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Isotope and Geochemical Studies for Tawau Geothermal Prospects, Sabah, Malaysia

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ABSTRACT

The main objectives of the studies were to determine the baseline isotopic and chemical characteristics of the geothermal outflowing fluids and the surface and shallow/deep groundwater systems which are useful to determine the recharge zones and origin of the water. The isotopic and geochemical data obtained may assist in assessment of geothermal resource potential and development. The extended sampling programme includes sampling for Tawau precipitations, catchments/surface waters, hot and cold springs for isotope and hydrogeochemical analyses. Isotope samples collected includes 18-O, deuterium and tritium. The data for 14-C/13-C (TDIC), 34-S/18-O (ppt.) were taken from the similar program, prior to this extended sampling. The hydrogeochemical samplings were mainly for the hot spring waters to determine the water type and the level of solutes in the geothermal waters. The isotope and geochemistry data may be used to estimate the subsurface or the reservoir temperatures. The sampling programme for Tawau precipitations includes at least one hydrological cycle in various catchments areas, to form the regression line for Tawau area. This regression line are created for the first time in this area. From the studies done, geochemically the water type in the Tawau geothermal prospect are steam-heated waters of typical upflow zone i.e high in SO4 and low in Cl contents in the Upper Tawau River(T2) and Balung areas. In the Lower Tawau River area (T1), the water type is chloride-bicarbonate i.e high in Cl and HCO3 contents and in the Apas Kiri area, the water type is chloride which is typical of the outflow zone of a geothermal system. The plot for Na-K-Mg for Apas Kiri geothermal waters shows that the waters are partially equilibrated, and plot for Cl-SO4-HCO3 shows that the waters are near matured chloride waters. Isotopically, the water in the Apas Kiri is enriched. The δ18-O is about -5‰ VSMOW and the δ2-H is about -45‰ VSMOW. The geothermal waters, which is δ18-O shifted for about -2‰ VSMOW from the surface waters, indicate that the old geothermal waters are in non-mixtures with the young groundwaters. This indicate that, the reservoir is capped by a confining sequence, in this system case called ‘clay cap’. The clay capping is one of the indications of a promising and stable geothermal reservoirs. For the Apas Kiri geothermal prospect system, the sub-surface temperature estimated by using several Na/K geothermometers are in the range of 185.7 – 220.3 ^{o}C (Fournier 1979), (158.3 – 198.9 ^{o}C, Arnorsson, 1983), 203.0-235.4 ^{o}C (Giggenbach 1988), 149.1-191.8 ^{o}C (Truesdell 1976). By using several quartz geothermometers, the range of 188.9-202.1 ^{o}C (F&P, 1982), 169.1-187.8 ^{o}C (Arnorsson, 1985), 178.58-201.08 ^{o}C (Fournier 1977, no steam loss). By using chalcedony geothermometers, the range of sub-surface temperature is 151.6-175.2^{o}C (Arnorsson, 1983), 157.3-183.4 ^{o}C (Fournier 1977). By using isotope techniques, alfa (SO4-H2O), the temperature estimate range from 152.17-195.14 ^{o}C.

1. INTRODUCTION

1.1 Background

There are five localities of thermal springs occurrence in Tawau area. They are in Apas Kiri, near Tawau Town, Upper Tawau River and in the Sg. Balung areas. In each locality, several thermal springs occur. In Apas Kiri area, at least 12 thermal springs sites were discovered. The average discharge of these springs were up to 2.0 l/s per spring, but for the whole old steaming ground of Apas Kiri area, it can be summed up to about 5-6 l/s. and the surface temperatures were ranging from about 40oC to 77.6 oC (boiling water), with near neutral pH.

Generally, the thermal springs occur within the Quaternary dacite extrusive volcanic rocks, which occupies most of the Apas Kiri - Mt Maria volcanic relics in Tawau. Their occurrence are mainly related to the post-volcanism and recharged by the meteoric water through the major faults within the extrusive volcanics. The thermal springs occur mainly within the major faults and manifested as thermal springs (**Fig. 1**). The faults are seems to be a deep seated faults.

For the project of Geothermal Resource Assessment and Evaluation Project, several hot springs occur in the Apas Kiri area were sampled for determination of reservoir temperatures. Other evaluations include the origin of groundwaters and the isotope and hydrogeochemical techniques were employed for this evaluation.

The major assessment criteria for geothermal resources by using isotope and geochemical techniques include:

- Origin and recharge areas
- Residence time/dating of water traversing the geothermal reservoir
- Processes undergone by the ascending fluid e.g. mixing with shallow groundwater, water-rock interaction, steam separation etc.
- Reservoir temperatures
- Identification of heat generating sources

- Chemical characteristics
- Overall heat energy potential of the geothermal reservoirs
- Recommendations for further detailed explorations

Geothermal energy is generally cost competitive with conventional sources. It is a green energy, which has less environmental impact as compared to the natural gas, oil or coal.

To investigate the potential of the geothermal resources, a water sampling for geochemical and isotopes were carried out, and surface water and geological observations were done.

Several fieldworks were carried out between mid 2007 and Sept 2009 for the isotope and geochemical studies.

The water samples were analysed for geochemical contents and isotope signatures for the sub-surface or reservoir temperature determination, and groundwater origins.

1.2 Evaluation

The dertermination of sub-surface temperatures were done by using the several cation and silica geothermometers, such as the quartz and chalcedony, Na/K, K-Mg and Na-K-Ca. Several geothermometers (cation and silica) were used based on the fact that majority of the waters are partially-equilibrated/partially matured. The quartz geothermometers (SiO2), are recommended for geothermal systems having subsurface temperatures of more than 180^oC (and this is usually a higher enthalpy systems).

The silica contents in a system are susceptible to dilution or precipitations, but for a higher enthalpy systems and where the δ18-O in the groundwaters are much shifted in isotopic signatures from the meteoric line, the usage of the SiO2 geothermometers are more reliable. So the usage of SiO2 geothermometers are to be used in a careful manner. The silica contents in the waters (of < 150^oC reservoir temperatures) are most likely governed by the chalcedony solubility in the waters.

Generally, the subsurface temperature results obtained for this assessment project, warrants further explorations.

2. SCOPE OF WORK

The scope of work for the geothermal resource assessment in Tawau includes classification of hot springs water type and chemical contents, evaluation of thermal springs and determine its reservoir temperatures, and isotope studies to determine the origin of water.

This project main aims are to focus on the origin of the outflowing chloride rich hot springs in Apas Kiri and create a deeper understanding on the possible sources of recharge into the geothermal system aquifers.

With this framework, the objectives of the study are:

(a) to establish the distinct isotopic and chemical characteristics of the outflowing hotsprings,

(b) to identify possible sources of recharge and determine the recharge mechanisms into the aquifer; and,

to come up with a proposal for a geophysical surveys area (delineation) which include magneto-tellurics/TDEM, gravity and 2D Resistivity Imaging.

3.0. METHODOLOGY

For the investigation project, the items listed below were carried out :

i) Geochemical samplings for surface and ground waters

ii) Isotope samplings (18-O/2-H) for surface and ground waters

iii) Analyses of samples

iv) Results interpretations

v) Surface geological assessments

The geochemical sampling includes sampling of groundwater issues from the thermal springs and the isotope sampling includes sampling of surface water and groundwaters.

The site investigation includes surface geological assessment, quality of hot springs in terms of surface temperature, pH, discharge rate, presence of hydrogen sulphide gas and other related occurrences.

The geochemical sampling focused on analyses and interpretations of several elements listed below :

i) pH at 25^{o}C (lab) and onsite pH.

ii) Dissolved SiO_2 contents

iii) Total Dissolved Solids (TDS)

iv) Total SiO_2 contents

v) Cations (Na, K, Mg, Ca, Li, Boron, etc.)

vi) Anions (Cl^-, SO_4^{2-}, HCO_3^-, etc.)

vii) Total Solids

viii) Turbidity

ix) Electrical Conductivity.

The isotope sampling includes sampling and analysis of 18-Oxygen and deuterium (in water).

The investigation covers the Apas Kiri and Mt. Maria areas, where the hot springs occur. Sg. Tawau, Sg. Kinabutan and Sg. Apas, are the major watersheds within the area. The Apas Kiri outflow region covers about approx. 3,000 km2,or about four topographical map sheets (**Fig. 3**). Since it has been established from previous isotopic and geochemical studies that the Apas Kiri geothermal prospect is an outflow region and is volcanic related (Javino, 2004), the detailed sampling program were concentrated in Apas Kiri and around Mt Maria, the upflow region (confirmed by the MT data).

