Reconstruction of Conceptual Model in Mataloko Geothermal Field (Nusa Tenggara Timur)

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Abstract. Mataloko Geothermal field is administratively located in the Todabelu Village, Golewa District, Ngada, Nusa Tenggara Timur (NTT) within 10 km to the east-southeast of Bajawa, the capital Ngada. Shallow reservoir is located in the rock alteration were identified as claycap zone. The formation of the reservoir zones in claycap zone is caused by normal faults Wae Luja that pass through this area, where this fault which causes the formation of fractures in this zone and as a channel entry of fluid from the reservoir into the shallow reservoir. Development of conceptual model is started by interpreting geosciences data (geology, geochemistry, geophysics). The first step is reprocessing of Magnetotelluric (MT) data as the main data. It is then integrated with the analysis results of geology, geochemistry, geophysics data to generate a conceptual model. The evidence by the temperature wells around 287.8\degree C from Geothermometer gas calculation (D’Amore dan Panich).

1. Introduction

The conceptual model of a geothermal system is the key to success in developing geothermal potential in a region. The conceptual model is the basis for evaluating resource calculations, especially volumetric calculations and modeling of geothermal reservoirs. In addition, the conceptual model is also important for field development plans, namely in choosing the location and target of the well to be drilled. This study intends to reconstruct the conceptual model of the Mataloko field (East Nusa Tenggara), the Mataloko geothermal field located in Toda Belu Village, Golewa District, Ngada Regency, East Nusa Tenggara. It is expected to provide an overview of the selection of target locations and wells to be drilled in the area of this investigation.

The Mataloko geothermal area is located in the Bajawa depression that is a major depression covering the city of Bajawa at the western side and Mataloko at the eastern side. In the depression zone, there are features of several scattered volcanic cones forming a straight line of north-south, northwest-southeast, and northeast-southwest as shown in Figure 1. The volcanic cones also form a line which is directed toward north-south with Mt. Inielika, indicating the presence of a dike-shaped magma chamber below which has the potential to become a heat source for geothermal activity in around the Bajawa area [6].

![Figure 1. Mataloko Location [13]](image-url)
2. Geoscience / Geoscientific and Well Data

2.1 Geological Structure
Control of the fault structure is very instrumental in the distribution of alteration rocks in the Mataloko region, especially in the Wae Luja area. The direction of the fault is northwest - southeast, the type of fault is a normal fault, where the northern part of the fault block is a fault block that is relatively moving down from the southern fault block. It is estimated that the Waeluja fault controls the fluid circulation of the Mataloko geothermal field/area. The Waeluja fault is marked by the appearance of fumaroles and rows of hot springs, straightness of the Waeluja River and united with changed stones. While alteration in the southern part of Boba village originates from a different geothermal system. It could be originated from a reservoir around Nage. [4]

Green tuff/Tuff Welas is thought to function as reservoir rock, because the physical properties of the two rock units show many fractures so that they are porous and permeable. While Volcanic Deposits 1 and 2, namely pyroclastic flow deposits function as Clay Cap. Moreover the young volcanic cone deposits around the mataloko, are the overburden. [4] The formation of a reservoir zone in the claycap zone is caused by Wae Luja's normal fault passing through this area, where this fault causes a fracture to form in this zone and as a fluid entry channel from the reservoir.

The geological structure that develops in this area consists of normal faults, volcanic straightness, parts of the Nage caldera wall and the structure of the rest of the crater wall. The general geological structure pattern is northwest southeast and other lines are north-south direction, reflecting the intrusion or chamber of magke shaped dyke under the Mataloko geothermal system. Wae Luja's normal fault structure is thought to be the structure that controls the appearance of geothermal manifestations in the Mataloko area. Existing volcanic alignments suggest that the appearance of volcanic cones occurs at a relatively concurrent time period through the same fracture media system. The remaining structure of the crater wall shows that in this area volcanism has occurred in the past. [1]

![Geological Map of the Mataloko Geothermal Region](image)

