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

Isotope and Geochemical Investigations on Tawau Hot Springs in Sabah, Malaysia

Fredolin Javino[1], Saim Suratman[1], Zhonghe Pang[2], Manzoor Ahmed Choudhry[3],

Joeffery Caranto[4], Manuel Ogena[4], Ibrahim Amnan[1]

[1]-Minerals and Geoscience Department Malaysia, [2]- China Academy of Sciences, China,

[3]- Pakistan Institute of Nuclear Science and Technology, Pakistan, [4]- Philippines National Oil Company, Philippines

fjavino@jmg.gov.my

Keywords: Tawau, Sabah, Malaysia, isotope, geochemistry, geothermal

ABSTRACT

Stable, radioactive isotopes and chemical concentrations have been used to investigate the origin, circulation time and subsurface history of geothermal waters of the Tawau region, particularly the Apas Kiri area. The Tawau region has the highest concentration of young volcanics rocks of Late Tertiary (Pliocene) to Quaternary age, which therefore offers the best possibility of a heat source sufficient for a substantial geothermal resource. Thermal manifestations are found in seven areas, namely Tawau (T1), Upper Tawau (T2), Apas Kiri (A1, A2 , A4 and A5), Balung (B1 and B2), Sungai Jepun (J1 and J2), Mostyn and Tingkayu. An old steaming ground and hot mud pools are also found in the Apas Kiri area. Discharge of springs was up to 2.0 l/s with the surface temperature from 41.1 to 77.6^{o}C. A maximum of eleven sites were selected for collection of first set of water samples and analysed for various isotopes (18-O, 2-H, 3-H of water, 13-C and 14-C of dissolved inorganic carbon; 34-S and 18-O of dissolved sulphates) and water chemistry. Isotopic and geochemical data show that the origin of thermal waters is meteoric water. The δ^{34}S (in SO4) value shows that the sulphate of all the sampled hot springs originated from a modern oceanic water (δ34-S of about +20%o VCDT). Tritium contents and δ^{18}O-δ^{2}H diagram indicate that there is no mixing with shallow young groundwater. The Apas Kiri shows δ^{18}O significant shift of up to 2%o VSMOW ; one of the processes involved for the significant enrichment in isotopic and chloride contents in Apas Kiri hot springs is steam separation/evaporation. As for the water chemistry, generally the Apas Kiri hot springs appear to have consistency in the levels of chloride, silica and cations, as well as spring temperatures that the water geothermometers reflect its good potential. The tritium content of all the hot springs is about zero showing circulation time more than 60 years, which suggests, these thermal waters were recharged before 1952 (nuclear weapon test). Reservoir temperatures estimated by δ^{18}O (SO_4-H_2O) model are very encouraging; Apas Kiri shows 152-196^{o}C, Sungai Jepun 124-156^{o}C and Tawau 112^{o}C. By using chemical geothermometers Na-K-Mg, the temperature obtained is ranging about 190-236^{o}C, in which the Apas Kiri is the highest.

1. INTRODUCTION

The geothermal resources in the Tawau-Semporna region, Sabah, Malaysia, is considered to be of high potential for geothermal energy resources. The initial investigations into the geothermal energy resources have been carried out mainly by the Minerals and Geoscience Department Malaysia (previously known as Geological Survey Department Malaysia) since the late 80s. The preliminary findings are summarized below :

a) Geothermal indications in the Tawau-Semporna region include many hot springs, mud pools and old steaming grounds. Geothermal secondary minerals such as chloride, pyrite and actinolite are widely distributed in the area.

b) The geology of the area with active geothermal indications consists of Late Tertiary (Pliocene) to Quaternary dacitic to basaltic lava and tuff. The volcanic activity is caused by the extension of the Sulu Archipelago Arc-Trench System into the Semporna Peninsula, which was most active during the Pleistocene (Fig.1).

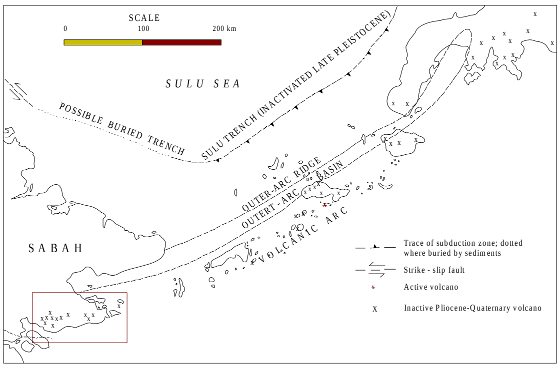

Figure 1: Geologic setting of the Tawau-Semporna area (modified after Hamilton, 1979 and Seismotectonic Map of Malaysia, 1986)

c) The most active area of the geothermal showings is the Apas Kiri, Tawau area, where the highest water temperature of 77.6^{o}C had been recorded. Subsurface temperatures in the Apas Kiri area were estimated using Na/K geothermometers to be between 189^{o}C and 236^{o}C and this temperature range shows that there is high potential for harnessing geothermal energy in this area (Figures 2 and 3).

2. LOCATION

The Apas Kiri is located 3 km to the north of Andrassy Peak, which is located within the Tawau-Semporna region, Sabah, Malaysia (Figures 2 and 4).

