Proceedings Indonesia International Geothermal Convention & Exhibition 2014
Jakarta Convention Center, Indonesia 4-6 June 2014

# Geochemistry Geothermal Area in Ampallas, Mamuju Regency, West Sulawesi

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**Keywords:** Geochemistry, Geothermal, Mamuju, Sulawesi.

## ABSTRACT

Ampallas geothermal area is located in Mamuju Regency, West Sulawesi. The geothermal manifestations in Ampallas are hotsprings, warmsprings, and cold alteration. The youngest product in Ampallas is associated with Manututu volcanic activity which is 0,3 ma or Pleistocene. Ampallas has chloride-bicarbonate type of waters based on $Cl\text{-}SO_4\text{-}HCO_3$ diagram and plots in partial equilibrium zone based on Na-K-Mg diagram. The temperature of reservoir is about 170$^o$C from Na-K geothermometry.

## INTRODUCTION

Sulawesi island has about 58 geothermal areas (Center for Geological Resources, 2012). Ampallas geothermal area investigated in 2013. It is located in Mamuju Regency, West Sulawesi Province, Geographically, it is located at coordinates 2°35'52" - 2°43'58" S and 118°51'19" - 119°3'13" E (Figure 1).

*Figure 1: Location of Ampallas Geothermal Area*

## GEOLOGY IN A BRIEF

Geologycally, Ampallas is consisted of volcanic rock in Miocene which has andesitic-basaltic composition (lava and breccia, and tuff), sedimentary rock in Miocene, young volcanic lava (andesitic-dacite lava) in Pleistocene, and alluvium. The youngest product in Ampallas is associated with Manututu volcanic activity which is 0,3 ma or Pleistocene (Figure 2).
The structures controlled in Ampallas geothermal area is normal faults dominated by northwest-southeast structure.

## MANIFESTATION

Geothermal manifestations in Ampallas are four cluster hotsprings/ warmsprings and cold alteration (Ampallas, Batupane, Gantungan, and Karema).

Ampallas hotsprings/warmsprings

It is located in Ampallas village, manifested along side Ampalllas river about 200 m. The temperature of hotsprings/warmsprings is about 35-66,6$^o$C, air temperature is 29,9$^o$C, pH 6,84 – 7,22, the conductivity is about 551 – 1920 µS/cm, and debit is about 0,5 l/s.

Batupane warmsprings

It is located in Batupane village. It comes up at breccia gap. The temperature of warmspring is about 40,3$^o$C, air temperature is 28,9$^o$C, pH 8,66, the conductivity is about 360 µS/cm, and debit is about 1 l/s.

Karema warmsprings

It is located in Karema village. The temperature of warmspring is about 48 $^o$C, air temperature is 29$^o$C, pH 9,88, the conductivity is about 1074 µS/cm, and debit is about 1 l/s.

Gantungan warmsprings

It is located in Gantungan village, manifested at the side of Gantungan river. The temperatur of warmspring is about 34,6$^o$C, air temperature is 25,9$^o$C, pH 8,77, the conductivity is about 527 µS/cm, and debit is about 0,5 l/s.

Ampallas cold alteration

It is located in Ampallas village, manifested at the Manututu foothills, about 400 m from Ampallas hotsprings. Alteration is already cold at the surface. The alteration is formed at Andesitic rock. There is sulfur deposition. The result of clay mineral based on *portable infra-red mineral analyzer* (PIMA) is kaolinite and monmorillonite. The type of the alteration is argylic type. The alteration process was happen in neutral fluids with temperature below 200°C.

Natural heat loss based on calculation from those manifestations is about 462 $kW_{th.}$