**Figure 2.** Geological Map of the Mataloko Geothermal Region. [15]
2.2 Vulcanostratigraphy

The geological of the Mataloko area is included in the successful volcanic rock environment of the Quarter. An overview of the volcano and the geology of the adjacent area indicates that the area is obtained from the andesite (Qma) Mataloko rock group. The Mataloko andesite (Qma) mountain group was breached and approved by a collection of small volcanoes called "genetic volcanoes", most of which still need the remaining inactive craters, but one mountain shows the presence of fumaroles (Wolo Bobo). The monogenetic volcano has a shallow magma chamber and erupts allegedly only 1-2 times, and then stops. This group of mono-genetic volcanoes is included in the unit "Quaternary volcanic cone" (Qvc), the products is represented in the form of lava and pyroclastic andesitic-basaltic compositions. These volcanoes are identified as Wolo Belu, Wolo rea and Wolo Manulalu in the north of the prospect area, while to the western side as these mountains are found as Wolo Nawa, Wolo Bina. The ages of Mataloko andesite (Qma) and the mono genetic volcano (Qvc) group are ranged from 0.15, 0.12 Ma and < 0.1 Ma [6]. The two rock groups above (Qma) and (Qvc) cover inconsistently Tertiary rock groups in the Maumbawa area. The Tertiary rock group that underlies the Mataloko geothermal field consists of Maumbawa basalt (Tvmb) and Tuff Welas (Tww). [6,9]

The two rock groups are exposed in the eastern part of the prospect area. Maumbawa basalt (Tvmb) and Tuff Welas (Tww) have undergone changes. The source of the eruption of Tuff Welas comes from the Welas Caldera which is far north of the Mataloko area. The age of the two Tertiary rocks is 3.37 Ma and 2.73 Ma [6,9], indicating that Pliocene-aged volcanic activity had occurred in the east and south of the Mataloko prospect area. The geological structures of the Mataloko region are associated with a longitudinal regional fault system in the Southeast-Northwest direction that is influenced by regional tectonic originating from the south. In general, geothermal appearance in Mataloko and its surroundings is associated with a system of structures or fractures, which are oriented towards the North West - Southeast, Southwest Northeast and as a medium for discharge of geothermal fluids at the surface [14].

The making of this geological model refers to data on the spread of geothermal manifestations accompanied by the chemical content of each manifestation and the distribution of the geological structure of the controller. Comparison with well data is also carried out in the form of alteration zones which indicate the division of zones in a geothermal system.

The area assessed by the prospect is in the well area as an upflow marked by the discovery of manifestations in the form of fumaroles. Based on the cross section it can also be interpreted that the reservoir rock is thought to be a proximal-medial facies that is predominantly composed of lava pyroclastic. Rocks that act as basement are sedimentary rocks. The existence of three wells is also displayed on the geological model made.

![Figure 3. Geological Model of the Mataloko Geothermal Region.](image-url)
2.3 Geochemistry - Trilinear Diagram SO\textsubscript{4}-Cl-HCO\textsubscript{3} Analysis

Geochemical survey activities carried out by analyzing the appearance of existing manifestations. Gas and hot water analysis carried out to estimate reservoir fluid conditions including reservoir temperature. Figure 4 show the manifestation in Mataloko Geothermal Field. Analysis of the trilinear diagram Cl-SO\textsubscript{4}-HCO\textsubscript{3} needed to determine the type of fluid present in each manifestation. In this diagram, you can see the distribution of manifestations leading to both corners of the diagram, which directed to SO\textsubscript{4} (Figure 5). From these results, it actually validates that the Mataloko area is sulphate waters. Other information obtained in this diagram shows that none of the manifestations in the Mataloko area are included in the category of mature waters. It means there is no fluid in the manifestation that comes from the activity of geothermal fluid below the surface. AP-1, AP-2 and AP-3 hot springs are in the category of steam-heated waters because they have SO\textsubscript{4} content. This indication shows that some of these hot springs are in the upflow zone of the Mataloko regional geothermal system. While other hot springs that have a high percentage of HCO\textsubscript{3} content indicate that, the manifestation area is an outflow zone of the Mataloko area geothermal system.