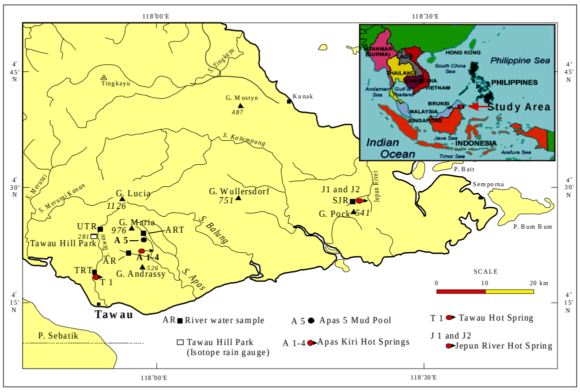

Figure 2. Location of Apas Kiri Area and other Hot Springs in the Tawau region, Sabah, Malaysia.

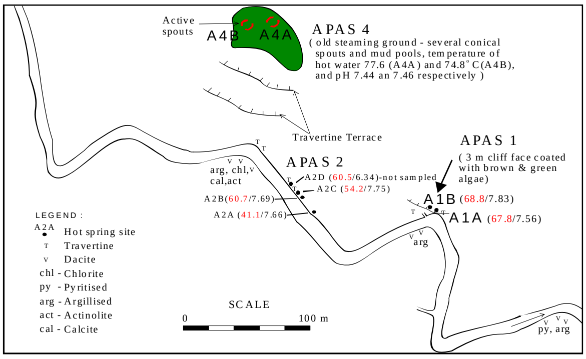

Figure 3. Sketch of hot springs in the Apas Kiri area (refer Fig. 2)

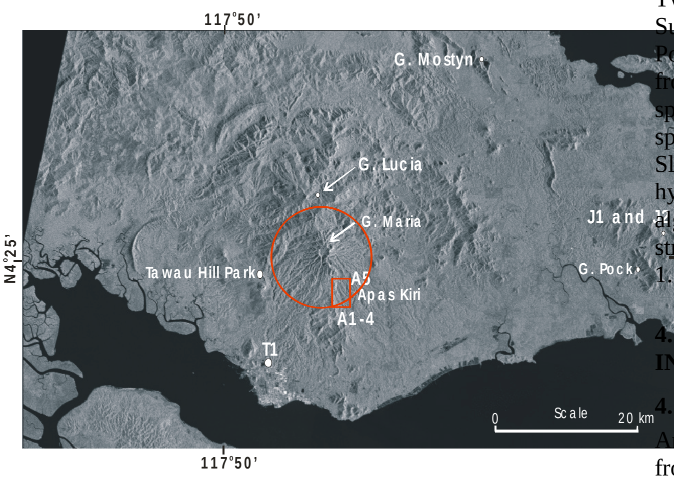

Figure 4. A radarsat image of the Tawau region, Sabah, Malaysia

3. GEOTHERMAL SURFACE MANIFESTATIONS

3.1 Apas Kiri

The type of geothermal surface manifestations occurring in the Apas Kiri area includes hot springs, seepages, 'old steaming ground' and mud pools. The geothermal activities are located in the vicinity of major lineaments (Figures 4 and 5) and the recorded temperature ranges from 41.1°C to 77.6 °C, with recorded flow rate of 0.3 – 1.0 l/s.

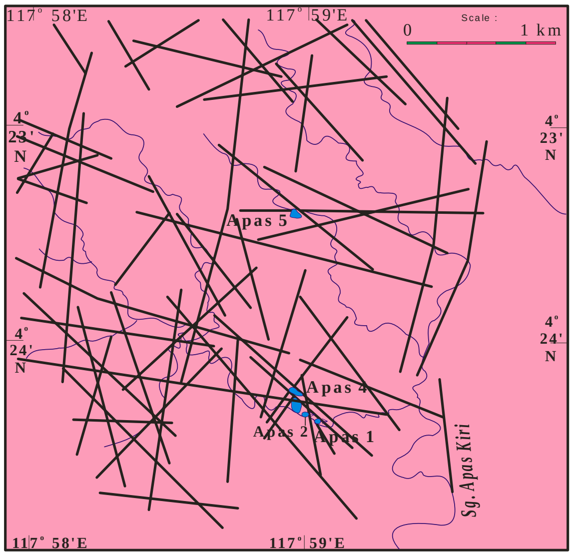

Figure 5. Linear structures of the Apas Kiri area based on aerial photographs

These manifestations occur over a 3 km^2 area in the Apas Kiri. On the other hand, the total possible resource area within the A5 mud pools, interpreted based on previous geophysical investigations, is at least 700,000 m^2.

3.2 Sungai Jepun

Two hot springs found (J1 and J2) on the right bank of Sungai Jepun, on the northeasterly foothills of Gunung Pock (Pock Peak). The hot springs appear to discharge from contact between solid rock and ash deposit. Larger spring issues 3-4 m above river level, while second springs emerges 2 m above stream level, 30 m upstream. Slight smell of H_2S and the rock nearby are hydrothermally altered and travertine is present. Green algae grow in the hot spring discharge and in the main stream. The recorded flow rate of the main spring (J1) is 1.5 – 2.0 l/s and the second spring (J2) is 0.5 – 1.0 l/s.

