Proceedings World Geothermal Congress 2010
Bali, Indonesia, 25-29 April 2010

Rinjani and Propok Volcanics as a Heat Sources of Geothermal Prospects from Eastern Lombok, Indonesia

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Keywords: Rinjani, Propok, Geohermal prospect, geology, age dating, MT, CSMT, hot springs.

ABSTRACT

The eruptive history of Sembalun–Propok-Rinjani volcanic complexes during the young Quaternary age had been studied. Those young volcanic complexes are as a good geothermal heat source of the Eastern Lombok prospects. The ages of Sembalun volcanic rock complex were formed during the last of 0.45 Ma. The pyroclastics of youngest Rinjani volcanic products was formed during a stratocone building stage between 0.012-0.006 M.a. The volcanic activity migrated more 5 km eastward for a low activity stage, erupting Propok pumice and Lembar dacitic lava flows. The Propok, Lembar and Rinjani volcanics seems to be as an up flow zone and good heat sources for a geothermal prospect of eastern Lombok Island. These areas are recognized by 10 Ohm-m resistivity zones of low frequency MT data and CSMT profiles. Out flow of neutral warm springs (25-38^{o}C) discharge at the eastward and northeast, approximately 2 km of the Propok craters. Therefore, these information may give an early assessment of Lombok geothermal prospects.

1. INTRODUCTION

Geographically, a complex of Sembalun-Propok-Rinjaani volcanics (1000–3726 m asl.) is located at the eastern part of Lombok Island, approximately 60 km from Mataram, the capital city of East Nusa Tenggara Province (Fig.1).

Volcanologically, Mt. Rinjani and Mt. Propok are not active volcanoes, having their last activities approximately 0.012-0.025 M.a (Nasution et.al., 2003), producing lavas and pyroclastic materials of andesitic to dacitic rock compositions. The thermal features consist of Fumaroles, steaming ground and hot springs, with temperature between 37–60^{o}C, having HCO_3-Cl type waters (Sundoro et.al. 2000). A low temperature of fumaroles (37^{o}C) on the Rinjani summit crater indicates an up flow fluid from the study area.

The geophysical surveys (MT and CSAMT methods) to define subsurface structures over a potential field are mostly used in many geothermal fields (eg.Ross, 1993; Mogi and Nakama, 1993; Widarto et al.,1997).

This paper describes the results of geological and geophysical studies to find out potential heat sources of the geothermal area.

2. FIELD METHOD AND EQUIPMENTS

Geological mapping of study area was conducted to understand the volcanic rock distribution, stratigraphy and volcanic structures. It is based on an aerial photo interpretation and field survey. Field sampling of fresh volcanic rocks and thermal features are mostly carried out at the lava flow outcrops along valleys and volcanic cones. Consequently, a young potential heat source will be obtained.

Two units of MTU-5A Phoenix Geophysics System were used to acquire data, cross-reference analyses were employed to obtained better data quality. The source of electro-magnetic (EM) energy for MT survey was a natural source with frequency range from 320 Hz to 0.001 Hz. By this frequency range, the effective exploration depth of this MT survey is estimated to reach 4,000 to 6,000 meters deep. The measurement of EM wave field was set up from evening to morning to reduce level of artificial noises. The time slot length or sampling rate used in this survey was 120 sec, thus lower frequency of EM wave will be obtained.

3.TECTONIC SETTINGS, GEOLOGY AND STARTIGRAPHY

Lombok island is located in the east Sunda arc on the crust of about 20-30km thick (Curray et al, 1977). Pleistcone-Holocene volcanic complexes on the island are caused by the northern subduction of Australian plate beneath Eurasian plate (Cardwell and Isacks, 1978; Hamilton, 1979). Calk-alkaline Quaternary volcanoes develop on the basement of Tertiary sedimentary, volcanic, and intrusive rocks. The Quaternary volcanic is divided into two types, the old volcanic complex and younger volcanic, simplified as followed:

3.1 Old Volcanics

The andesitic lavas and pyroclastics of old Sembalun volcanic complex in the eastern part, is topographically separated from one another, having an age of ± 0.45 Ma.

