Characteristic of geothermal fluid at East Manggarai, Flores, East Nusa Tenggara

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Abstract. The research area is located in East Manggarai and its surrounding area, Flores. In the study area there are two geothermal systems, i.e. Mapos geothermal system which is associated with Anak Ranakah volcano and Rana Masak geothermal systems which is associated with Watuweri volcano. The difference within these systems is shown by the relative content of conservative elements of Cl, Li and B. Geothermal surface manifestations in Mapos include 4 hot springs having temperatures of 34.3-51.4°C and bicarbonate and sulphate-bicarbonate waters; the discharge area in Rana Masak consist of 3 hot springs with temperatures of 38-46.6°C and chloride and chloride-bicarbonate water. Stable isotopes δ18O and δD analyses showed that the geothermal fluid derived from meteoric water. The Mapos geothermal system is a high temperature system having reservoir temperature of 250-270°C with natural heat loss of 230 kW. The Rana Masak geothermal system is a low temperature system having reservoir temperature of 120-140°C with natural heat loss of 120 kW.

1. Introduction
East Manggarai is located at Flores Island, East Nusa Tenggara. The research is conducted around Ruteng and Borong to find the geothermal potential (Figure 1). This research is integrated geothermal survey conducted by CGR (Center for Geological Resources) to discover energy resources for electricity in the eastern Indonesia. The previous study is reconnaissance was also conducted by CGR in 2013. The aim of this research is to identify the characteristic of the geothermal reservoir in the research area, particularly temperature and the depth of reservoir based on water geochemistry study from the surface manifestations. Hopefully this research can be used for further data as a geothermal power development in East Manggarai.

Geological studies conducted by CGR in 2014 mention that the research area consists of several morphology i.e. volcanic cones, volcanic slope, lava dome, and undulating hills. The stratigraphy of research area consists of volcanic rocks such as lava, pyroclastic and volcanic breccia. There is basement in the research area which consists of sedimentary rocks having Tertiary age (Tmk) which underlie all volcanic products aged Quaternary. The geological map of the research area is presented in Figure 2 made by Center for Geological Resources [1]. The lava is dominantly andesite with the characteristic: grey, porphyritic, pyroxene and plagioclase phenocryst, mafic groundmass, in some-places have sheeting joint structure. Volcanic breccia is the product of volcanic eruption in the research area with the component consisting of igneous rock. The pyroclastic rock formed from a...
pyroclastic flow with quartz and plagioclase in composition. Sedimentary rock (Tmk) consists of interbedded sandstone, claystone and tuff, grey to white, in some places is calcareous and altered. Strike of the bedding is N40° – 50°E with dip 20°-35° to the SE. There are several faults relatively trending NNW-SSE and NE-SW in the research area (Figure 2).

**Figure 1.** Research area.

**Figure 2.** Geological map of research area (made by Center for Geological Resources, 2014).
2. Methodology
In this study data have been collected in the field, including data on geology and geochemistry (hot water and cold water samples), laboratory analysis, and interpretation. Analysis of water samples has been conducted at CGR laboratory focused on the chemistry and stable isotope from the water samples. Water chemistry analysis has been conducted on 7 hot waters and 2 cold water samples. The purpose of chemistry analysis is to determine the element content in the water i.e. Na$^+$, K$^+$, Li$^+$, Fe$^{3+}$, Ca$^{2+}$, Mg$^{2+}$, As$^{3+}$, Al$^{3+}$, Cl$^-$, SO$_4^{2-}$, HCO$_3^-$, F, CO$_3^{2-}$, B, SiO$_2$, and NH$_4^+$. Analysis of stable isotope δD (deuterium) and δ$^{18}$O (oxygen-18) were conducted on all hot water samples and 6 samples of cold water. The purpose of stable isotope analysis is to know the origin of geothermal fluid by using graph δD vs δ$^{18}$O (see Section 3.4).

