Geochemical Study of Ampallas Geothermal Area, Mamuju District, West Sulawesi Province

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Abstract. Ampallas is one of the areas with geothermal potential which located in Mamuju district, near from the capital city of West Sulawesi. This research was carried out to understand the characteristic of this geothermal field based on chemistry of the surface manifestation, including fluid characteristic and soil anomaly. Geothermal research in Ampallas area focused on 4 hot springs; Ampallas, Batupane, Karema, and Gantungan. With average temperature around 34 – 67°C. Ampallas 1,2,3,4,7,8 hot springs water type is chloride – bicarbonate, which means it came from the reservoir while Batupane, Gantungan, Karema and Ampallas 5 are all bicarbonate type. Ampallas 1,2,3,4,7,8, Karema and Gantungan hot springs fluid plotted in partial equilibrium zone while Batupane and Ampallas 5 plotted in immature water zone. It means the Ampallas hot springs (except Ampallas-5) mixed with meteoric water right after reached the equilibrium state. It is also concluded that Ampallas 5 hot springs came from the same reservoir with Batupane, but not Gantungan and Karema hot springs. The speculative resource potential of Ampallas geothermal system is estimated around 30 MWe. But if detailed geophysical method was applied the result could be more accurate.

1. Introduction
Located inside the “ring of fire”, made Indonesia rich with tectonic activities. This created many geothermal energy potentials which suitable to be developed. One of them is Ampallas in West Sulawesi. The tectonic activities and the geology settings made Ampallas as a potential area for geothermal energy development.

Ampallas composed mainly from volcanic rocks. And the tectonic activities has made a lot of faults and fractures on the rocks, hence making it a good condition for a reservoir rocks with high permeability.
The faults also made a way for the fluid onto the surface and creating manifestations such as hot springs. This geological setting has made Ampallas potential to be researched.

Ampallas located in Kaluku and Mamuju subdistrict, Mamuju district, West Sulawesi.

Figure 1: Ampallas research area location, Mamuju district, West Sulawesi

2. Method
This research is using both geology and geochemistry method as its main method. In addition, the geophysics method is only for preliminary survey so it acted as supporting data. In the future it needs a survey with a more detailed geophysics method.

The geology method is used for collecting data regarding the geology condition, such as lithology, morphology, tectonic activity, and surface manifestation. While the geochemistry is used to obtain fluid and soil chemistry related data, such as fluid characteristic, reservoir condition, and soil anomaly distribution.

3. Geology

3.1 Lithology
There are 14 lithology units in Ampallas research area (from the youngest); Karampuang Limestone (Qg), Manututu Andesite Dome (Qkm), Manututu Andesite (Qlm), Mamuju Limestone (Tmgm), Mamuju Conglomerate (Tnkm), Mamuju Tuff (Tnmt), Ampallas Conglomerate (Tmka), Mamuju Andesite (Tmlm), Ampallas Tuff (Tmta), Ampallas Breccia (Tmba), Membungkeng Andesite (Tmlb), Ahuni Basal (Tnlb), Paweang Tuff (Tmtp), and Tandung Breccia (Tmbt).

Tandung Breccia, Paweang Tuff, Ahuni Basal, and Membungkeng Andesite were the product of tertiary volcanic activity which took place around middle Miocene – late Miocene. And in almost the same time, Ampallas Breccia together with Ampallas Tuff and Mamuju Andesite were precipitated with estimated time middle Miocene – late Miocene. These volcanic products located in the south west area. Mamuju Tuff becomes more abundant to the south west. On the other side of the research area, Ampallas Conglomerate can be found in estuary consisting of andesite, basal, and tuff fragments from the previous
rocks. And more to the south west the sedimentation process took place and precipitated Mamuju Conglomerate and Mamuju Limestone.

The tectonic activity became active again around Pliocene – Pleistocene. This tectonic activity formed Manututu andesite followed by Manututu Andesite Dome. The last tectonic activity was the formation of Manututu Andesite Dome in Pleistocene, or around 0.3 – 1 million years old. The dating was estimated by using the fission track method. This latest volcanic product was estimated as the heat source for Ampallas geothermal system.