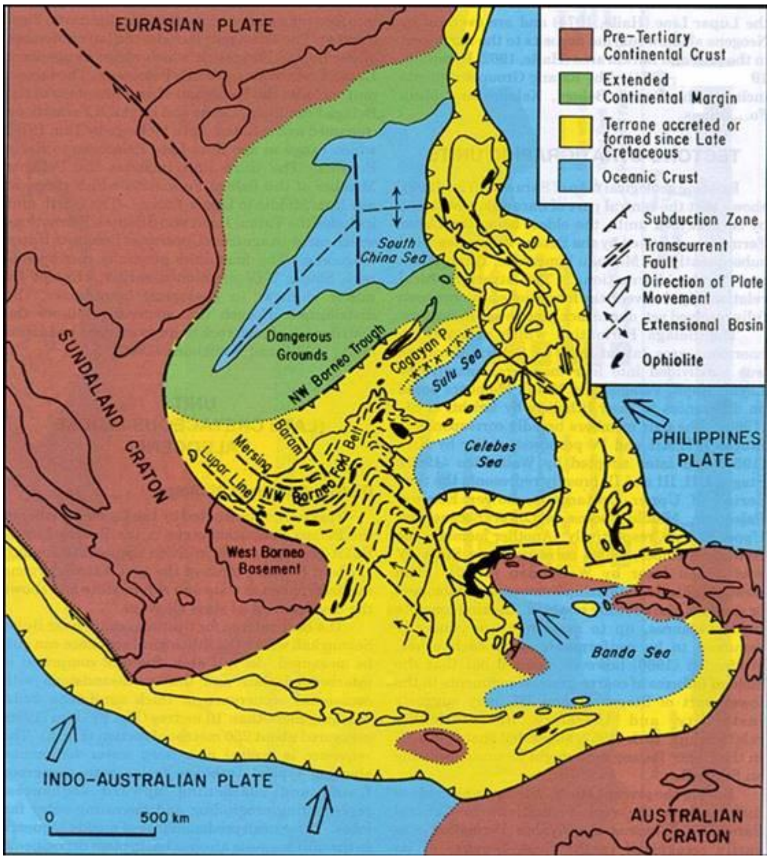

Figure 1: Tectonic map of the Celebes and Sulu Seas subduction zones (Tongkul, 1991).

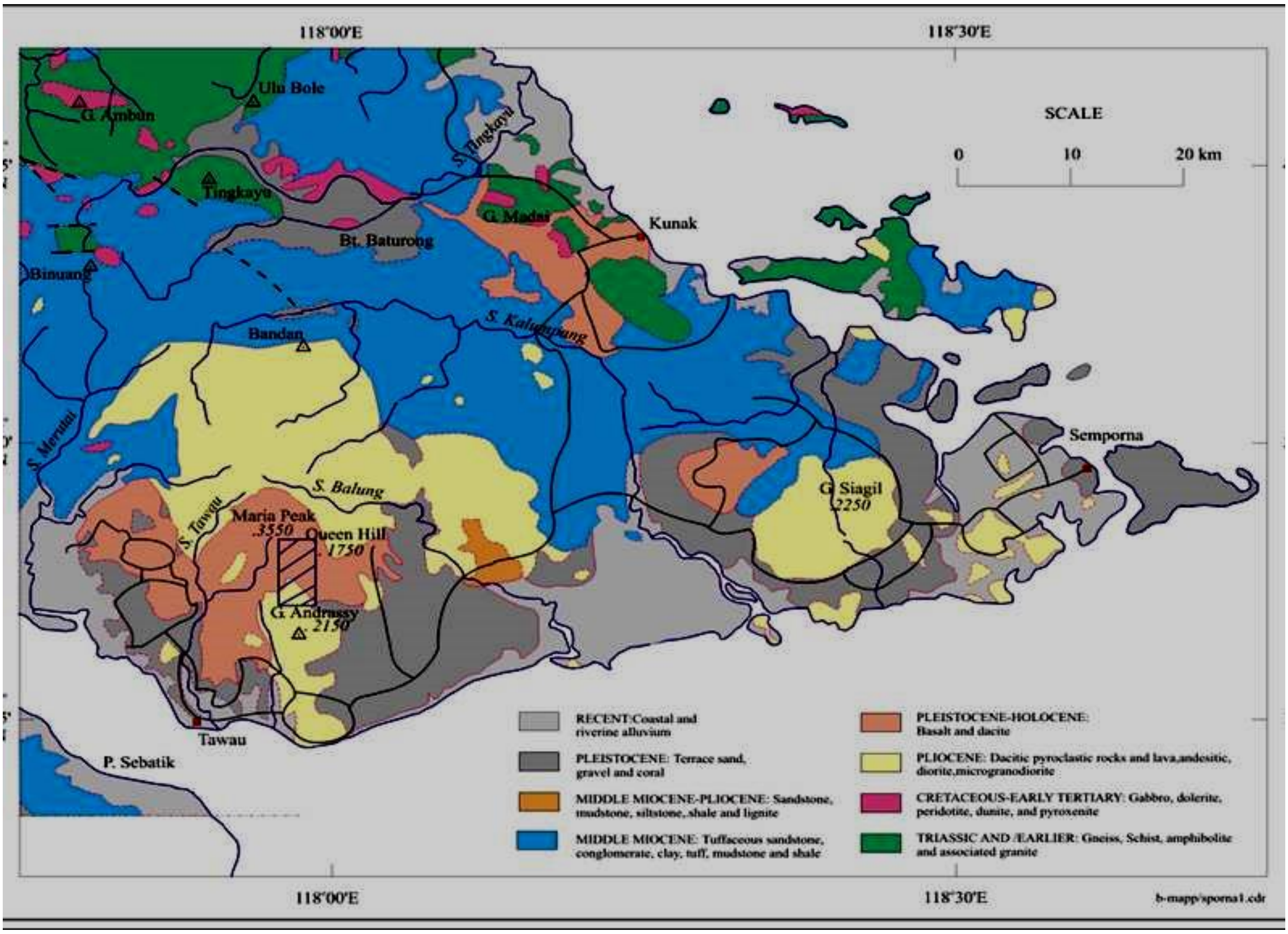

Figure 2: Simplified geological map of the Tawau-Semporna Peninsular.

4.0. GEOLOGY

Geothermal fluids may evolved through three geological processes or mechanisms:

i) Intrusion and cooling of magmas in the water bearing shallow crust

ii) Deep circulation of meteoric water in areas with high or normal heatflow

iii) High heat flow in areas with confined aquifers capped by a heat-insulating blanket of low heat-conductive rock.

Tectonically, the Tawau-Semporna Peninsula falls within the subduction zone between the Sulu Sea and Celebes Sea, indicated by the volcanic arc from Tawi-Tawi in the Philippines, to the Tawau-Semporna peninsula. The Sulu trench were inactivated in the Late Pleistocene, which left the inactive Pliocene-Quaternary volcano in the Tawau-Semporna Peninsula (**Fig. 2**).

In the study area of Mount Maria geothermal prospects, the major faults are interpreted from the SRTM data. It can be seen that the major faults are in the N-S direction. These major faults may represents the fracture created during the updoming of the Mt Maria volcanic eruption during Pliocene-Quaternary time. These fracture systems are important as to allow the geothermal systems to be recharged from the meteoric waters (**Figures 2 and 4**).

5.0. DATA AND ANALYSES

The field data collected during the fieldwork were recorded for general description on geology, land use, status and condition of hot spring areas.

The geochemical analyses were carried out in Minerals and Geoscience Department of Malaysia, Sabah (JMG) laboratories, whereas the isotope analysis were carried out at the International Laboratories of Vienna (IAEA) and Pakistan Institute of Nuclear Science and Technology.

The samples were collected in two sets of 1,000ml, 500ml and 100ml leak-tight sampling bottles. The 1,000ml and 500ml samples were to be analysed for geochemical and isotope whereas the 100ml samples were analysed for isotopes. The acidification of all the 500ml samples were done to preserve the cations for geochemical analyses.

The purposes to analyse the cations and anions are mainly to determine the water types and to determine the probable reservoir temperatures, whereas the analysis of isotopes are mainly to determine the origin of waters and to estimate the reservoir temperature in order to evaluate the thermal systems.

6.0. WATER CHEMISTRY OF THE THERMAL SPRINGS

The pH and EC values of thermal waters were measured. The pH values for thermal waters are near neutral and the electrical conductivities range from 2,030 to 4,750 uS/cm for the thermal waters.

The geochemical results of thermal springs were analysed and plotted by using ternary diagrams, such as Cl-SO4-HCO3 and Na-K-Mg. From the Cl-SO4-HCO3 ternary diagram, most of the samples are plotted near Cl corner (Fig. 6). The high Cl concentration in the thermal spring in Apas Kiri are due to its location as the outflow zone and is related to volcanic rock host. The boron contents are attributed to the depth of water circulation or deeply seated magma body. In all the samples for Apas Kiri area, the boron content is comparatively higher for A1-4 thermal springs which range from 46.1mg/l to 55.6 mg/l, whereas for the T1 hot spring the level is lower i.e. 14.20 mg/l (**Table 2**).