Ion balance calculations are also performed to assess the eligibility samples. Ion balance calculation is following this equation: $(\sum \text{anions} - \sum \text{cations})/((\sum \text{anions} + \sum \text{cations})$, and the result should not be greater than 5%.

3. Result and analysis
There are 7 surface manifestations in research area appearing as hot springs (Figure 3). The manifestations characteristics are presented in Table 1. Chemistry and isotope analysis is performed to all hot water samples. Cold water sample has also taken from the wells and spring in the research area. This is useful for isotope analysis to know the origin of geothermal fluid. There are 6 cold water samples taken in the research area and its vicinity, 2 were analyzed chemistry and all samples are isotope analyzed. Water chemistry and isotopic data are shown in Table 2. Result of water chemistry analysis then can be used to define the type of geothermal water and geoindicators using ternary diagram. Geoindicator diagram can be used to determine how many reservoirs in the research area.

The first step that must be done to analyze data on the geothermal area is to assess the feasibility of the sample by calculating the ion balance. Ion balance below 5% is assessed as eligible data for further analyses [2]. All ion balance of the sample is below 5%, so the samples in the study area could be used for further analysis (see Table 2).

![Figure 3. Location of hot spring manifestations and cold water (image from http://maps.google.com, August 2014).](http://maps.google.com)
## Table 1. Location and characteristic of surface manifestation in research area.