4. PREVIOUS WORK ON GEOCHEMICAL INVESTIGATIONS

4.1 Chemistry of Thermal Waters

Analysis results (Table 1) showed that the thermal water from the Apas Kiri have the characteristics of neutral pH sodium chloride water ; they have high concentrations of

4.2 Chemical Geothermometry

The subsurface temperature of the area has been estimated using different chemical parameters as shown in Table 2. The silica geothermometer gave a low subsurface temperature probably due to the silica dilution of the waters in the Apas Kiri area.

The Na/K geothermometer on the other hand, gave a high subsurface temperature for the waters at Apas Kiri.

Table 1. Chemistry of waters from springs in the Apas Kiri area.

Note:
1. All cations & anions are expressed in ppm.
2. Total solids are expressed as mg/l, conductivity as µohm & turbidity as N.T.U.
3. na-not analysed

Locality:
Apas 1: Outflow Spring (contaminated with cold water seepage).
Apas 5: Hot outlet at Mud Pool.

(Extracted and modified from P.S. Lim, Geo. Soc. Malaysia, Bulletin 29, July, 1991).

Samples	**Apas 1**	**Apas 5**
Site Temp. ^oC	60	60
pH at 25^oC	7.4	6.7
Dissolved SiO_2	6.0	na
Total SiO_2	86	75
Ca	150.9	142.37
Mg	34.1	12.9
K	77.5	93.5
Na	760	925
Li	5.4	5
HCO_3	705.16	544.12
SO_4	312.5	476
Cl	1250	1410
F	0.65	0.63
B	21	60
As	150	250
Fe	0.3	0.2
Mn	0.3	0.8
Total Solids	3158	3446
Turbidity	2.55	*
Conductivity	4910	5320
Na/K	16.7	16.9
Na/Ca	8.78	11.14
Na/Li	42.4	56.1
Cl/B	10.25	7.17
Cl/SO_4	6.12	8.03
Cl/F	581.6	1205

Table 2 - Subsurface temperature calculated from chemical geothermometers

(Extracted and modified from P.S. Lim, Geo. Soc. Malaysia, Bulletin 29, July, 1991).

			Subsurface Temperature				
			Silica		**Na/K**		
Location	**Charge**	**Spring Temperature**	**Truesdell**	**Fournier**	**Truesdell**	**Fournier (1971)**	**Giggenbach**
Apas	-10	75.6	127.9	130.2	191.9	220.5	234.8
Apas	-14	72.2	129.9	132.6	193.1	221.4	235.2
Apas	-10	69.0	126.9	128.9	189.6	218.7	234.0
Apas	-4	60.0	120.8	121.7	188.7	217.9	233.0

4.3 Resistivity Study

A resistivity investigation was carried out in the Apas Kiri area as a result of the high subsurface temperature found in the area. The results of the investigation are shown in (Figures 6 and 7). An area within the A5 is found to be of good potential ; the geophysical contour within the A5 area is seen as ‘open-ended contour’ suggesting the resource area may extend to the north of the Apas Kiri.

5. THE PURPOSE OF THE CURRENT STUDY

Generally, the study targets to evaluate more precisely the potential of geothermal reservoirs for further exploration and exploitation using isotope and geochemical techniques.

The specific objectives would include investigations on the origin and dating of water, its chemical characteristics and subsurface history, determination of reservoir temperatures, heat source and potential of the geothermal reservoirs, ranking and recommendation for detailed exploration.

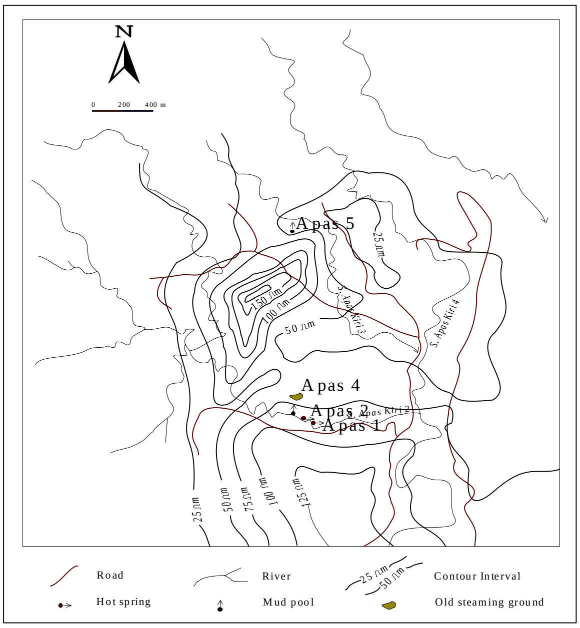

Figure 6. Isoresistivity Map (AB = 1000 m), Apas Kiri Area, Tawau (modified from P.L.N., 1991).