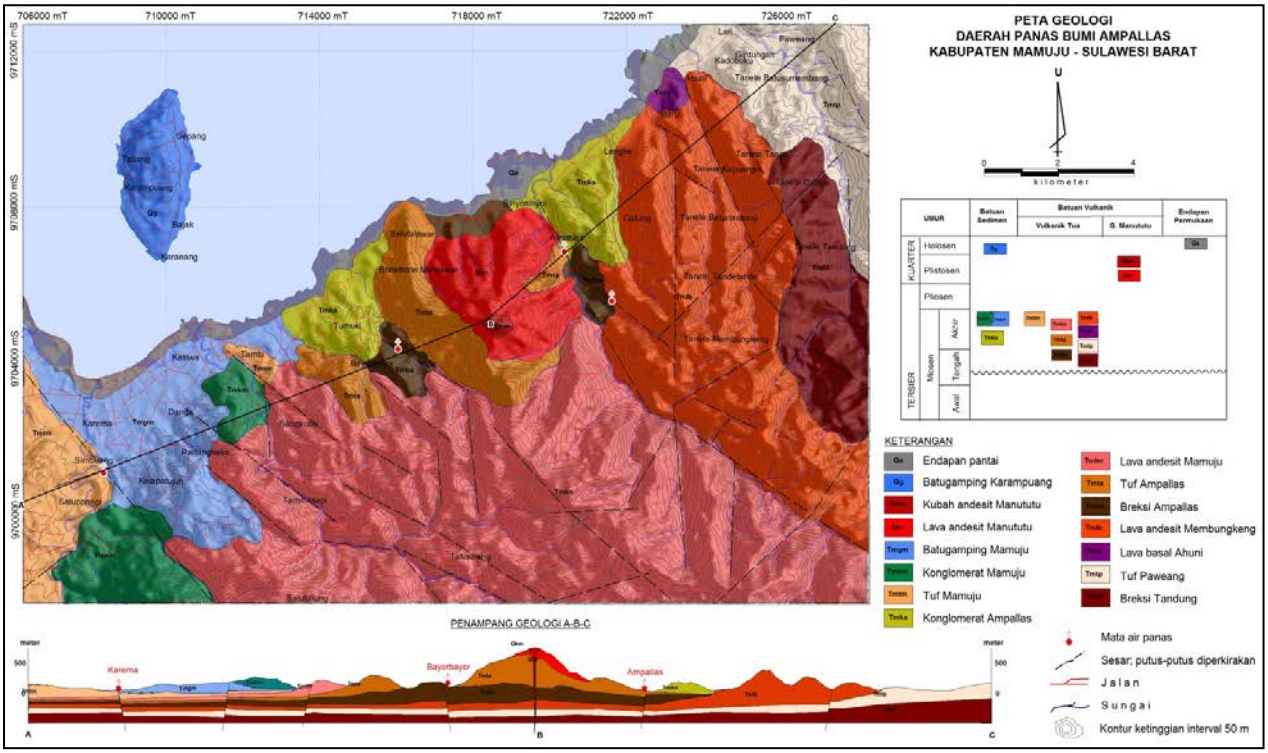


*Figure 2: Geological Map of Ampallas Geothermal Area*

## GEOCHEMISTRY

The thermal waters was classified based on ternary diagram of Cl-$SO_4$-$HCO_3$, Cl-Li-B, and Na-K-Mg (Giggenbach, 1991).

### Cl-$SO_4$-$HCO_3$ ternary diagram

Based on waters analysis, Ampallas hotsprings are grouped into Chloride-bicarbonate waters, while the Batupane, Karema, Gantungan warmsprings and cold waters of Ampallas are plotted into bicarbonate waters (Figure 3). It could be an indication that Ampallas hotsprings come directly from reservoir and good permeability, but it is diluted with the ground waters. Batupane, Karema, and Gantungan warmsprings are mixing with cold waters at the surface.

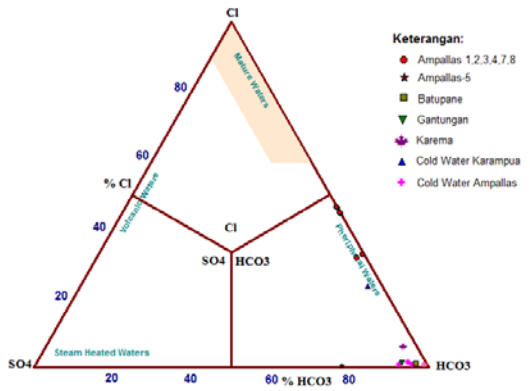


*Figure 3: Classification of thermal fluids using Cl-$SO_4$-$HCO_3$ ternary diagram*