![Figure 4. Manifestations of Mataloko Geothermal Field](image)

The results of the chemical analysis of Mataloko hot water as reported show types of sulfate (SO\textsubscript{4}) and high silica, chloride which is low and does not contain bicarbonate. Because hot springs have low pH/acidic, the calculation of subsurface temperature with a water geothermometer cannot be done because the chemical content in acid hot water does not represent the reservoir condition but rather is the result of interaction on the surface.
2.4 Geochemistry - Trilinear Diagram Na-K-Mg Analysis

This diagram analysis is used to show the solubility and equilibrium levels of the chemical elements of hot water in the Mataloko area (Figure 6). From the samples analyzed in this diagram, all hot springs are in an immature water state. This indicates that the hot fluid in each of these hot springs has been diluted by groundwater or meteoric water. Based on this data, water geothermometers (SiO₂, Na / K and Na-K-Ca) cannot be used to estimate the temperature value of the reservoir zone below the surface. In other words, the water geothermometer value is less or even not representative to estimate the temperature value of the geothermal reservoir in the Mataloko area.
Table 1. Results of Analysis of Mataloko Regional Hot Water Chemistry [6].

| No. | Items             | AP.1  | AP.2  | AP.3  |
|-----|-------------------|-------|-------|-------|
| 1   | pH                | 2.26  | 2.56  | 2.52  |
| 2   | E.C (mmhos/cm)    | 2000  | 670   | 7.30  |
| 3   | Natrium (mg/l)    | 19.78 | 18.48 | 18.48 |
| 4   | Kalium (mg/l)     | 8.33  | 5.17  | 9.33  |
| 5   | Lithium (mg/l)    | 0.83  | 0.5   | 0.87  |
| 6   | Kalsium (mg/l)    | 13.75 | 35.00 | 17.50 |
| 7   | Magnesium (mg/l)  | 21.75 | 13.50 | 18.00 |
| 8   | Fe (mg/l)         | 39.79 | 11.60 | 6.78  |
| 9   | NH₃ (mg/l)        | 0.00  | 0.00  | 0.11  |
| 10  | Arsen (mg/l)      | 0.41  | 0.30  | 0.47  |
| 11  | Klorida (mg/l)    | 17.65 | 17.21 | 12.95 |
| 12  | SO₄ (mg/l)        | 457.15| 233.05| 227.35|
| 13  | HCO₃ (mg/l)       | 0.00  | 0.00  | 0.00  |
| 14  | Boron (mg/l)      | 0.20  | 0.15  | 0.15  |
| 15  | Flour (mg/l)      | 1.50  | 1.00  | 1.00  |
| 16  | SiO₂ (mg/l)       | 222.08| 172.21| 259.46|
| 17  | Temperatur AP (°C)| 90.90 | 85.60 | 84.30 |
| 18  | Delta 18 O        | -1.2  | -4.1  | -4.0  |
| 19  | Delta D           | -15.8 | -29.7 | -29.5 |

The estimated temperature value that is relative to the current condition of the well is the D'Amore Panichi gas geotermometer with an estimated reservoir temperature of around 287.8°C (Geothermometer Gas - D'Amore dan Panichi). The geochemical model seen in Figure 7 is based on information on geochemical data in the Mataloko area. The upflow zone is indicated by the presence of surface manifestations in the form of fumaroles and sulphate hot spring located near Well. This model also contains information about the temperature contours made based on the results of gas geotermometer analysis and well data which shows that the average temperature value of the geothermal reservoir Mataloko area is around 287.8°C (Geothermometer Gas - D'Amore dan Panichi).
2.5 Geophysics

The 3-D inversion of MT data in this study was carried out using the MT3Dinv-X (Daud et al, 2012) software that applies inversion methods to data space occams. [11].

Identification of the presence of geothermal systems in the Mataloko area is indicated by the results of 3-D inversion of MT data. Conductive layers that are characteristic of the geothermal system as a result of hydrothermal alteration processes appear in inversion models 3-D. This can be seen in the cross section of line 1 resistivity which leads Northeast - Southwest (Figure 8) and line 2 which leads north – south (Figure 9).

Figure 4. Shows the results of 3-D inversion of MT data on line 1. The clay cap layer is shown by a yellowish red zone. This layer has resistivity values between 1-11 ohm-meters with varying thickness of about 200 m on the updome section and around 500 m at the edges even lower resistivity in the southwest part thicker than the northeast. The upper part of the updome shape of the low resistivity anomaly has several surface manifestations such as fumarole and sulphate hot spring. This shows that the upflow zone of the system Mataloko geothermal is indeed in the area.

