GEOCHEMICAL CHARACTERIZATION OF THERMAL WATERS IN HULULAIS GEOTHERMAL PROSPECT.

By *)

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ABSTRACT

The Hululais area is one of several Quartenary andesitic-dasitic volcanic centers of the Sumatera volcanic arc. The Hululais prospect area concentrates mostly on the West side of the major zone of crustal weaknesses created by the Northwest - Southeast trending Sumatera fault system. The Northwest - Southeast and Northeast - Southwest structures controll the existense of the Hululais volcanic system and the presence of thermal manifestations. The prospect area is characterized by the appearance of fumaroles, hotsprings and altered rocks.

Fluids chemistry analyses on hotspring waters show a dilution of shallow meteoric groundwater and indicate that some may originate from a single hot water reservoir. However, hotspring waters located in the Southern parts contain higher ratio Cl/HCO3 than those located in the North indicating less shallow ground water contaminations. Higher HCO3/SO4 ratio in the Northern hot springs designates the fluids flows from South to North. The upwelling fluids mostlikely take a place beneath Suban Agung (North) and move laterally Northward to Semelako area (South). The presence of magmatic steam in Suban Agung fumarole is indicated by high content of N2, He Ar and isotopic data. Recharge area is located at about 600 meters above sea level. Mercury anomaly forms a lineation trending Northwest-Southeast that coincides with the main fault pattern in this area.

The subsurface temperature estimates using solute and gas geothermometry were obtain ranges values of 240 - 300 °C respectively. These are confirmed by isotope data which show enrichments in their isotopic content as a result of evaporation from high temperature fluids of more than 180 °C. These analyses indicate that Hululais can be categorried as high enthalpy geothermal system.

INTRODUCTION

The Hululais geothermal prospect is located in Kabupaten Rejang Lebong administrative area or is situated in Bengkulu Province, Sumatera or about 160 kilometers northwest of Bengkulu, (Fig.1).

Figure 1. INDEX MAP HULULAIS AREA, BENGKULU

It is geologically situated close to the Bukit Barisan Quartenary volcanic belt of Sumatera. Exploration surveys were carried out in 1994 (B. Budiardjo, Nugroho and A Rachman).

Sixteen hot spring waters, two fumarolic gasses, sixty-eight soil airs and one hundred seventy-seven soil samples have been collected. Hot water and gas were analyzed by using spectophotometry, chromatography and titimetry methods.

Mercury content in soil and air were analyzed by using spectophotometry and mercury analyzer with gold film detector. Oxygen-18 and deuterium in hot water samples were analyzed using mass spectometer. The purpose of these surveys was to understand hydrothermal activity in this area including fluid movement, fluid processes effect, subsurface temperature and hydrological model.

GEOLOGICAL SETTING

Sumatera lies along a NW-trending sector of the Sunda Trench, at the convergent boundary between the subducting oceanic India Plate - Australia Plate and overriding continental Southeast Asia Plate. Sumatera at present forms of the oblique subduction between the Oceanic India-Australia plate and the Eurasia plate. The stresses result in the development of both volcanic arc and the major Sumatera transcurrent fault system, which axially bisects the Sumatera island along the axis of the Barisan Mountain (Rock et al., 1982). The Hululais geothermal prospect area is mostly concentrated on the west side of graben, along major zone of crustal weakness created by the Northwest -- southeast trending Sumatera fault system.

The volcano of G. Bukit Hululais has developed on a base of Tertiary marine sediments and has been active throughout the Quartenary period. The local stratigraphy consist of marine sediments, diorite, andesitic and basaltic breccias, tuffs and lavas. Lithology of the Hululais prospect can be divided into three groups : Tertiary marine sediment and igneous rocks that consist of diorite and andesite, Pleistocene igneous rocks associated with tuff breccias, Holocene alluvium and hot spring deposits, Fig.2.

There are no active volcanoes within the prospect area, but there are an extensive andesite-ryolite lavas and dacite-ryolite ash flow tuffs dated between 1.33 - 0.91 m.a. The youngest eruptive rocks in this region are 1100 years in age resulting in pyroclatic rocks and effusively Obsidian with activity center at the Bukit Pabuar. Volcanic activity remnant is also reflected by rim structure and lava dome at Bukit Hululais at the end of Pleistocene which is supposed as a heat source of the Hululais geothermal system. Some of Pleistocene volcanic rocks in this area has been hydrothermally altered in a manner which indicates mainly steam heating, but also the action of acid condensates.