The SiO2 concentration in the thermal spring waters is between 69.9 mg/l and 83.1 mg/l for Apas Kiri and for T1 is 65.2 mg/l. Silica addition to waters may be accomplished by alteration of silicate minerals or dissolution of quartz in alkaline conditions.

7.0. HYDROGEOLOGY

The main lithology covering the headwaters of the Sg. Tawau, Sg. Kinabutan and Sg. Apas watersheds are Quaternary volcanic rocks composed of dacitic, andesitic and basaltic lavas. In the lower Sg. Tawau-Sg. Kinabutan-Sg. Apas area, where these rivers flows out to the sea, the rugged terrain breaks into a gentle plain where the lithology is composed mainly of Quaternary alluvial deposits of terrace sands, clays and gravels within the coastal and riverine deposits. A transition zone exists between the pyroclastic deposits and the Quaternary Alluvium on the southern side of the rivers that is composed of reworked pyroclastic materials

Pumping tests data available from hydrogeological activity in the Quoin Hill area, which is underlain by basalt and breccia, shows good hydraulic conductivity values of 6.09×10^{-2} m/day and transmissivity values of $2.11 m^2$/day (Jaineh et al, 2007). Another encouraging example of pumping test data available for jointed/faulted dacite aquifer is in the SMK. Tagasan Semporna area where the transmissivity is 96.4 m^2/day and conductivity is 19.27 m/day (Jaineh et al, 2004). It is postulated, however, that the permeability within the identified transition zone is relatively higher than the shallow aquifer to some degree of magnitude. This so called transition zone may be identified through resistivity surveys.

Hot groundwater flow is generally vertical-diagonal within the Apas Kiri geothermal prospect (A1-A5), i.e. from the deep aquifer to the surface. It is also postulated that the hot groundwater T1 within the flat topography also flows upwards, but probably originated from the main reservoir (upflow) through horizontal/diagonal trend, and the hot water travels along the major fault systems (Fig. 4). Hydrogeological data observed within the basalt in the Quoin Hill area and dacite in the semporna area, show that the fractured and jointed basalt and dacite are promising aquifers.

8.0. HYDROLOGY

Most of the land area in the headwaters of Upper Sg. Tawau-Kinabutan-Apas watersheds are moderately steep to steep terrains covered with forests, grass and shrubs. Farther downslope, several lands were already converted for agricultural purposes where oil palm, cocoa and other root crops were cultivated for many years, probably since 1970s. Towards the low lying areas of Tawau Region, urban developments have encroached to many parts of the coastal line.

Tawau region of Sabah, is equatorial / tropical and this means the climate is generally hot and sunny all year round. The average temperature in the lowlands like Tawau is 32 ^{o}C.

Generally, Sabah has 'Dry Season' i.e. from April to October and the 'Wet Season' from November to March.

From the project precipitation data collection within the Tawau region (Andrassy - Quoin Hill - Tawau Hill Park), average total annual precipitation is 2,464.55 mm (averaged from five isotope raingauges). At Tawau Region, ambient air temperature is coldest during the month of January-February and December with minimum 22°C and maximum 32°C, and warmest during May, Oct-Nov, with minimum 22-23°C and maximum 32-33°C.

8.0. HYDROCHEMISTRY

There are mainly three types of water identified from the thermal springs of Tawau area which include chloride, SO4 and Na-K or HCO3 (**Fig. 10**).

In the year 2002, geochemical sampling in Apas Kiri recorded the contents of chloride ranged from 1,078-1,330 mg/L. The present sampling also shows the chloride contents range from 1,086 – 1,365 mg/L Based on previous records, the contents of chloride is about 1,000 mg/L. This indicate that the Apas Kiri level of chloride contents is very high i.e. exceeds 1,000 mg/L and is consistent since the year 2002. The level of chloride shows that the Apas Kiri hot springs are related to volcanism and this strongly validates that the hot springs in Apas Kiri is part of the natural outflow region of the Mt Maria geothermal prospect.

Plot for chloride vs. boron **(Fig. 8**) indicate that the thermal springs A5 is the nearest to the heat source (reservoir). The thermal spring A4 has the highest temperasture recorded and the content of chloride are mostly more than 1,200 mg/l for the Apas Kiri outflowing thermal springs (**Fig. 9**).

Table 1. Isotope data for thermal spring Apas kiri area.

Sample ID	StationID	Sample_Date	Geology	Elevation (m)	d18-O	d2-H
A1-A	A1-A	2007-April	Dacite	163	-5.16	-39.58
A1-B	A1-B	2007-April	Dacite	163	-5.00	-45.56
A2A	A2A	2007-April	Dacite	160	-5.14	-41.92
A2B	A2B	2007-April	Dacite	160	-4.98	-46.82
A2C	A2C	2007-April	Dacite	160	-4.80	-44.48
A4A	A4A	2007-April	Dacite	180	-5.25	-39.97
A4B	A4B	2007-April	Dacite	180	-4.58	-47.20
A5A	A5A	2007-April	Dacite	265	-4.92	-46.19
A6	A5B	2007-April	Dacite	181	-5.03	-39.32
A5B	A6	2007-April	Dacite	265	-4.76	-47.28
T1	T1	2003	Dacite	35	-6.41	-41.7

Table 2. Isotope data for cold spring and precipitate in Apas Kiri-Tawau Area.

SampleID	Geology	Elevation(m)	d18-O	d2-H
Jln Guthrie 1	Dacite	120	-7.13	-47.69
Jln Guthrie 2	Dacite	120	-6.11	-40.17
Kg Gudang 4	Dacite	200	-6.96	-46.17
Kg. Gudang 4_2	Dacite	200	-6.67	-46.56
Mark Pang 1	Dacite	210	-6.38	-40.24
Mark Pang 2	Dacite	210	-6.13	-40.18
SK Andrassy	Dacite	110	-6.36	-40.57
AKC1	Dacite	190	-6.09	-41.72
AKC2	Dacite	190	-6.05	-41.97
IR7 Nov 2007(P)	Dacite	310	-9.79	-66.32
IR8 Nov 2007(P)	Dacite	227	-8.99	-64.49
IR9 Nov 2007(P)	Dacite	182	-10.06	-76.93
IR10 Nov 2007(P)	Dacite	288	-10.08	-74.41

Table 3. Isotope geothermometers for thermal springs in Apas Kiri area.

Spring Code	Date of sampling	O-18 (water)	O-18 (Sulphate)	Alpha^{18}O	T°C	$\alpha_{(SO4-H2O)}$	T $\alpha_{(SO4-H2O)}$ °C
A1A	7/17/2003	-5.06	6.3	1.0114581	158.0004689	1.01141777	158.5565856
A1B	7/16/2003	-5.13	6.7	1.0118798	152.3146179	1.011891	152.167257
A2A	7/17/2003	-4.91	6.4	1.0113306	159.7659507	1.01136581	159.2761064
A2B	7/16/2003	-4.97	5.4	1.0104294	172.8970722	1.0104218	173.0134996
A2C	7/17/2003	-4.83	4.2	1.0090337	195.8514595	1.00907383	195.1410023
A4A	9/26/2002	-5.08		ND	ND	ND	ND
A5	7/19/2003	-4.69	5.6	1.0103334	174.3684578	1.01033849	174.2903117
J1	7/15/2003	-6.05	8.1	1.0142318	124.3021019	1.01423613	124.2560469
J2	7/19/2003	-6.11	5.4	1.0115839	156.281101	1.01158076	156.3233011
T1	7/20/2003	-6.41	8.9	1.0154059	112.2614528	1.01540877	112.2335929