### Cl-Li-B ternary diagram

The alkali metal probably least affected by secondary processes is Li, so it may be used as a "tracer" for the initial deep rock dissolution process and as refernce to evaluate the possible origin of the other two important "conservative" constituents of thermal waters, Cl and B (Giggenbach, 1991). Based on Cl-Li-B ternary diagram (Figure 4), all samples from Ampallas hotsprings are plotted into Cl corner. This indicates that the Ampallas geothermal system is could be associated with volcanic-magmatic and the Ampallas hotsprings formed through absorption low B/Cl magmatic vapors. Karema warmspring is plotted into Cl-B zone, an indication sedimentary rock interaction. This diagram also shows that Ampallas hotsprings are groupped into one cluster, indicate they come from the same reservoir; while batupane, Karema, and Gantungan warmsprings have different source from Ampallas. Considering the geological setting in Ampallas, there are three reservoir in Ampallas geothermal area : Ampallas (consists of Ampallas hotspring and Batupane warmspring), Karema (consists of Karema warmspring), and Gantungan (consists of Gantungan warmspring).

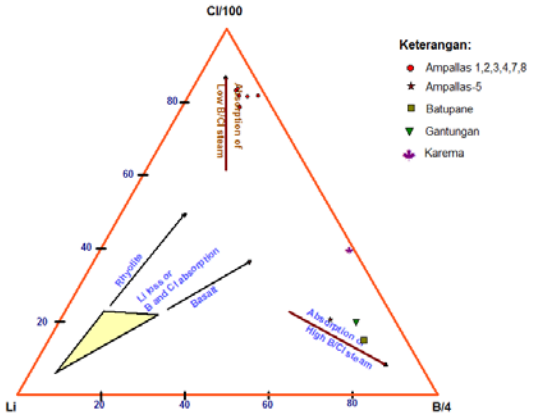


*Figure 4: Cl-Li-B Ternary Diagram of Ampallas*

**Na-K-Mg ternary diagram**

Na-K-Mg ternary diagram (Figure 5) shows that Ampallas and Karema are plotted in partial equilibrium. It could be used to estimate reservoir temperature using Na-K geothermometry through extrapolating in this diagram. Temperature reservoir using this method is about 170°C.

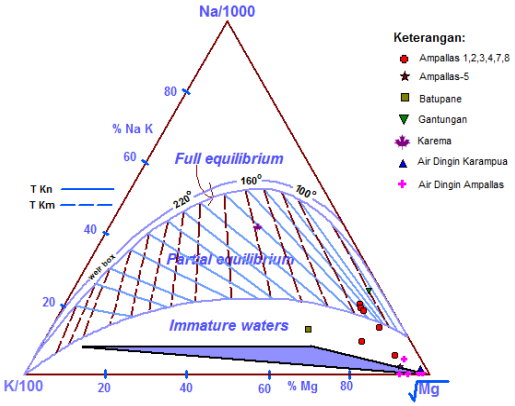


*Figure 5: Na-K-Mg Ternary Diagram of Ampallas*

**Origin of The Fluids**

The stable isotope compositions of oxygen and hydrogen for Ampallas is shown in figure 6. It shows that the value of $\delta^{18}O$ for Ampallas is 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). While Karema, Batupane, and Ampallas-5 is plotted at meteoric waters line.

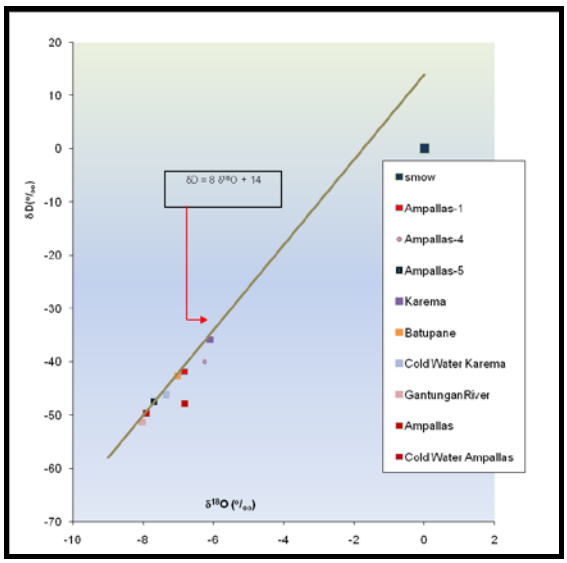


*Figure 6: Isotop Diagram of Ampallas*

**Gas**

Gas bubling comes up from Ampallas hotspring was sampled. The result of analysis is (Table 1):

