Geothermal Well Targeting in Consideration To Geological Structures of Mataloko Field, Flores

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Abstract. Mataloko is one of the geothermal fields on the island of Flores, East Nusa Tenggara, which is an area of exploration, production and is expected to be able to be used for electricity generation. Geologically, Mataloko area is quite strong affected by faults and fractures geological structures. Drilling geothermal well should be considered carefully in respond to active tectonic activity in Nusa Tenggara islands in particular Flores. Directional drilling should be planned in an area where geological structures are less affection to the well drill direction. Wae Luja – Ratogesa area is an example area where geological structures should be considered accurately. Results of geological mapping have significant attention to geological structures while geophysical data analysis should be heavily considered for subsurface geological structural analysis. Exploration shallow wells have been drilled to a depth of 756.47 meters showing temperature of above 185 degrees Celsius. Using geological as well as geophysical data analysis, it is interpreted that base of cap rock is approximately at the elevation of +855 masl to +20 masl. Combining the analysis results directional drilling could be planned carefully.

1. Introduction
Flores Island in East Nusa Tenggara Province has long been explored in geothermal energy resource. PT PLN and The Indonesia Ministry of Energy and Natural Resources have developed the geothermal energy up to building up geothermal electric power generation plants. East Nusa Tenggara area is the eastern end of the Banda arc having a volcanic arc extending from Sabang on the north tip of Sumatera, Java to Wetar island at the eastern tip of Nusa Tenggara. The consequence of this volcanic arc region is that besides there are many active volcanoes, there is also an abundance of geothermal energy potential as a result of post volcanic activity.

According to Sitorus et al (2016) [1], East Nusa Tenggara has at least 18 geothermal areas in regencies of Manggarai, Ngada, Ende, Flotim, Lembata, and Alor having potential capacity of up to 1055 MWe (Figure 1). Mataloko is one of the potential geothermal field locating in Ngada Regency. The integrated exploration study since 1997 recognized the prospect area with potential up to 63.5 MWe. The exploration hole of MT-02 produces 14.48 – 14.71 ton/hour dry steam or approximately similar to 1.4 MWe.

To explore and produce geothermal energy resources, it is necessary to study the geology of the island of Flores, especially around the Mataloko area. Geological, geochemical, and geophysical research has been widely carried out. There have been three exploration wells that provide important
data and information for further well drilling. With the existing wells, it is known the potential of the Mataloko field which is the basis for deeper exploration drilling in this field.

As a result of tectonics and magma extrusion forming a series of volcanoes, the geological structure of the island of Flores, especially the Mataloko area, is quite complex. Therefore, it is necessary to conduct studies, analysis and evaluation whose results will be used for planning and drilling deep exploration wells.

2. Methodology
This study aims to determine the direction of new well drilling based on previous studies, namely geology, geophysics (Gravity, MT) and well data (lithology, alteration, pressure and temperature profiles). The drilling target is made based on conceptual model developed using Leapfrog geothermal software.

2.1. Geology of Mataloko
Tectonically, Flores island is located near the connection of two tectonic plates, the Eurasian Plate and the Indian Ocean Plate. The thin earth crust of the island makes it easy for the extrusion of magma to form a series of volcanoes. Geologically, Mataloko area is located in a young volcanic zone characterized by two active volcanoes. Those are Mount Inelika in the middle and Mount Ineria in the south including Mounts Wolo Bobo and Ebulobo. Mount Wolo Bobo which looks like Mount Inelika is characterized by a number of tuff cones scattered in a north-south direction. The same lineage (northwest-southeast) is present in the Mataloko area. This straightness reflects the dike-shaped magma chamber under the Mataloko Geothermal Field (Muraoka et al., 1999) [2].

