calcareous sandstones (Tpp), Limestone (Qpg), Sandstones (Qpp), Colluvium (Qk), and Alluvium (Qa). From oldest to youngest, these are:

1. Metamorphic rocks (Km) - consisting of schist, gneiss, and limestone similar to Pompangeo metamorphic complex which is older than Cretaceous.

2. Calcareous sandstones (Tpp) - consisting of carbonate sandstones, shale, limestone, and conglomerates. This lithology is marine sediments deposited after the unification of three tectonic events in Sulawesi began to expire, in the early Pliocene. The age of this unit is Pliocene.

3. Limestones (Qpg) - consisting of spreading reef limestone hills forming a corrugated morphology.

4. Sandstones (Qpp) - composed of sandstone and conglomerate. This unit was deposited after removal of the products of Plio-Pleistocene tectonic activity.

5. Colluvium (Qk) - consisting of schist massif, gneiss, and limestone.

6. Alluvium (Qa) - consisting of pebbles, gravel, clays, sands, and mud.

The geological structure controlling the Maranda geothermal area is dominated by north-south trending structures associated with reverse faulting of Poso which is in the west and the pattern structure relative east-west trending as antithetic (Figure 2). Tectonic activity in the Plio-Pleistocene produced some normal faults trending northwest-southeast at Maranda, Pantangolemba, Mauro, and Sincang the youngest generation. The Sincang and Maranda fault control the presence of several thermal manifestations in Maranda, while geothermal manifestations in Pantangolemba are controlled by the Pantangolemba fault. The presence of the normal Sincang fault likely separates the Kawende and Maranda geothermal system. The Pantangolemba geothermal system is also split from the Maranda geothermal system by the normal Pinedapa and Mosau fault. As such, there are three geothermal systems in the Maranda geothermal area, they are: Kawende, Maranda, and Pantangolemba. The regional Maranda geothermal system is associated with magmatic activity, the youngest occurred in the Plio-Pleistocene.

2. THERMAL MANIFESTATIONS

Maranda has several manifestations consisting of hot springs, steaming ground, mud pots, and alteration. These are divided into four groups: Maranda, Kawende, Kilo, and Pantangolemba.

1. Maranda Group

   This consists of hotsprings (Maranda 1-7), mud pots, steaming ground, and alteration. The hot springs discharging alongside the Tovu river have temperatures from 65°C – 100°C, pH ranging from 6-9, flow rate is about 0.5 to 5 l/s, electrical conductivity from 1,740 to 2,640 µS/cm, no taste, the smell is not too sharp, travertine deposition is very thick. The mud pots have temperatures of 100°C in air temperature of 28.5°C; an area of about 0.5 meter x 0.5 meters, there is a strong discharge of air bubbles. The steaming ground covers an area of about 0.2 km x 0.2 km with temperatures between 40°C-96°C in air temperature of 29.2°C. Interaction between thermal fluids and rocks in geothermal systems commonly produces a suite of secondary minerals whose identity and abundance depends on the prevailing physical and chemical conditions (Browne, 2012). Hydrothermal alteration at Maranda appears at steaming ground. The results of analysis of altered rock by using a portable infra-red mineral analysis (PIMA) showed that it consists of halosite, opal, Mg-chlorite, and anchorite. Mineral associations indicate that the alteration occurred in environments with temperatures below 150°C from a fluid that was slightly acid, as indicated by argillic alteration. The fluid in the reservoir is deduced to be below 200°C and of almost neutral pH.

2. Kawende Group

   Consist of the Kawende hot spring with a temperature of 48°C (air temperature is 27°C), pH = 7.65, flow rate of about 1 l/s, and electrical conductivity of 1,274 µS/cm. There are no travertine deposits in this hot spring.

3. Kilo Group

   This group consists of two hotsprings, the Kuala Merah-1 and Kuala Merah-2. Both hotsprings discharge from limestone. The Kuala Merah-1 has a temperature of 65°C, pH of 6.87 and flow rate of 1 l/s. The Kuala Merah-2 has a temperature of about 86°C, pH of 6.42 and flow rate of about 4 l/s. Both have an electrical conductivity of about 1,420-1,863 µS/cm. Both have travertine deposition around them.

