

Structural Traps of a Non Volcanic Hosted Geothermal Field Based on Geophysical Data of Waesalit Area Buru Island-Indonesia

Alanda Idral

Centre for Geological Resources - Indonesian Geological Agency
alanda_idral@dim.esdm.go.id or idal_idral@yahoo.com

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ABSTRACT

Waesalit geothermal field lies approximately 60 km SW of Namlea, the Capital City of Buru Regency, Maluku Province.

Geophysical methods (gravity, geomagnetic and resistivity) were carried out to delineate the structural traps of a non volcanic hosted geothermal field in Waesalit, Buru Island-Indonesia.

Geophysical data indicates moderate to high gravity and low geomagnetic anomalous around the Waesalit hot water, whilst the resistivity data show the resistivity value around the hot water is relatively high (20 – 110 ohm-m) compare to the value of a volcanic geothermal system (10 – 20 ohm-m).

Based on geophysical data, the structural traps of a non volcanic hosted geothermal field in the area is relatively similar to volcanic hosted geothermal area, whilst the heat source is considered to be associated to volcano-tectonic process on metamorphic rock.

1. INTRODUCTION

Waesalit geothermal field lies approximately 60 km SW of Namlea, the Capital City of Buru Regency, Maluku Province-Indonesia, and the UTM coordinates are 9615000 mU – 9620000 mU dan 261000 mT – 271000 mT, (figure 1). The manifestation consists of hot waters, alteration rocks, silica sinters and fumarols. The reconnaissance survey of geothermal manifestations in Buru Island was carried out in 2005 by Center for Geological Resources-Indonesian Geological Agency, and in the following year an integrated study was established by the same institution

The paper try to study the structural traps of a non volcanic hosted geothermal field in Waesalit Buru Island-Indonesia based on geophysical data that is correlated to geological and geochemical investigations and their correlation with hydrogeology, thermal structure and geothermal reservoir.

2. GEOLOGY AND GEOTHERMAL MANIFESTATIONS

The geothermal manifestation in the area is covered by Permian metamorphic rocks and Quaternary sedimentary deposit. The metamorphic rocks consist of schist, phyllite, and quartzite, whilst sedimentary deposit is composed by claystone, river deposit and alluvium.

The geological structures that are developed in the area consists of Waekedang and Waesalit oblique transform faults, Waetina strike slip fault and normal fault of Debu. The faults trending, generally, NE-SW and NW-SE, (PMG, 2007), figure 2.

The surface geothermal manifestations that are spread out along Waekedang river consists of hot waters (T: 99.2 – 101.6 °C), fumarols, hot grounds (T 85 - 98 °C), silica sinters and altered rocks (figure 3). The altered rocks is composed by clays mineral such as kaolinite, illite and alunite. The present of illite indicates the zone of phyllic hydrothermal with relatively high temperature (240 - 300°C), whilst the alunite indicates zones of advanced argillic. Alunite mineral, generally, associated with acidic hot water with high sulfide contents. Meanwhile, around Waesalit hot waters are also found yellowish sulphuric deposit that spread out from NE to SW.

3. HOT WATER GEOCHEMISTRY

Based on geochemical data, Waesalit hot waters are bicarbonate type with normal pH, and SO₄ is relatively high enough for a non volcanic hosted geothermal manifestation. Plotting of Na-K-Mg indicated Waesalit hot water lies at upper part of partial equilibrium line. Isotop O₁₈ and deuterium data shows the hot water is out site of a meteoric line. All of geochemical data indicated the hot water derived from deep waters. The range of reservoir temperature in term of surface chemical geothermometer is 227° - 247°C (SiO₂-conductive cooling), PMG-2007 and is classified as high enthalpy, (Badan Standarisasi Nasional, 1999).

4. GEOPHYSICS

4.1 Gravity

Regional and bouguer gravity anomalous trending E-W and the value of both anomalous tend to decrease to the north. of Waesalit hot waters, and the altered zone are covered by intermediate to high of regional and bouguer gravity anomalous (figure 4a-4b.).