*Table 1: Gas Analysis Result of Ampallas*

| Gas (%mol) | concentration |
|---|---|
| He | 0,00035 |
| $H_2$ | 0,000161 |
| $O_2$ | 0,062616 |
| Ar | 0,005786 |
| $N_2$ | 0,340114 |
| $CH_4$ | 0,548185 |
| CO | 0 |
| $CO_2$ | 0,042217 |
| $SO_2$ | 0 |
| $H_2S$ | 0 |
| HCl | 0,000571 |
| $NH_3$ | 0 |
| ratio | |
| $N_2$/Ar | 58,7 |
| He/Ar | 0,06 |
| $CH_4$/Ar | 94,7 |
| $CO_2/H_2$ | 262,8 |
| $CO_2/CH_4$ | 0,077 |
| $CO_2/N_2$ | 0,124 |

Gases in geothermal discharges usually are $CO_2$, $H_2S$, $NH_3$, $N_2$, $H_2$, dan $CH_4$, referred to as the "*non condensible gases*" (Nicholson, 1993). The higher component of the gases is $CH_4$ (0,54% mol), indicates that it comes from alteration of sediment rock. $H_2S$ is not detected in Ampallas gas bubles. Ratio of $CO_2$/ $H_2$ is very high, which indicates outflow of the system. Figure 7 shows that gases in Ampallas hotspring has been mixing or condensing with meteoric water in certain depth. Volatile gases from crustal rocks also contribute to supply gas in Ampallas geothermal reservoir (Figure 8).

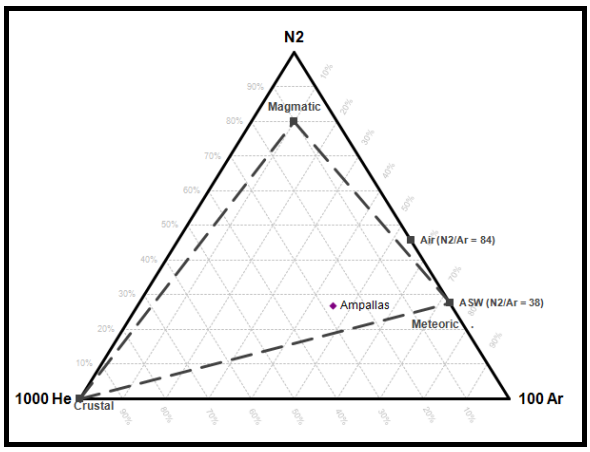


*Figure 7: $N_2$-He-Ar ternary diagram of Ampallas*

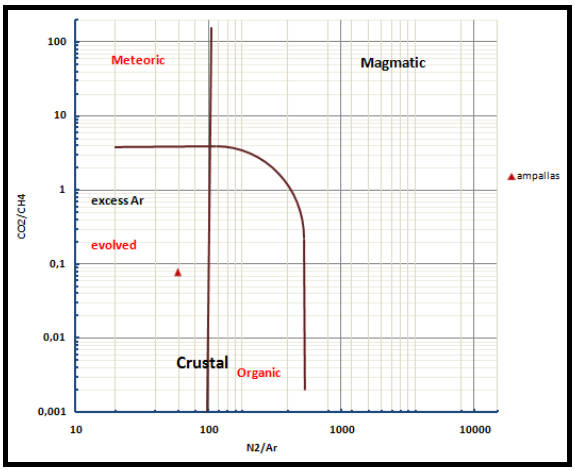


*Figure 8: Origin of Fluids Diagram in Ampallas (Norman dan Moore, 1999)*

**Geothermometers**

Chemical geothermometry was used to estimate subsurface temperatures. Using quartz conductive cooling and adiabatic cooling, Na-K-Ca, and Na-K (Giggenbach), the geothermometer for Ampallas are shown in table 3. Considering condition of Ampallas hotspring which is neutral, the temperature is about 66$^{o}$C, Chloride-bicarbonate type of waters, and plotted on partial equilibrium, so the Na-K (Giggenbach) geothermometer is suitable to approach the resevoir temperature which is about 170 $^{o}$C (medium entalphy).