4. Pantangolemba Group

   Consist of three hotsprings: Pantangolemba-1, Pantangolemba-2, and Pantangolemba-3, with temperatures of ranging from 42°C - 52°C, pH from 7.25 to 7.64, flow rates from 2 - 5 l/s, and electrical conductivity of 898-948 µS/cm. Travertine also appears around the hot springs.

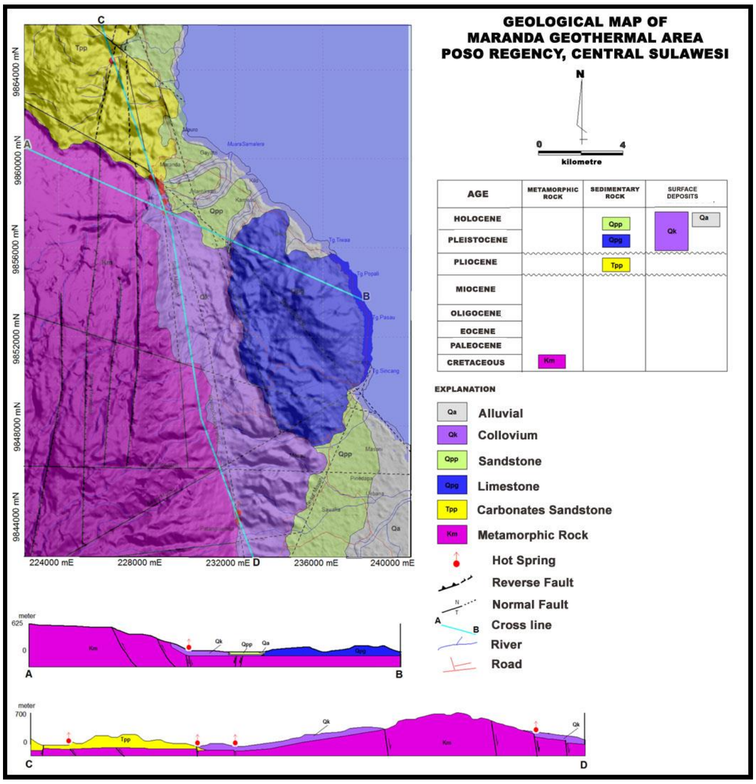

Figure 2: Geological Map of Maranda, Poso, Central Sulawesi

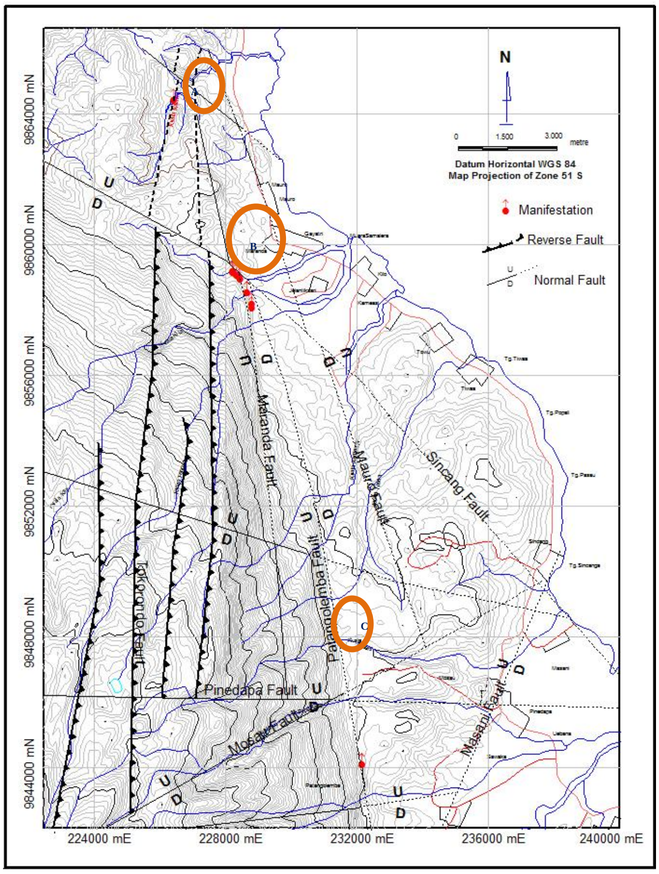

Figure 3. Map of Geothermal Manifestations at Maranda (A= Kawende Group; B= Maranda Group and Kilo Group; C= Pantangolemba Group)

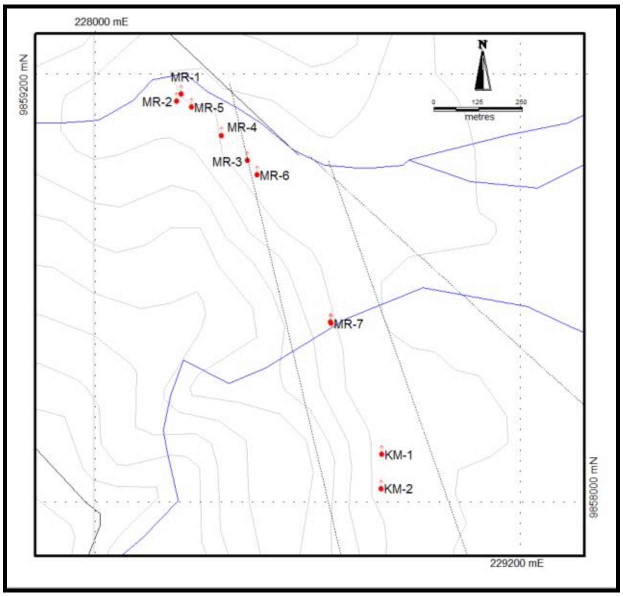

Figure 4. Map of Geothermal Manifestation at Maranda Group and Kilo Group

2. GEOCHEMISTRY

2.1 Water Chemistry

Results of water analysis are plotted on the following ternary diagrams: Cl-SO4-HCO3, Na-K-Mg, and Cl-Li-B (Figure 5). Based on the results of the analyses, Maranda-3, Maranda-6, and Maranda-7 plot within the chloride field leaning towards the SO_4, while Maranda-1, Maranda-2, Maranda-4, and Maranda-5; Kuala Merah-1 and 2, as well as Pantangolemba 1-3 are in the bicarbonate-chloride zone. Cold waters are located in the bicarbonate corner. The Kawende hot spring is chloride type and has different characteristics from the others because it has no SO_4. Characteristics of the Kawende, Maranda-3, Maranda-6, and Maranda-7 waters with high chloride and neutral pH could be an indication that these are derived directly from the geothermal reservoir. Surface discharge of these waters is typical from springs of good flow. They contain appreciable SiO_2, a predominance of Cl, Na, and K; but Ca is low (Nicholson, 1993). The Maranda-1, Maranda-2, Maranda-4, Kualan Merah 1 & 2, Pantangolemba 1-3 waters have higher concentrations of HCO_3 indicating that these have reacted with surface waters during their ascent or alleged association with rising hot geothermal fluids containing primarily CO_2 gas that dissolved in the shallow aquifer. This type of waters happen because of the dilution of chloride fluid by either groundwater or bicarbonate water during lateral flow. These probably are the margins of upflow zones or an outflow of geothermal systems (Nicholson, 1993).