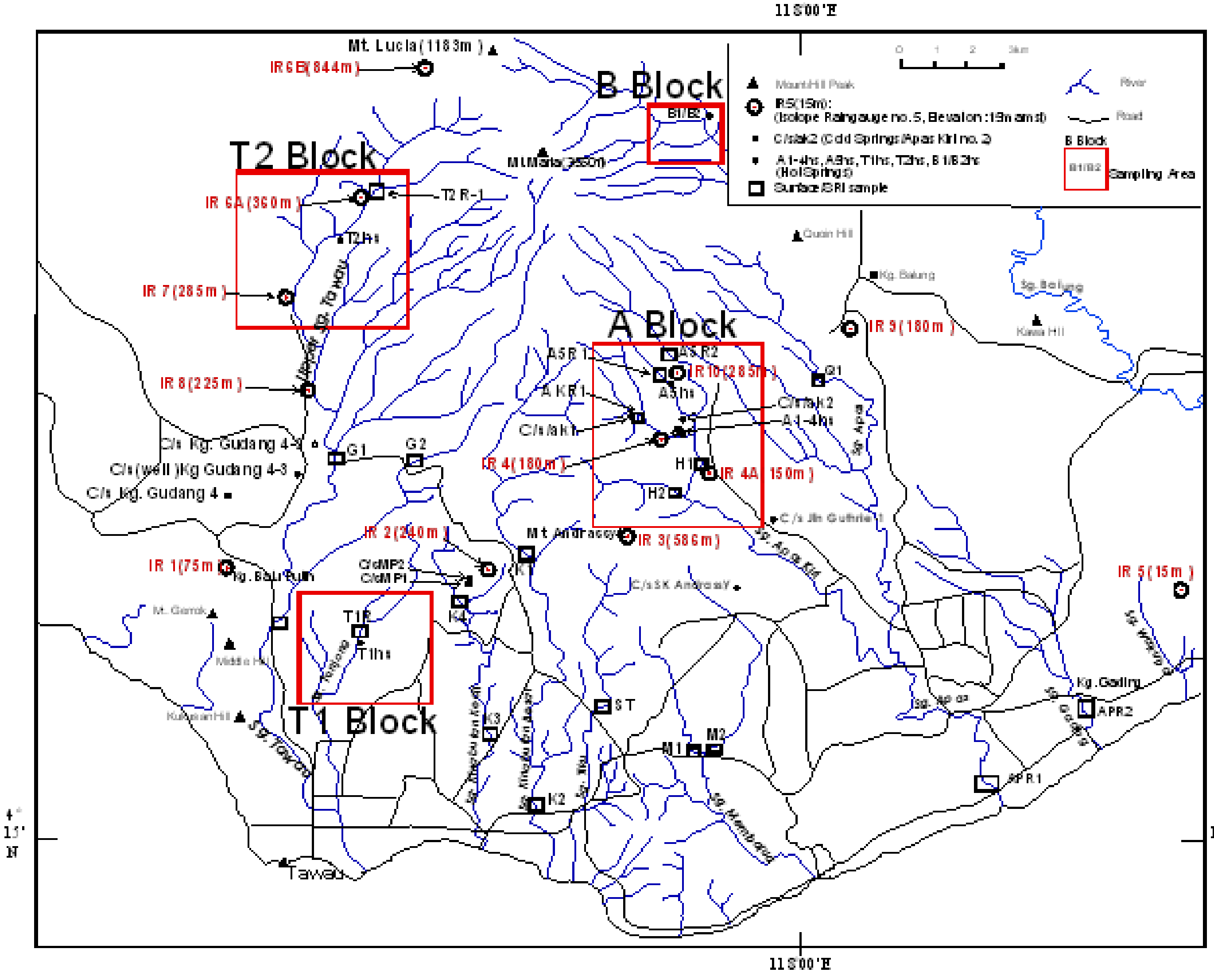

Figure 3: Location of sampling points for thermal and cold springs, precipitates and surface waters, Tawau region.

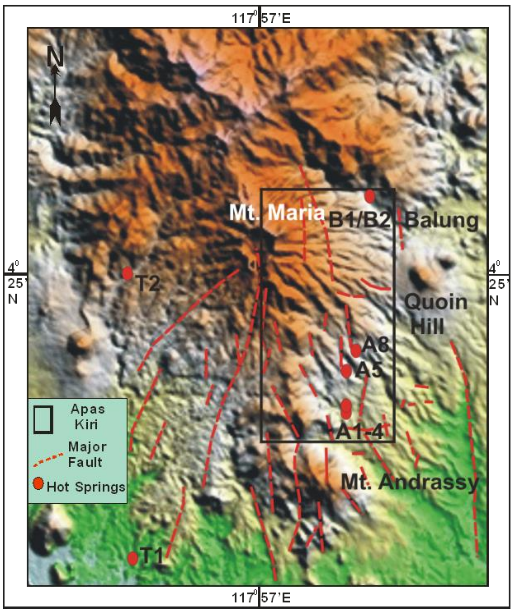

Figure 4: SRTM map of the Mt. Maria Quaternary volcanic complex, Tawau area, showing the major interpreted faults / fracture systems.

Field physico-chemical parameters and basic chemistry data indicate three different types of groundwater in the study area i.e. SO4, Cl and Cl-HCO3 waters (**Fig. 5**). The SO4 waters occur in the northwestern part of Apas Kiri (Upper Sg. Tawau T2 and Sg. Balung B1/B2 areas) which related to the upflow zone of the geothermal prospect. The chloride waters are mostly occur in the A1-4 hot springs and the Cl-HCO3 occur in the Tawau T1 area.

The waters in the A1-4 hot springs were very conductive with electrical conductivity (EC) range from 4,200-4,750 μs/cm and the corresponding temperatures were 41.1 - 77.6 ^{o}C, but the lower temperature of 41.1 ^{o}C recorded . whereas in the A5 hot spring the EC were 2,600 μs/cm with corresponding temperatures were 60^{o}C and in T2 were 2,030 μs/cm with 48.8 ^{o}C.

The field sampling temperature and electrical conductivity (EC) showed no particular trend but there is somehow a reduction in electrical conductivity with temperatures drop. Groundwaters within the A1-4 hot springs have relatively higher temperature and conductivity of more than 4,000 μs/cm.

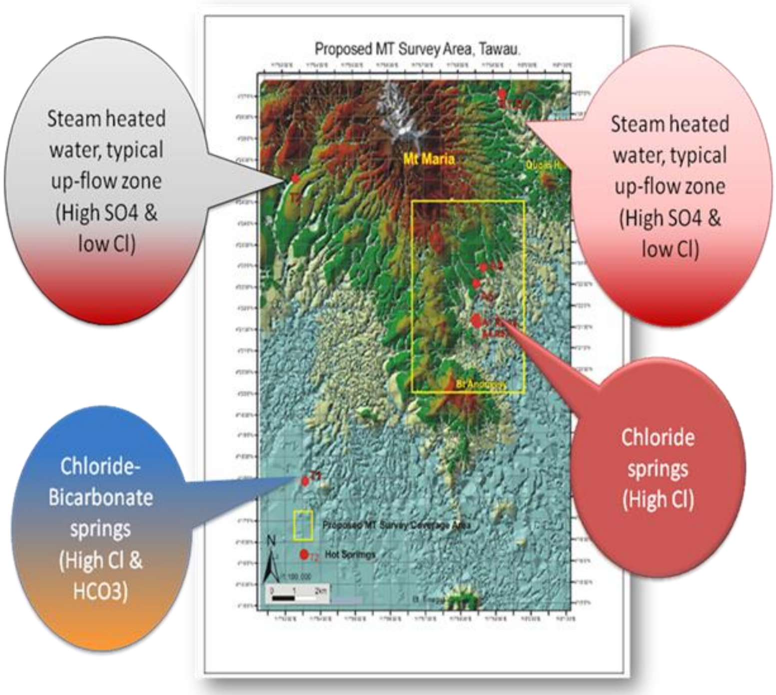

Figure 5: An elevation map showing the survey area of Apas Kiri (rectangular block) and all the major thermal springs in the vicinity of Mt. Maria geothermal resource potential in Tawau. Also shown are the water types in different localities.

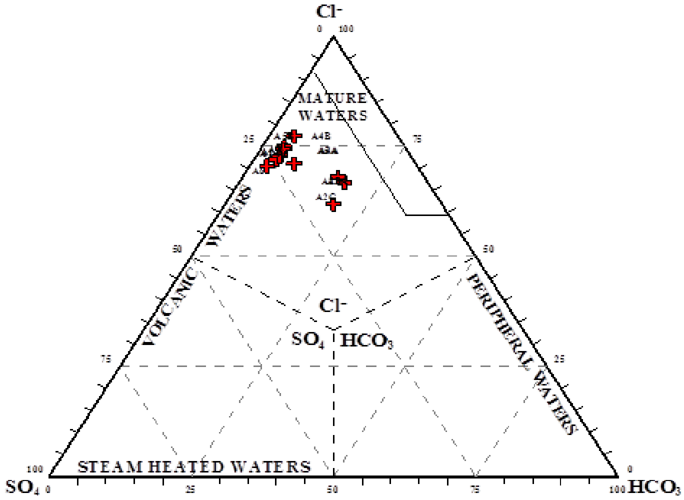

Figure 6: Cl-SO4-HCO3 ternary diagram. It is clearly shown in the diagram that the Apas Kiri geothermal waters are near the Cl-mature waters.