The lination of residual gravity anomaly trending NW-SE and NE-SW in the west north and east south of survey lines. High lenses residual gravity anomalous are found around Waesalit and Waekedang hot waters and in the north northeast of survey lines, (figure 4c). The high residual gravity anomaly is considered to be associated with concealed volcanic intrusive rocks, while relatively low residual gravity anomaly in the southeast survey line is caused by depression zone that is filled with sedimentary deposit

The present of concealed volcanic intrusive rock underneath Waesalit hot water is clearly supported by the present of sulphur deposit around the manifestations and. 2.5 D gravity modelling (figure 5)

Gravity anomaly is also identified 5 fault structures which are trending NW-SE and NE-SW, those faults control the geothermal manifestation in the area.

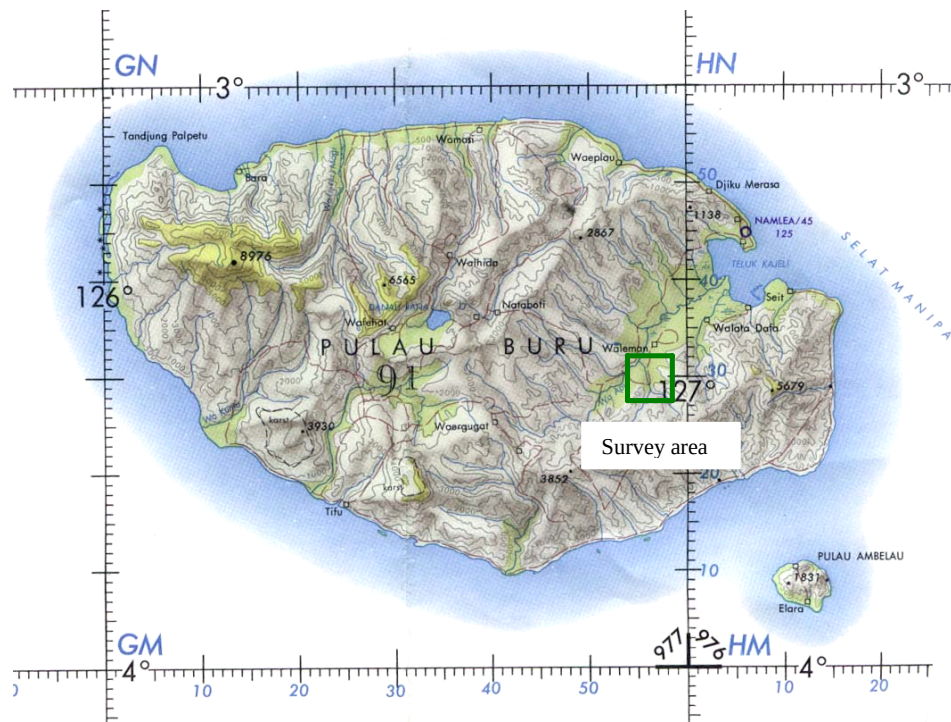


Figure 1: Waesalit survey area

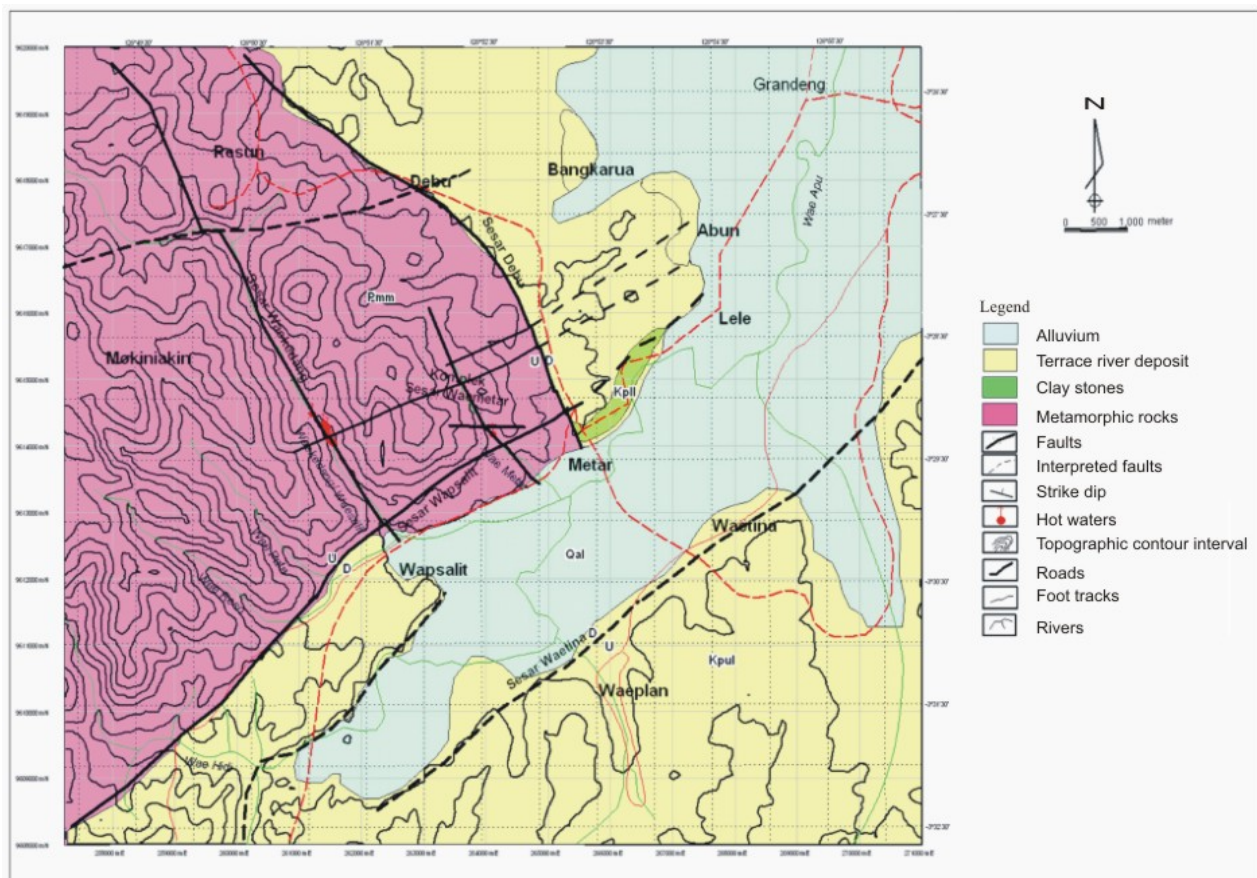


Figure 2: Geological map of Waesalit area (PMG)