The ratio of Cl/B is generally used to indicate the source of a common reservoir fluid (Nicholson, 1993). The value difference of this ratio depends on the lithology and B adsorption into the clay layer during the process of fluid flow. There is a positive correlation of Cl/B between Maranda 1-7 and Kuala Merah 1 & 2, which indicates that they come from the same source. Pantangolemba 1-3 tend to have a different value Cl/B from Kuala Merah and Maranda, which could indicate a different reservoir source. Kawende also has a different value of Cl/B also from Pantangolemba and Maranda, so there is a possibility that Kawende has different reservoir from Maranda and Pantangolemba. Ratios of Cl/B suggest that there are three different reservoirs for Kawende group, Maranda and Kuala Merah group, and Pantangolemba group. Plots on Cl-Li-B ternary diagram (Figure 5) also show that Maranda 1-7 and Kuala Merah 1-2 are in one group, while Kawende and Pantangolemba are separated from this group. It indicates that Maranda and Kuala Merah group come from the same reservoir. It is different from Kawende and Pantangolemba which probably come from another geothermal reservoir source.

Alkali metals are the least likely to be affected by secondary processes so lithium (Li), can therefore be used as a tracer of the early dissolution of rocks at depth and to evaluate the origin of the two 'conservative' components. There are also Cl and B to consider (Giggenbach, 1991). On the Cl-Li-B ternary diagram (Figure 6), Maranda 1-7 and Kuala Merah 1 & 2 are grouped in zones for Li to Cl, this may also indicate that the composition of hot springs were affected by leaching of rocks. Manifestations of Kawende are chloride rich, where there is the possibility of magmatic vapor absorption as the B/Cl ratio are low. The Pantangolemba 1-3 waters are in the middle of the zone in the direction of boron vapor absorption as indicated by the ratios of B/Cl.

The Na-K-Mg diagram (Figure 5) shows, Maranda-7 located outside the theoretical line called the weirbox zone. In this zone, solute concentration increases due to steam loss at atmospheric pressure. This indicates that hot water in Maranda-7 comes directly from the geothermal reservoir. Fluids from Maranda-3, Maranda-6, and Kawende lies in partial equilibrium field, indicating that after reaching equilibrium there was no indication of mixing with surface water. On the Na-K curve, it is in a straight line and at moderate temperatures (around 160-180°C). The other waters are in the immature zone (Mg corner) indicating that the geothermal fluid has undergone interaction with surface water. It is consistent with concentration of Mg ion in Maranda-1, 2, 4, 5, Kuala Merah-1, Kuala Merah-2, and Pantangolemba 1-3 which from 4.1-14.41 mg/L. This concentration indicates that these waters are mixing with ground water, which can be relatively Mg-rich. Magnesium in geothermal fluids are usually very low about 0.01-0.1 mg/kg as it is readily incorporated into secondary mineral such as illite, montmorillonite, and chlorite (Nicholson, 1993).