The structural geometry of the geothermal zone lies along NW-SE regional tectonic structure. There are two main directions of fault presence here trending in NW-SE and NE-SW. The former is represent regional fault system of Sumatera that supposed as horizontal fault with relatively vertical dipping or possible gently dipping to northeast. The latter occurred as a normal fault which dipping to northwest. Both fault systems control the permeability the Hululais prospect and ascending the fluids to discharge as surface thermal features.

GEOCHEMISTRY

Surface thermal features in the Hululais prospect consist of several fumarole, steaming ground, mud pool and hot springs, which are mostly hot acid sulfate springs associated with fumarole at elevation 900 - 1020 meters above sea level. Thermal features are shown by fumarole complex with temperature of 95 - 98° C, hot mud pools with temperature of about 71 - 83° C, and neutral pH hot springs with a relatively high chloride-bicarbonate content at temperature of 50 - 83° C, steam heated waters with temperature of 70 - 85° C associate with acid alteration rocks.

Sixteen hot springs and two gas samples were collected from selected sites during 1994 (Fig.3) Simple classification of the various fluid composition in terms of their major anions, this is conveniently done through a CL-SO4-HCO3 diagram (Fig.4) for the best indications on the likely origin of the springs. The CL-SO4-HCO3 diagram also allows for the indentification of mixing trends between different and large groups of water samples.

A related emphasis in current qualitative assesment of water chemistry is ditermining the maturity of spring waters. The Giggenbach's Na-K-Mg ternary diagram is often used to identify the degree of fluid maturity of the thermal spring waters (Fig. 5) and assess their applicability for geothermometers. Another use of this diagram is delineation, in certain cases, of dilution trends among different thermal waters in a prospect that allow hydrologically-connected springs to lie along distinctive dilutions line such as those in Bukit Hululais.

Considering their chemistry constituents of hot springs, they can be classified as sulfate,