Figure3: Waesalit hot water, hot ground and silica sinter

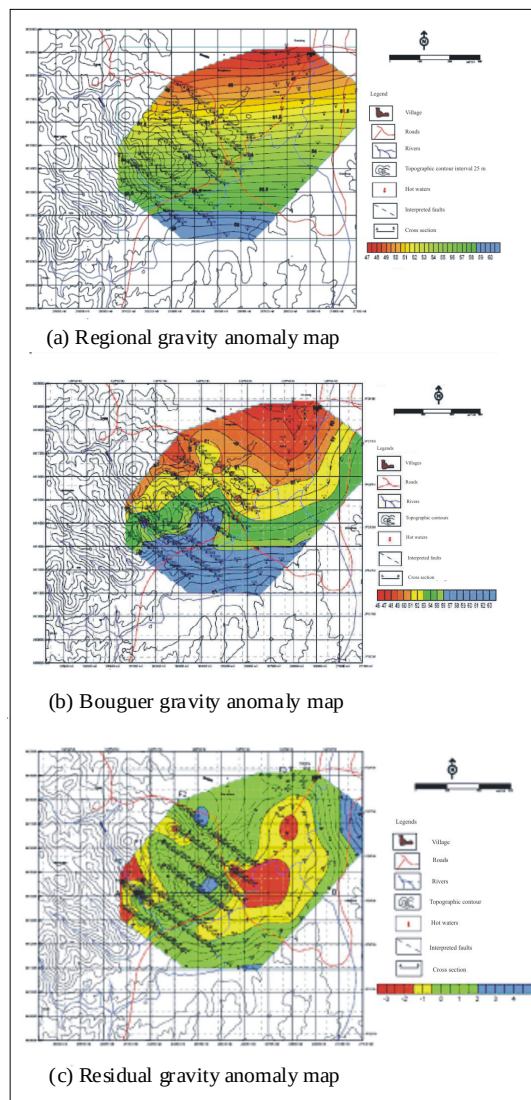


Figure 4: Gravity anomaly map

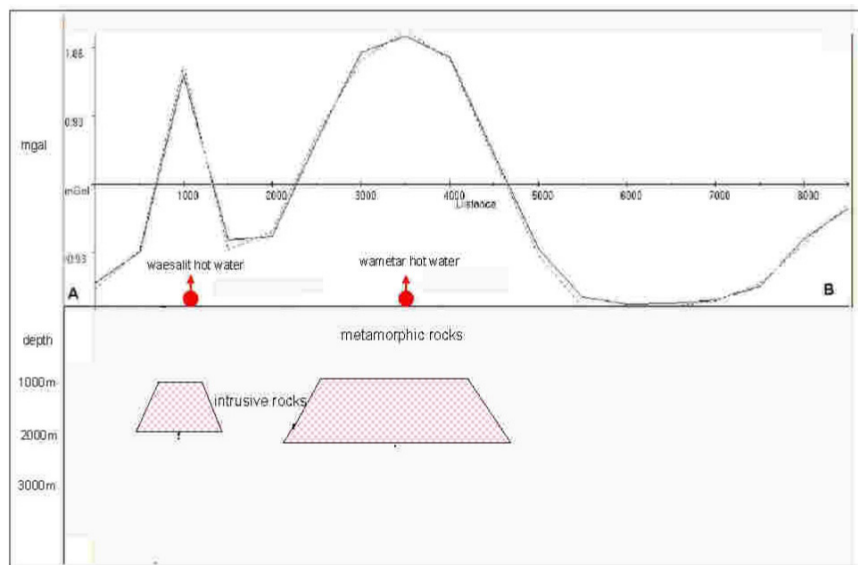


Figure 5: 2.5-D gravity model along cross section A-B

2 Geomagnetic

In general, low geomagnetic value (negative) is surrounded high geomagnetic value (positive) in the middle of survey area. (figure 6). Low geomagnetic value in the NW is associated with metamorphic rock such as schist, phyllite and quartzite (non magnetic rocks). However, very low geomagnetic value (> 500 nT) surrounding Waesalit hot waters is associated with altered rocks as seen in the field. The altered rocks is caused by hot hydrothermal liquid that demagnetized the rocks, and so give low geomagnetic value or response, whilst low geomagnetic value in the SE survey area is associated with depression zone that is filled with sedimentary deposits. High geomagnetic value in the middle of survey area is considered to be associated with phyllite rocks that poor of quartz compare to schist. Such as gravity data, geomagnetic data is also identified faults structure that is trending NE-SW, NW-SE and N-S, those fault control the geothermal surface manifestations.

4.3 Resistivity

4.3.1 Apparent Resistivity maps

Apparent resistivity map for AB/2: 250 m – AB/2: 1000 m (figure 7) showed three zone of apparent resistivity, such as: high apparent resistivity or resistive zone (> 110 ohm-m) in the north NW; moderate apparent resistivity or semi conductive zone ($60 - 110$ ohm-m) in the middle of survey area; and low apparent resistivity or conductive zone (< 60 ohm-m) in the south SE and around Waesalit hot waters. Low resistivity value around Waesalit hot waters indicate the manifestation is associated with upflow geothermal fluids (Anderson et. al . 2000).

