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The Preliminary Conceptual Model of Tolehu Geothermal Resource, Based on Geology, Water Geochemistry, MT and Drilling

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ABSTRACT

The low topography Tolehu geothermal area, approximately 70 m above sea level is located in an Ambon volcanic island, Indonesia and has long been studied. The re-surveyed by additional MT-TDEM methods, continued by shallow gradient thermal drillings and an exploration well, which is 930 m is to constrain a preliminary conceptual model for the prospect. The integrated 1D and 3D MT inversion images with data from geochemical thermometry and wells had indicated a temperature resource having over 200ºC.

Shallow cores of about 150 m depth and deeper drill cuttings until 930 m depth were analyzed by using petrography and X-ray methods. At the shallow level, they had confirmed that the low resistivity detected by MT-TDEM surveys closely correlated with the distribution of low and high temperature smectite-illite and chlorite clay alteration. The extreme temperature of a thermal gradient well at the shallow hole represents 123^{o}C at the depth of 150 m. The deeper level of overlying volcanic rocks assumed as a clay cap, due to the greater tendency of clay minerals, eq. illite, smectite, phyrophlite, chlorite clay to inhibit the formation of fracture permeability relative to more brittle clays. The top of the permeable reservoir generally conformed to the geometry of the base of the low resistivity clay alteration. The rough correlation of geothermometry with the 5 and 10 ohm-m contours below the transition from smectite-illite - illite to chlorite clay were used to predict the depth of the cap rocks, with a maximum 800 m depth.

The water dominated reservoir has shown the Chloride's concentration lower than 5000 ppm at the 930 m depth, which indicates sea water un-involved to the geothermal system. The extended wells will be drilled to the south an old volcanic complex to confirm the elements of the model and to prove geothermal reservoir until 1.5 to 2 km depth.

1. INTRODUCTION

Geographically, a complex Tolehu geothermal area (10–450 m asl.) is located at the eastern part of Ambon Island, approximately 20 km from City of Ambon, the capital city of South Maluku Province (Fig.1).

Volcanologically, Mt. Eriwakang (± 350m asl.) and Mt. Salahutu complex (± 900m asl.) are not active volcanoes, which have no information of their last activities. They produce lava and pyroclastic materials of andesitic to dacitic rock compositions. The thermal features consist of inactive fumaroles, and hot springs, with temperature between 37–80^{o}C, having HCO_3-Cl type waters (Nasution, et.al. 2010). A low temperature of fumaroles (40^{o}C at 40 m depth) on the Banda village crater indicates an up flow fluid from the study area.

The geophysical surveys (MT methods) to define subsurface structures over a potential field are mostly used in many geothermal fields (eg.Ross, 1993; Mogi and Nakama, 1993; Uchida, 2010).

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

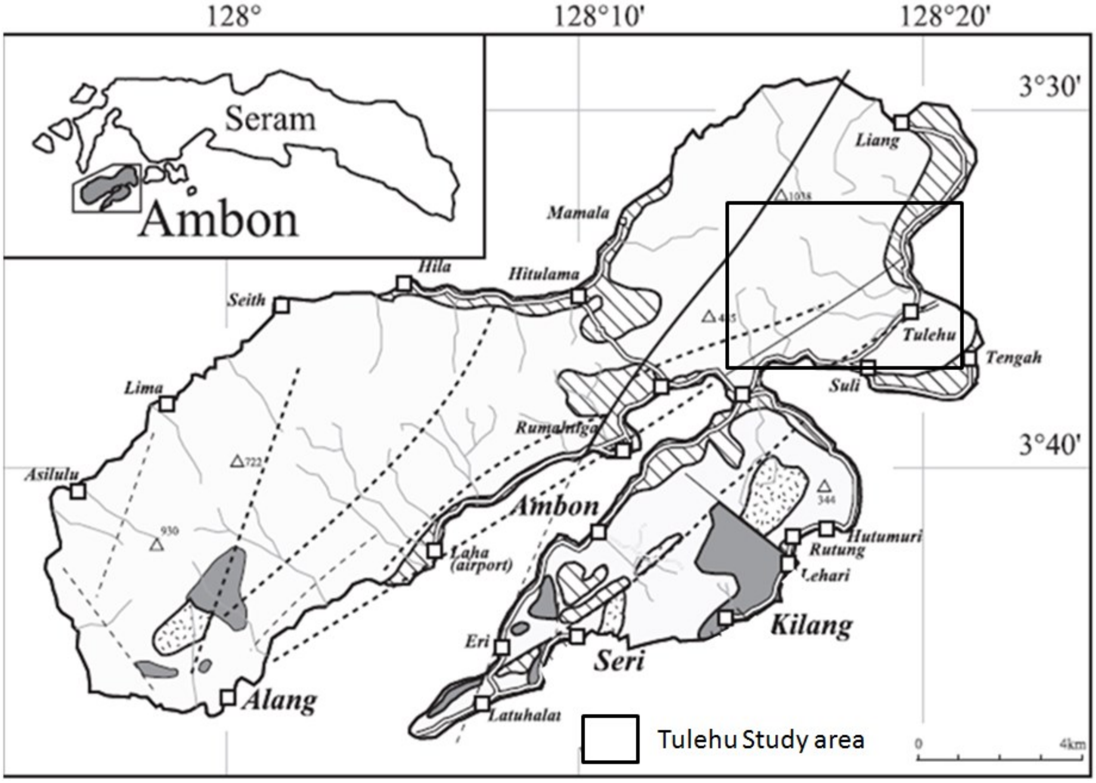

Figure 1: Location of Tolehu geothermal study area, Ambon islands (modified from Monnier et al., 2003)

2. FIELD METHOD AND EQUIPMENTS

2.1 Geology

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.