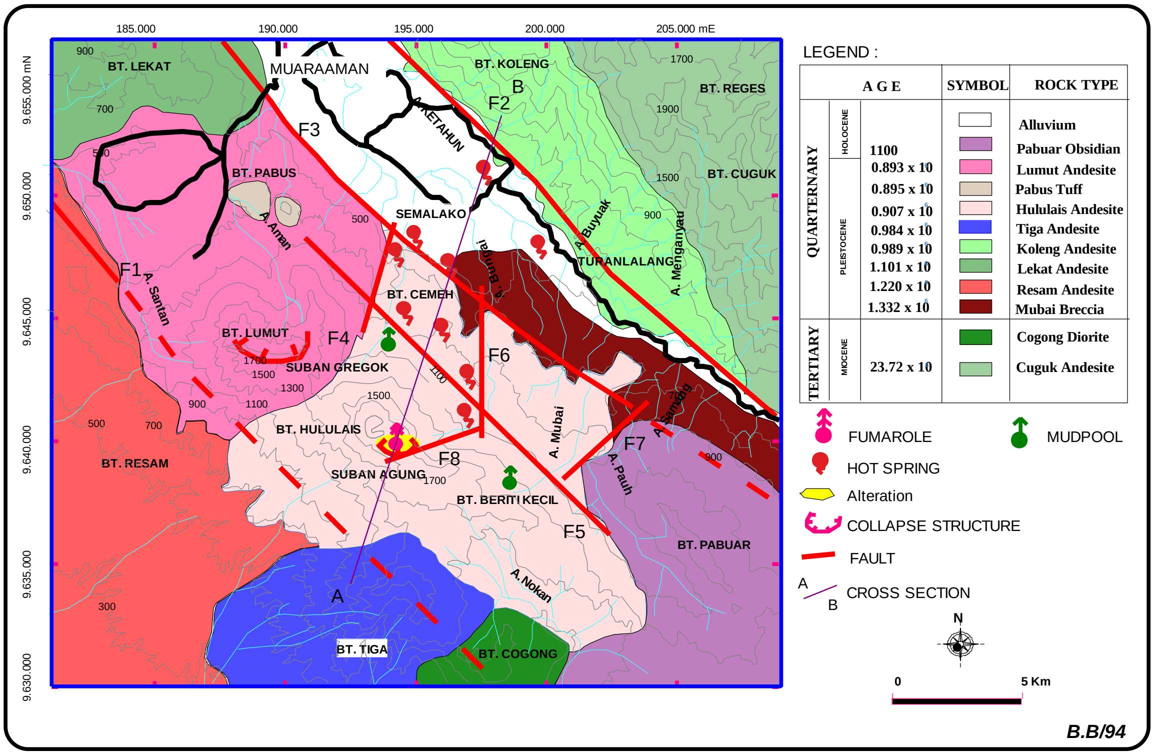

Figure 2 : GEOLOGICAL MAP OF HULULAIS AREA

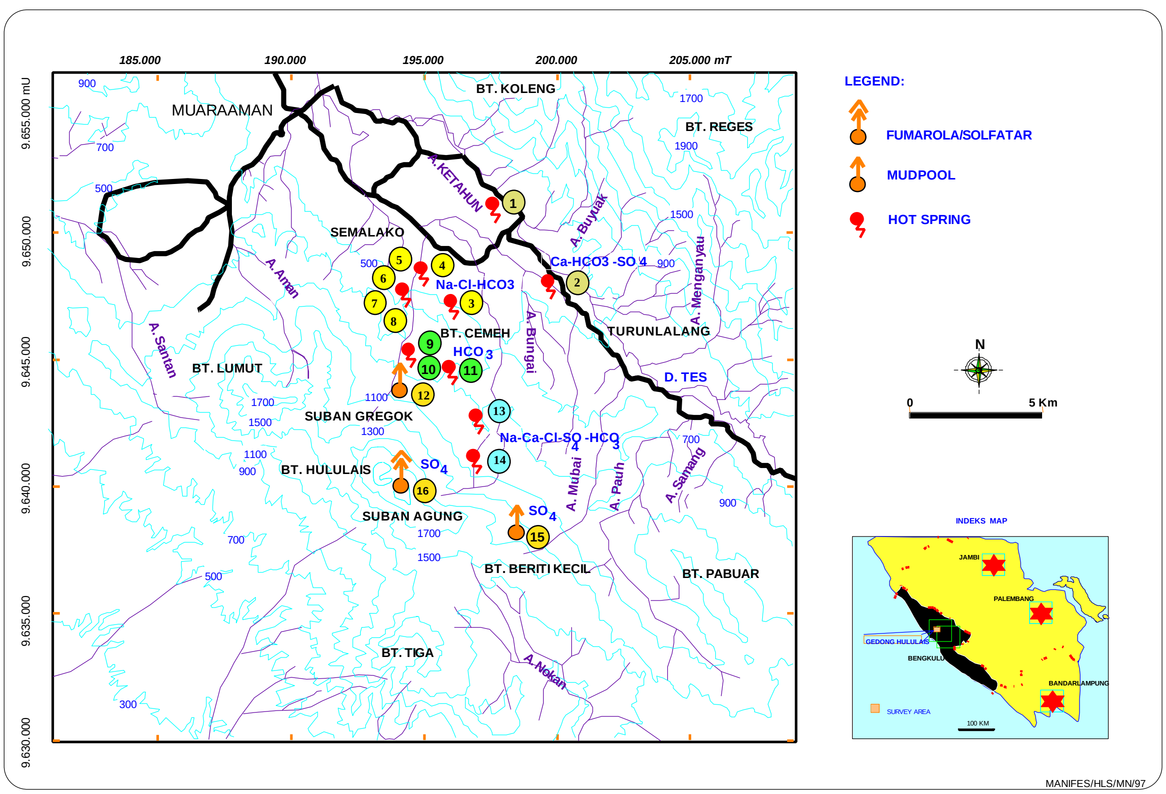

Figure 3 . DISTRIBUTION MAP OF THE HULULAIS THERMAL FEATURES

bicarbonate, sodium chloride bicarbonate and sodium calcium chloride sulfate bicarbonate waters.

This combination is typical of high temperature liquid water geothermal system in mountain terrain.