| No | Manifestation | Coordinate (Zone 51S) | Elevation | T air | T water | Debit | pH | Conductivity (umhos/cm) | Sampling Date | Description |
|----|---------------|------------------------|-----------|-------|---------|-------|----|------------------------|---------------|-------------|
| 1  | Mapos-1 hot spring (APMP-1) | 232.674, 9.039.323 | 724 | 28.6 | 51.4 | 1.4 | 5.9 | 1.300 | 8 March 2014 | Hot water pool with 3.6 m diameter, clear, tasteless – a bit acid, H₂S smell, have continuous gas bubbles, has residual silica around the spring, has mud deposit that contain Sulphur in the flow. |
| 2  | Mapos-2 hot spring (APMP-2) | 232.680, 9.039.324 | 727 | 29.2 | 50.1 | 0.4 | 6.1 | 1.284 | 8 March 2014 | Clear, tasteless - a bit acid, slightly smell of Sulphur, has mud deposit that contain Sulphur in the flow. |
| 3  | Compang Teber hot spring (APCT) | 234.991, 9.041.552 | 650 | 26.8 | 45.0 | 0.5 | 6.2 | 2.160 | 11 March 2014 | Clear, odorless, a bit acid, has iron oxide deposit and thin sinter carbonate. |
| 4  | Waelareng hot spring (APWL) | 227.323, 9.038.454 | 707 | 29.3 | 34.3 | 0.5 | 6.1 | 964 | 12 March 2014 | Clear, a bit acid, odorless. |
| 5  | Rana Masak-1 hot spring (APRNM-1) | 240.836, 9.034.332 | 243 | 32.0 | 46.6 | 0.6 | 6.0 | 16.216 | 9 March 2014 | Hot water pool with 4.8 m diameter, clear, odorless, salty, have continuous bubbles, has wide (100x100m) sinter carbonate, has salt deposit and iron oxide deposit. |
| 6  | Rana Masak-2 hot spring (APRNM-2) | 240.845, 9.034.331 | 242 | 29.0 | 43.0 | 0.4 | 5.9 | 16.210 | 9 March 2014 | Hot water pool with 4.8 m diameter, clear, odorless, salty, have continuous bubbles, has wide sinter carbonate, has salt deposit and iron oxide deposit. |
| 7  | Rana Roko hot spring (APRNK) | 240.144, 9.026.390 | 65 | 27.0 | 38.0 | 0.5 | 6.1 | 6.200 | 10 March 2014 | Hot water pool with 0.76 m diameter, clear, odorless, salty, have continuous bubbles, has sinter carbonate, has salt deposit and iron oxide deposit. |
| Code     | APMP -1 | APMP -2 | APRNM-1 | APRNM-2 | APRNk | APCT | APWL | ADNH | ADRL | ADRNM | ADCT | ADWK | ADNC |
|----------|---------|---------|----------|----------|--------|------|------|------|------|-------|------|------|------|
| pH       | 5.9     | 6.1     | 6.0      | 5.9      | 6.2    | 6.1  | 6.1  | 7.2  | 7.1  | -     | -    | -    | -    |
| Conductivity (umhos/cm) | 1.300 | 1.284 | 1.020 | 1.620 | 2.160 | 964  | 102  | 889  | -    | -    | -    | -    |
| SiO₂ (mg/L) | 27.55 | 26.75 | 29.99 | 31.21 | 136.66 | 61.52 | 135.22 | 60.61 | 114.97 | -    | -    | -    |
| B (mg/L)  | 1.27    | 1.49    | 103.97  | 92.07   | 10.79  | 0.57 | 0.66 | 0.09 | 0.57 | -    | -    | -    |
| Al³⁺ (mg/L) | 0.03   | 0.05    | 0.04    | 0.04    | 0.03   | 0.03 | 0.04 | 0.03 | 0.03 | -    | -    | -    |
| Fe³⁺ (mg/L) | 0.13   | 0.12    | 0.00    | 7.59    | 2.16   | 1.08 | 0.00 | 0.00 | 0.00 | -    | -    | -    |
| Ca²⁺ (mg/L) | 152.50 | 161.00  | 547.10  | 486.10  | 360.90 | 322.10 | 71.80 | 7.67 | 34.60 | -    | -    | -    |
| Mg²⁺ (mg/L) | 31.85  | 32.94   | 115.83  | 115.46  | 96.69  | 11.68 | 34.46 | 6.37 | 17.71 | -    | -    | -    |
| Na⁺ (mg/L) | 127.60 | 128.70  | 2311.20 | 1995.30 | 466.20 | 117.80 | 66.90 | 5.52 | 135.00 | -    | -    | -    |
| K⁺ (mg/L) | 11.15  | 10.58   | 308.41  | 264.64  | 11.52  | 5.97 | 9.32 | 2.86 | 9.88 | -    | -    | -    |
| Li⁺ (mg/L) | 0.10   | 0.10    | 8.38    | 7.76    | 0.13   | 0.13 | 0.02 | 0.04 | 0.03 | -    | -    | -    |
| As³⁺ (mg/L) | 0.05   | 0.05    | 0.76    | 1.37    | 0.00   | 0.01 | 0.01 | 0.00 | 0.00 | -    | -    | -    |
| NH₄⁺ (mg/L) | 1.16   | 1.14    | 5.58    | 6.86    | 1.65   | 2.17 | 0.98 | 0.89 | 1.30 | -    | -    | -    |
| F⁻ (mg/L) | 0.19   | 0.12    | 1.00    | 0.10    | 0.44   | 0.14 | 0.00 | 0.01 | 0.21 | -    | -    | -    |
| Cl⁻ (mg/L) | 18.26  | 20.47   | 456.24  | 4169.30 | 1050.44 | 8.76  | 0.00 | 0.40 | 55.43 | -    | -    | -    |
| SO₄²⁻ (mg/L) | 470.50 | 492.75  | 282.70  | 272.70  | 306.53 | 942.44 | 32.80 | 1.70 | 39.69 | -    | -    | -    |
| HCO₃⁻ (mg/L) | 299.70 | 297.98  | 683.17  | 924.20  | 544.72 | 189.56 | 505.11 | 68.63 | 390.00 | -    | -    | -    |
| CO₃²⁻ (mg/L) | 0.00   | 0.00    | 0.00    | 0.00    | 0.00   | 0.00 | 0.00 | 0.00 | 0.00 | -    | -    | -    |
| δ¹⁸O (‰) | -6.44  | -6.28   | -4.64   | -4.71   | -4.86  | -6.07 | -6.17 | -5.56 | -5.31 | -6.54 | -6.16 | -6.12 | -6.83 |
| δD (‰) | -34.31 | -34.47  | -26.76  | -26.16  | -24.16 | -30.28 | -31.31 | -26.51 | -26.65 | -35.34 | -33.07 | -31.48 | -38.12 |