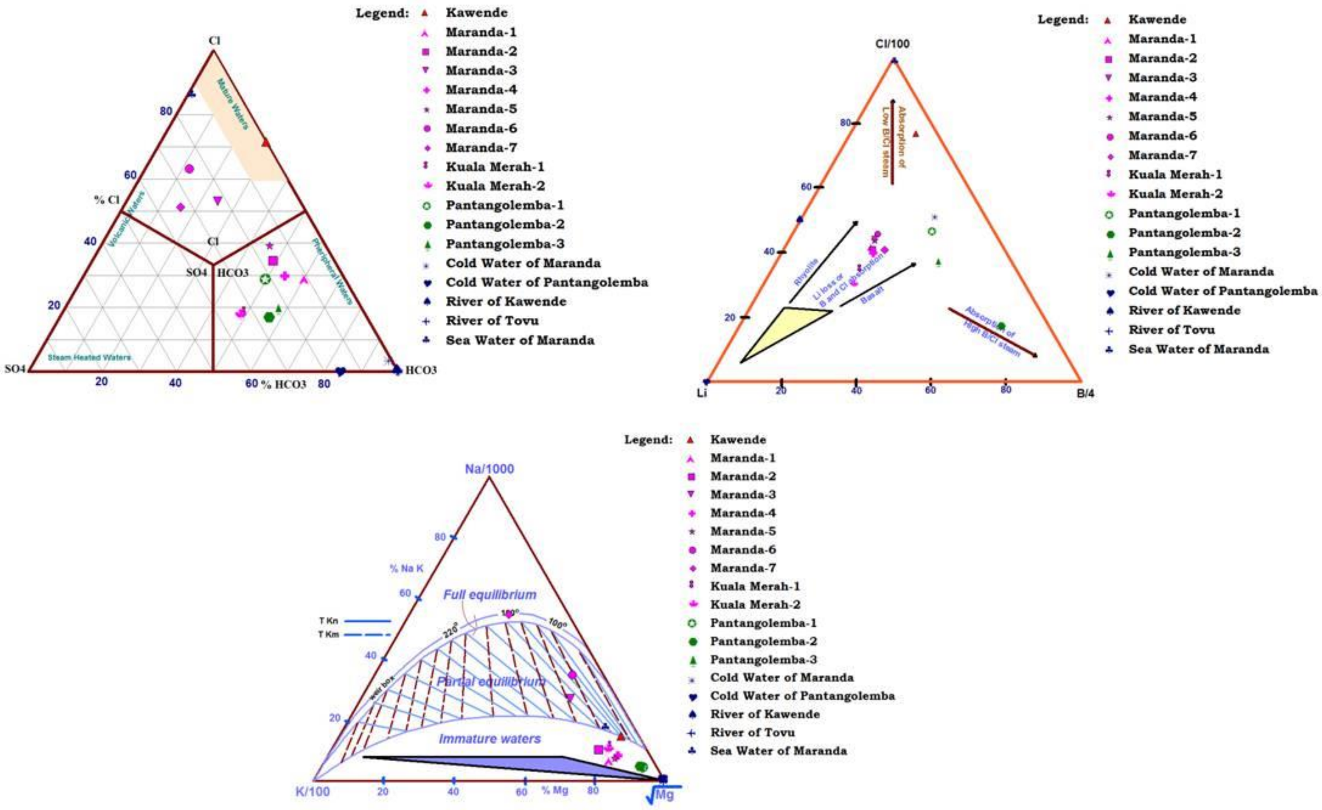

Figure 5. Ternary Diagram of Cl-SO$_4$-HCO$_3$; Ternary Diagram of Cl-Li-B; Ternary Diagram of Na-K-Mg

Giggenbach (1986) suggest a diagram that evaluates CO_2-fugacities in geothermal systems by use of K, Mg and Ca contents of discharge waters. The diagram uses log (K^2/Mg) versus log (K^2/Ca) to evaluate reactions involving calcium which can lead to calcite formation. The most important reaction leading to the formation of calcite in geothermal systems is the conversion of Ca-aluminum silicates to calcite (Giggenbach, 1988). Figure 6 shows that Maranda group and Pantangolemba group fall below full equilibrium line. This means that the waters may simply have formed by close to iso-chemical dissolution of rock without much re-equilibration (Giggenbach, et al, 1988) and an indication of calcite formation. This is supported by surface deposition of travertine and limestone as dominant lithology of Maranda. Kawende plot at full equilibrium line, suggesting that there are no calcite formation because the CO_2 contents of the deep, rising waters are too low to induce rock alteration or the CO_2 content of the water is externally controlled.