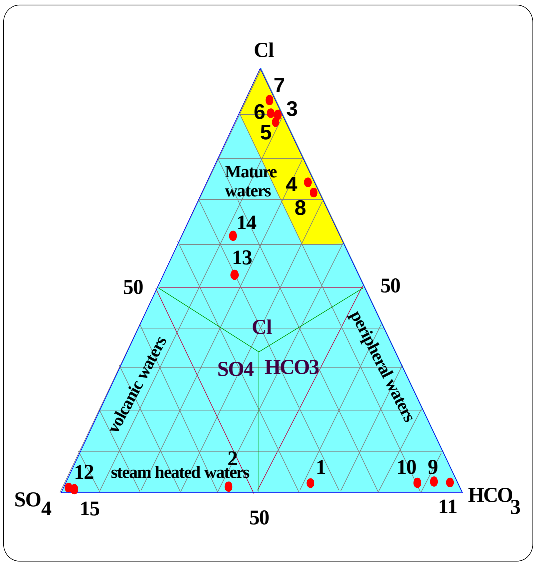

Figure 4. CL/SO4/HCO3 Ternary diagram

- **Sulfate waters**, characterized by high content of H2S. The sulfate content is highly variable due to derived from oxidation of hydrogen sulfide in the vadose zone. This water type distributed in Suban Gregok, Beriti Kecil as hot mud pools and also in Suban Agung as fumaroles, acid hot spring with temperature of 70 - 83° C and 90 - 98° C, respectively (sample 12 & 15). Hot smoky steam blow up, residual silica and sulfur sublimation common occur at around Suban Agung fumaroles. Suban Agung, Beriti Kecil and Suban Geregok occurs directly to the East and the North of the main place of Bt.Hululais at altitudes between 1450, 1100 and 1050 m.

- **Bicarbonate waters**, characterized by high content of HCO3 found as warm springs at Bukit Cemeh, pH neutral with temperature of 35 - 44°C (sample 9, 10 & 11).

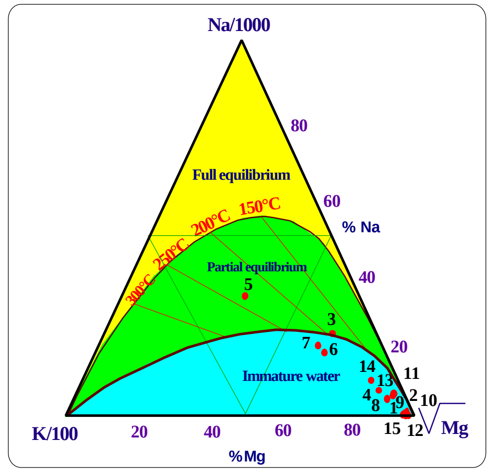

Figure 5. Na/K/Mg TERNARY DIAGRAM

These springs are found to the west and southeast of Bt. Cemeh at elevations between 700 and 850 m. The fluids indicate shallow groundwater heated by steam of hot deep fluid rich in CO2 content which going up to the surface. The hot spring was discharged from rock contact between andesitic lava and alluvial at Kotok river. No altered rocks occurred here but there is silica and bicarbonate deposit around the springs.

- **Sodium Chloride Bicarbonate waters**, characterized by high content of that ionic composition. This fluid found in six hot springs at Semelako, neutral acidity, temperature of about 40 - 70°C (sample 4, 5, 6, 7 & 8). The Semelako groups of springs occurs in the Ngai river to the South of Talangsakti village at elevations of about 400 - 550 m. By using Na-K-Ca method, reservoir temperature estimated as high as 200°C.

- **Sodium Calcium Chloride Sulfate Bicarbonate waters,** characterized particularly of high content those ions. The hot spring found in Suban Agung Hilir northeast of Suban Agung with temperature of about 46 - 53°C, neutral pH, high chloride content (sample 13 & 14). These springs are found on the West side of the Kotok river to the Northeast of Suban Agung at elevations of about 1000 m.

- **Calcium Bicarbonate Sulfate waters**, this springs mainly high content of those ions. Discharge from alluvial plain of Punduk Badaro and Turun Lalang at altitudes of about 400 m. as warm springs with temperature of about 41 - 43°C, neutral acidity. There is no deposit and sulfur smell be present here (sample 1 & 2).

The chloride/boron ratios of hot spring's chemistry show similar values that indicate the fluids derive from one source, whereas the ratios of CL/HCO3 (Fig.6) demonstrate the Northern parts have higher ratio than the Southern ones which indicate the fluids in this part move more direct to the surface.