**Description:** APMP-1: Mapos-1 hot spring; APMP-2: Mapos-2 hot spring; APRNM-1: Rana Masak-1 hot spring; APRNM-2: Rana Masak-2 hot spring; APRNk: Rana Roko hot spring; APCT: Compang Teber hot spring; APWL: Waelareng hot spring; ADNH: Nehos cold water; ADRL: Rana Loba cold water; ADRNM: Rana Mese cold water; ADCT: Compang Teber cold water; ADWK: Wae Kolang cold water; ADNC: Nceang cold water; - : not analyzed.
3.1. Types of Geothermal Water

The types of water are classified by major anion, which refer to the relative content of Cl\(^-\) (chloride), SO\(_4^{2-}\) (sulphate), and HCO\(_3^-\) (bicarbonate), as illustrated in the ternary diagram (Figure 4). The study area has four types of water:

3.1.1. Chloride

Belonging to this type of water are APRNM-1 and APRNM-2. This manifestation has a pH of 5.9-6 and tasted a bit salty. Around these hot springs there is a wide travertine deposit occurs. This water is not a chloride water type coming from the reservoir. High chloride content is derived from a mixture of water formation. That statement is also supported by the content of Ca, Na, and K that is quite high.

3.1.2. Chloride-bicarbonate

Belonging to this type of water is APRNK. It is characterized by clear water with a pH of 6.1 and there are deposits of thin sinter carbonate near the discharge. This type of water formed by the mixing of the water in the reservoir that contains high Cl with groundwater which has high bicarbonate content (dilute waters).

3.1.3. Bicarbonate

Belonging to this type of water is APWL, characterized by clear water and odorless, with pH close to neutral (6.1). This type of water is formed by adsorption of CO\(_2\) gas and condensation of vapor to the groundwater (steam condensates/steam heated waters).

3.1.4. Sulphate-bicarbonate

Belonging to this type of water are APMP-1, APMP-2, and APCT. Characterized by clear water with pH 5.9-6.2 with a slight smell of sulfur, they present mud deposits around the discharge. This hot spring is formed as a result of vapor and gas on the upflow zone that contains H\(_2\)S and CO\(_2\) condense with meteoric water thus forming condensates water (steam condensates).

![Figure 4](image-url) Ternary diagram Cl-SO4-HCO3 to classified types of geothermal water.
3.2. Geoindicator
Cl-Li-B diagram is used to identify similarities the geothermal fluid reservoir [2]. Based on the Cl-Li-B diagram (Figure 5) and the geographic location of the manifestations, the research area has two reservoirs, which are reservoir Mapos and Rana Masak.

3.2.1. Mapos Reservoir
Reservoir Mapos is estimated to have a heat source derived from active volcano Mt. Anak Ranakah. It can be seen from the characteristic of the manifestation that contain sulfur, and high content of sulphate in the springs that indicates the influence of \( \text{H}_2\text{S} \) gas coming from active volcano. This reservoir has 3 sulphate-bicarbonate manifestations (APMP-1, APMP-2 and APCT), and one bicarbonate water manifestation that is APWL. The content of B/Cl in this reservoir ranges from 0.07 to 0.28 due to the fluid interaction with the surrounding rocks and steam heating.

3.2.2. Rana Masak Reservoir
Reservoir Rana Masak is estimated has heat source derived from Mt. Watuweri, it can be seen from the geographical location of manifestations and hydrology pattern. This reservoir has chloride water discharge (APRNM-1, APRNM-2) and chloride-bicarbonate water (APRNK). The reservoir shows B/Cl value between 0.01-0.02, which is caused by fluid-rock-steam-interaction.