3.2 Younger volcanics

They are constructed by Stratocone building stage, Low activity stage, Syn-caldera stage and Post-caldera stage. Two volcanics which associated with geothermal potential heat source are Rinjani and Propok volcanic. During strato-cone building stage, Rinjani (3726 m) which is characterized by strongly altered edifice as old eruption centers, form an east-west crater, having a 800 m wide and 500 m deep. A continuous stratigraphic sequence above lava flows in the lower part of Rinjani volcano is observed at the northern flank. Scoria flow containing charcoals gave ^{14}C ages of 11980 ± 40 years B.P.

During a low volcanic activity stage, the volcanic activities compose of dacitic Propok lava distributing 7 km in length and ± 50 m in average thickness originated from an ENE-WSW fissure, while the Propok dacitic pumice deposited close to the Propok eruption center.

Rinjani fall deposits (ash, pumice, scoria) on the eastern part, and along the caldera rim of Segara anak (Fig.2), derived from the present crater of Rinjani summit.

3.3 Syn - to Post Caldera stages

During the caldera forming stage, the main eruption products are emplaced, at the outside and inside of Segara Anak caldera, known by un-welded to welded dacitic ignimbrites (Fig.2). Post caldera stage of Rinjani is recoqnized by development of Barujari active volcano (2400m) which is located inside a caldera. It erupted in 1884, 1904, 1906, 1909 and 1915, producing ash materials (Kusumadinata, 1979). The Barujari eruption in 1944, 1966, 1994, 2004 and 2009 produced pyroclastic materials and lava flows of basaltic andesite.

3.4 The Geological structures

Based on image (JERS-1) and landsat, the fracture dan fault structures show south-east directions (Fig.2), caused by a north-south tectonic compression of Sunda arc (in Java, Bali, Lombok and Flores). This lateral compression is initially formed by simetrical and un-simetry folds and faults, followed by transcurrent faults, which show twin conjugates normal faults (Suryono, 1986). A structural level concept (Mattauer, 1967 in Bles and Feuga, 1986) represents the study area is part of upper structural level, having brittle rocks, showed by a ”rose diagram” frequence and a cumulative length of the northwest-southeast fault systems (Fig.2) indicating subsurface permeable rocks of Sembalun, Propok and Rinjani volcananics.

4. GEOPHYSICS

Geophysical observation of MT was carried out at Mt. Propok, having measurement at 20-25 points, which distribute in 4 irregular lines with a spacing of 250 m (Fig.3a). For 2-D inversion, data from two sections were used, which pass through geothermal prospective areas. The first section, it passes through eight MT points, MP-20, 19, 27, 33, 39 to MP- 24, 13 and 14 (line-2); The second section, it passes through six MT points MP-23, 19, 26, 18, 17 to MP- 16 (line-4). Good data was mostly on a frequency higher than 1 Hz. However, for frequency below 1 Hz, the data is intermediate quality.

In general, 2-D inversion results for the three sections show a similar vertical resistivity distributions, from the upper to the lower layers. The upper layer has resistive values of 80 – 300 Ohm-m, which may be related to overburden, consisting of fresh of lava and pyroclastic materials. The thickness of upper layer is ranging between 500 to 1,000 meters.

The second layer has low resistivity values lower than 10 Ohm-m with a thickness of 1,000-3,000 meter. Presumably, the low resistivity derives from a combination of caprocks, which are rich in conducted minerals as known as conductive layer, and hydrothermal layers containing electrolite of hot water. Both components cause the second layers as conductive one. They are also supported by lateral and vertical CSAMT distributions (Nasution, et.al. 2009), representing low resistive zone at the Propok area (Fig.3b).

Below the conductive layers, resistive rocks which range from 15 – 40 Ohm-m take place, which is 1,500– 3,000 meter deep. This zone is assumed as a convection current area, propose to be a reservoir geothermal location. At deeper level (3,000 to 5,000 m deep), a very high resistivity layer is found. The resistivity values are mostly higher than 1,000 Ohm-m, that is of deep basement rocks, which is considered as a part of heat source.