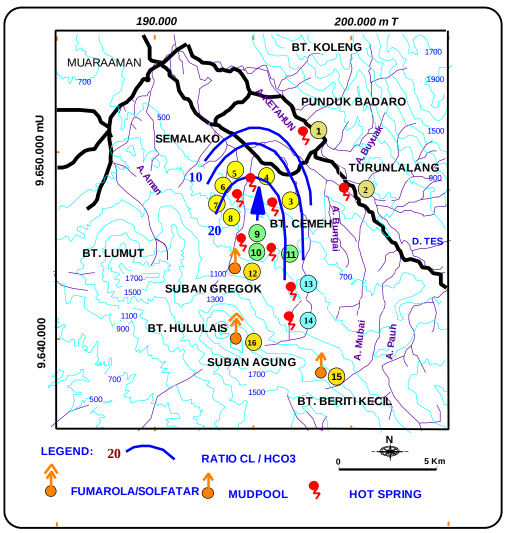

Figure 6 . RATIO CL / HCO3 DISTRIBUTION MAP

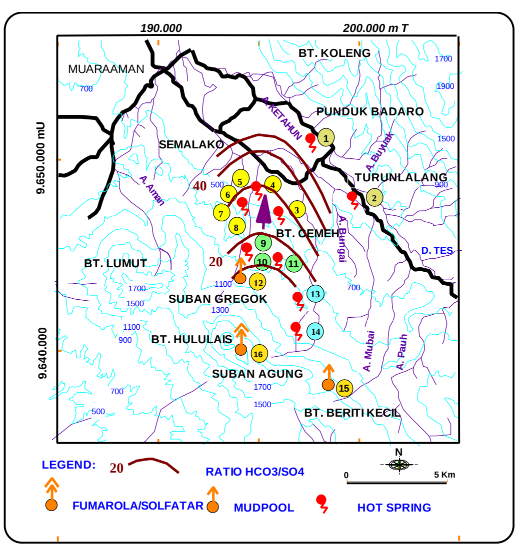

Figure 7 . RATIO HCO3 / SO4 DISTRIBUTION MAP

The comparison of HCO3/SO4 (Fig.7) increase from South to Northward (Suban Agung to Semelako), that reveal the fluids move out toward to North.

GAS AND MERCURY ANOMALY.

The distribution anomaly of mercury in soil air concentrated in the vicinity of fumarole complex at Suban Agung and likely lineament trending in Northwest - Southeast, presumably coincide with the main fault trend. Anomaly also found in Suban Gregok detected by mercury content in soil, (Fig.8). They could be controlled by faults that trending in similar direction.

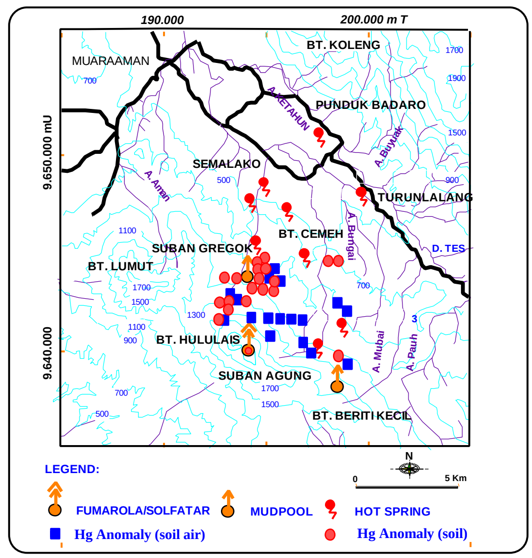

Figure 8 . MERCURY ANOMALY MA

The composition of gases from mature hydrothermal reservoirs differs significantly from those leaked from a degassing magma or a magmatic-hydrothermal system. Gases from the latter system often contain significant quantities of SO2, HCl and HF. In cases where such species are absent, gas ratio of CO2/N2 and N2/Ar can indicate magmatic affinity by comparation with values from active degassing valcanoes or known acidic magmatic-hydrothermal systems.