Plotting the manifestation on the ternary diagram Na-K-Mg (Figure 6) shows all the water can be classified as immature waters, which means the water is already mixed with meteoric water or groundwater.

![Figure 5. Ternary diagram Cl-Li-B shows 2 reservoirs in research area.](image)

![Figure 6. Ternary diagram Na-K-Mg shows water from manifestation is immature waters.](image)

3.3. Reservoir Temperature and Natural Heat Loss
The reservoir temperature has been calculated by using the geothermometer Na/K and K/Mg [3]. This method is applied because it is often used in a geothermal field in Indonesia. It shows as well results that approach to the actual reservoir temperatures. Based on the geothermometer calculation, Mapos reservoir temperature is 250°-270°C, and Rana Masak reservoir temperature is 120°-140°C.

Natural heat loss is the heat that comes out from the geothermal area through the surface manifestations. There are 2 types of natural heat loss in this case. The first one is natural heat loss that comes out through convection that happens to hot spring flow. The second is through evaporation if the manifestation in the form of hot pool that has area. Natural heat loss is calculated in each discharge
manifestations then summed in each group. Total natural heat loss is sum between convection and evaporation. After calculated, natural heat loss from Mapos Reservoir is around 230 kW and Rana Masak Reservoir is around 120 kW.

3.4. Origin of Geothermal Fluid
Based on the plotting of δD and δ18O contents from each manifestation (Figure 7), geothermal fluid on the research area has content of δD and δ18O which is not much different from the local meteoric water, this shows that the geothermal fluid in research area is derived from meteoric water. Stable isotope variation δD and δ18O local meteoric water follow a linear equation which is calculated based on 6 samples of cold water taken in research area, that is:

\[ \delta D = 8\delta^{18}O + 17, R^2 = 1 \]

The isotope data plotting is generally showed enrichment δD and δ18O, this is caused by surface evaporation or steam heating. But on the ADNH, APRNM-1 and APRNM-2 the addition is only on δ18O (Figure 7) this is caused by water rock interaction. The reaction between rock and fluid at the depth causing exchange of oxygen with a heavier isotope will be concentrated in the solution phase [2].

![Figure 7. Stable isotope plot for the sample investigated in this study.](image)

3.5. Estimating Depth of Reservoir
Determination depth of reservoir has been performed by using statistical data of temperature reservoir measurements at several drilling locations of geothermal fields in Indonesia presented by Hochstein and Sudarman [4] (Figure 8). From the data, we obtained a graph by using quadratic regression with the following equation:

\[ y = -0.0257x^2 + 0.4446x + 31.248 \]
\[ R^2 = 0.7573 \]

with: \( y \) = well depth,
\( x \) = bottom temperature of reservoir,

The equation above is then applied to the research area. The reservoir Mapos is characterized by temperature of 250°C having depth of about 1.500 m while the reservoir Rana Masak temperature 120°C having depth about 300 m (Figure 8).
3.6. Tentative Model of Geothermal System

From all data that has been taken and processed, a made tentative model of the geothermal system of the study area has been developed. Figure 9 shows the tentative model of the geothermal system in research area made by CGR [1].

Figure 8. Estimation of the reservoir depth using statistical data of geothermal field in Indonesia. Modified from Hochstein and Sudarman [4].

Figure 9. Tentative Model of Geothermal System in the Research Area (made by Center for Geological Resources, 2014).
4. Conclusion
The research area is located at East Manggarai and its vicinity. The geology of the research area consists of volcanic products such as lava and pyroclastic with Quaternary age, and there are Tertiary sedimentary rocks basement.

The water geochemistry shows that the research area has two reservoirs: Reservoir Mapos and Reservoir Rana Masak. Reservoir Mapos has temperature 250-270°C with 1500 m depth, associated with active volcano Mt. Anak Ranakah and natural heat loss 230 kW. Reservoir Rana Masak has temperature 120-140°C with 300 m depth, associated with Mt. Watuweri and natural heat loss 120 kW. The isotope data show that reservoir water is mixed with meteoric water.

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