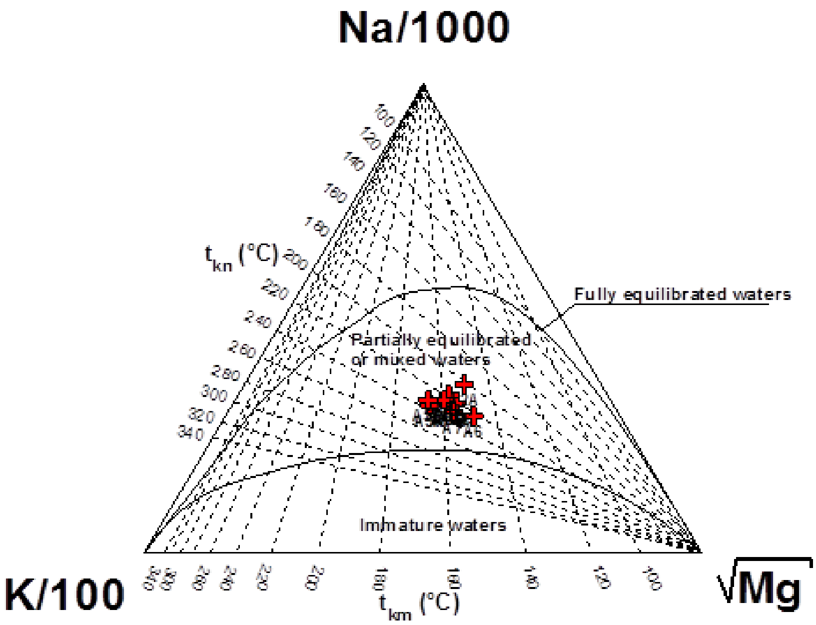

Figure 7: Na-K-Mg ternary diagram (Giggenbach Triangle). All the geothermal waters for Apas Kiri area are plotted within the partially equilibrated waters.

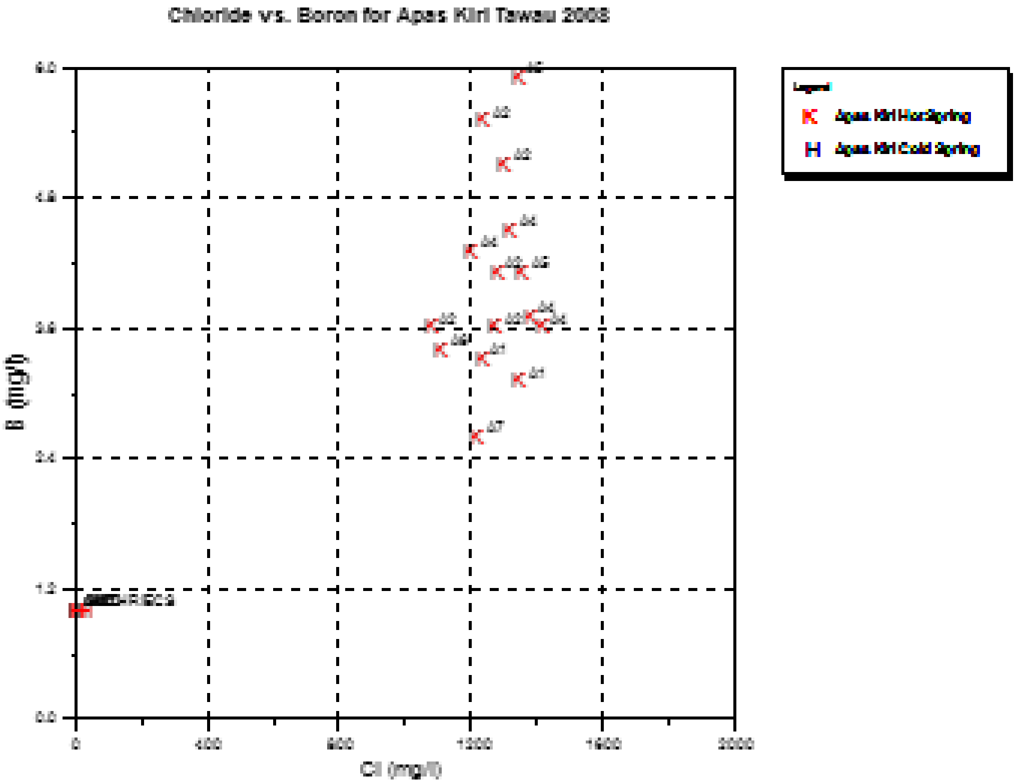

Figure 8: Plot for Chloride vs. Boron for Apas Kiri. The A5 is comparatively the nearest to the heat source (reservoir).

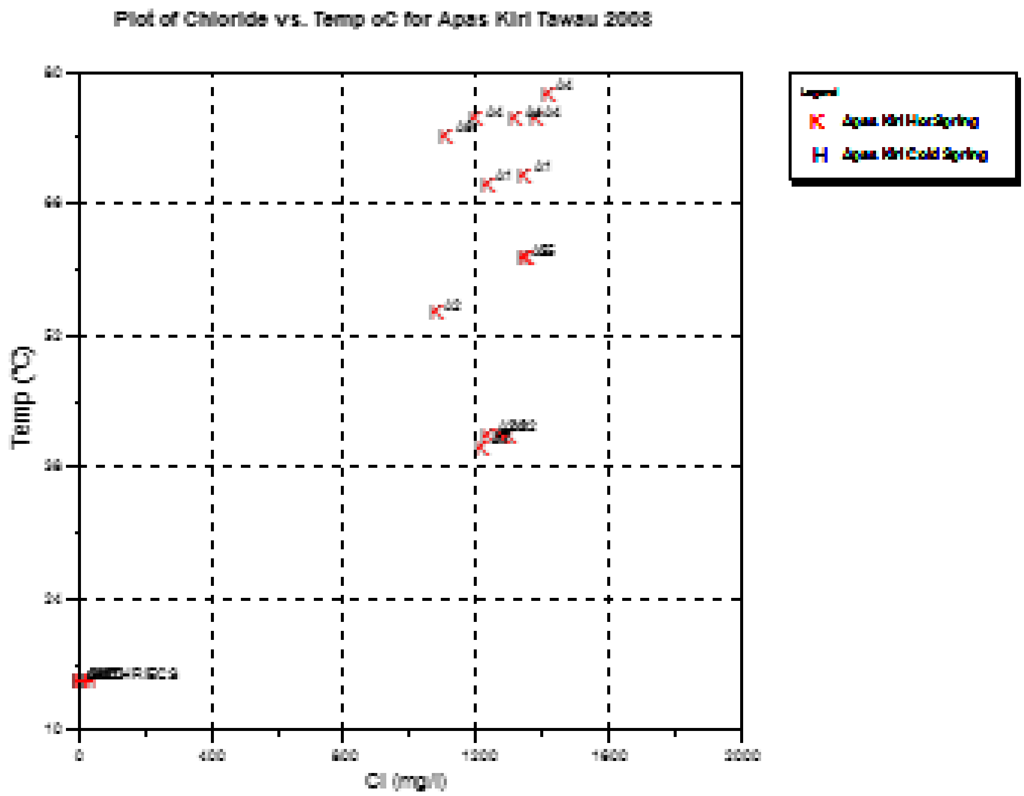

Figure 9: Plot for Chloride vs. Temperature. The A4 has the highest temperature recorded.

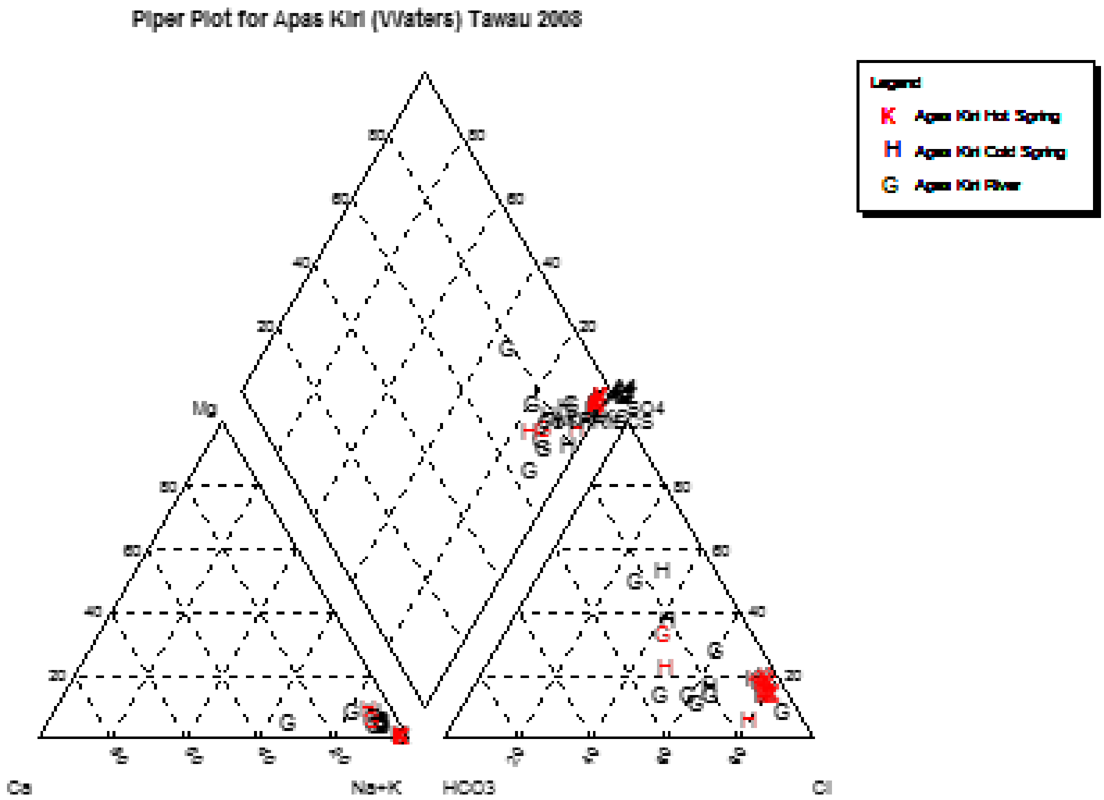

Figure 10: Piper diagram for Apas Kiri area waters. For the thermal springs, three major type of waters identified.