High apparent resistivity zone is considered to be associated with fresh metamorphic rocks. Moderate apparent resistivity

zone at AB/2 750 m and AB/2 1000 m showed tongue shape that is trending NW to the Waesalit hot waters or to the high topographic zone and open to the SE or to the low topographic area. This condition indicates up flow zone in the moderate resistivity zone of geothermal system. Meanwhile, zone of moderate resistivity tends to increase with increasing the distance electrode current of AB/2. Low lenses resistivity area that covers Waesalit hot waters is associated with altered rocks that is caused by hot fluids goes up through foliations, faults and rock fractures of metamorphic rocks. Low resistivity zone in the south SW survey area is associated with sedimentary deposit.

4.3.2 True resistivity cross section

Figure 8 shows the true resistivity cross section that is trending NW-SW (A..3100-E.5500). The section indicates vertically and laterally: resistive layer with very high resistivity value; semi resistive layer with high resistivity value; semi conductive layer with moderate resistivity value; and conductive layer with low resistivity value. Resistive layer ($100 - >500$ ohm-m) is composed by fresh and weathered metamorphic rocks (schist, phyllite and quartzite). The layer is up to 100 m depth. Semi resistive layer ($100-200$ ohm-m), the thickness is > 700 m. The layer is interpreted as fresh metamorphic rocks. Semi conductive layers ($50 - 90$ ohm-m), the layer is considered as weathered and slightly altered of metamorphic rocks that is found at $100 - 450$ m depth of local ground, with the thickness of > 750 m. Conductive layer ($20 - 30$ ohm-m) or clay cap is an altered metamorphic rock and or concealed intrusive volcanic body. The clay cap is found at the depth of > 850 m with the resistivity value of 20 ohm-m. Underneath this layer, at the depth of > 1000 m, is found another semi resistive layer with the resistivity value of 125 ohm-m. The layer is interpreted as a reservoir.

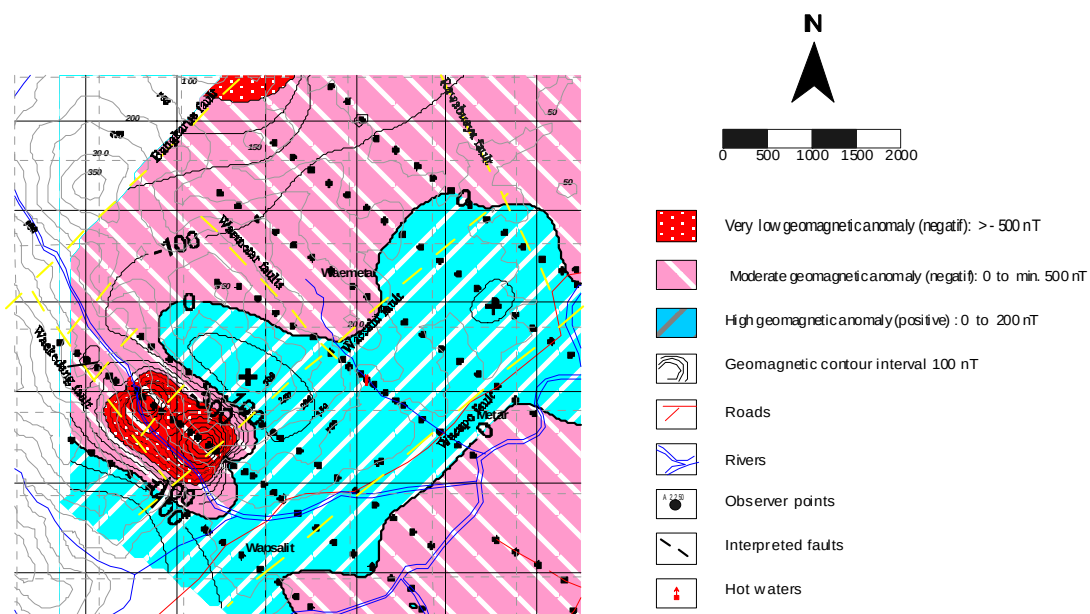
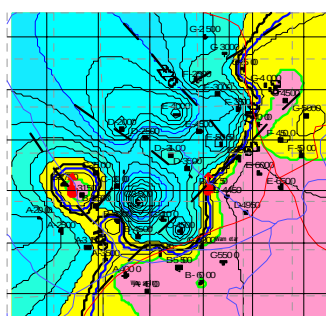
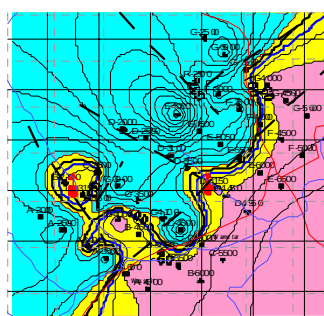