2.2 Water and gas chemistry

Geochemical water and gas analyses may give information on geothermal prospects. White et al. (1971) studied characteristics of chemical elements in high-temperature and high-pressure fluid. Mahon and Ellis (1977) classified geothermal prospects based on their water geochemistry and volcanic activity. Giggenbach (1988) classified hot springs by anion type, effect of dilution and associated rocks. These methods give geothermal information of potential areas.

Field samplings of hot water and gases were carried out in 1994 and 2009. The hot spring water samples were mostly collected from the surroundings of the Tolehu and Eriwakang volcanic areas. The temperatures of water and fumaroles range from 37^{o}C to 80^{o}C. The analytical methods used for hot springs are listed in Table 1.

Table 1: Laboratory analysis methods for hot springs

Parameter	pH	Cond.	HCO_3	CL	SO_4	SiO_2	B	F	Na	K	Ca	Mg	Li	NH_3
Method	PH	CM	TM	TM	CO	CO	TM	CO	FE	FE	TM	TM	FE	CO
Unit		μ S/cm	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l

Legend: CM: Conductivity meter; TM: Titrimetry; CO: Colorimetry; ICP: Ion Chromatrograph

To assess the subsurface temperature, water and gas geothermometry were used, composing of Na/K, SiO_2 and D'Amore and Panichi (1980) respectively.

2.3 Geophysical method

Three 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 2,000 to 4,000 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

3.1 Tectonics

In general, the tectonic of Seram-Ambon Series is strongly influenced by the interaction of the Australian, Pacific-Philippine and Eurasian plates from the Late Miocene until the present. This interaction has led to periods of thrusting, uplift and erosion of the Island. The processes active are reflected in the presently observed structural style (Kemp and Mogg, 1992).

Regional geology of Ambon Island is located in the northern Banda arc. They represent the low-K suite results from the evolution of basaltic magmas derived from mantle melting above the Western Irian Jaya plate which subducts along the Seram trough (Honthaas at al., 1999), as shown in a Fig.2. Based on these authors, the volcanics represent a new Plio–Quaternary island arc, i.e. the Ambon arc, extending west–east from Ambelau to the Banda Archipelago active low-K volcanoes through Kelang, southwestern Seram, Ambon, Haruku and Saparua (Honthaas at al., 1999).

Pleistcone volcanic complexes on the islands of Ambon, Haruku to the east are caused by the northern subduction of Australian plate (Western Irian Jaya Plate) beneath Ceram Trough (Honthaas at al., 1999 ;). The volcanic arc had a crust of about 20-30km thick (Curray et al, 1977; Hamilton, 1979).

According to Honthaas at al.,(1999), the time of magmatic events and the geochemical features of the studied lavas are clearly different from those of the southern part of the Banda arc, in which the low-K suite. This is in agreement with earlier seismic evidence for two different slabs subducting beneath the Seram–Ambon continental block and beneath the southern Banda arc (from Wetar to Manuk), respectively.

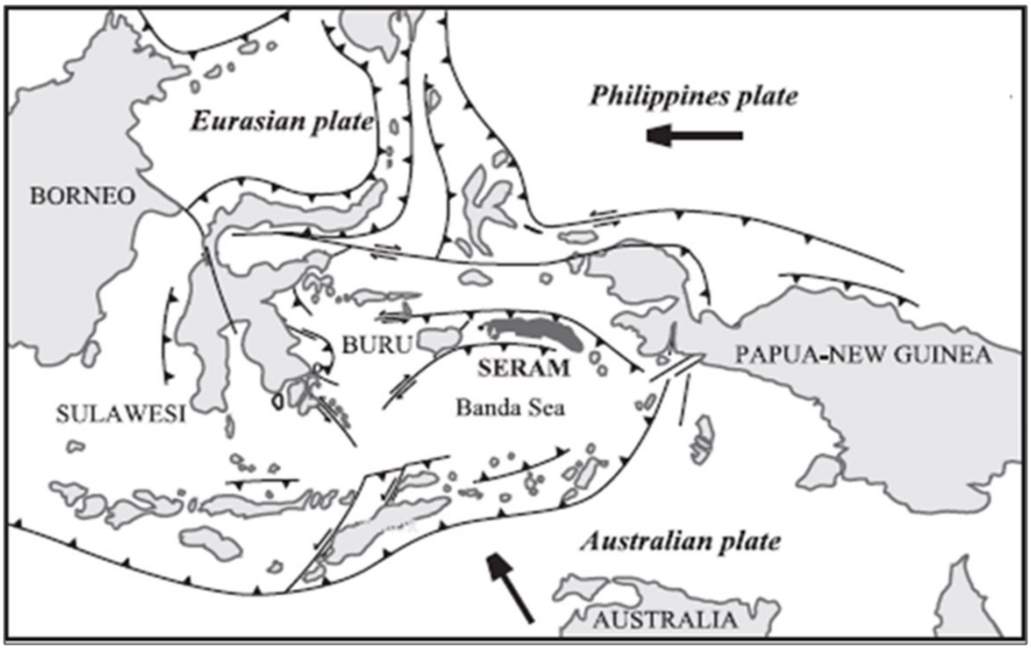

Figure 2: The tectonic maps of eastern part of Indonesia, where Seram-Ambon islands in a part of the archipelago (from Monnier et. al., 2003)

3.2 Geology

The sediments, the Calk-alkaline and tholeitic volcanic rocks of Neogene to Quaternary ages develop on Tolehu geothermal prospect area. The Tertiary sedimentary basement, volcanic, and intrusive rocks are deposited in the lower part, and distributed in the northern area. The Quaternary volcanic and young lime stone are mostly distributed in the southern area (Fig.3). They are simplified as follow.