10.0. ISOTOPE HYDROLOGY

10.1 Local $\delta^{18}O$ and $\delta^{2}H$ in Precipitation >

Isotopic analysis results from the 2002 and 2007-2008 sampling for Tawau region, which are also now included in the IAEA Program (GNIP-Global Network for Isotopes in Precipitations and GNIR -Global Network for Isotopes in Rivers), were used to determine the Local Meteoric Water Line (LMWL).

The list of isotopic composition of the different water sources is found in Tables 6 and 7.

10.2 Groundwater, Hotspring and Geothermal Water Recharge

The plot of $\delta^{2}H$ and $\delta^{18}O$ composition of the different water sources in the study area are shown in Fig. 16, which indicates two different water groups: the surface waters are plotted within the regression line represents the precipitate, rivers and cold springs, whereas the hotspring waters are shifted about $-2.0^{o}/_{oo}$ for $\delta^{18}O$. Waters originated from the surface or rivers and cold springs have different set of isotopic signatures, whereas the waters originated from the deep reservoirs, which is tapped from the outflowing hotsprings, are isotopically enriched. The Apas Kiri hot springs (A1-5) are grouped as similar origin and the thermal waters does not mixed with the young groundwaters. It could be deduced that the old groundwaters of the hotsprings are separated by a confining sequence, namely 'clay cap'. This could also be deduced that the isotopically enriched hotspring waters are recharged from the same elevation. The isotopic composition of the cold springs are plotted for reference and it could be noted that it plotted away from the thermal waters. The plot also indicate that the recharge point for the cold/shallow springs and deep/thermal groundwater is different.

From the **Fig. 11**, the hermal springs indicates The old waters of Apas Kiri hot springs does not mix with the young waters. A confining sequence is present ; this confining sequence is probably the hydrothermal clay cap. The straight line crossing the hot springs plot from the LMWL is a line plotted in relation to the andesitic waters ($\delta^{18}O$ +10, $\delta^{2}H$ -20).

10.3 Local Meteoric Water Line – LMWL.

The isotope data taken for the first round interpretation is from July 2007 to June 2008, a one hydrological complete cycle.

The raw data is plotted to obtain the regression equation as follows :

$$\delta D = 7.4418\ \delta^{18}O + 7.4888$$

The correlation between $\delta^{2}H$ and $\delta^{18}O$ is shown on Figure 12.

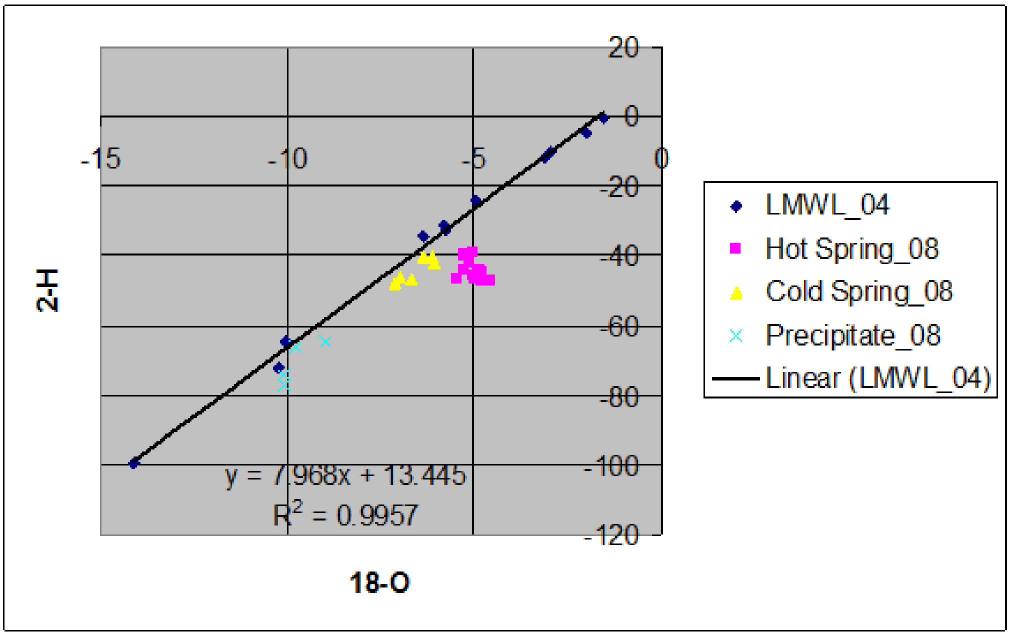

Figure 11: The stable isotope value for Apas Kiri, Tawau area.

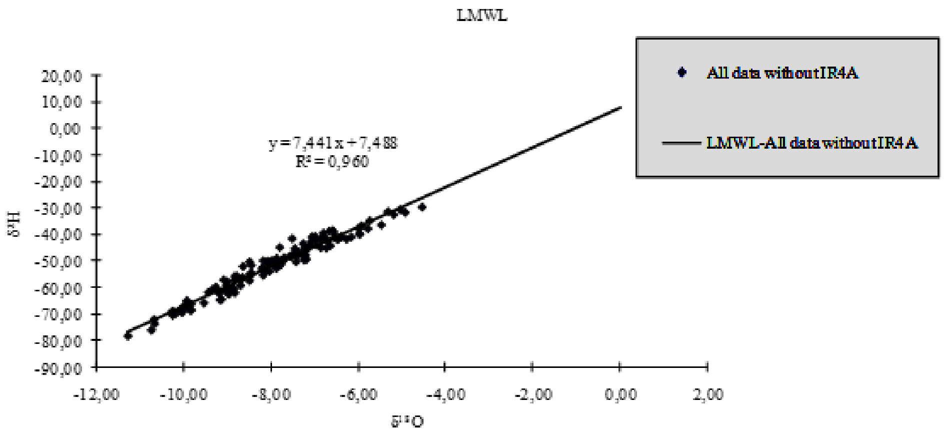

Figure 12: Local Meteoric Water Line, Tawau.

10.4 Altitude effect.

Weighted means of the isotopes in precipitation have been calculated using the rainfall amount of each station over the years 2007-2008.

$$\delta\, ^{18}O = -0.0017H - 7.4724$$

$$\delta\, D = -0.0108H - 48.394$$

The two equations mean that, for ^{18}O, the depletion gradient is 0.17‰ per 100 meter increase in elevation, with a corresponding decrease of 1.08‰ for ^{2}H..

The stable isotope composition of the geothermal water at Apas Kiri, cold springs and the different types of water sources are shown in Tables 1 and 2. The isotopic values of the precipitation recharging the geothermal system, as deduced from the andesitic and geothermal water dilution line, is about -45.0 $^{o}/_{oo}$ for $\delta^{2}H$ and about -5.0 $^{o}/_{oo}$ for $\delta^{18}O$, which indicates that the geothermal system is recharged by about 20% magmatic water and 80% from precipitation (Fig. 11).

The groundwater isotopes also further validates the varying recharge elevations for the different water types of surface waters, hot and cold groundwaters.

It is interpreted that that the recharge elevation for the deep geothermal systems is within and around the Mount Maria volcanic crater relics, which has elevations of about 800 – 1,000 m amsl. It is assumed that the meteoric recharge is through the fractures systems, faults and joints.

From the precipitation sampling through isotope raingauges, the isotopic contents obtained are heavier than that of the thermal waters. The thermal waters in Apas Kiri outflowing hot springs have the range from -39.32 $^o/_{oo}$ to -47.28 $^o/_{oo}$ for δ^2H and from -4.58$^o/_{oo}$ to -5.25$^o/_{oo}$ for δ^{18}O. In this case, the geothermal systems were recharged during the different season. Seasonal isotopic variation affects the isotopic signatures in precipitations and the meteoric water recharged will have different isotopic contents, in this case the precipitations isotopic signatures ranged from about -47.00 $^o/_{oo}$ to -58.00 $^o/_{oo}$ for δ^2H and from about -7.50$^o/_{oo}$ to -9.00 $^o/_{oo}$ for δ^{18}O. This is clearly shown in **Figs. 13** and **14**, which plots the average isotopic composition of rainfall from ten stations for one hydrological cycle (2007-2008). Hence, local precipitation during the years 2007-2008 has different isotopic contents due to seasonal effects, nevertheless the equations are well and can be applied to deduce recharge elevations for normal shallower and younger groundwaters.