Another gas chemistry application is the use of CO2/H2S ratio to qualitatively infer location of upwelling zones and charactrize system permeability. For non-acidic systems, low values are often found in upstream part of the reservoir with lower values associated with outflows and margins. Uniform values of widely scattered gas dicharges may thus imply a fairly well-connected and permeable reservoir. Exploration application of gas chemistry is calculation of gas geothermometers.

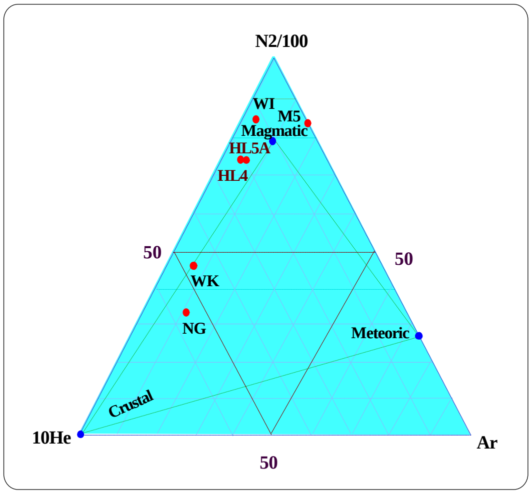

Figure 9 . N2/He/Ar TERNARY DIAGRAM

Two sample gasses have been taken from Suban Agung and Suban Gregok fumarole. There is evidence for the presence of magmatic steam in those fumarole, it is indicated by high content of N_2, He and Ar. The N_2/Ar ratios in the samples were quite high. The ratio at Suban Agung is between 1072 and 1136. High ratios frequently indicate a high magmatic or crustal component.

Figure 9 taken from Giggenbach (1989) illustrates this point. It appears that the steam from Suban Agung is derived directly from a solidifying magma rather than a geothermal reservoir consisting mainly of meteoric water. In respect to this, the H_2/Ar geothermometer gives a value of 385°C, also indicating a high temperature origin more commensurable to a cooling magma than a convective geothermal system. The low CO_2/H_2S ratios usually indicate the most direct migration from the reservoir (K. Nicholson,1987). The ratio of CO_2/H_2S from fumarole at Suban Agung is 40, relatively low. Therefore, presumably this area close to the upflow zone. By using D'Amour-Panichi geothermometer was obtained 272 - 292°C.

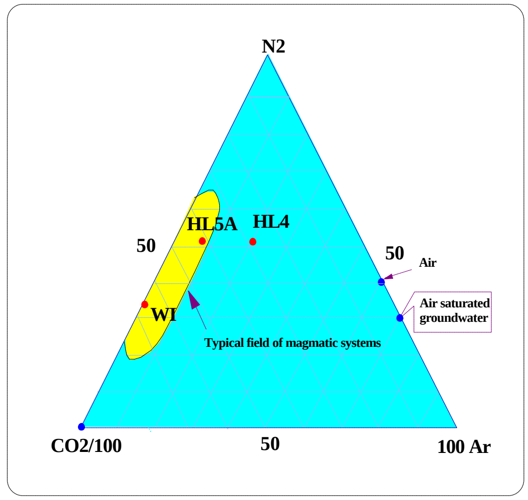

Figure 10. N2 - Ar - CO2 TERNARY DIAGRAM

ISOTOPE

Isotope analysis was demonstrated by oxygen 18 and deuterium that was taken from some hot spring samples in vicinity of the area. Plotting of δ D versus δ O-18 show the trajectories of data sets with slopes other than horizontal from sample 7 to 13 that indicate effect of mixing (Fig. 11).

Mixing effect is also confirmed by their composition that trending to the bicarbonate water from sample 7 (chloride water) to 13 (bicarbonate water). Sample 7 is chloride water and positive shifting for its δ O-18 content, therefore the composition of original deep chloride water close to this sample. Other plotting is chloride content against δ D and δ O-18 showing linear array (from sample 9 to 7) where chloride decreases and also depleted in oxygen - 18, but relatively constant in deuterium (Fig.11).