3.2.1 The Old Sedimentary materials

The sedimentary rock composed of sand stone and tuff of Tertiary age (Fig.3). They crop out at Wairutung River, at 420066.864mT; 9603718.067mU, and 72 m asl, having grey to dark color rocks. Their thickness is about 1.5 to 15 m, exposure along 100 m length, with the strike and dip 285 to 310^o and 11^o respectively.

3.2.2 The Neogene volcanics

The Stratigraphy of Neogen Volcanic rocks composed of Basaltic Tanjung lava, the dacitic lava and pyroclastic Salahutu unit, the andesitic lava and pyroclastics Bukit Bakar unit, the andesitic lava and pyroclastic Huwe unit and the pyroclastic Kadera (Fig.3). Their outcrops are exposed based on eruptive locality types, as shown in Fig. 3. There is no K/Ar dating of these rocks. Therefore, they are probably Neogene in ages.

3.2.3 The Quaternary volcanic and sediment

Based on rock formations, which covering the fields of Tolehu geothermal area, the rocks compose of Quaternary volcanic and limestone (coral reef) materials. The older volcanic is the Eriwakang volcanic deposits, which composed of ash, pumice, block lavas, exposed on the eastern flank, and along the creek of Banda small river (Fig.3). The Eriwakang volcanic are covered by coral reef, which probably derived from marine environment. The coral reef has 30-50 m thick covers surrounding of the Eriwakang volcanic. The Mt. Eriwakang seems to be a part of submarine volcano during Early of Quaternary age.

The superficial deposits consist of river, beach and low land volcanic deposits. They are mostly found in Tolehu beach, low land river Wairutung and Baguila bay. They compose of lost sand, lahars, clay, soil which is called as alluvial (Fig. 3).

During strato-cone building stage, Salahutu volcanics (900 m asl.) which is characterized by altered edifice as old eruption centers form small craters. A continuous stratigraphic sequence above pyroclastic material in the lower part of northern flank Mt. Eriwakang , strong altered zones are observed. They are Banda and Hatuasa alteration zones, which cropping out along at Banda Hatuasa fault. The altered rock containing soil carbon gave ^{14}C ages of 3000-5000 ± 40 years B.P (PLN report, 1994). They assume as a young geothermal activity of the Tolehu prospect area.