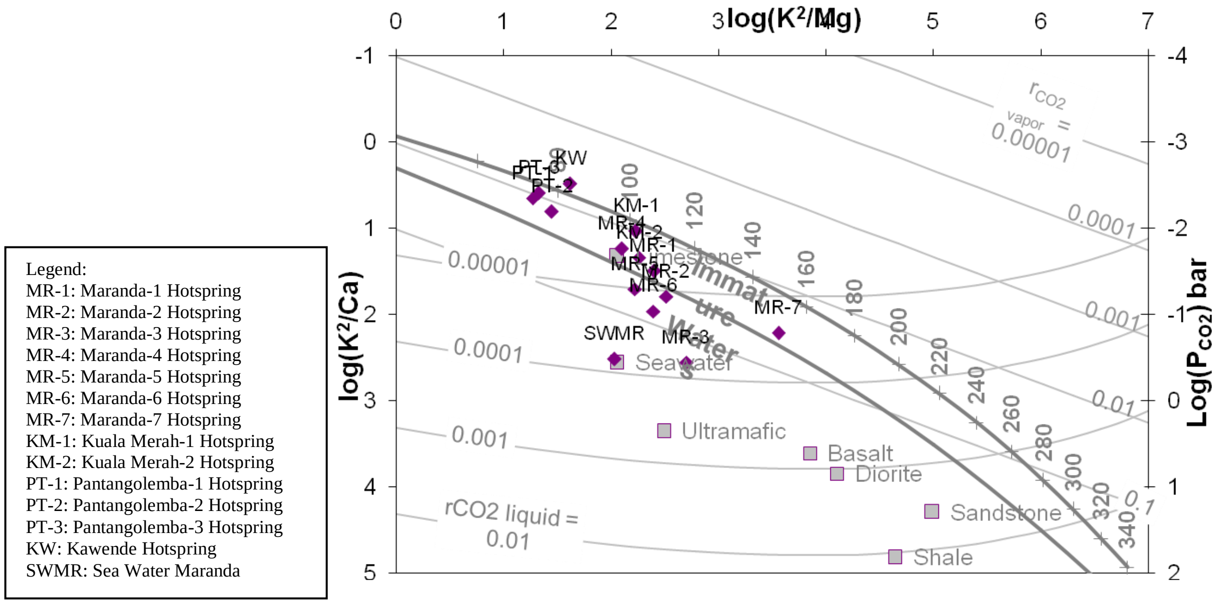

Figure 6. Diagram of Evaluation of water-rock equilibration temperatures and CO_2 partial pressure using relative K, Mg, and Ca contents of water samples

2.2 Isotope

In general, a geothermal fluid will undergo a process of adding oxygen-18 ($\delta^{18}O$ shifting) of water that comes from a meteoric source (Craig, 1963 in Nicholson, 1993). Deuterium isotope changes will not occur because the rocks generally have low hydrogen concentrations. Isotope data are plotted with the equation for Meteoric Water Line: $\delta D = 8\ \delta^{18}O + 14$. Results of the analyses for ^{18}O and ^{2}H (D) isotope concentrations of the samples from Maranda 1-7, Kuala Merah 1-2, Kawende, and Pantangolemba 1-3, tend to stay away from meteoric water line because of rock-water reactions at depth. This reflects that the hot springs waters are derived at depth. For comparison the isotopic measurements for cold water plot on the meteoric line.