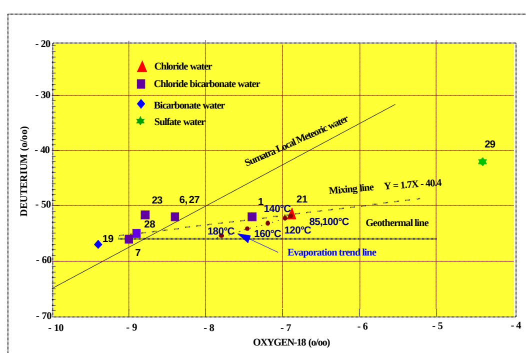

Figure. 11 : OXIGEN - 18 VS DEUTERIUM DIAGRAM

This straight line trend indicates effect of boiling. Intersection of these trend lines and the ordinate represent the end member of isotopes content shown by deuterium and oxygen -18 values at about -54 and -9.3 o/oo respectively, similar to surface water isotopic content. This values are close to the isotope composition of sample 4 and 13. Considering this reason supposed the recharge area is situated around those sample locations at elevation about 600 meters above sea level.

Evaporation trend line presumably follows linear equation that is Y = .7 X - 40.4. With slope value 1.7 suppose the high enthalpy evaporation occurs at temperature more than 180 °C. According to thermal separation of the geothermal fluids, the isotopic composition of the reservoir is about - 56 o/oo for deuterium and - 8.25 - 7.9 o/oo for oxygen - 18.

DISCUSSION AND CONCLUSION

The Prospect occurs in moderate-high terrain of Quartenary volcano, with the presence of some discharges such as boiling neutral springs, fumarole and acid alteration rocks. There are two principle local structural trends i.e NW trending fault, paralel to the Sumatera faults system. The second structure is NE trending faults, which is associated with intensive altered rock and some fumaroles and hot springs. This faults likely control the permeability of the geothermal system in this area. The reservoir is infered to be associated with fractured Tertiary marine sediments basements overlain by Quartenary volcanics.

The distributions of thermal feature mainly developed at north flank of the Bukit Hululais. This phenomena could be observed beginning from high elevation fumarole at Suban Agung and acid sulfate hot mud pool at Suban Gregok, then going down to Northward at Bukit Cemeh bicarbonate warm spring, sodium chloride bicarbonate water type take place at Semelako and finally calcium bicarbonate sulfate water type take a place at Lower elevation Turunlalang. High sodium chloride contents as found in Suban Agung Hilir and Semelako's hot spring indicate that the geothermal fluid system dominated by hot water.

The estimation of geothermal center activity situated at Bukit Huluais from which fluids flow out to Northward represented by distribution of the ratio of HCO_3/SO_4. Distributions of this ratio indicate that the highest ratio is in Semelako hot spring (sample 3 & 4), whereas the lowest one is situated at Subang Agung and Bukit Beriti Kecil. These phenomena also indicate that the fluids already migrate long away from its source which is situated beneath Bukit Hululais or Suban Agung, then likely flowing out to Northward at Semelako.

However, the ratios of CL/HCO_3 show that the Northern parts (Semelako complex) have higher ratio than the Southern part (Suban Agung Hilir complex) which indicate that the fluids move more direct and hotter in the northern complex. The ratios of chloride/ boron show similar ratio as demonstrated by Suban Agung Hilir's and Semelako's hot springs, indicating that they are derived from a single reservoir.

This distribution seems to reflect the hydrology of geothermal system which show the upflow zone situated beneath Bukit Hululais or Suban Agung. The fluids are likely to flow Northward and exposed on the surface as Semelako hot spring. (fig.12).

High boron concentrations relative to chloride and high calcium and magnesium values suggest the composition of waters that are controlled by local sedimentary rocks. The presence of marine sediments and limestone control the composition of the local hot waters.

Deuterium - oxygen-18 correlation indicates that geothermal fluids are affected by boiling and mixing processes, this interpretation is substantiated by plot of those isotopes against chloride. Suban Agung has an isotopic composition close to magmatic "andesitic water" (AW) of Gigenbach (Fig.13). There is evidence for the presence of magmatic steam in those fumarole, it is indicated by high content of N_2, He, Ar and isotope (Fig.9).