5. DISCUSSION

The geology of study area is characterized by an Old Quaternary volcanic of Sembalun, and Young Quaternary Propok-Rinjani volcanic, having carbon-14 ages less than 0.012 Ma. The products mostly consist of andesitic to dacitic rocks of a calc alkaline suite. Hydrothermal alteration occurred and closed to a main old crater of Rinjani. The structures and fractures, which pass through the Rinjani-Propok complex, are mostly southeast-northwest directions, and associated with active thermal features indicating of young volcanic activities. It suggests the existent of prospective heat source of geothermal system.

Quaternary volcanic activity of study area was started by Sembalun volcanic complex, Propok and Rinjani complexes, affect and a young heat source, indicating a shallow cooling magma chamber (diorite to Granodiorite), as was shown by several existing geothermal fields (Darajat, Wayang Windu and Kamojang complexes). The thermal features of Propok-Rinjani complexes are composed of SO_4, HCO_3 and Cl type waters. Na-K and geothermometry represents the subsurface temperature between 220-250^oC (Nasution et.al., 2009) which is a good indicator for a geothermal reservoir.

Reservoir parameter and cap rocks are usually represented by a stratigraphy of altered lavas and pyroclastics materials, which are caused by hydrothermal processes. When altered rocks change to hydrothermal clay below the surface, they may become a cap rock layer of geothermal system. This system is clearly recognized from a low resistivity anomaly of MT result (<10 Ohm-m) to medium resistivity (15-40 Ohm-m) Propok-Rinjani geothermal system.

Several faults and volcanic structures are well recognized. They may be showing a heat transfer medium from a cooling magma to the surface, and a migration channel system to the shallow level, where a convective heat may occur below Propok-Rinjani complex. Structure and fracture zones as permeable rocks are recognized as productive zones. Therefore, the area has a parameter for a potential heat sources and a potential geothermal system. The deeper heat sources may probably derived from dioritic to granodirotic intrusions of the complex.

MT survey is successful in identifying the extent of the alteration halo overlying active geothermal systems, reflecting an area of conductive clay. The high resistive zones are found out at the shallow and deeper levels, particularly at below 500 m to 1 km depth which are shown at the east flank of Rinjani and Propok volcanic (Fig. 4a and 4b). The low resistive zone has values smaller than 10 Ohm-m. These values presumably have a low temperature of gases (< 400^{o}C) that may affect condensate layer at lower part at the surrounding complex.

Below the condensate layer, a zone of low resistivity values (15-40 Ohm-m) may occur, and usually associated with a vapor or a water zone. Based on these values, the geothermal complex are probably associated with a hot water geothermal system. Therefore, one detailed exploration well is recommended to be drilled at the most productive area (Fig.4a).

The value obtained from the 2-D inversion process of CSAMT lateral and vertical distribution is shown by resistivity variation from deep volcanic rock layers, indicating a condensate zone (Fig.3b and 4b). This zone may be affected by H_2S oxidation, containing hydrated alteration minerals. These values may be associated with an impermeable materials at the depth, representing a cap rock as a self-sealing process. At some places, alteration processes may occur toward the surface layers, as shown at the east flank of Rinjani (Fig.4a and 4b).

Based on the geology, geochemistry and geophysical data, the model of geothermal system may give a better structural configuration at the sub-surface (Fig. 5). It shows a flow of the geothermal fluids in reservoir. Therefore, these models may be used for the future exploration target of the area.

6. CONCLUSION

The young Quaterary volcanic of Propok-Rinjani are one of a newly geothermal prospect area in Lombok volcanic flank indicating H_2S gases is intensively affect the fresh rocks. MT and CSAMT analyses point out resistivity variation of conductive and resistive layers. Two-dimensional inversion result shows that upper layer has 80 – 300 Ohm-m, which may be related to relatively fresh pyroclastic and blocky materials, with a thickness of 500-1000 m. The second layer has resistivity lower than10 Ohm-m, which is 1000-3000 m thick, possibly associated with a conductive structure and it represents a fluid flow from a deeper level. A potential reservoir is assumed at the depth of 1500 m to 3000 m, indicated by resistivity values of 15- 40 Ohm-m. A very high resistivity value (>1000 Ohm-m) at a deeper level (3000 m to 6000 m deep) may be related to dioritic to granodioritic (basement) rock, which are potential heat sources of the area.