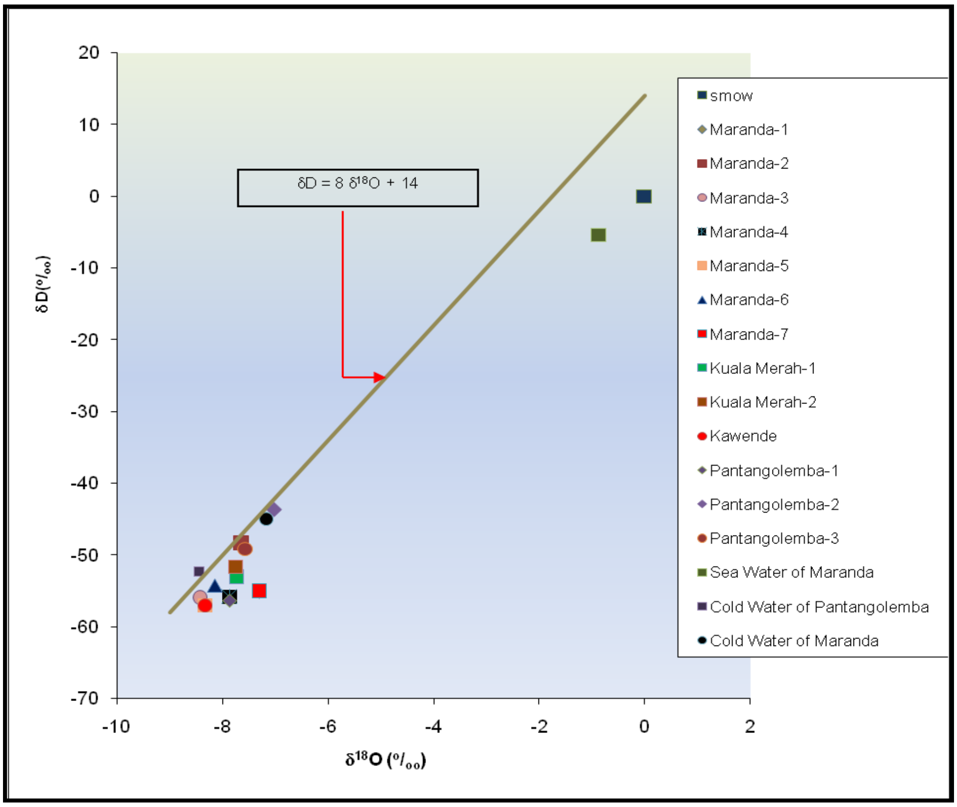

Figure 7. Plots of $\delta^{18}O$ vs $\delta^{2}H$ (Deuterium) isotopic composition

2.3 Geothermometry

There are three geothermal systems in this area: Maranda, Kawende, and Pantangolemba, as suggested by different Cl/B ratios and geological structures. These hot springs can be used for geothermometry since their waters have analyses with ion balance less than 5% disparity and have neutral pH.

For Maranda, the silica geothermometers suggest temperatures between 129°C to184 °C (with no steam loss) and 126°C to 171°C (with maximum steam loss). For Na-K geothermometer the values range from 143°C to 289°C. The Na-K-Ca geothermometer gives temperatures of about 141-205°C. Maranda-1, 2, 3, 4, Kuala Merah-1&2, and Pantangolemba 1-3 fall inside immature waters in the Na-K-Mg diagram (Figure 5). The use of chemical geothermometers for estimating subsurface temperatures is not appropriate in this case. Maranda-6 and Maranda-7 represent fluids from a reservoir where there has been no mixing with surface waters as indicated by low Mg, low Ca, and plots within the full equilibrium and partial equilibrium zones of the Na-K-Mg ternary diagram (Figure 8). These hotspring fluids can be used for representative geothermometry. Using silica maximum steam loss, both have the same value of 171°C. The temperature of the reservoir for the Maranda geothermal system is about 170°C and can be categorized as medium temperature.

Fluid geothermometry for Kawende springs suggest the following fluid temperatures: 110°C (Tsilica), 160°C (TNa-K), and 101°C (TNa-K-Ca). It is appropriate to use TNa-K for measuring reservoir temperature in Kawende, because the fluid is neutral pH and plots within the partial equilibrium zone. Nicholson (1993) stated that fluids with Ca concentration less than 50 mg/L are suitable for using Na-K geothermometers. Since the concentration of Ca in Kawende fluids is only 30 mg/l, the 160°C temperature estimate of TNa-K for the Kawende geothermal system is valid.

Geothermometry application for Pantangolemba fluids suggests the following temperatures: 85-94°C (Tsilica), 222-235°C (TNa-K), and 95-106°C (TNa-K-Ca). Pantangolemba has high of Ca (> 50 mg/L), and it indicates mixing with surface waters. In this case Na-K-Ca geothermometry is suitable for estimating reservoir temperature. Pantangolemba geothermal system would possibly have reservoir temperature close to 106°C.

3. SUMMARY

The Maranda geothermal area is a non-volcanic environment. There are several manifestations such as hot springs, mud pots, and steaming ground. These can be grouped into: Maranda group, Kilo group, Kawende group, and Pantangolemba group. The temperatures of the manifestations range from 42°C to 100°C (Maranda-6, Maranda-7, steaming ground, and mud pots have the highest temperature).