3.2 Geological Structures

Geological structures in Ampallas area is dominated by normal faults with northwest – southeast orientation and southwest – northeast orientation. These faults then made a depression zone in the middle of Ampallas area and believed as the one that control the presence of these hot springs.

4. Manifestation

There are 4 hot springs that became the main objects in this research; Ampallas, Batupane, Gantungan, Karema. Ampallas hot springs located in Ampallas village. It was found on the river bed and has temperature around 35 – 66°C with atmosphere temperature 29°C. The pH was around 6,8 – 7,2 with the electrical conductivity 551 – 1920 µs/cm. The flow rate was around 0,5 – 1 L/s.

Batupane hot spring located in Batupane village. It was found in the crack between breccia rocks and has temperature of 40,3°C with atmosphere temperature of 28,9°C. The pH was 8,6, with the electrical conductivity 360 µs/cm. The flow rate was 1L/s. Gantungan hot spring located in Gantungan village. It was found on the riverbed of Gantungan river and has temperature of 34,6°C with atmosphere temperature of 25,9°C. The pH was 9,8 with the electrical conductivity 527 µs/cm. The flow rate was 1 L/s. Karema hot spring located in Karema village. It was found as a man-made hot spring and has become a tourism object. The temperature was 48°C with atmosphere temperature of 29°C. The pH was 8,7 with the electrical conductivity 1074 µs/cm. The flow rate was around 0,5 L/s.

| Table 1: Hot springs characteristics |
|-------------------------------------|
| Hot Springs | Ampallas | Batupane | Gantungan | Karema |
| pH          | 6,8 - 7,2 | 8,6      | 9,8       | 8,7    |
| Temperature (°C) | 35 - 66 | 40,3    | 34,6     | 48     |
| Electrical Conductivity (µs/cm)   | 551 – 1920 | 360     | 527      | 1074   |
| Water Flow (L/s)                 | 0,5 - 1  | 1       | 1        | 0,5    |

Beside the hot springs, there was other manifestation like altered rocks. In one of Manututu Andesite area, located in north side of Mt. Manututu foothills, the rock has been altered. This area still has a hint of sulphuric scent and on some of the joints can be seen thin layers of sulphur mineral. The host rock still can be seen clearly but the andesite has been altered in a weak intensity. Using the portable infrared mineral analysis (PIMA), the clay mineral was analyzed and shown that the clay minerals area kaolinite and montmorillonite with argilic types alteration. Geographically it is located at 719441 mT and 9707717 mS on elevation 39 m asl.
5. Geochemistry

5.1 Water types

The result obtained from the lab shows that Ampallas 1,2,3,4,6,7,8 hot spring is chloride–bicarbonate type hot spring. And with near neutral pH it could be assume that Ampallas hot spring came directly from the reservoir. Unlike Ampallas hot spring, Karema, Gantungan, Ampallas 5 and Batupane hot springs are bicarbonate type hot springs. This means that the hot springs are either mixed with meteoric water or heated surface water but not from the reservoir. In other words Gantungan, Karema, and Batupane hot springs indicated outflow setting.

Table 2: Cl-SO₄-HCO₃ contents of Ampallas, Batupane, Gantungan, and Karema hot springs

| Hot Springs | Cl   | SO₄ | HCO₃ |
|-------------|------|-----|------|
| Ampallas -1  | 513,26| 1,53| 596,37|
| Ampallas -2  | 492,07| 0,85| 606,64|
| Ampallas -3  | 532,69| 1,99| 609,05|
| Ampallas -4  | 174,7 | 12,24| 360,63|
| Ampallas -5  | 1,37  | 78,92| 283,04|
| Ampallas -7  | 355,37| 1,5 | 435,31|
| Ampallas -8  | 161,09| 1,88| 329,89|
| Batupane     | 3,01  | 6,6 | 238,26|
| Gantungan    | 4,2   | 20,65| 316,71|
| Karema       | 31,68 | 17,9| 481,69|

According to Na-K-Mg plotting, Ampallas (except Ampallas 5), Karema, and Gantungan hot springs located in partial equilibrium area. Which means it indicates that shortly after the hot springs reach the equilibrium state, they mixed with meteoric water on the surface. Batupane and Ampallas 5 hot spring located in immature water area, which means that the hot springs are dominated with meteoric water.