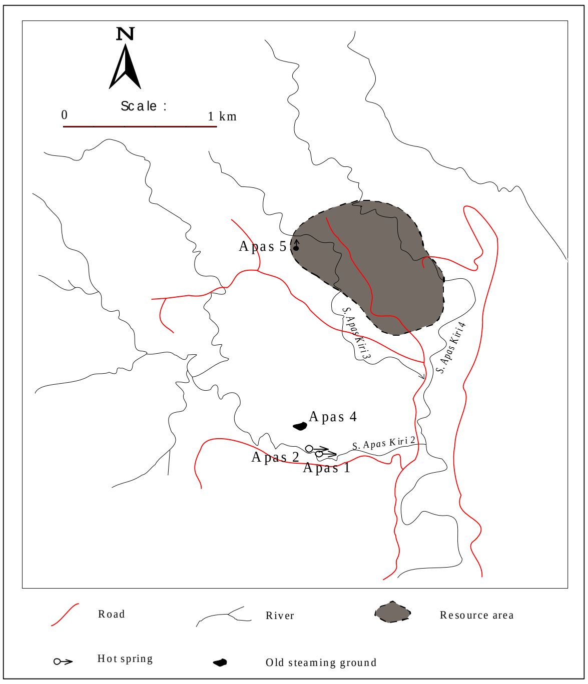

Figure 7: Probable resource area indicated by resistivity (modified from P.L.N., 1991)

6. GEOLOGY

The Apas Kiri area is underlain mainly by dacitic lava, tuff and agglomerate of Late Tertiary (Pliocene) to Quaternary age (Fig. 8). The dacitic agglomerate is found mainly in the west, northwest and northeast whereas dacitic lava and tuff are found in the central, south and eastern portions. The dacitic rocks are both mesocratic and melanocratic. The agglomerate is made up of angular clasts of dacitic lava and tuff in a fine-grained volcanic matrix.

The dacitic rocks are well jointed. An aerial photograph study (Fig. 5) showed that most of the linear structures are predominantly northwest, north and northeast direction. As seen on radarsat imagery (Fig. 4), most of the geothermal manifestations occur around the Mount Maria Peak, namely the Apas Kiri (A1, A2, A4 and A5), Balung, upper Tawau (T2) and Tawau (T1) hot springs. These joints may reflect fracture zones due to updoming by magmatic pressure. These major fracture zones may play an important role in creating adequate fracture permeability for the outflow of geothermal fluids, especially in the upper Tawau and Balung areas where the hot springs are located close to these fracture zones. The lineament south of Maria Peak may represent a major north-south fracture zone which permits inflow of meteoric water into the geothermal system. It is inferred that the centre of reservoir is beneath the Mount Maria Peak, or more precisely at the southeast of Maria Peak as indicated by the presence of H_2S and geochemical characteristic of the hot spring waters.

The alteration in the rocks are mainly calcitised, chloritised and argillised. Pyritisation and silicification is more dominant in the northeast and the western part. Epidote and actinolite have been found in the rocks. The agglomerate are commonly oxidised and argillised.

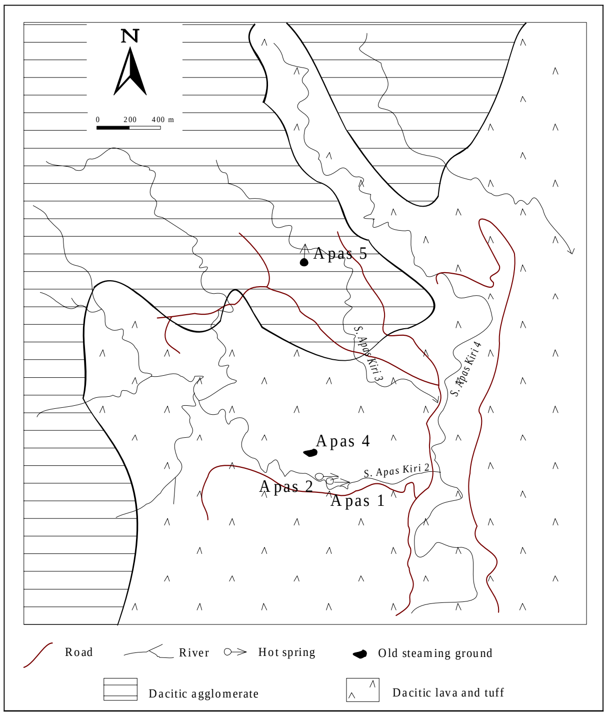

Figure 8. Simplified geology of the Apas Kiri area

7. SAMPLING AND ANALYSIS

First set of sampling for isotope and geochemical includes collection of water for 18-O, 2-H, 3-H in water, 13-C and 14-C (in TDIC), 18-O & 34-S in sulphates. A collection of the Tawau precipitates for year 2003 were also included for 18-O, 2-H, 3-H. Analyses for major chemical ions and isotopes such as 18-O, 2-H, 3-H, 13-C and 14-C were carried out at the IAEA (Vienna) and the PNOC Laboratories). The results are shown in Tables 3, 4, and 5.

8. RESULTS AND DISCUSSIONS

The discharge temperature of the hot springs of Tawau region varies from 41.1 to 77.6°C in which the A4A is the highest. The thermal waters in Apas Kiri has high concentrations of chloride, sodium and bicarbonate ions with pH of about neutral. In Apas Kiri, the EC ranges between 3,910 uS/cm and 4,750 uS/cm, in Sungai Jepun 1,969-2,300 uS/cm and in Tawau 2,030 uS/cm. The chemistry shows that the thermal waters of the Apas Kiri area are sodium chloride water type (Table 3 and Fig. 12).