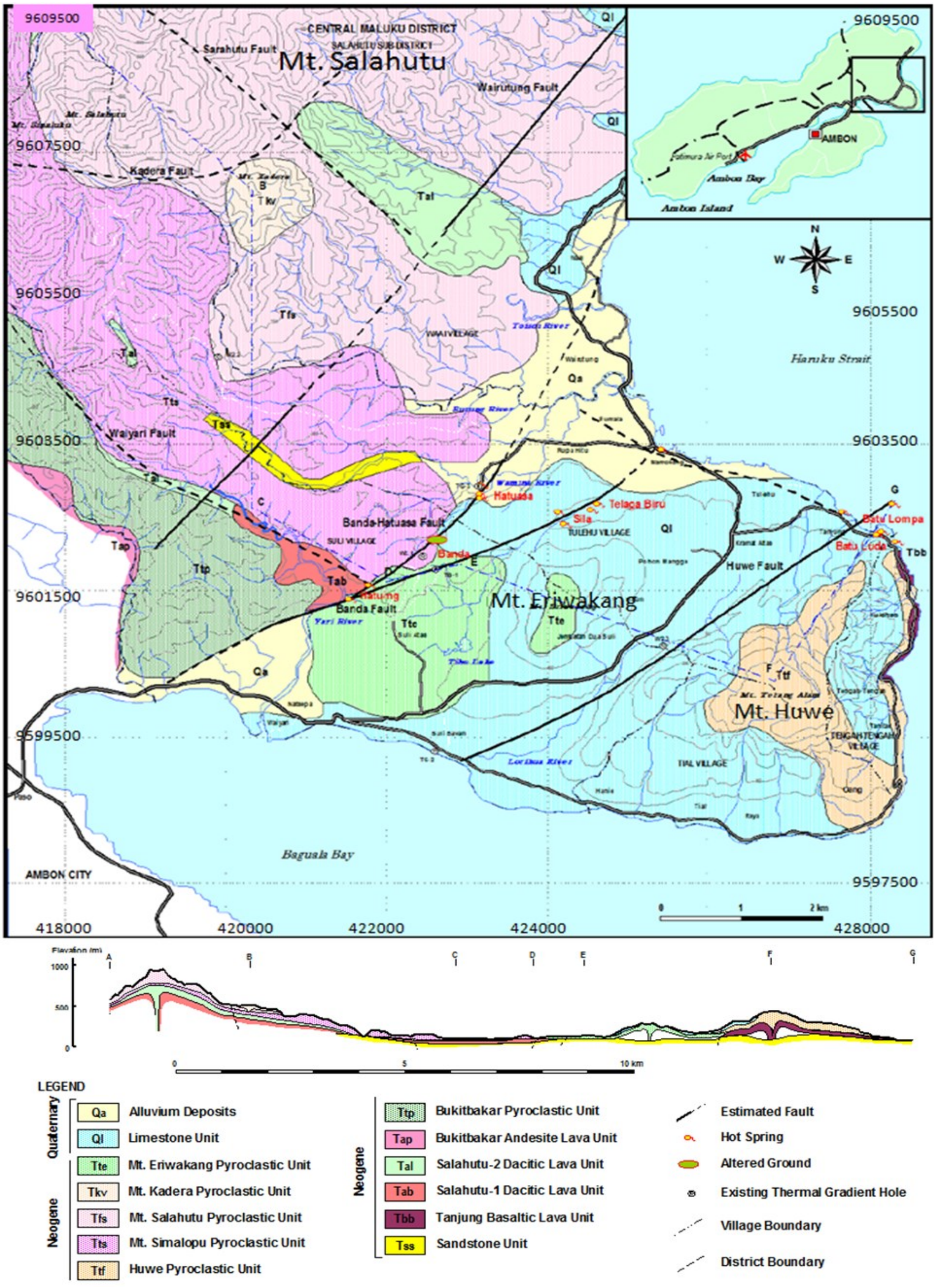

Figure 3: The Geology of Tolehu geothermal prospect area, Ambon

3.2.4 The geological structures

Based on image and landsat, the fracture dan fault structures, generally show south-west to north-east directions (Fig. 3), caused by a north-south tectonic compression by the northern subduction of Australian plate (Western Irian Jaya Plate) beneath Ceram Trough (in Ambon, Haruku, Ceram and small island to the East and west islands). This lateral compression is initially formed by simetrical and un-simetry folds and faults, followed by normal and 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 and a cumulative length of the southwest-northeast fault systems (Fig. 2) indicating subsurface permeable rocks of Banda village area, along Tolehu volcananic area.

The faults composed of Wairutung, Huwe, Banda Hatuasa, Waiyari, Salahutu Tolehu and Kadera faults (Fig.3). The Wairutung fault, which located at the northern part of the study area, is a normal fault with dipping to the SE direction. The Huwe fault, which located at the southern part, is a normal fault, having a dip to the NW direction. The Banda-Hatuasa fault, which located at the central part of study area, is a normal fault, having a dip to the NW and the fault pass through the Banda alteration zone. The Banda fault, which located in central part, is a normal fault with dipping to the NW direction and passing through hot spring areas. The SE-NW Tulehu fault, which located at Tolehu village, is a normal fault with dipping to the NE direction. Based on distribution of those faults, they are associated with a good permeability for Tolehu geothermal prospect.

The Waiyari fault, which located to the west of study area, has a right-lateral fault. The Salahutu fault, which located to the northern area, has a right-lateral fault. The Kadera fault, which located to the north of study area, is a normal fault with dipping to the South (Fig.3). The similar thing with these faults, they are probably associated with permeability for the reservoir rocks.

4. GEOCHEMISTRY

4.1 Water chemistry

The chemical composition of the water samples in Ambon Island was investigated in terms of relative Cl\ SO_3 and HCO_2 contents. The results shown in Fig. 1 and Table 3 permit us to distinguish Na-Cl type waters Na_Cl_HCO2 type waters and Ca_HCO_2 type waters "diamonds" [Further indications are provided by plots of alkali versus Cl]. In the Li vs Cl plot the Samples distribute along a unique alignment joining the low TDS cold springs with the thermal springs of Pulau Batulompa. This spread of points indicates the occurrence of mixing between a high Cl\ high Li component and a low Cl\low Li end member. The former is likely water coming from a deep\ high enthalpy geothermal reservoir\ while the latter is a shallow groundwater. A similar mixing trend is also observed in the Na vs Cl and K vs Cl plots. The physical and chemical characteristics of the hydrochemical types were identified in Figs. 4-6

Table 3 Chemical analysis of Ambon, Haruku hot springs (from Marini et al.,1999)

Location	N	T°C	pH	Li	Na	K	Mg	Ca	Fe	HCO_3	SO_4	Cl	SiO_2	Al	Σ_{cat}	Σ_{an}	%dev
Hatuasa	1	55.5	7.3	10.0	792	96.4	25.3	379	0.29	399	1.00	1900	212	0.32	59.34	60.27	−1.6
Hatuasa	2	28.0	7.4	0.5	51.0	4.9	12.6	59.0	0.46	242	0.30	82.3	33	0.26	6.42	6.35	+1.1
Hatuasa	3	54.0	7.3	9.8	771	93.9	19.0	368	0.17	387	5.50	1830	223	0.28	57.28	58.15	−1.5
Hatuasa	4	49.0	7.6	8.0	792	75.5	12.6	105	0.17	314	4.00	1340	205	0.19	43.82	42.96	+2.0
Hurnala	5	45.0	7.4	11.2	1310	108	63.2	135	0.12	628	93.7	2310	121	0.40	73.39	77.37	−5.3
Sila	6	80.0	7.4	28.0	1980	259	202	1010	0.67	145	101	5750	228	0.04	163.8	166.6	−1.7
Sila	7	89.0	7.2	27.0	1960	250	189	989	0.29	133	104	5710	216	0.06	160.4	165.4	−3.0
Sila	8	72.0	7.5	28.0	1980	259	177	1030	0.79	169	128	5730	192	0.05	162.8	167.2	−2.6
Sila	9	30.0	8.3	0.4	35.0	3.9	10.1	42.1	0.29	157	0.20	68.0	26	0.01	4.62	4.55	+1.6
Telaga Biru	10	46.0	7.6	14.4	1310	142	20.2	320	0.25	181	31.0	2710	123	0.01	80.46	80.14	+0.4
Telaga Biru	11	54.0	7.5	14.8	1330	149	22.7	328	0.12	47	35.5	2870	135	0.02	82.14	82.61	−0.6
T. Batulompa	12	53.0	6.9	7.6	831	72.9	60.6	303	3.06	616	0.40	1860	156	0.01	61.92	62.61	−1.1
Wesarisa	13	26.0	7.7	0.2	14.2	1.2	5.05	67.4	0.17	242	nd	10.5	48	0.08	4.45	4.26	+4.4
P. Batulompa	14	89.0	6.5	60.0	5400	583	909	1430	2.52	109	880	14200	270	0.61	404.8	419.9	−3.7
P. Batulompa	15	87.0	7.4	62.0	5450	602	935	1470	0.08	72	720	14300	201	0.56	411.8	418.6	−1.6
T. Batulompa	16	49.5	7.1	13.8	1410	135	96.0	177	0.88	362	244	2550	135	0.64	83.36	82.99	+0.4
Tulehu	17	51.0	7.5	6.6	573	65.3	60.6	118	0.12	701	50.5	987	184	0.94	38.41	40.41	−5.1
Tulehu	18	56.0	7.1	4.4	438	43.8	45.5	101	0.96	707	2.00	575	163	0.87	29.60	27.91	+5.9
Hurnala	20	35.5	7.7	14.0	1230	138	101	236	0.04	278	264	2430	47	0.26	76.72	78.55	−2.4
Wayela	21	27.0	8.0	0.1	7.1	0.8	7.50	50.5	0.04	199	0.20	8.1	37	0.31	3.49	3.56	−2.1
Hatuasa	22	28.0	8.0	0.3	27.5	3.0	5.05	63.2	0.08	193	0.10	54.2	16	0.22	4.89	4.71	+3.8
Karkuri	23	41.0	7.5	5.0	500	49.0	15.2	152	0.08	233	0.05	1010	47	0.24	32.53	32.26	+0.8
Talang Haha	24	56.0	7.4	8.5	698	75.5	60.6	236	nd	374	0.05	1540	123	0.17	50.26	49.57	+1.4
Telaga Biru	29	39.0	7.7	13.6	1320	133	5.05	312	0.08	143	17.0	2700	86	0.13	78.88	79.01	−0.2
Telaga Nini	30	31.0	8.1	0.1	5.7	0.6	5.05	59.0	0.25	217	0.05	4.6	5	0.09	3.64	3.76	−3.1
Seawater	SW	4	7.8	0.2	10560	380	1270	400	–	140	2710	19000	–	–	–	–	–