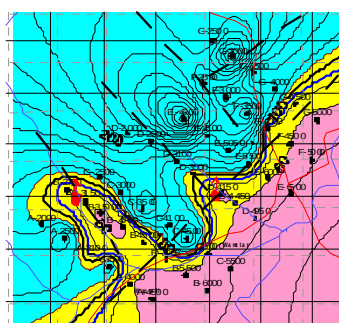
Figure 6: Total geomagnetic map



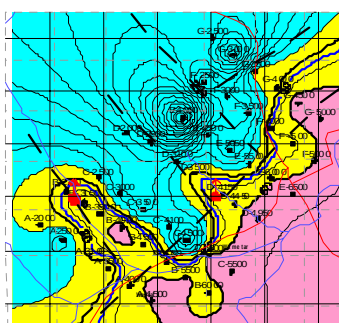
AB/2= 250m



AB/2= 500m



AB/2= 750m



AB/2= 1000m

Figure 7: Apparent resistivity map

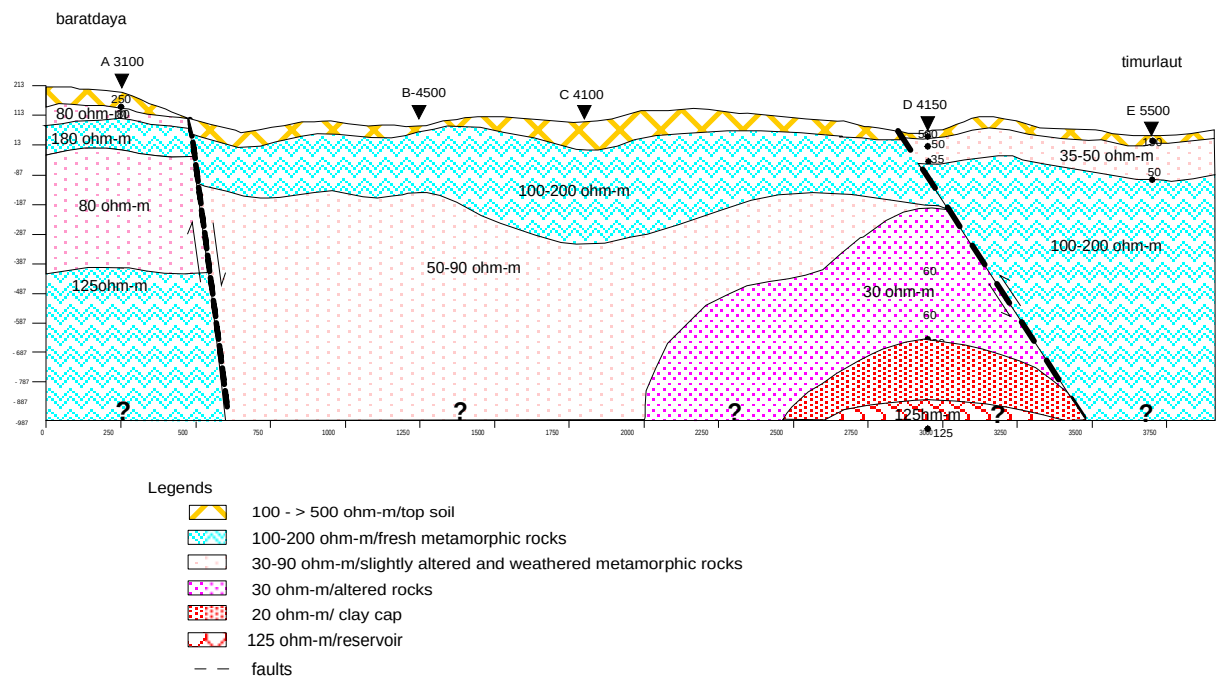


Figure 8: True resistivity crosssection

5. DISCUSSION

5.1 Structural traps of Waesalit geothermal field

The occurrence of geothermal system in Indonesia is, generally, associated with quaternary or recent volcanism and non volcanism. Buru island (Waesalit geothermal field) lies in the western end of a non volcanic Outer Banda Belt. The belt is built up from small islands, such as Buru, Seram, Tanimbar, Timor and Sumba Islands, that stretch along Banda sea. As Buru island is not part of a volcanic belt, therefore the Waesalit geothermal prospect is considered to be associated with tectonic activity and or a concealed volcanic intrusive body (vulcano-tectonic). The assumption is supported by geology, and geophysics data as mention in section 4.1. Both activity caused the occurrence of faults and joints in the area. The present of faults structures such Waekedang and Waemetar faults, that is trending nearly E-W and NE-SW respectively, control the manifestation to the surface. The cross cut structures and metamorphic foliation that open when the stress released caused the hot fluids goes up to the surface and so hot ground and altered rocks occurred. The present of altered zone around Waesalit hot water is supported by low geomagnetic value around the hot water as mention previously. All those conditions are a good indicators for the development of geothermal system in the Waesalit area. Therefore, based on geoscientific data, the structural traps of a non volcanic geothermal field in the area consists of hydrogeology, geothermal system, clay cap, reservoir, and heat source (figure 9).