Geologically, Mataloko is a volcanic area that has displayed surface manifestations of geothermal areas. Volcanic clusters in this area were genetically an area of magma extrusion to form a series of volcanoes known as genetic volcanoes. Some of the mountains still display the remains of an inactive crater, but there are still ones that display a fumarole, namely Mount Wolo Bobo. Figure 2 shows a geological map of the Mataloko area and its surroundings. Many types of volcanic rock formed in the geological history of this area.
2.2. Mataloko Geothermal Area

From the appearance of rock types, the Mataloko area has many types of volcanic rock with geothermal activity which are quite prospective. There are many variations of volcanic rock types and their alterations due to the flow of heat energy and their location which is very much affected by tectonic plates followed by magma extrusion, causing this area to have a lot of fault and fracture structures.

The complexity of the geological structure, especially faults and fractures, causes that exploration and production drilling must be carried out very carefully so that accidents do not occur. Figure 3 shows a map of the geological structure of the Mataloko area and its surroundings.

The effect of the complexity of the geological structure is shown in the drilling of the MT-4 exploration well. This well not only penetrated various types of volcanic rock, but this well had penetrated 3 fault structures. The MT-4 well has cut 3 fault zones, namely at depths between 47.20-54.10 m, 71-126 m and 659-702 m. Drilling of these wells is not only concerned with the complexity of the geological structure, but due to faults and burrows which cause intensive fluid flow and result in hydrothermal alteration that occurs in many rock layers penetrated by the MT-4 well (Figure 4) [4].
Figure 3-a. Geological structure map of Mataloko area and its surroundings [3]
Figure 3-b. Geological structure map with surface manifestation of Mataloko geothermal field [12].

Figure 4. A) Log lithology, Casing Configuration, and B) P & T Profile of MT-4 geothermal well at Toda Belu, Mataloko [4].
2.3.  General Analysis of Mataloko Geothermal Exploration

Three shallow exploratory wells MTL-1, MT-2 and MT-3 have been drilled in the Mataloko geothermal field at Well-pad A. The first exploration well (MT-1), completed in year 1999 has shifted to MT-2 because MT-1 was plugged back with cement due to a sudden flowing and blowout of steam with gases (H2S & CO) around the cellar while drilling 9 5/8” hole at a total depth of 207.26 m on 18 October 2000 [5].

The next MT-2 exploration well has a total depth of 180.02 m, capable of delivering dry steam of 14.48 – 14.71 tons/hour (WHP = 5.79 – 5.88 barg) which is equivalent to ± 1 MWe (Sitorus et al., 2001) [6]. Further, it is known that the MT-2 dry steam well (superheated 0.12–21.28° C) is classified as high enthalpy (2713.5 – 2727.3 kJ/kg) at a temperature range of 151.9–176.8° C [7].

There are other three wells, namely Well MT-4, MT-5 and Well MT-6. Well MT – 4 was completed in 2003 and reached up to 756.47 meters depth. This well completed with slotted liner installed from 735 masl to 227 masl. Only one pressure and temperature measurement conducted in flowing condition in this well [8][9]. It is found that the drilling of MT-4 has also undergone mud lost circulation due to fractured zone caused by faults along the well hole.

3.  Discussion

Drilling geothermal exploration wells in the Mataloko field faces a formidable challenge. For example, technically drilling in the MT-4 well has lost circulation of mud, both Partial Lost Circulation and Total Lost Circulation. Not only lost circulation, but also in the well test the geothermal fluid experiences changes in pressure, temperature, and phase. According to Wahyuningsih et al (2004) [10], based on the pressure-temperature profile below the surface of the MT-4 well, it appears that the steam temperature range of 179.44 - 205.52 ºC at a depth of 550 - 747 m is greater than the saturation temperature. This condition indicates that the feed zone around a depth of 650 m flows superheated steam to the well bore MT-4. When steam flows and enters a depth of 500 m to the surface, the steam temperature decreases, even below the saturation temperature. Dry steam turns into wet steam (containing the water fraction) as it enters the cold zone at a depth of between 500 - 250 m and the water fraction is concentrated around a depth of 100 m.