4.2 Subsurface temperature of water through SiO2&Na/K geothermometry

Chemical geothermometry using SiO_2 and Na-K components can be used for estimating the subsurface reservoir temperatures, particularly for neutral pH water. The application of SiO_2 geothermometry is available for neutral pH hot spring water, judging from the measured water temperature at the sites. The silica concentrations are high compared to other thermal discharges, particularly at Sila and Hatuasa hot springs showing 236.00 mg/l. In using SiO_2 geothermometry by Fournier (1981), the formula is

t^o = 1522/ (5.7 – log C SiO_2) – 273. By using this formula, the sub-temperature of Tolehu hot spring represent > 220°C. This is supported by silica sinter deposits which are found around Sila and Hatuasa hot spring areas.

The ratios of Na/K are represented in Table 1. The Na/K ratio in thermal water is basically controlled by the equilibration of ion exchange between the water and host rock minerals (mainly alkali feldspars). A high ratio of Na/K was found indicating that potassium poor minerals are formed in the country rock.

In using Na/K geothermometry of Fournier (1981), the formula is "t°C = 1,217/ [(log C Na/K) + 1.483] - 273". The calculated temperature of thermal discharges of water samples from Sila show the subsurface temperatures from 210 to230°C.

By using Na/K geothermometry of Giggenbach (1988), the formula is "t°C = 1390/ [(log Na/K) + 1.75] - 273". The calculated subsurface temperature of water samples from Sila and Hatuasa are from 230 to 240°C.