The geochemical analysis results, as shown on Table 3, generally shows that the water sample chemistry appears to have consistency in the levels of chloride, silica and cations, as well as spring temperatures that the water geothermometers reflects good potential of Apas Kiri (Fig. 13).

The isotopes analysis result for river and rainfall samples shows that the levels of tritium (Tables 4) ranges from 0.8-1.5TU for the river and 1.4-7.6TU for the Tawau precipitate which are considered very low i.e. ranges from -1.57%o to -10.23%o VSMOW. As for the rivers, the δ18-O levels range from -6.67%o to -7.26%o VSMOW. The mean δ18-O value for the Tawau precipitate -6.13%o VSMOW ; this mean-value could be used for projection to the linear LMWL to determine for the end-members of meteoric water and could be projected to the Apas Kiri isotopic content for the other end-members.

From the isotopic and geochemical data obtained, it shows that the origin of thermal waters are meteoric waters. The $\delta^{34}S$ (in SO4) value shows that the sulphate of all the sampled hot springs originated from a modern oceanic water (δ34-S of about +20%o VCDT). Tritium contents and δ18-O-δ2-H diagram indicate that there is no mixing of shallow young groundwater. The Apas Kiri shows δ18-O significant shift of up to 2%o VSMOW ; one of the processes involved for the significant enrichment in isotopic and chloride contents in Apas Kiri hot springs is steam separation/evaporation (Fig. 14).

The triangular plot of main anions for hot springs of the Tawau area (Fig. 9) shows that the A5 is the nearest to the heat source rock or in general, the Apas Kiri area, as indicated by the enhanced amount of chloride. Plots of boron vs. chloride (Fig. 11) further validate the Apas Kiri hot springs are located near to the heat source rock. The chloride, when plotted against temperature (Fig. 10), could indicate that the hot springs in Apas Kiri varies in temperature, probably due to its location. The A4A and A4B hot springs are located away from the river surface water, thus the surface temperatures are higher compared to the other hot springs. The isotope and geochemical characterisitcs of the Apas Kiri show that it is an outflow region. Reservoir temperatures estimation by using δ18-O (SO_4-H_2O) model are very encouraging ; Apas Kiri shows 152-196 °C, Sungai Jepun 124-156 °C and Tawau 112 °C. By using chemical geothermometers Na-K-Mg, the temperature obtained is ranging about 180-236 °C, in which the Apas Kiri is the highest (refer Tables 2 and 6 and Figures 13 and 15).

8.1 Origin of Geothermal Waters

Isotopic data can well differentiate between the three possible types of origin of thermal waters i.e magmatic, oceanic and meteoric. Ranges of δ18-O of all the sampled hot springs of (i) Apas Kiri: -4.69 to -5.13%o VSMOW, (ii) Sungai Jepun: -6.05 to -6.11%o VSMOW and (iii) Tawau: -6.41%o VSMOW. As for the δ2-H (i) Apas Kiri: -37.0 to -41.2%o VSMOW, (ii) Sungai Jepun: -35.4%o to -36.1%o VSMOW and (iii) Tawau: -41.7%o VSMOW. These data do not show the presence of any significant amount of magmatic water which generally has δ18 : +6 to +9%o and δ2-H: -40 to -80%o VSMOW (Pearson et al ,1980; Giggenbach, 1992). The important feature of the fluids emerging from the hot springs in Apas Kiri is their consistency in the levels of chloride, silica and cations, which is high compared to the other sampled hot springs in the area ; the maximum EC is 4,750uS/cm for Apas Kiri hot springs, while Sungai Jepun is 1,969-2,300 uS/cm and Tawau is 2,030 uS/cm. The chloride content of Apas Kiri ranges from 1,078-1,336 ppm, whereas Sungai Jepun ranges from 146-147 ppm and Tawau is 353 ppm. Normally the ocean waters show δ18-O and δ2-H of about 0%o VSMOW, the salinity from 33,500 to 37,600 ppm and chloride about 19,300 ppm (Clark et al., 1998).

Modern oceanic sulphates has δ34-S values of about +20%o VSMOW (Krouse, 1980). From the δ34-S values, obtained for this sampled hot springs in Tawau, are reflective of modern oceanic origin. The presence of very low or about zero tritium content in the hot springs water also suggests that the water has no mixing with the young groundwater.

8.2 Tritium and Radiocarbon Dating

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 3-H content which suggest that the circulation time is more than 60 years. The tritium has half-life of 12.43years.

14-C 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 14-C 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.

9. CONCLUSIONS

The thermal waters of hot springs in Tawau are originated from local meteoric water. The $\delta^{34}S$ (in SO4) value shows that the sulphate of all the sampled hot springs originated from a modern oceanic water (δ34-S of about +20%o VCDT), and do not have any mixing of shallow young groundwater. One of the major processes involve is steam separation/evaporation, which indicated by the significantly enriched isotope and chloride contents in Apas Kiri hot springs. The hot springs of Apas Kiri is significantly enriched or has δ18-O shift of up to 2%o. Tritium data of all the hot springs are about zero which indicate that the duration of deep circulation of thermal fluids is more than 60 years i.e. the recharge occurred before 1952 (nuclear weapon test). The 14-C activities corrected by 13-C data suggest that the age of the sampled hot springs in Tawau ranges from 15,200 to 38,700 years.