High ratios of N_2/Ar frequently indicate a high magmatic or crustal component. The H_2/Ar geothermometer (Gigenbach) gives a value of 385 °C again indicating a high temperature

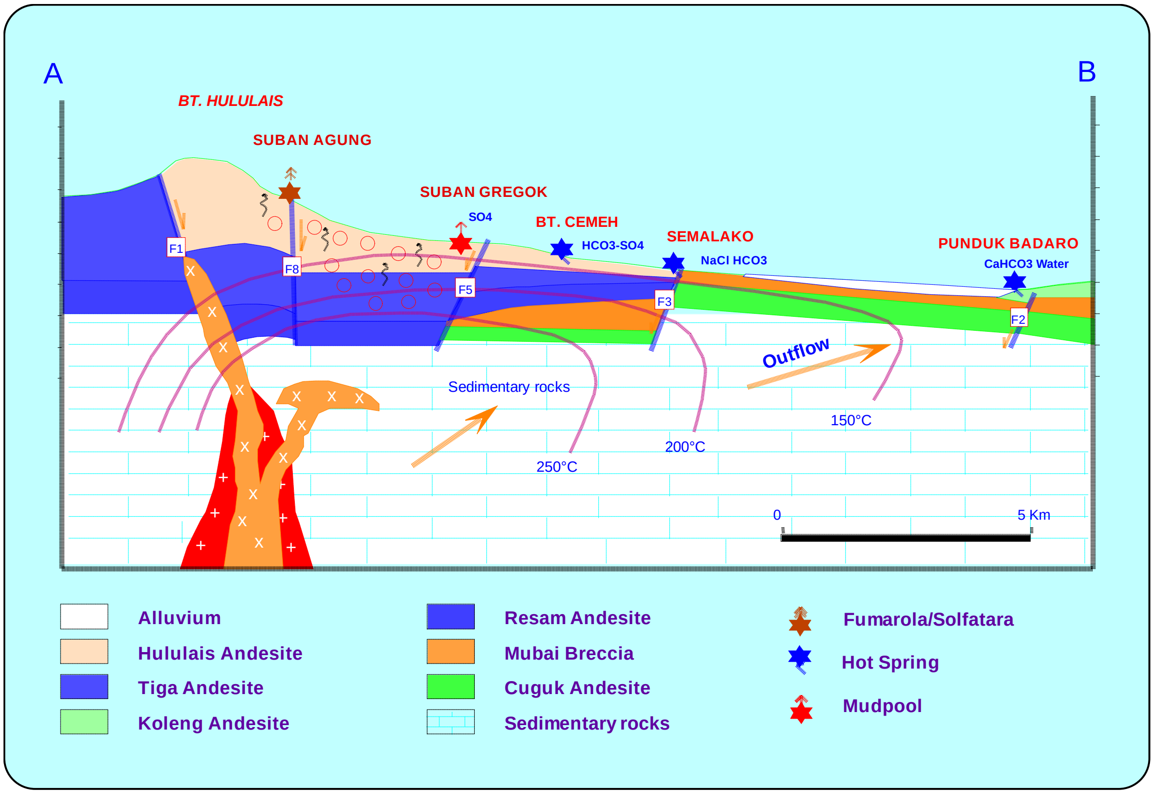

Figure 12. CONCEPTUAL MODEL OF THE HULULAIS HYDROTHERMAL PROSPECT

origin more commensurable to a cooling magma than a convective geothermal system Plot of N2-CO2-Ar and N2-Ar-He Suban Agung fumarole taken from Gigenbach fall into magmatic (Fig.10).

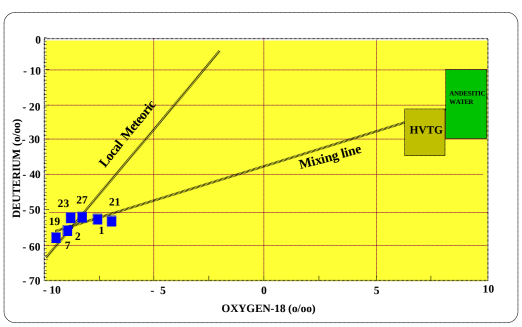

Figure. 13 : OXIGEN - 18 VS DEUTERIUM DIAGRAM

Chemical and isotopic geothermometers were used to estimate reservoir temperature. Result for both liquid (Na-K-Ca) and gas (D'Amour-Panichi) geothermometers indicate minimum reservoir temperature between 240°C and 300°C. Isotope geothermometers yield an estimated temperature of 180°C. Minimum reservoir temperature is inferred close to 200°C. These values suggest that the Hululais geothermal prospect can be groupped into high enthalpy geothermal system.

Acknowledments

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