10.5 Groundwater Dating with ^{3}H (in water) and 14-C (TDIC).

The duration of circulation in deep reservoir has been estimated by the radioactive isotopes 3-H, and 14-C. The sampled hot springs in Tawau has about zero tritium content which suggest that the circulation time is more than 60 years. The tritium has half-life of 12.43years. Carbon-14 has half life of 5,730 years. It is useful for dating geothermal fluids as they have normally much longer circulation time. The dilution of Carbon-14 is accounted for in the decay equation by the dilution factor or fraction, q, and the age of groundwater is determined by the radioactive decay equation.

q = d^{13}C(DIC) - d^{13}C (Soil Sed) / d^{13}C (Soil CO_2) - d^{13}C (Soil Sed),

where d^{13}C (Soil Sed) = 0 and t = -8267 ln (a /q.a_0),

where a = d^{14}C(DIC) of the 14-C sample and a_0 = 100 pMC.

By using the above formulae, age of hot springs water obtained are as follows :

A1A = 15,200 years, A1B = 16,400 years, A2B = 15,300 years and T1 = 38,700 years.

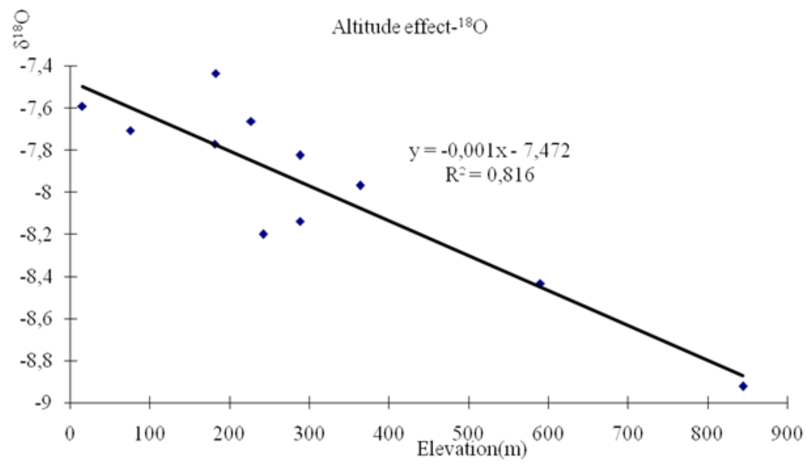

Figure 13: Altitude effect ^{18}O, Tawau area.

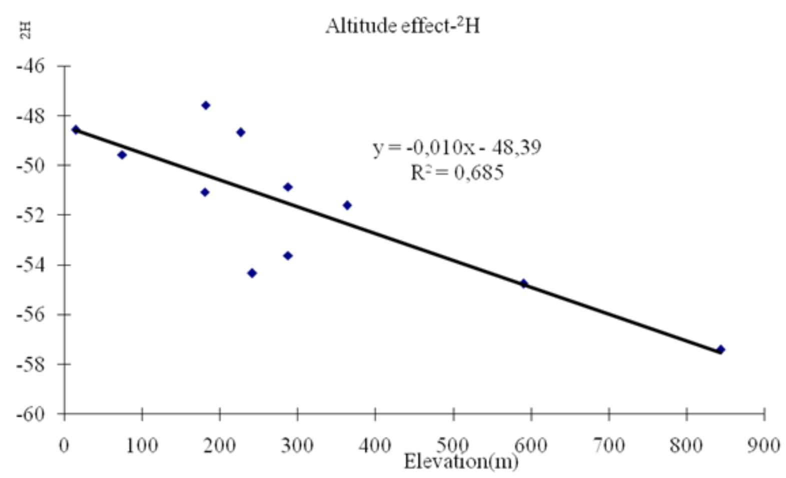

Figure 14: Altitude effect ^{2}H, Tawau area.

11.0. RESULT AND DISCUSSION

11.1 Cl-SO4-HCO3 Ternary Diagram

In order to distinguished between the main water types and to determine which waters are most suitable for application of solute geothermometers, the Cl-SO4-HCO3, a ternary diagram, is used (**Fig. 6**). All the thermal waters are plotted near the Cl corner in this diagram and there are no plot within the SO4 and HCO3 corners. The thermal water if plotted near the HCO3 corner is not sufficiently mature and HCO3 could be mostly derived from CO2-rich groundwater and possibly from magmatic activity. In upper parts of margins of geothermal systems where thermal waters are mixed with cold waters, temperatures of geothermal fluids with high bicarbonates and dissolved CO2 contents are well below the boiling temperatures.

For the Cl-SO4-HCO3 ternary diagram, the more contents of HCO3 may indicate mixing with cold groundwaters (peripheral water) and may be due to presence of carbonate rocks in the area but for the Apas Kiri area, no evidence of carbonate rocks occur. Obviously, the Apas Kiri thermal spring waters have more chloride contents which indicate the water is Cl-mature.

11.2 Na-K-Mg Ternary Diagram and Geothermometry

In order to determine the reservoir temperatures of the geothermal waters, chemical geothermometers were applied.

The sub-surface temperature estimated by using several Na/K geothermometers are in the range of 185.7 – 220.3 oC (Fournier 1979), 158.3 – 198.9 oC (Arnorsson, 1983), 203.0-235.4 oC (Giggenbach 1988), 149.1-191.8 oC (Truesdell 1976). By using several quartz geothermometers, the range of 188.9-202.1 oC (F&P, 1982), 169.1-187.8 oC (Arnorsson, 1985), 178.58-201.08 oC (Fournier 1977, no steam loss). By using chalcedony geothermometers, the range of sub-surface temperature is 151.6-175.2 oC (Arnorsson, 1983), 157.3-183.4 oC (Fournier 1977). By using isotope techniques alfa (SO4-H2O), the temperature estimate range from 152.17-195.14 oC (Table 8).

From the Na-K-Mg ternary diagram (the Giggenbach Triangle), all the hot springs water are plotted within the partially equilibrated waters and non is plotted near the Na, K or Mg corners (**Fig. 7**). If the water sample are plotted near to Mg corner, it is indicating that the thermal fluids are in mixture of cold groundwaters. If the samples are relatively high in Mg concentrations, this is due to the HCO3- type of water, and hot spring waters stand alone and further supported by the plot of isotopic data, where the old hot spring waters are in non-mixture with the young groundwaters (**Fig. 11**). It is actually difficult to estimate the reservoir temperature when it is plotted near the Mg corner.

Since most of the waters are considered mature or equilibrated, therefore the solute and silica geothermometries are yielding meaningful equilibration temperatures but still all the sub-surface temperatures are merely a suggested (estimated) reservoir temperatures, and drilling may confirm the exact temperatures.

12.0. CONCLUSIONS

The geothermal resource potential assessments, based on chemical and isotope studies were carried out for the thermal springs in Apas Kiri and some other adjacent thermal springs, in the vicinity of Mt. Maria inactive young Quaternary volcanics in Tawau.

The partially equilibrated thermal waters in the Apas Kiri area are recharged by meteoric waters through fracture systems probably within the Mt Maria vicinity and outflows in the Apas Kiri area through the old steaming ground (A1-5) and its vicinity. The major type of thermal waters classified includes steam-heated waters in the northern part of survey area (Upper Tawau River and headwaters of Balung River areas), chloride-bicarbonate waters in the Tawau Town T1 area, and chloride waters in the Apas Kiri area outflow zone (**Fig. 5**).

The different water types are also distinguished based on their isotopic composition. The old thermal spring waters in Apas Kiri are in non-mixture with the young groundwaters, indicating the geothermal reservoir is capped by a confining sequence namely ‘clay cap’. The thermal spring waters are also related to the andesitic water where the probable mix ratio is 20:80, based on the graph projections. A further study is recommended to determine the andesitic water relation to the meteoric water recharge to the geothermal systems in Mt. Maria volcanic complex.

Thermal waters dating using the Carbon-14 provided significant information for the geothermal resource. The age of thermal springs water obtained for A1A is 15,200 years, A1B is 16,400 years, A2B is 15,300 years and T1 is 38,700 years.

The estimated reservoir temperatures obtained by using several Na/K geothermometers are in the range of 185.7 – 220.3 oC (Fournier 1979), (158.3 – 198.9 oC, Arnorsson, 1983), 203.0-235.4 oC (Giggenbach 1988), 149.1-191.8 oC (Truesdell 1976). By using several quartz geothermometers, the range of 188.9-202.1 oC (F&P, 1982), 169.1-187.8 oC (Arnorsson, 1985), 178.58-201.08 oC (Fournier 1977, no steam loss). By using chalcedony geothermometers, the range of sub-surface temperature is 151.6-175.2 oC (Arnorsson, 1983), 157.3-183.4 oC (Fournier 1977). By using isotope techniques alfa (SO4-H2O), the temperature estimate range from 152.17-195.14 oC.