As a result of the reassessment of the data, it is concluded that the Apas Kiri (which is an outflow region) and Mount Maria areas have the best geothermal potential, which mean the center of reservoir or upflows are beneath the southeastern part of Mount Maria, but may extends to the North of Apas Kiri (Balung Area). The estimation of reservoir temperatures by δ18-O (SO_4-H_2O) model are very encouraging ; the Apas Kiri shows 152-196^oC, Sungai Jepun 124-156^oC and Tawau 112^oC. By using the chemical geothermometers Na-K-Mg (inclusive of previous estimations), the temperature obtained is ranging about 180-236 ^oC, in which the Apas Kiri is the highest.

ACKNOWLEDGEMENTS

The authors wish to acknowledge:

- to the Director General of JMGM Dato' Yunus Abd. Razak for his support in this project.
- to the Director of JMG Sabah, Alexander Yan, and Engineering Geology Head Mr. Adam Liau, for their support in this project.
- to the IAEA in Vienna, Austria.
- to Prof. Klaus Froehlich for his ideas on investigation strategies and for the isotope data interpretation.
- to Prof. Dr. Luis Araguas-Araguas of Isotope Hydrology Section, IAEA, Vienna.
- to Dr. Yunus Daud of University of Indonesia, Jakarta.
- to the Technical University of Graz and the Joanneum Research Institute of Graz, especially Prof. Ralf Benischke, Dr. Albreicht Leis, Dr. Peter Reichl and Dr. Beyene Yehdegho for their time spent, ideas and supervisions on data interpretation and work strategies.
- to the Director of Sabah Parks Datuk Lamri Ali, and his officers Fatimah Simin and Simon Limbawang for their supports in this project, especially on Tawau precipitate collection.

REFERENCES

Clark, I.D. and Fritz, P. (1998). Environmental Isotopes in Hydrogeology. Lewis Publishers Boca Raton, New York.

Giggenbach, W.F., (1992). Isotopic shift in waters for geothermal and volcanic systems along convergent plate boundaries & their origin, *Earth and Planetary Science Letters*, 113: p495-510.

Hamilton, W., 1979. Tectonics of the Indonesian Region. *U.S. Geological Survey Professional Paper, 1078.*

Krouse, H.R., 1980.Sulphur isotopes in our environment. In : *Handbook of Environmental Isotope Geochemistry, Vol.1*.P.Fritz and J.-Ch. Fontes (eds.). Elsevier Scientific Publishing Company Amsterdam-Oxford-New York. p222-257.

Lim, P.S., 1991. Geothermal prospecting in the Semporna Peninsula with emphasis on the Tawau area. *Geological Society of Malaysia, Bulletin 29, July, 1991, pp135-155.*

Lim, P.S., 1991. Prospects and Potential Areas of Geothermal Resources in Sabah. Proceedings of the 22nd Geological Conference, 1991, p186-194.

Pearson, F.J. and Rightmire, C.T., (1980), Sulphur and oxygen isotopes in aqueous sulphur compounds. In: *Handbook of Environmental Isotope Isotope Geochemistry*,Vol.1.P.Fritz and J.-Ch. Fontes (eds.). Elsevier Scientific Publishing Company, Amsterdam-Oxford-New York. p227-257.

State Electricity Corporation (P.L.N.), 1991. Resistivity Survey at Andrassy Area, Tawau Sabah.

Table 3. Chemical composition and field data of the hot springs in Tawau region, Sabah, Malaysia

Nos.	Sample ID	Location	Sampling Date	Longitude	Latitude	Altitude (m)	T°C	EC	pH at 25°C	Na	K	Mg	Ca	Cl	SO4	HCO3	SiO2	Li	B
1	A2A	Apas Kiri	27/Apr/04	117°58'30"	4°21'33"	160	41.1	3910	7.66	716.0	68.50	14.60	194.0	1078.0	281.0	567.0	71.1	3.66	46.10
2	A2C	Apas Kiri	27/Apr/04	117°58'30"	4°21'33"	160	54.2	4750	7.75	847.0	75.50	16.10	208.0	1231.0	317.0	627.0	69.9	4.17	51.30
3	A5	Apas Kiri	27/Apr/04	117°59'1"	4°22'39"	270	60.0	2600	8.02	858.0	86.80	13.10	165.0	1336.0	297.0	239.0	83.1	4.73	55.60
4	A2B	Apas Kiri	27/Apr/04	117°58'30"	4°21'33"	160	60.7	4340	7.69	792.0	76.20	16.10	208.0	1213.0	315.0	619.0	74.3	4.07	51.10
5	A1A	Apas Kiri	27/Apr/04	117°58'30"	4°21'33"	163.5	67.8	4300	7.56	815.0	77.90	16.70	212.0	1198.0	312.0	668.0	80.2	4.12	45.50
6	A1B	Apas Kiri	27/Apr/04	117°58'30"	4°21'33"	163.5	68.8	4350	7.83	810.0	78.40	16.50	211.0	1218.0	313.0	649.0	81.9	4.15	51.40
7	A4B	Apas Kiri	27/Apr/04	117°58'30"	4°21'33"	180	74.8	4380	7.44	838.0	81.1	16.70	214.0	1237.0	323.0	668.0	81.8	4.18	52.00
8	A4A	Apas Kiri	27/Apr/04	117°58'30"	4°21'33"	180	77.6	4200	7.46	837.0	82.9	16.80	215.0	1246.0	323.0	606.0	77.8	4.28	52.50
9	J1	Jepun River	28/Apr/04	118°22'50"	4°28'4"	60	64.9	1969	8.22	255.0	3.77	0.18	322.0	146.0	1182.0	ND	47.7	<0.05	1.39
10	J2	Jepun River	28/Apr/04	118°22'50"	4°28'4"	60	63.9	2300	8.48	265.0	3.87	0.07	321.0	147.0	1204.0	ND	49.1	<0.05	1.73
11	T1	Tawau Town	28/Apr/04	117°55'47"	4°17'47"	35	48.8	2030	7.69	297.0	22.60	9.15	125.0	353.0	338.0	288.0	65.2	1.07	14.20