Table 3: Na-K-Mg contents of Ampallas, Batupane, Gantungan, and Karema hot springs

| Hot Springs | Na   | K    | Mg  |
|-------------|------|------|-----|
| Ampallas -1  | 535,6| 19,74| 3,85|
| Ampallas -2  | 521,43| 20,97| 4,02|
| Ampallas -3  | 522,53| 20,97| 4,59|
| Ampallas -4  | 229,79| 29,05| 3,51|
| Ampallas -5  | 90,86 | 24,12| 13,04|
| Ampallas -7  | 370,09| 16,07| 5,05|
| Ampallas -8  | 181,27| 19,62| 8,72|
| Batupane     | 88,47| 16,27| 0,19|
| Gantungan    | 141,72| 1,96 | 0,19|
| Karema       | 316,99| 16,6 | 0,08|

And looking from the Na-K relationship in the Na-K-Mg chart, Ampallas hot springs located in 170°C straight line which indicates the estimated reservoir temperature. This is similar with the estimation calculation of the reservoir, which is 169 – 173°C.

5.2 Cl-Li-B Diagram

From chloride, lithium, and boron contents in the hot springs, it can be seen that almost all Ampallas hot springs have high chloride concentration. This can be assumed that Ampallas hot springs is associated with magmatic rock environment. Unlike Karema, Gantungan, and Batupane hot springs. Karema hot springs plotted between chloride and boron, while Gantungan and Batupane have higher
boron contents. This indicated that Gantungan and Batupane hot springs are associated with sedimentary rock environment.

Table 4: Cl-Li-B contents of Ampallas, Batupane, Gantungan, and Karema hot springs

| Hot Springs   | Cl   | Li  | B   |
|---------------|------|-----|-----|
| Ampallas -1   | 513.26 | 0.39 | 2.64 |
| Ampallas -2   | 492.07 | 0.39 | 2.9  |
| Ampallas -3   | 532.69 | 0.37 | 2.76 |
| Ampallas -4   | 174.7  | 0.04 | 1.41 |
| Ampallas -5   | 1.37   | 0.01 | 0.17 |
| Ampallas -7   | 355.37 | 0.35 | 2.51 |
| Ampallas -8   | 161.09 | 0.09 | 1.11 |
| Batupane      | 3.01   | 0.02 | 0.6  |
| Gantungan     | 4.2    | 0.02 | 0.6  |
| Karema        | 31.68  | 0.01 | 1.92 |

And if using Cl/B ratio, which is commonly used to measure common reservoir source (Nicholson, 1993), it can be seen that Ampallas hot springs have relatively same Cl/B ratio. Which means that those hot springs may came from the same reservoir. Karema and Gantungan have different Cl/B ratio value from Ampallas so it can be assumed that those hot springs didn’t come from the same reservoir as Ampallas hot springs, while Batupane and Ampallas-5 hot spring may have come from the same reservoir.

5.3 Isotope

In general, geothermal fluids will have a process of $^{18}$O isotope ($\delta^{18}$O shifting) increase, in this case is meteoric water (Craig, 1963 in Nicholson, 1993). The enrichment of $^{18}$O in geothermal fluids relative to local meteoric water is caused by rock-water reactions at depth. Deuterium isotope increase can’t happen in rocks because in general the deuterium concentration is too low. From the isotope analysis data using meteoric water line equation $\delta D = 8 \delta^{18}O + 14$, it shows that fluid from Ampallas-1 hot springs is drifting away from the local meteoric water equation line. This indicates that the fluid from Ampallas-1 hot spring came straight from the reservoir.