In particular, the loss of circulation could be caused by geological conditions, where the MT-4 well has penetrated three fault zones. According to Nanlohi et al. (2005) [4], the MT-4 well intersects three fault zones, each at a depth of between 47-54.10 m, 71-126 m and 659-702 m. The structural zone at a depth of 47-54.10 m and 71-126 m is probably related to the deep resistivity discontinuity as proposed by Tagamori et al. (2002) [11], while the fault zone at a depth of 659-702 m is thought to be a Wae Luja fault segment.

Based on the experience of drilling up to MT-6, PT PLN (2020) [12] as the manager of the Mataloko geothermal field conducted an intensive study for planning and implementing the next well drilling. In particular, the lost circulation experience in the MT-4 well that breaks through three fault zones is the basis for the next drilling plan. By taking the lesson that drilling is carried out in areas with complex fault zones, boreholes should not be drilled along and in the direction of the fault plane, instead it should be planned to cross or to cut the fault area. Figure 5 shows the proposed well drilling plans at Wellpad A, B, C, and D.
Figure 5. Map of the proposed trending well plans grouped into Wellpad A, B, C, and D for geothermal exploration in the Mataloko field [12].

The well planned is a directional drilling that cuts the fault area. For example, in Wellpad A, three wells (MTA-01, MTA-02, and MTA-03) are planned to cut the Wae Luja fault to avoid lost circulation or other troubles. Figure 6 shows the cross-section of the MTA-01 well and the direction of its drilling. The drilling target is made based on conceptual model developed using Leapfrog geothermal software.

From the appearance of the geological structure of the Mataloko area, four major fault areas are a concern of this planning, namely the Wae Luja, Matawae, Tiwulina and Taranage faults. By knowing the direction of the fault plane, it is possible to anticipate drilling tools and equipment when penetrating the fault area, including the possibility of clamping of pipes and drill bits, lost circulation and other obstacles.

Figure 6. Geological cross section in the direction of the well MTA-01 proposed as directional drilling to cross the Wae Luja fault [12][16].
In connection with the dynamics of the island of Flores, tectonism and volcanism have caused quite a number of earthquakes around the island of Flores. Tectonism shows many large faults that are formed due to the movement of the earth's crust. Figure 7 shows the earthquake intensity and the relationship of the earth's crust around the island of Flores [13].

It should be noted that the tectonic movement of the island of Flores averaged over 30 mm/year to the southwest shown by plate motion vectors. The 1992 Flores earthquake and tsunami occurred on December 12 on the island of Flores in Indonesia. With a magnitude of 7.8 and a maximum Mercalli intensity of VIII (Severe), it was the largest and also the deadliest earthquake in 1992 [14][15]. Meanwhile, in the north of the island of Flores there are many epicenter earthquakes with a scale above 7 [13].

With this illustration, it is necessary to pay attention to the exploration of geothermal energy in East Nusa Tenggara, especially in Mataloko, Flores.

![Figure 7. The dynamics of tectonic plates in Nusa Tenggara to Western Australia as indicated by the direction of movement of the tectonic plates, the epicenter of the earthquake and the geological structures around the area which are formed due to tectonic movements of the earth's crust plates [13].](image)

**Figure 7.** The dynamics of tectonic plates in Nusa Tenggara to Western Australia as indicated by the direction of movement of the tectonic plates, the epicenter of the earthquake and the geological structures around the area which are formed due to tectonic movements of the earth's crust plates [13].

### 4. Conclusions

Mataloko is a prospect geothermal area that has a quite significant geological structures. From the drilling of the existing exploration wells, data and information can be obtained which should be the basis for consideration of the next well drilling plan. Important things that can be used as lessons include:

1. The occurrence of total lost circulation when crossing the geological structures (fault & fracture zones).
2. If the geological structure is in dynamic conditions, it can pinch and even break the pipe or drill bit.
3. The geothermal system that is formed is influenced by the shape and geometry of the geological structure.
4. The geothermal system can be evaluated by chemical analysis, by detecting hydrothermal alteration
to determine which cap rock, reservoir rock, and heat source are.
5. With respect to tectonism and volcanism of Mataloko area, it is important to pay attention of the
Flores island dynamics concerning the geological structures that formed by earth’s crusts and plate
tectonic movement.

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