Note : ND - Not Detected

Table 4. Isotopic composition and field data of the rivers and rainfall in Tawau region, Sabah, Malaysia

Nos.	Sample ID	Location	Altitude (m)	Sampling Date	$\delta^{18}O$ [‰ VSMOW]	$\delta^{2}H$ [‰ VSMOW]	^{3}H [TU]	± 2σ [TU]
River water :								
1	AR	Apas Kiri River	160.0	7/19/2003	-6.67	-39.7	1.5	0.4
2	ART	Apas 5 River Tributary	270.0	7/19/2003	-6.67	-40.3	1.3	0.4
3	SJR	Jepun River	60.0	7/19/2003	-6.79	-42.7	1.1	0.3
4	TRT	Tawau River Trib. near T1	35.0	7/20/2003	-7.26	-44.8	1.3	0.3
5	UTR	Upper Tawau River	265.0	7/19/2003	-7.19	-42.5	0.8	0.3
Rainfall, elevation 281 m amsl.:								
6	TP2	Tawau Hill Park		3/19/2003	-1.99	-4.9	7.6	0.6
7	TP3	Tawau Hill Park		3/31/2003	-10.23	-72.0	na	na
8	TP4a	Tawau Hill Park		4/13/2003	-2.98	-10.3	na	na
9	TP4b	Tawau Hill Park		4/30/2003	-1.57	-0.2	na	na
10	TP5a	Tawau Hill Park		5/18/2003	-14.10	-99.6	na	na
11	TP5b	Tawau Hill Park		6/10/2003	-4.99	-24.3	na	na
12	TP6	Tawau Hill Park		7/7/2003	-5.79	-32.8	na	na
13	TP7	Tawau Hill Park		7/18/2003	-10.01	-64.3	na	na
14	TP8	Tawau Hill Park		8/4/2003	-6.37	-34.6	1.4	0.4
15	TP9	Tawau Hill Park		9/30/2003	-5.84	-31.3	na	na
16	TP10	Tawau Hill Park		10/18/2003	-3.11	-11.5	na	na

Note : na - not analysed

Table 5. Isotopic composition and field data of the hot springs in Tawau region, Sabah, Malaysia

Nos.	Sample ID	Location	Sampling Date	$\delta^{18}O$ [‰VSMOW]	$\delta^{2}H$ [‰VSMOW]	$\delta^{34}S_{sulphate}$ [‰ VCDT]	$\delta^{18}O_{sulphate}$ [‰ VSMOW]	^{3}H [TU]	± 2σ [TU]	$\delta^{13}C_{DIC}$ [‰ VPDB]	$^{14}C_{DIC}$ [pMC]	± 2σ [pMC]
1	A2A	Apas Kiri	7/17/2003	-4.91	-37.0	20.1	6.4	< 0.6	na	na	na	na
2	A2C	Apas Kiri	7/17/2003	-4.83	-39.3	19.0	4.2	< 0.6	na	-3.5	58.7	8.6
3	A5	Apas Kiri	7/19/2003	-4.69	-38.7	17.5	5.6	< 0.6	na	na	na	na
4	A2B	Apas Kiri	7/16/2003	-4.97	-39.0	20.2	5.4	< 0.6	na	-5.1	4.0	0.6
5	A1A	Apas Kiri	7/17/2003	-5.06	-39.8	19.7	6.3	< 0.6	na	-5.7	4.5	1.2
6	A1B	Apas Kiri	7/16/2003	-5.13	-39.9	19.8	6.7	< 0.6	na	-5.4	3.7	0.7
7	A4A	Apas Kiri	9/26/2002	-5.08	-41.2	na	na	< 0.6	na	na	na	na
8	J1	Jepun River	7/15/2003	-6.05	-35.4	16.5	8.1	0.4	0.4	-7.2	na	na
9	J2	Jepun River	7/19/2003	-6.11	-36.1	16.2	5.4	0.4	0.3	-23.6	na	na
10	T1	Tawau Town	7/20/2003	-6.41	-41.7	20.9	8.9	< 0.6	na	-10.8	< 0.8	na