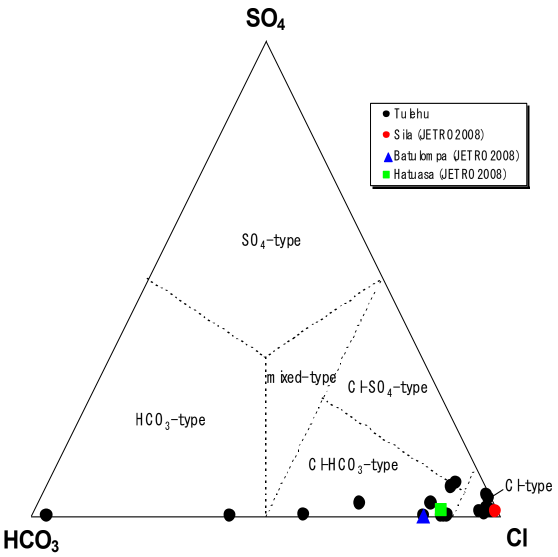

Figure 4: The tipe of hot water sample area

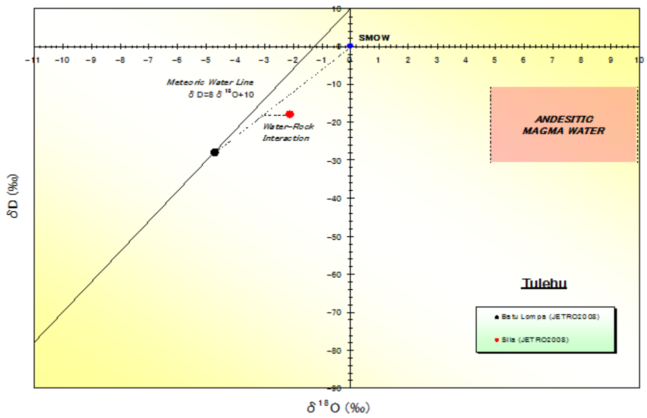

Figure 5: The isotop data of Batulompa and Sila

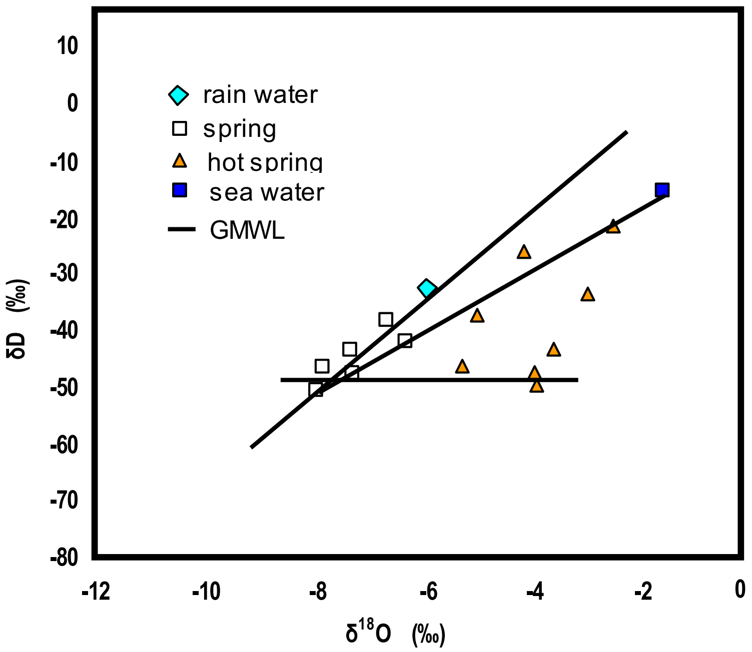

Figure 6: The isotop result of Tolehu geothermal prospect

5. GEOPHYSICS

Geophysical observation of MT was carried out at flank of Mt. Salahutu to Mt. Eriwakang, having measurement at 34 points, which distribute in 7 sistimatic lines (line A to Line G) with a spacing ± 750 m (Fig.7). The 3-D inversion, data from seven sections is used, where they pass through geothermal prospective Banda-Tolehu areas (Fig.8). The first to the seven sections show passing through line-A to line G, where every line having four (4) to five (5) MT points, as shown on Figs. 8 and 9 . Good data was mostly on a frequency higher than 1 Hz. However, for frequency below 1 Hz, the data is intermediate quality.

The data analysis represents the horizontal and vertical resistivity distribution over study area. These distribution assist interpretation from standpoint of electrical resistivity structure. Composed of 3 resistivity layers; shallow high resistivity layer (about 5 - 50 ohm-m), intermediate low resistivity layer (< 5 ohm-m) and deep high resistivity layer (> 20 ohm-m).

There are detection of 3 resistivity discontinuities, they are R1, R2 and R3 (Fig. 9). The Low resistivity zone (< 5 ohm-m) extends between R1 and R2. Relatively high resistivity body extends under this low resistivity zone.

In general, 3-D inversion results for the three sections show similar vertical resistivity distributions, from the upper to the lower layers. The upper layer has resistive values of 10 – 50 Ohm-m, which may be related to overburden, consisting of fresh rocks of blocky lava and pyroclastic materials. The thickness of upper layer is ranging between 50 to 150 meters.

The second layer has low resistivity values lower than 10 Ohm-m with a thickness of 300-700 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 MT distributions (Nasution, et.al. 2010), representing low resistive zone at the Banda-Hatuasa areas (Fig. 3b).

Below the conductive layers, resistive rocks which range from 15 – 100 Ohm-m take place, which is 800–2500 meter deep. This zone is assumed as a convection current area; propose to be a reservoir geothermal location. At deeper level (2500 to 4,000 m deep), a high resistivity layer is found. The resistivity values are mostly higher than 100 Ohm-m, that is of deep basement rocks, which is probably as a part of heat source.