5.1.2 Hydrogeology

Hydrogeology of the area is classified into three category, such: recharge, discharge areas and run off waters

Meteoric water penetrate into the rocks after passing through the high permeability rocks such cracks and joints, and then keep the water in high porosity rocks as deep or short aquifers, called recharge area and its found at moderately deeping morphology around the manifestation. Discharge area occurred around river flow zones (WaeApo and Pemali rivers) or at relatively flate morphohology. Run off water occurred when meteoric water relatively small or can not penetrate into the rocks and will flow as run off waters or into the river.

Waesalit hot waters occurred along Pemali river or between a discharge area and run off water. The meteoric water, that penetrate into the rocks via primary and or secondary permeability of rocks, and then the waters is heated up by heat source via conductor rocks by convection and or conduction, after that it goes up to the surface as hot waters.

5.1.3 Geothermal system

The present of silica sinters and sulphur deposit around the manifestation, and supported also by geochemical data as mention previously in section 3., therefore Waesalit hot water is up flow type, whilst the geothermal system in the area is considered to be hot water dominated system.

5.1.4 Clay cap

The clay cap is considered to be altered metamorphic and or altered concealed volcanic intrusive body as a result of contact between hot fluids and those both rocks. Figure 7 showed a clay cap is found at the depth of 850m below the observed point (D-4150) with the resistivity value