In addition, the resistivity cross section also Presents/shows high resistivity anomalies beneath the conductive layer. On line 1, high resistivity anomalies can be seen appearing in parts close to the field.
Figure 8. Results of 3-D inversion of magnetotelluric data on line 1

Figure 9. Results of 3-D inversion of magnetotelluric data on line 2

Figure 9. shows argilitic alteration zones (yellow) which are interpreted as clay stamp zones. This zone has an estimated resistivity value between 1-11 ohm-m. Furthermore, the prophylitic zone (blue lines) is below the argilitic zone with estimated resistivity values between 20 - 200 ohm-m. Both zones are interpreted based on the MT model.

2.2 Wells Data
There were 6 wells which have been drilled in Mataloko geothermal prospects with different conditions.

| No. | Well’s Name | Year | Total Depht (m) | Remark |
|-----|-------------|------|----------------|--------|
| 1   | MT-01       | 2001 | 207.26         | The exploration wells occur bursts and clogged |
| No. | Well's Name | Year | Total Depht (m) | Remark |
|-----|-------------|------|-----------------|--------|
| 2   | MT-02       | 2001 | 180.02          | The exploration wells drain steam, used for mini-plants |
| 3   | MT-03       | 2004 | 613.0           | The exploration well using APBN Cost, flows steam, including into the gathering system of the Mataloko’s Power Plant. |
| 4   | MT-04       | 2004 | 756.47          | The exploration wells using APBN costs, wells can flow steam, low steam quality, wells will be used as research wells |
| 5   | MT-05       | 2005 | 378.20          | The exploration well using APBN Cost, flows steam, including into the gathering system of the Mataloko’s Power Plant. |
| 6   | MT-06       | 2005 | 123.26          | Reinjection wells use APBN Costs |

3. Conceptual Model

The conceptual model is a descriptive or qualitative model that combines and unifies important physical parameters of a geothermal system. The information discussed from the beginning of this chapter is then integrated into a model that represents the Mataloko field geothermal system. The conceptual model of the Mataloko geothermal field has been successfully made based on the interpretation of various types of data including geological data, geochemical data, geophysical data, and well data.

Figure 5. shows some information about the Mataloko field geothermal system. The clay cap layer is characterized by a yellow layer. The thickness of this layer reaches 200 meters (elevation 600 to 400 meters above sea level) in the updome section and 500 meters at the edges (elevation 400 to 100 meters above sea level). The thickness of the reservoir layer is about 1,000 to 2,500 meters. The layers that become the basement of the Mataloko geothermal system are thought to originate from Welas / Green Tuff sedimentary rock formations based on volcanological geological data.

The upflow zone in Mataloko's geothermal system leads to Wolo Sasa volcanic cones, Wolo Belu, and other young volcanic cones. This is evidenced by the presence of surface manifestations in the form of fumaroles and SO$_4$ hot spring.

The conceptual model is presented on Figure 6. The geology, manifestations, geochemistry, geophysics and wells data study for the conceptual model construction are summarized as below:

From manifestation and alteration zone analysis, heat source is probably located vertically beneath the surface manifestation zone such as hot spring and fumaroles alteration zone. Furthermore, this hypothesis is supported by geophysical MT measurement. The heat source suspected comes from the remaining volcanic cone forming magma/plutonic Body around Mataloko such as the Wolo Sasa volcanic cones, Wolo Belu, and other young volcanic cones. The remaining magma forming a speckled lava dome can also be the origin of the heat source that forms the Mataloko Geothermal Field.

From geophysics study, cap rock region exists at 600 m to the surface. Reservoir region exists below the cap rock region.
Figure 10. Conceptual Model of Mataloko Field

4. Conclusion
Important points that can be concluded from this study are:
1. Based on the results of MT data interpretation and well data, the reservoir in the Mataloko area consists of deep reservoir at a depth of 1.000-2.500 meters.
2. This shallow reservoir is located in the alteration rock (alteration) identified as the claycap zone.
3. The formation of a reservoir zone in the claycap zone is caused by Wae Luja's normal fault passing through this area, where this fault causes a fracture to form in this zone and as a channel for the entry of fluid from the deep reservoir into a shallow reservoir.
4. Drilling that has been done has only penetrated the shallow reservoir zone and has not reached the deep reservoir zone, this is evidenced by the well temperature around 287.8°C (Geothermometer Gas - D’Amore dan Panichi).