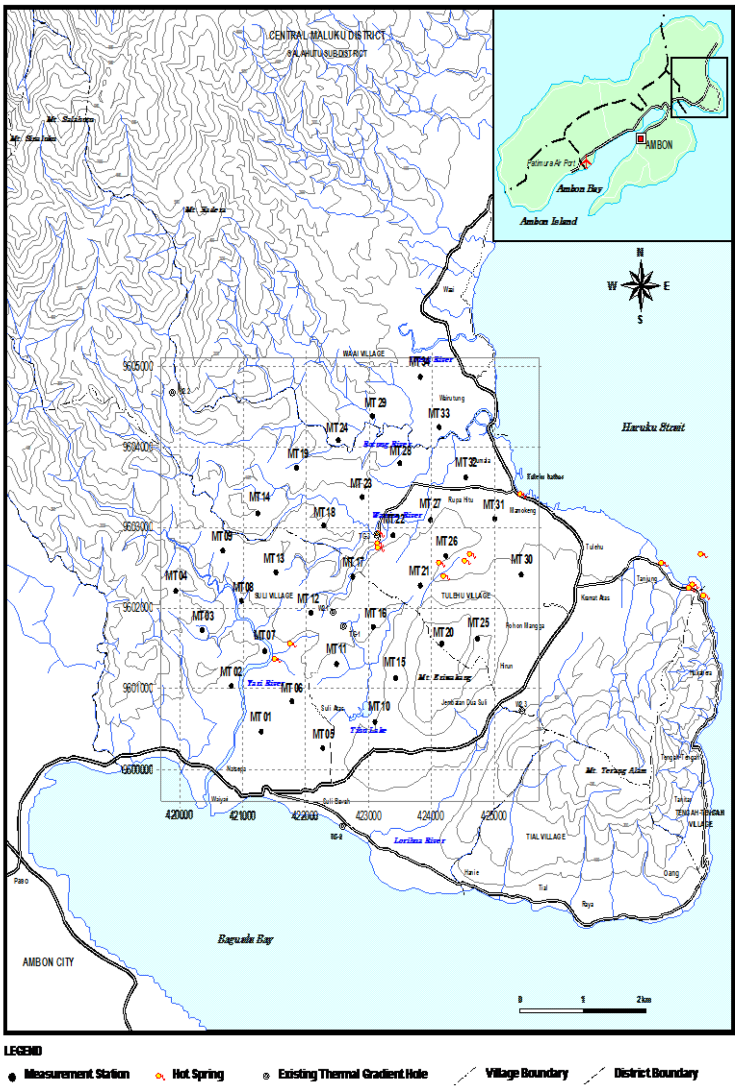

Figure 7: The geophysical lines for MT study

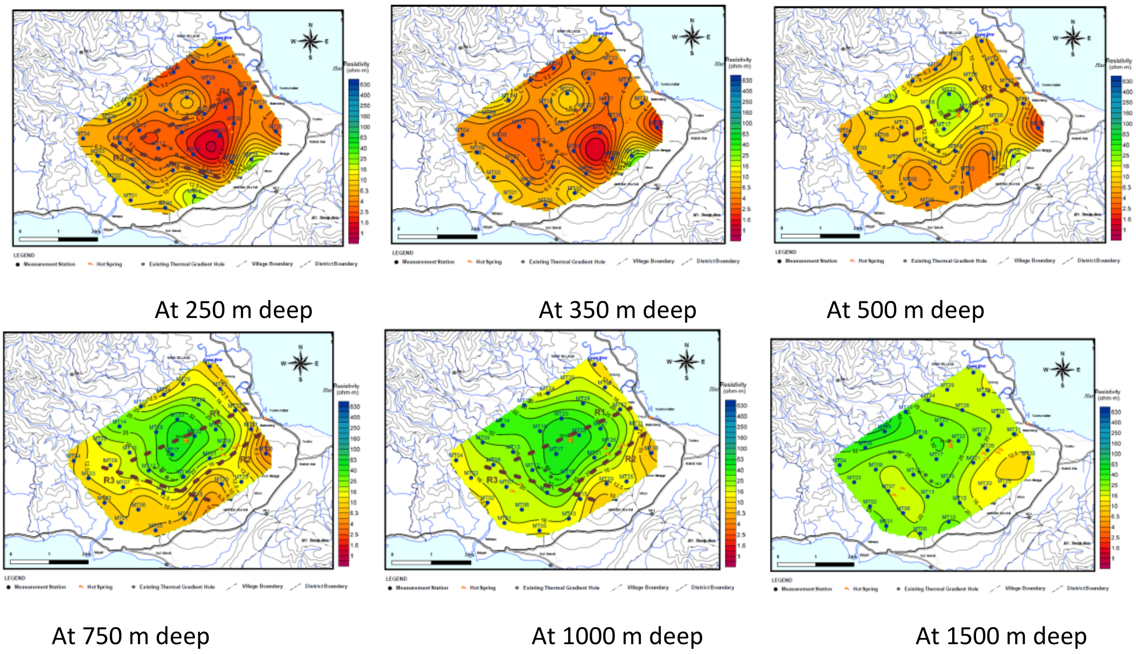

Figure 8: The Lateral distribution of resistivity values to the subsurface

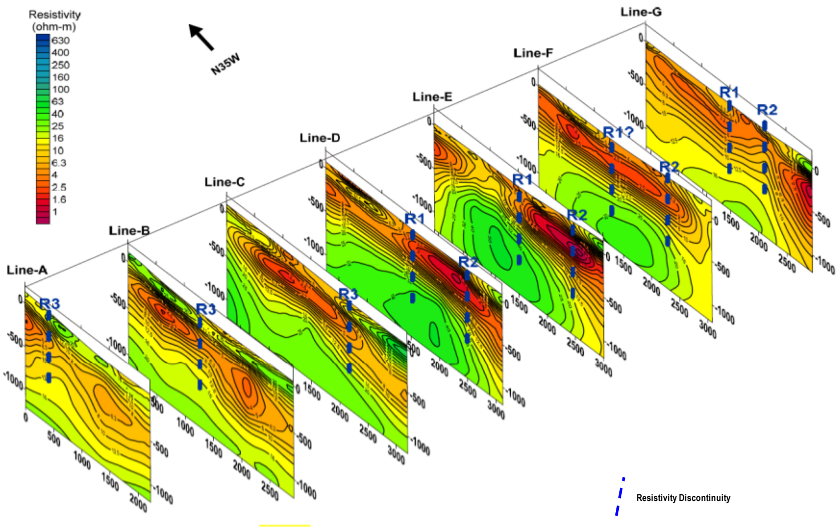

Figure 9: The vertical distribution of resistivity values to the subsurface of Banda-Hatuasa and Eriwakang area show 3 resistivity layers

6. DRILLING

Based on geo-scientific data (geology, geochemistry and geophysics), they represent: 1). the heat sources are probably an intrusive rock and Mt. Eriwakang old volcano 2). The chemical subsurface temperature (Na/K) is about 230°C 3). While the MT data show an up-flow zone, which associated with conductive layer at the upper part is located between lines B to F. Therefore, a drilling target for exploration wells is proposed formerly at line C, which close to R-3 structure (Fig. 9).

There are three gradient thermal wells (maximum depth 150m) and one deep exploration well (930m), were carried out. The gradient thermal well at the prospect area show low resistivity zone, indicate argilitic material, and has temperature 120°C at the depth of 150 m. The depth well (600-930 m) represents geological log data signs a high temperature and high permeability minerals, such as Epidot and Wairakite respectively. Therefore, the geothermal reservoir shows fractured rocks of permeable rock formation.

7. DISCUSSION

The geology of study area is characterized by an Old Quaternary volcanic of Salahutu, and Young Quaternary Eriwakang volcanic. The products mostly consist of andesitic to dacitic rocks of a tholeitic to calc alkaline suite. Hydrothermal alteration occurred and closed to an old crater of Banda volcanic. The structures and fractures, which pass through the Banda Hatuasa complex, are mostly southwest-northeast 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 Salahutu volcanic complex, Mt. Bukit bakar, Mt.Kadera, Mt. Huwe and Mt. Eriwakang, affect and probably 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).