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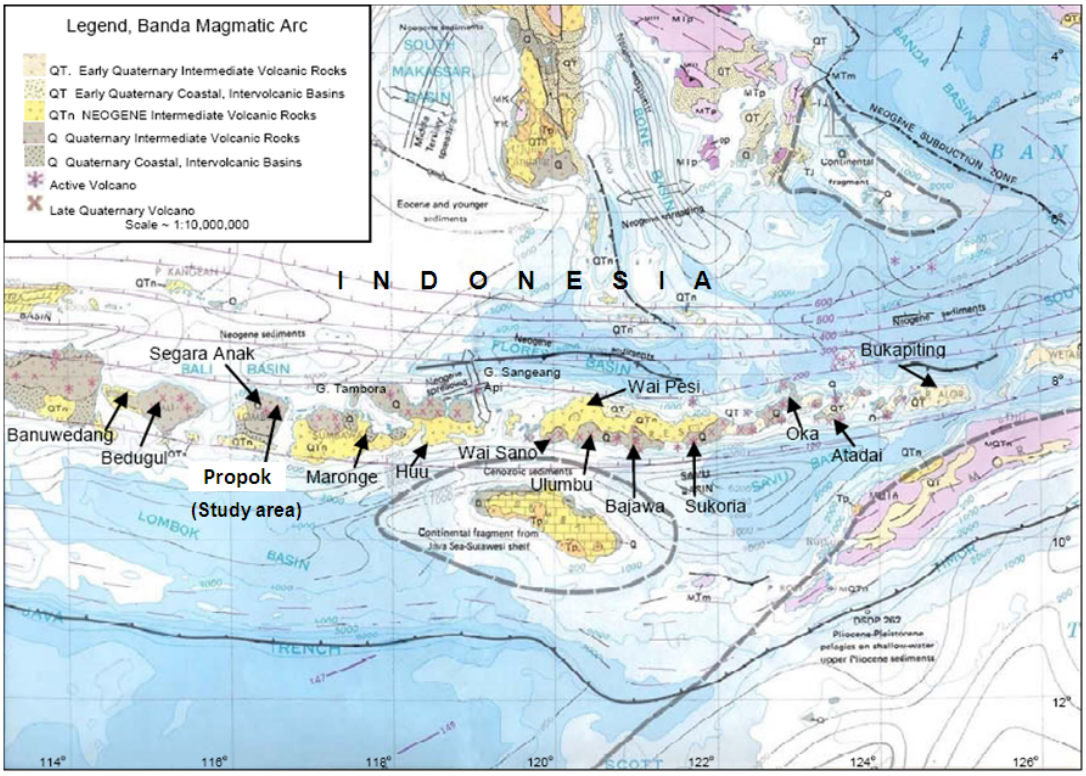

Figure.1 The location of Propok prospek, Lombok (From Johnstone, 2005, ct. map of Hamilton, 1979).