All of the promising initial results warrant for further investigations. The estimated reservoir temperatures are presented in **Table 6**.

A DEM (Digital Elevation Model) was created to view the major surface faults/joints and fracture for the Mt. Maria geothermal resource potential areas. These DEM are important to interpret the extensions of the geothermal systems, and for the next detail study e.g. geological mapping and geophysical surveys.

13.0. RECOMMENDATIONS

For the next course of investigations, the following work list are recommended to ascertain the extent of the geothermal systems :

i. Detailed geological mapping for the whole Mt. Maria volcanic complex. This includes mineralogical and fluid inclusions studies.
ii. Detailed survey to further map the thermal springs, to identify the exact outflow and upflow regions.
iii. Further water and gas samplings.
iv. SO4-H2O models for δ18O for the rest of the thermal springs.
v. Water datings.

As for the geophysical surveys, the items listed as follows may be carried out :

i. Design for the geophysical surveys for the northern part of the study areas.
ii. Gravity surveys for the Mt. Maria volcanic complex.
iii. Further Magnetotellurics(MT) surveys with Time Domain Electromagnetic (TDEM) survey corrections.
iv. Drilling.

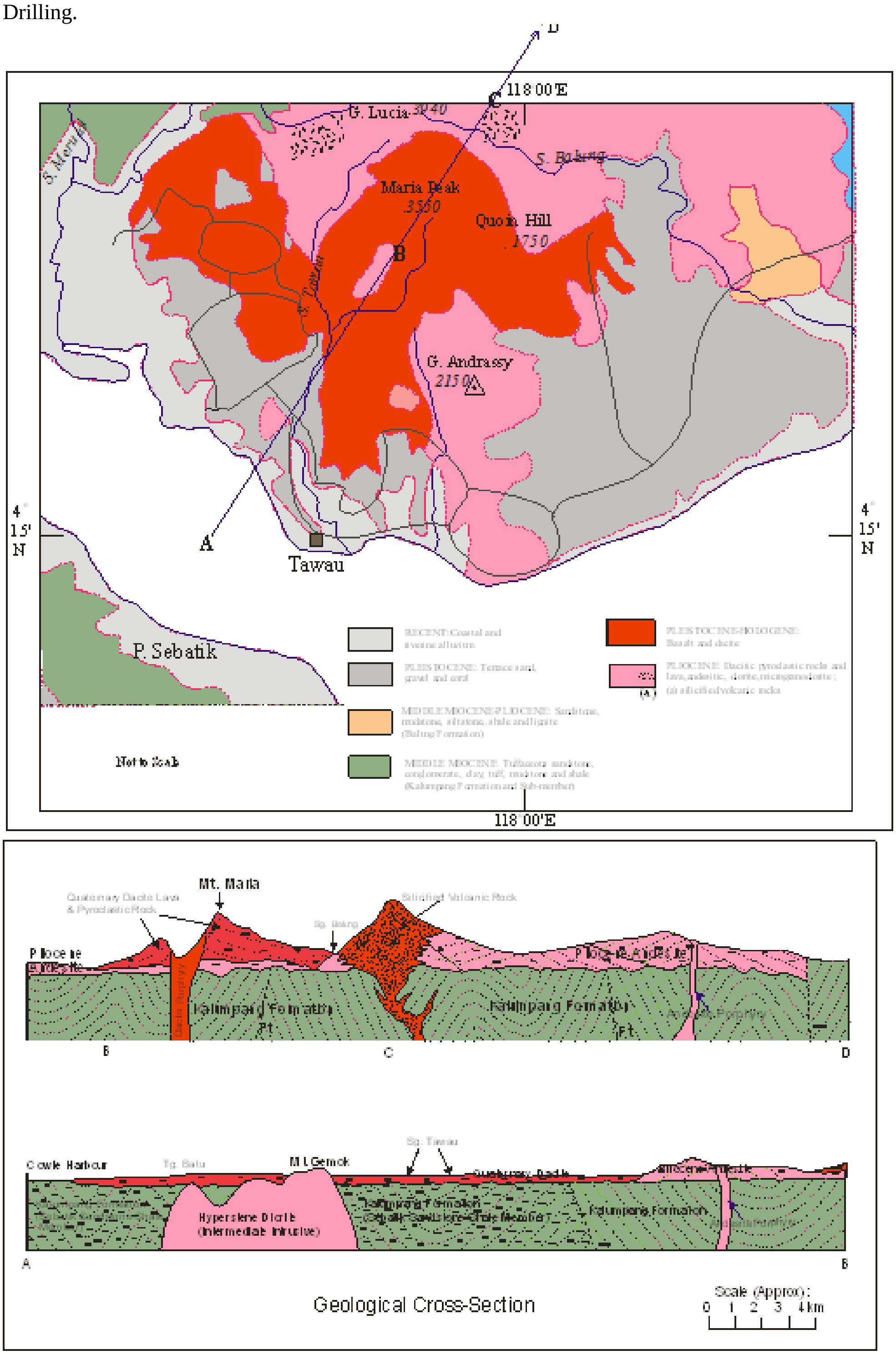

Figure 15. Geological cross sections

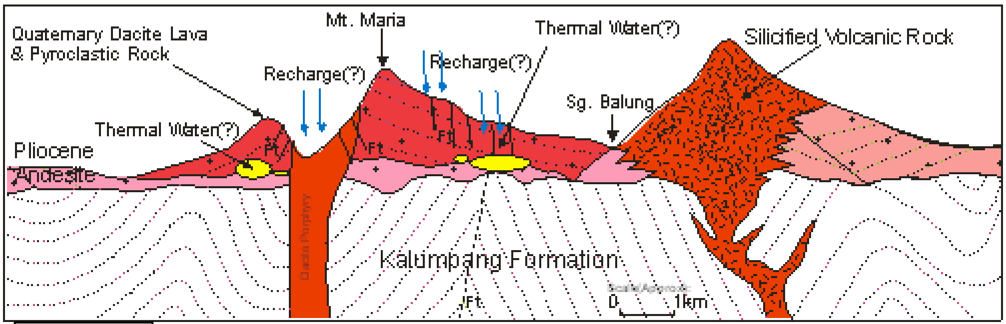

Fig. 16a Probable(A) thermal waters occurrence based on geological and isotopic data.

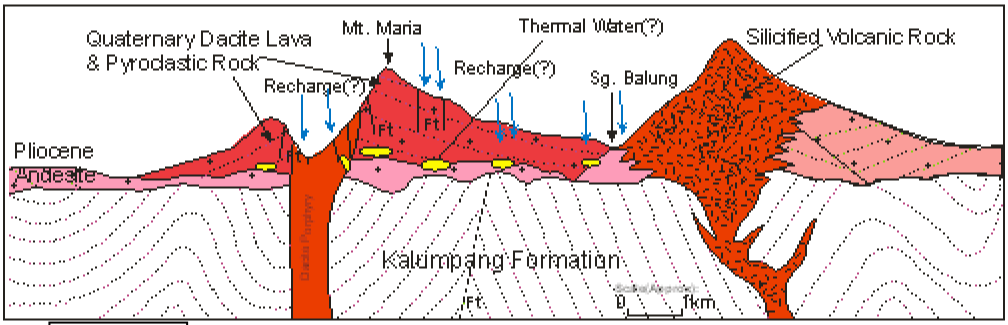

Fig. 16b Probable(B) thermal waters occurrence based on geological and isotopic data

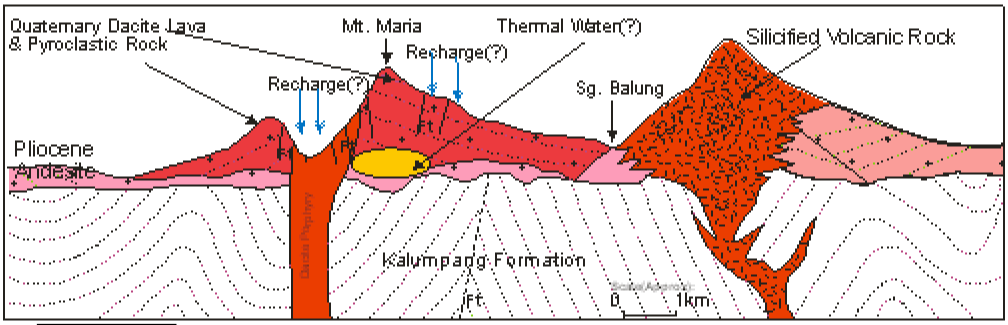

Fig. 16c Probable(C) thermal waters occurrence based on geological and isotopic data.

Figure 16 a-c : Probable thermal waters occurrence based on geological and isotopic data.

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