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 (15-60 Ohm-m) Banda-Hatuasa 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 Banda-Hatuasa-Sila 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 Banda-Sila- Hatuasa and Eriwakang volcanic (Figs. 8 and 9). The low resistive zone has values smaller than 10 Ohm-m. These values presumably have a low temperature of gases (< 300^{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, detailed exploration well is recommended to be discussed at the most productive area (Fig.8).

The value obtained from the 3-D inversion process of MT lateral and vertical distribution is shown by resistivity variation from deep volcanic rock layers, indicating a condensate zone (Fig.8and 9). This zone may be affected by H_2S oxidation, containing hydrated alteration minerals. These values may be associated with 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 Eriwakang (Figs. 8 and 9).

Based on preliminary geological, geochemical, and geophysical data, including volcanological data and distribution of thermal discharges, the Prospect Tolehu are good for future developing geothermal energy for electricity, at least 20-30 MW. Detail potential resources are carrying out geophysical exploration (MT).

The model of geothermal system may give a better structural configuration at the sub-surface (Fig. 10). It shows a flow of the geothermal fluids in reservoir. Therefore, these models may be used for the future exploration target of the area.

The thickness of the permeable zone is approximately 250 meter span from a depth of 650 meters below surface. A water dominated reservoir was identified from its fluids characteristics. The permeability of the reservoir was in the range of 10-20 mDarcy and Skin Factor of more than negative 11, but this data were recovered while the well was in the very early time after completion. The reservoir formation pores could be blocked by fine material from the drilling operation that had used mud and hi-vis drilling fluids.

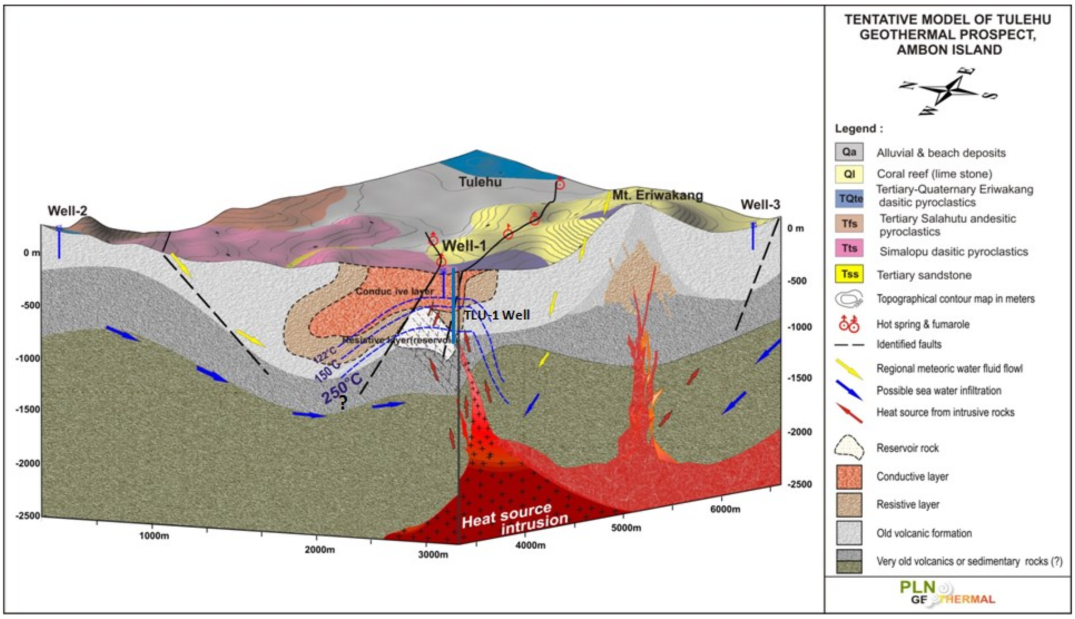

Figure 10: The Preliminary Conceptual Model of Tolehu Geothermal Prospect, based on geology, geochemistry, geophysics and drilling

8. CONCLUSIONS

The Quaterary volcanic of Eriwakang is probably one of a newly geothermal prospect area in Tolehu volcanic flank, indicating H_2S gases intensively affected the fresh rocks. MT analyses point out resistivity variation of conductive and resistive layers. Three-dimensional inversion results show that upper layer has 10 – 50 Ohm-m, which may be related to relatively fresh pyroclastic and blocky materials, with a thickness of 50-250 m. The second layer has resistivity lower than10 Ohm-m, which is 350-700 m thick, possibly associated with a conductive structure and it represents a fluid flow from a deeper level. A potential reservoir with a temperature of 230^oC is assumed at the depth of 800 m to 2000 m, indicated by resistivity values of 15- 100 Ohm-m. A very high resistivity value (>100 Ohm-m) at a deeper level (3000 m to 4000 m deep) may be related to dioritic to granodioritic (basement) rock, which are potential heat sources of the area.

In general Tulehu geothermal field is proven to possess geothermal reservoir having a potential energy resources that can be exploited from its fluids by drilling geothermal wells. By the end of TLU-1 well completion test it was observed that the geothermal fluids had once reached a temperature of 115^0C at the surface when the well was opened after the completion test. It has certainly higher temperature at the reservoir depth, and even higher if the reservoir is let to heat up in a certain time. Looking at the data and information from the TLU-1 drilling operation, there can be drilled other wells nearby to supply a geothermal power plant of a certain capacity depending on the performance of the geothermal wells.

Monitoring of fluid chemistry from depth well represent neutral chloride waters, which shows in partial equilibrium reservoir water. Therefore, this depth well has indicated a top reservoir geothermal system.

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