*Table 3: Geothermometers for Ampallas*

| Sampel | Quartz cond | Quartz adiabatic | Na-K-Ca | Na/K (Giggenbach) |
|---|---|---|---|---|
| Ampallas-1 | 122 | 119 | 156 | 163 |
| Ampallas -2 | 119 | 117 | 160 | 169 |
| Ampallas -3 | 111 | 110 | 159 | 169 |
| Ampallas -4 | 93 | 95 | 208 | 252 |
| Ampallas -5 | 118 | 117 | 231 | 324 |
| Ampallas -7 | 130 | 127 | 159 | 173 |
| Ampallas -8 | 115 | 114 | 188 | 239 |

**Soil Hg**

Anomaly of soil Hg could help indicating the permeability area or an *upflow* of the system, because the volatile of species Hg will be concentrated into secondary mineral above the steam zone (Nicholson, 1993). Anomaly soil Hg in Ampallas gives anomaly value > 60 ppb around Ampallas hotspring and Karema warmsprings. This could be an indication of good permeability at this area.

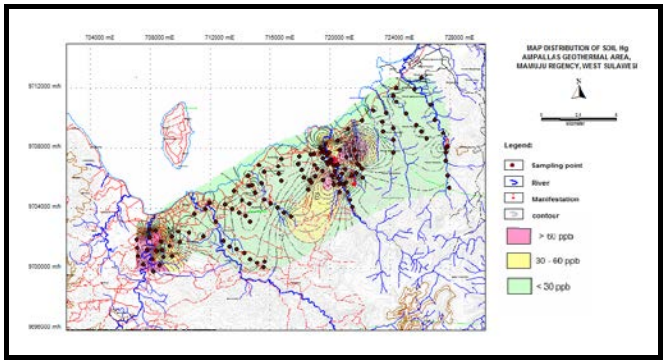


*Figure 9: Map of anomaly soil Hg*

**Conceptual Model**

Ampallas geothermal area has cold alteration and hotsprings manifesations. The cold alteration could be an upflow of the system, while Ampallas-5 warmspring and Batupane warmspring are an outflow of Ampallas geothermal system.

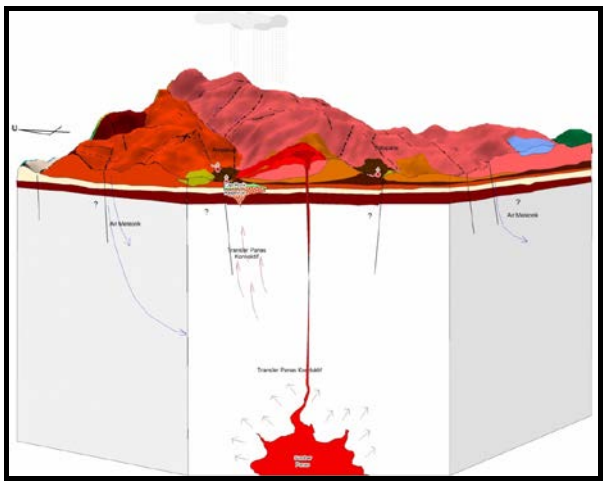

*Figure 10. Tentative model of Ampallas geothermal area*

**CONCLUSION**

Geochemistry in Ampallas geothermal area could be concluded:

1. Geothermal manifestations in Ampallas geothermal area could be divided into 3 sources: Ampallas (consists of Ampallas hotspring and Batupane warmspring), Karema (consists of Karema warmspring), and Gantungan (consists of Gantungan warmspring).

2. Ampallas hotspring is chloride-bicarbonate type and plotted in partial equilibrium

3. Reservoir temperatur is about 170$^{o}$C from Na-K (Giggenbach) geothermometer.

**ACKNOWLEDGMENTS**

We would like to thank to Center for Geological Resources, Bandung for support this research.

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