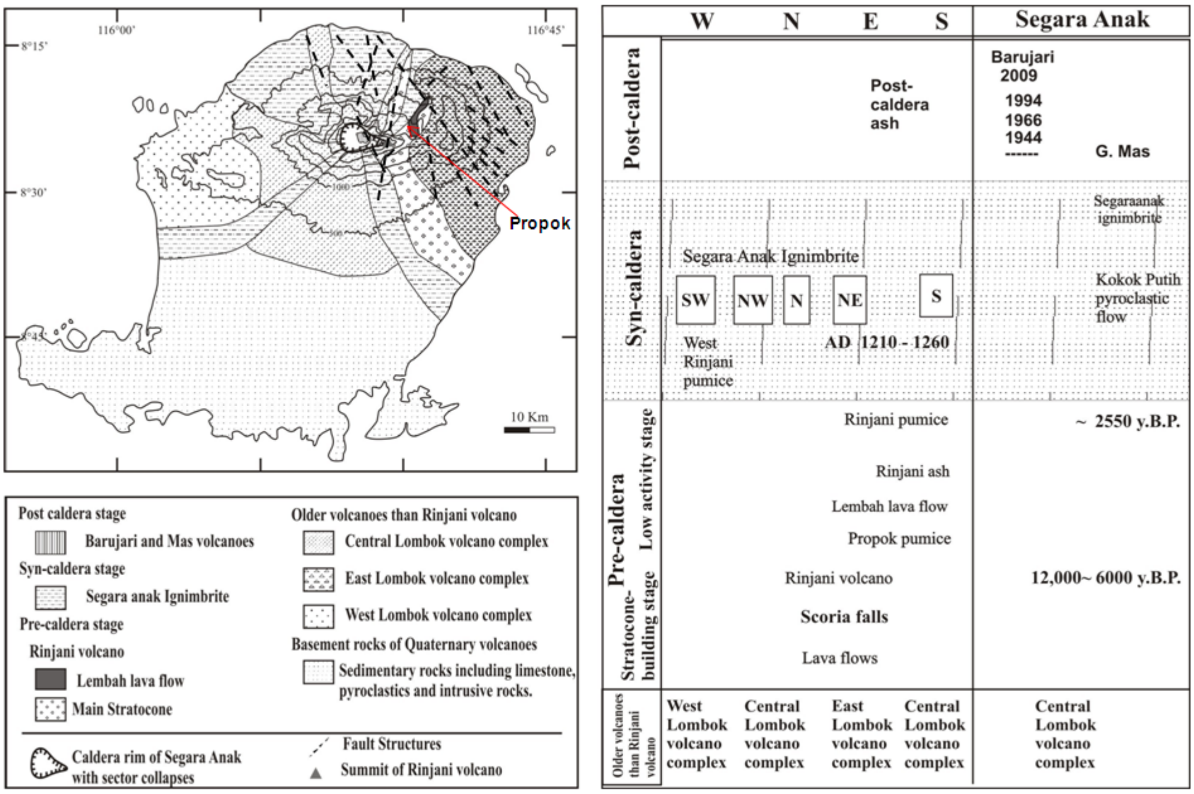

Figure. 2 Distribution and stratigraphy of Study area (Modified from Nasution et.al., 2003)