5. Recommendation
Some useful suggestions for further research include:
1. To increase confidence in the prospect of geothermal energy in the Mataloko area, further investigation is needed, both geological, geochemical and geophysical surveys to the west from the Mataloko prospect area to the Bobo Nage prospect zone.
2. Deeper drilling on existing wells to penetrate the deep reservoir zone to obtain higher temperatures and pressures and better permeability.

6. Acknowledgment
The author is grateful to DRPM Universitas Indonesia for funding this research under Hibah PITTA 2019 program. The author also thanked PT PLN Persero for allowing us to conduct research and retrieve data and management PT Newquest for supporting data processing and knowledge sharing.

Reference
[1] Dahlan. 2010, Studi Kelayakan Pengembangan Lapangan Panas Bumi Mataloko, Institut Teknologi Bandung.
[2] Daud, Y. 2016, March 1. Lecture Notes - Resource Assessment and Conceptual Model. pp. 1-47.

[3] Fredy, Dani. Aswin, Chasin. M, Kasio, Budianto. A, 1997, “Geologi Daerah Panasbumi Mataloko, Kabupaten Ngada - Flores Nusa Tenggara Timur”. Bandung. Pusat Sumber Daya Geologi. (Unpublished Report)

[4] Grant, M., Donaldson, I., & Bixley, P. (1982a). Geothermal Reservoir Engineering. NewYork: Academic Press.

[5] Kasbani Wahyuningsih R and Sitorus K 2004 “Subsequent State of Development in the Mataloko Geothermal Field, Flores, Indonesia”. Proceedings of the 6th Asian Geothermal Symposium, Mutual Challenges in High- and Low- Temperature Geothermal Resource Fields, 101-106.

[6] Maruoka et. Al, 2002. “Tectonic, Volcanic and Stratigraphic Geology of the Bajawa Geothermal Field, Central Floress, Indonesia.”, Bull. Geol. Surv. Japan, 53, 109-138

[7] Minarto, E. Astoro, T. 2006. “Identifikasi Struktur Sesar Bawah Permukaan dengan Menggunakan Konfigurasi Half-Schlumberger (Head-On) pada Eksporasi Panasbumi Daerah Mataloko.” Jurusan FMIPA ITS.

[8] Minister Decree of ESDM – RI 2015 No: 4824 K/30/MEM/2015 About Giving Assignment to PT. PLN for Geothermal Business (35 years) in Mataloko Geothermal Working Area, Ngada District – East Nusa Tenggara”.

[9] Nasution, A., Maruoka, H., Rani, M., Takahashim, l., Takahashi, M., Akasako, H., Matsuda, K., and Badrudin, M 2002 “Geothermal Prospects of Flores Island In Indonesia Viewed From Their Volcanism And Hot Water Geochemistry”. Bull. Geol. Surv. Japan, 53, 87-97.

[10] Pradipta, Y. Sutopo. Berian Pratama, Heru. 2019. "Natural state modeling of Mataloko Geothermal field, Flores Island, East Nusa Tenggara, Indonesia using TOUGH2 simulator”. IOP Conf. Series: Earth and Environmental Science 254 (2019)

[11] Siripunvaraporn et al. 2005. “Three-Dimensional magnetotelluric inversion: data-space method”. Physics of The Earth and Planetary ineteriors 150.

[12] Sueyoshi Y Matsuda K Shimoike T Koseki T Takahashi H Futagoishi M Sitorus K and Simanjuntak J 2002 Exploratory Well Drilling and Discharge Test of Wells MT-1 and MT-2 in Mataloko Geothermal Field, Flores, Indonesia Bulletin of the Geological Survey of Japan 53 307-321

[13] Uchiro, T. 2005. “Three-Dimensional Magnetotelluric Investigation in Geothermal Fields in Japan and Indonesia”. Japan. Proceedings World Geothermal Congress (2005) - Turkey

[14] Wahyuningsih R and Sitorus K 2007 Program Pengembangan PLTP Skala Kecil Lapangan Panas Bumi Todabelu – Mataloko, Ngada, NTT Subdirektorat Panas Bumi Badan Geologi Kementerian Energi dan Sumber Daya Mineral.

[15] PT PLN Geothermal, 2010. Laporan Studi Geoscience Lapangan Panas Bumi Mataloko, Kabupaten Ngada. Nusa Tenggara Timur (Unpublished Report).