Geological mapping suggests that the heat source of Maranda is associated with magmatic activity (granite intrusion), the youngest occurred in the Plio-Pleistocene. The geological structure controlling the Maranda geothermal area is dominated by north-south trending structures associated with reverse faulting of Poso which is in the west and the pattern structure relative east-west trending as antithetic. Rock alteration of argillic (units of colluvium) is interpreted as cap rock of the Maranda geothermal system. The cap rock is estimated to be in the zone of structural depression bounded by Maranda and Sincang faults, shaped radial curved up to half. The cap rock of Kawende is expected as alteration of calcareous sandstone. The cap rock of Pantangolemba is alteration of the colluvium unit.

Maranda-3, Maranda-6, Maranda-7, and Kawende are chloride waters; while the rest are chloride-bicarbonate waters. Cl/B ratios of the hotsprings fluid suggest three different geothermal systems: Kawende, Maranda, and Pantangolemba. This conclusion is supported by the geological structures with normal faults trending northwest-southeast at Maranda, Pantangolemba, Mauro, and Sincang that control these systems.

The Maranda geothermal system has chloride type of waters, as shown by Maranda-7 and Maranda-6 hot springs, indication that these are close to the upflow zone. This is supported by isotope shifting of Maranda-7 (fluids from deep reservoir). The temperature reservoir is about 170^{o}C based on the silica maximum steam loss geothermometer. There is a probability of calcite formation for this system.

The Kawende geothermal system also has alkali chloride fluid and the temperature of its reservoir is 160°C from Na-K geothermometry. There is still no evidence about the upflow and outflow zone for Kawende. Ratio of Cl/B suggests that it comes from a different reservoir. Kawende fluids is mature as it plots at partial equilibrium, has high concentration of chloride and less indication of mixing. Isotope data also supports the finding that Kawende comes from a deep reservoir.

The Pantangolemba geothermal system has bicarbonate type of waters, indicating mixing with surface waters and a reservoir temperature of about 106°C from Na-K-Ca geothermometry.

Tentative model of Maranda geothermal area (Figure 8) shows possibility of heat source, reservoirs, cap rocks, and manifestations.

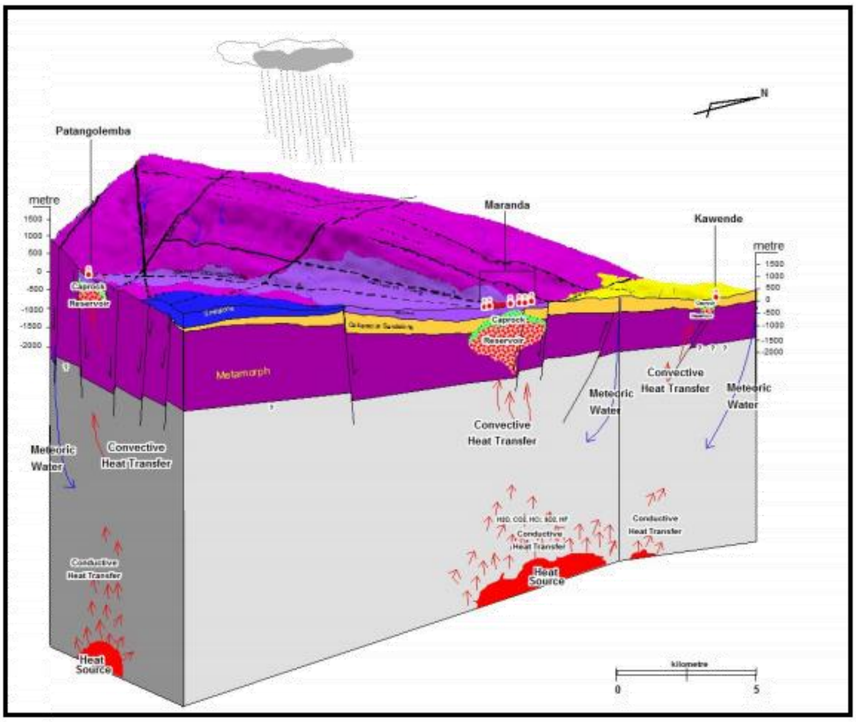

Figure 8: Tentative geothermal model of Maranda

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