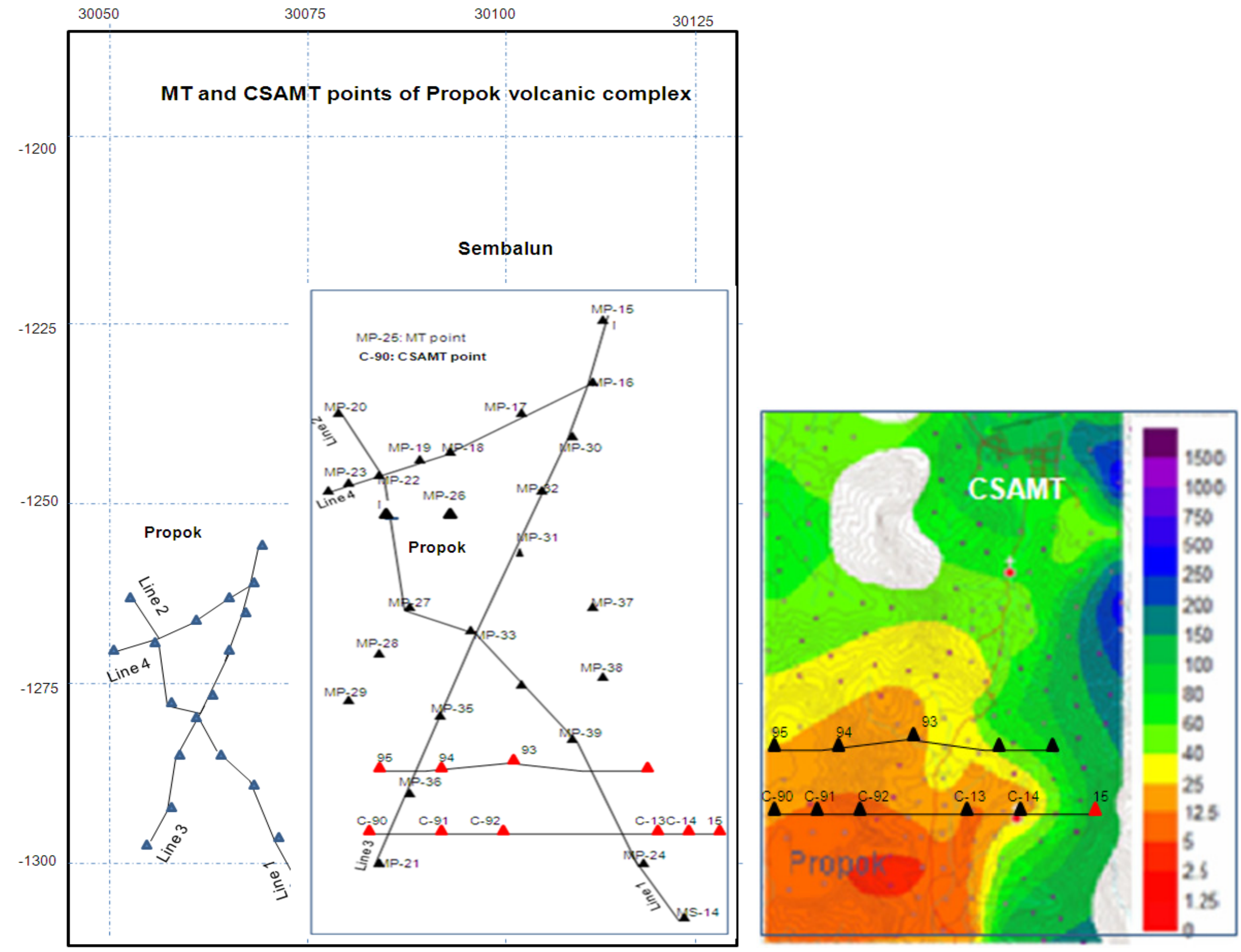

Figure.3 MT Measurement of Propok(A) and low CSAMT Distribution (B)