![Figure 2: The result of oxygen-18 isotope from hot springs](image-url)
6. Geothermal system

Ampallas geothermal system was found in tertiary volcanic and quarter volcanic rocks. This can be assumed that it associated with volcanic environment. The heat source was estimated came from Manututu Andesite Dome (0.3 – 1 million years old) as the youngest volcanic product.

The manifestation found in the research area was hot springs and altered rocks. The altered rocks show that the cap rock was composed by clay mineral as the result from the rock alteration due to contact with the hot fluids. The alteration type is argilic type. There are three hot spring locations near Mt. Manututu in Ampallas area; Ampallas hot springs (1,2,3,4,6,7,8) located in the northeast area, Ampallas-5 hot spring in the east area, and Batupane in the west area.

Fluids from Ampallas hot spring has chloride – bicarbonate type and located in partial equilibrium. This means that the fluid came from the deep and a moment after it just reach equilibrium state, it mixed with meteoric water. While Karema, Gantungan, and Batupane located in Immature water area and have bicarbonate type. This shows that they are mixed with meteoric water a lot or basically just heated up meteoric water.

The Ampallas geothermal system was estimated came from different system with Karema and Gantungan geothermal system, and Ampallas-5 and Batupane came from the same geothermal system. The altered rock found in Ampallas was the resulted from the interaction between the rocks and the hot fluid. Both altered rocks and the sulphur deposit indicate that Ampallas hot springs are located in upflow area. But from geology analysis, it is concluded that Ampallas, Ampallas-5, and Batupane hot springs came from the same reservoir. The reservoir located in a small Ampallas depression zone under Mt. Manututu. Ampallas hot springs interacted more with the youngest volcanic rocks while the other hot springs interacted more with the older volcanic rocks. And as the altered rocks and sulphur deposit indicates, Ampallas hot springs located in upflow area while Ampallas-5 and Batupane probably located in the outflow area in Ampallas geothermal system.

7. Estimated Geothermal Resource potential

Using geology and geochemistry method, this research can conclude the geothermal speculative resource potential. It was estimated that the reservoir temperature is around 169 – 173°C. So Ampallas geothermal system is included in medium enthalpy geothermal system (Hochestein, 1990 in Dickson and Fanelli, 1990).

Table 5: Classification of geothermal resources by temperature. (Dickson and Fanelli, 1990)

| (a)   | (b)    | (c)    | (d)    |
|-------|--------|--------|--------|
| Low enthalpy < 90°C | < 125°C | < 100°C | ≤ 150°C |
| Intermediate | 90-150 | 125-225 | 100-200 |
| High enthalpy > 150 | > 225  | > 200  | > 150  |

Source: (a) Mattier and Cataldi, 1978.
(b) Hochestein, 1990.
(c) Benderitter and Corny, 1990.
(d) Haenel, Rybach and Siegner, 1988.
Table 6: Power per unit area

| Reservoir Temperature Limit (°C) | Power per Unit Area (MWe/km²) |
|----------------------------------|-------------------------------|
| Low Temperature < 125            | 5                             |
| Medium Temperature 125-225       | 10                            |
| High Temperature >225            | 15                            |

From this research it is known that the prospect area is approximately 3 km². Using the equation:

$$\text{Hel} = \text{A} \times \text{Qel} \quad \text{............(1)}$$

Hel = Speculative Resource Potential (MWe)
A = Prospect Area (km²)
Qel = Power per unit area (MWe/km²)

it can be obtained the speculative resource potential for Ampallas geothermal system, which is about 30 MWe, although this is just the speculative potential. Which means this potential is not very accurate. By using detailed geophysics method the result can become more accurate.