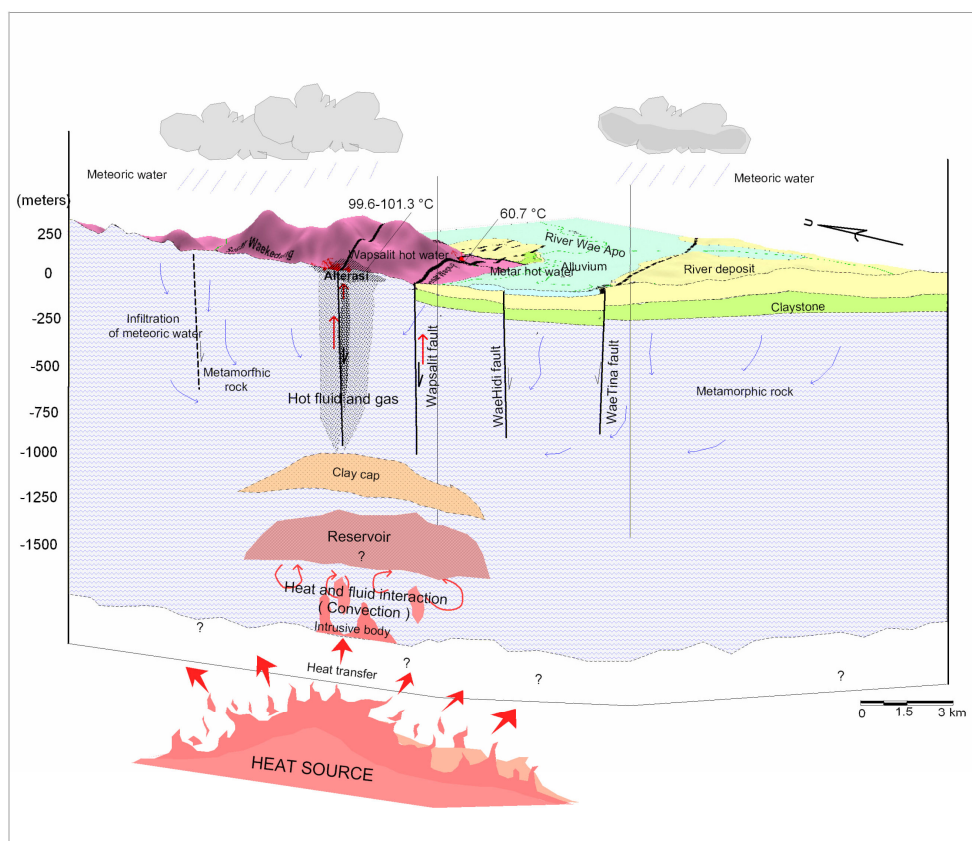


Figure 9: Cartoon Model of Waesalit geothermal sytem (modified from PMG 2006)

of 20 ohm-m. Geomagnetic data also indicated very low geomagnetic anomaly occurred around the manifestation. Low geomagnetic value around waesalit hot water is associated with demagnetised rocks in the area. The type of alteration rocks is considered to be the same as the type of altered zone found in the surface (advance argillic and phyllic ?).

5.1.5 Reservoir

A reservoir is a place where fluids are heated up by a heat source. A reservoir occurs as a result of tectonic processes, in which joints, cracks and faults (Waekedang and Waemetar faults) that act as secondary reservoir permeabilities, developed during the time. Based on resistivity data the top of the reservoir layer with the resistivity value of 125 ohm-m exists at a depth of > 1000 m below D-4150 (figure 7) and the thickness of the reservoir is unknown as the resistivity data only identified the top of the reservoir. The figure also shows the reservoir zone occurring in a semi-conductive area on the resistivity map (figure 6). The reservoir rock is considered to be metamorphic and rocks and/or concealed intrusive volcanic body that has good secondary and/or primary permeabilities.

5.1.6 Heat sources

Waesalit hot waters occur at the Permian age of metamorphic environment rocks, in which the rocks can not be acted as a heat source. Based on geophysical data there is an indication of an intrusive body underneath. The presence of an intrusive body is also supported by the presence of sulphur deposits around the manifestations. All those data indicate that the heat source is considered to be a concealed intrusive volcanic body?

6. CONCLUSION

The Waesalit hot waters are characterized by moderate to high gravity and low geomagnetic values, whilst the resistivity data show the resistivity value around the hot water is relatively high (20 – 110 ohm-m) compared to the resistivity value of a volcanic geothermal system (10 – 20 ohm-m). Based on geophysical data, the structural trap of a non-volcanic hosted geothermal field in the area is relatively similar to a volcanic hosted geothermal area, whilst the heat source (concealed volcanic intrusive body) is considered to be associated to volcano-tectonic process on metamorphic rock.

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