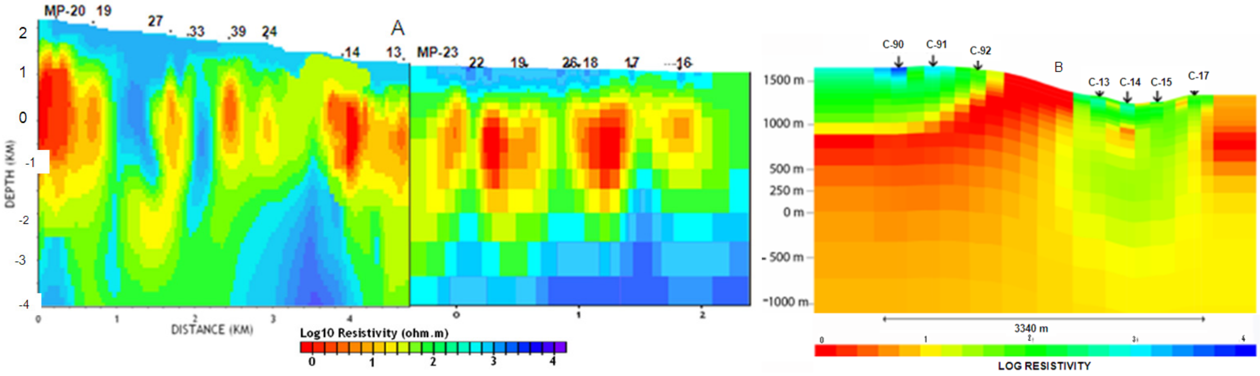

Figure.4 The Cross section MT (A) and CSAMT (B) of Propok area

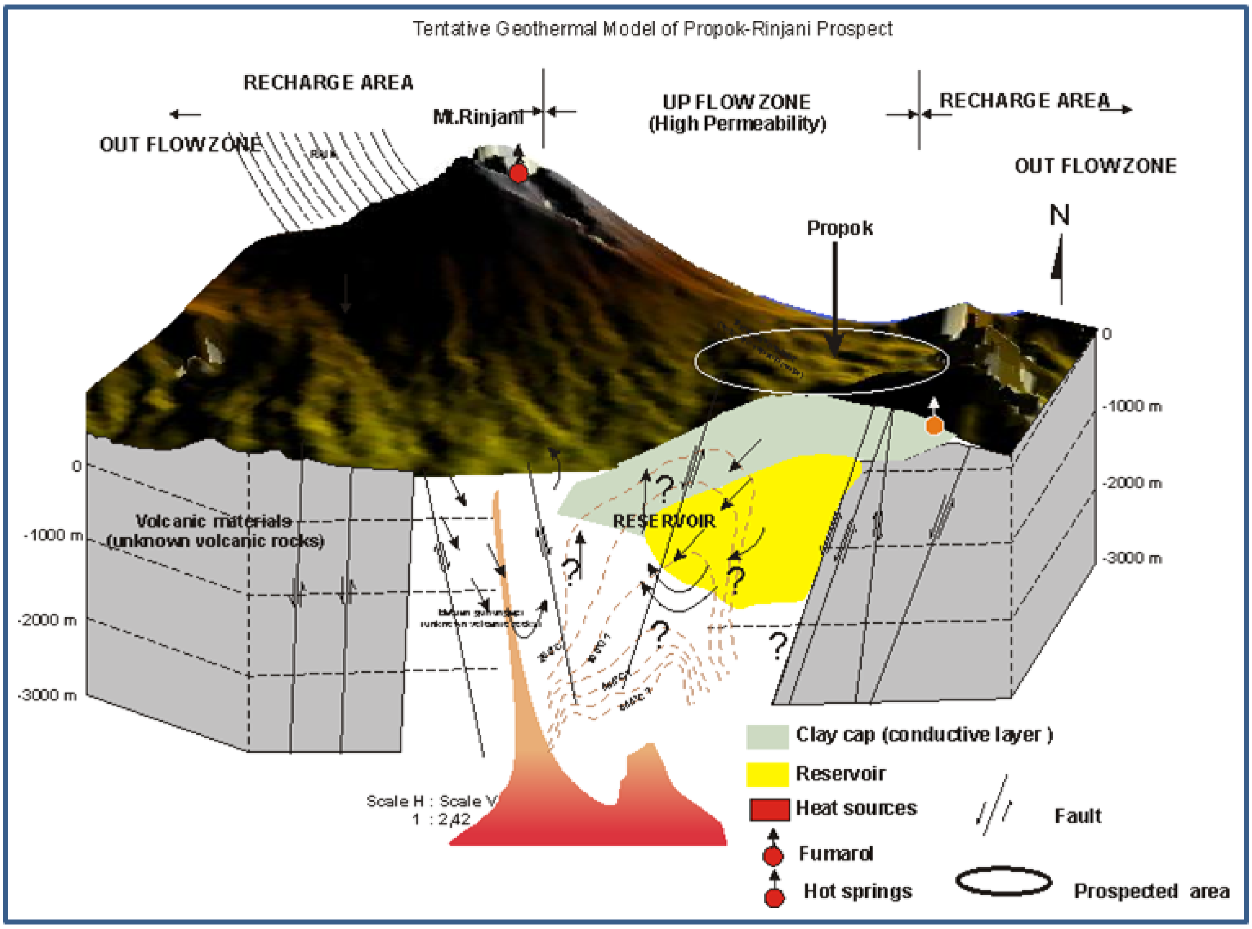

Figure. 5 Geothermal tentative model of Propok-Rinjani Prospect