Figure 3: Geological map of Ampallas geothermal area
Figure 4: Tentative model of Ampallas geothermal system
Ampallas area is consisted from 14 rock units. The Ampallas geothermal system itself is associated with young Mt. Manututu volcanic activity (0.3 – 1 million years old). There are many tectonic activities (tertiary) that made this area a potential for geothermal system by creating many faults and joints. Hot springs and altered rocks are manifestations that created in Ampallas area. There are 4 hot springs; Ampallas, Batupane, Gantungan, and Karema. Ampallas 1,2,3,4,7 and 8 hot springs water type is chloride – bicarbonate, which means it came from the reservoir while Batupane, Gantungan, Karema and Ampallas 5 are all bicarbonate type. Ampallas 1,2,3,4,7,8, Karema and Gantungan hot springs fluid plotted in partial equilibrium zone while Batupane and Ampallas 5 plotted in immature water zone. It means the Ampallas hot springs (except Ampallas-5) mixed with meteoric water right after reached the equilibrium state. It is also concluded that Ampallas 5 hot springs came from the same reservoir with Batupane, but not Gantungan and Karema hot springs. The altered rocks and sulphur deposit were found near the Ampallas hot springs. The altered mineral is clay mineral included in argillic type. Both the altered rocks and sulphur deposit indicated upflow area, so it can be concluded that Ampallas hot springs located in the upflow area, while Ampallas-5 and Batupane hot springs located in the outflow area of Ampallas geothermal system. The speculative resource potential of Ampallas geothermal system is estimated around 30 MWe. But if detailed geophysical method was applied the result could be more accurate. Ampallas geothermal area is an interesting area to be researched and to be developed. With more detailed method, like magnetotelluric, the result could be much more accurate.

Figure 5: (a) Cl-SO$_4$-HCO$_3$ diagram, (b) Figure 6: Na-K-Mg diagram, (c) Cl-Li-B diagram

8. Conclusion
Ampallas area is consisted from 14 rock units. The Ampallas geothermal system itself is associated with young Mt. Manututu volcanic activity (0.3 – 1 million years old). There are many tectonic activities (tertiary) that made this area a potential for geothermal system by creating many faults and joints. Hot springs and altered rocks are manifestations that created in Ampallas area. There are 4 hot springs; Ampallas, Batupane, Gantungan, and Karema. Ampallas 1,2,3,4,7 and 8 hot springs water type is chloride – bicarbonate, which means it came from the reservoir while Batupane, Gantungan, Karema and Ampallas 5 are all bicarbonate type. Ampallas 1,2,3,4,7,8, Karema and Gantungan hot springs fluid plotted in partial equilibrium zone while Batupane and Ampallas 5 plotted in immature water zone. It means the Ampallas hot springs (except Ampallas-5) mixed with meteoric water right after reached the equilibrium state. It is also concluded that Ampallas 5 hot springs came from the same reservoir with Batupane, but not Gantungan and Karema hot springs. The altered rocks and sulphur deposit were found near the Ampallas hot springs. The altered mineral is clay mineral included in argillic type. Both the altered rocks and sulphur deposit indicated upflow area, so it can be concluded that Ampallas hot springs located in the upflow area, while Ampallas-5 and Batupane hot springs located in the outflow area of Ampallas geothermal system. The speculative resource potential of Ampallas geothermal system is estimated around 30 MWe. But if detailed geophysical method was applied the result could be more accurate. Ampallas geothermal area is an interesting area to be researched and to be developed. With more detailed method, like magnetotelluric, the result could be much more accurate.
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References
Dickson, M. H. and Fanelli, M. 2004. Geothermal Energy. Istituto di Geoscienze e Georisorse, CNR. Pisa, Italy
Nicholson, Keith (1993), “Geothermal Fluids, Chemistry and Exploration Techniques,” *Springer Verlag Inc*
Fournier, R.O. (1981), “Application of Water Geochemistry Geothermal Exploration and Reservoir Engineering, Geothermal System: Principles and case Histories,” *John Willey & Sons. New York*
Ratman, N. and S. Atmawinata (1993), “Peta Geologi Regional Lembar Mamuju,” *Pusat Penelitian dan Pengembangan Geologi. Bandung*
Pusat Sumber Daya Geologi (2010), “Survei Panas Bumi Pendahuluan/Regional,” *Badan Geologi, Kementrian Energi dan Sumber Daya Mineral. Bandung*