Note : na - not analysed

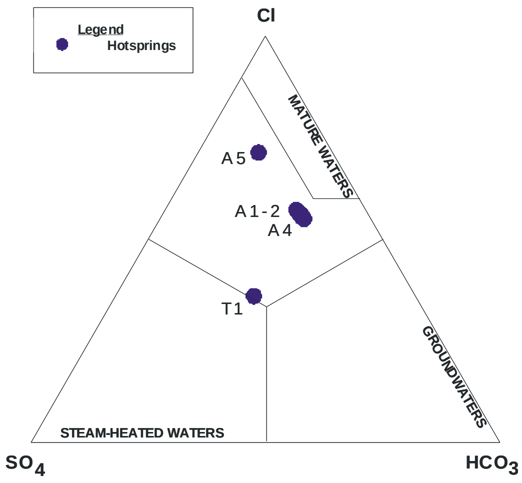

Fig. 9. Triangular plot of main anions for hot springs of Tawau area

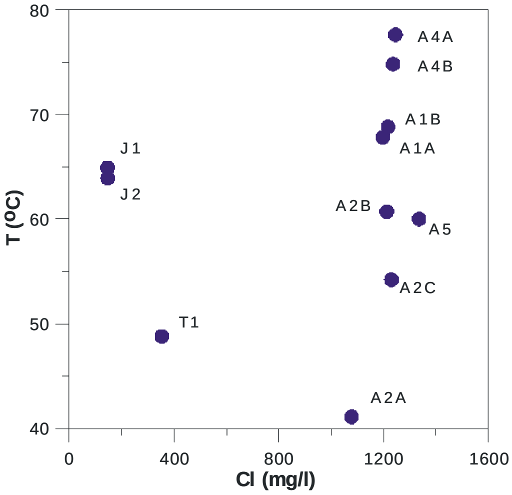

Fig. 10. Plot of Chloride vs. Temperature for hot springs of Tawau area

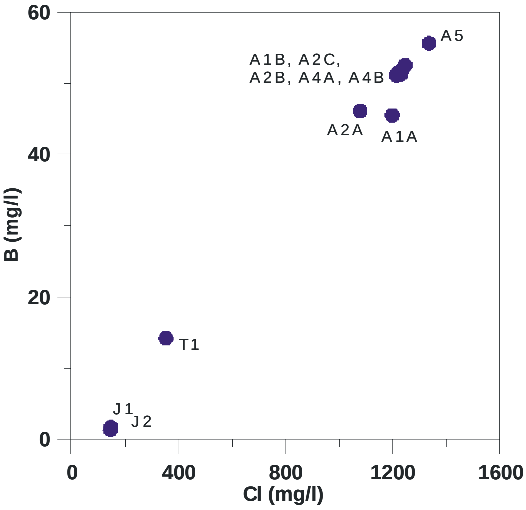

Fig. 11. Plot of Chloride vs. Boron for hot springs of Tawau area

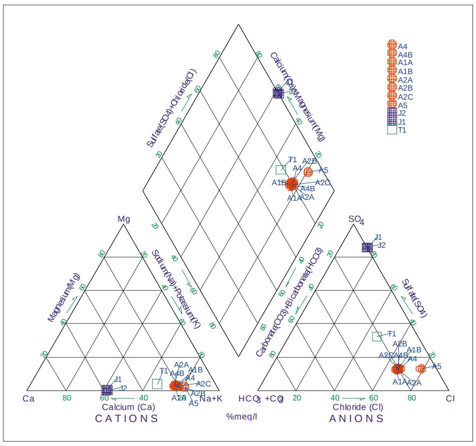

Fig. 12. Piper diagram of hot springs water samples of Tawau area

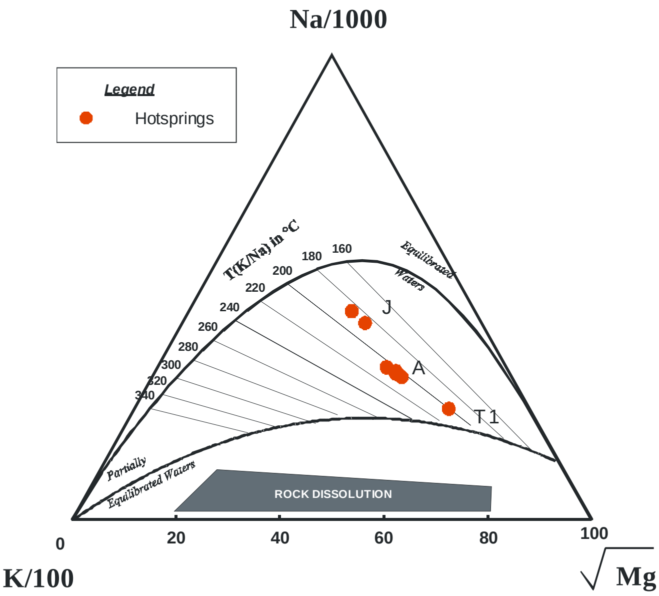

Fig. 13. Evaluation of Na-K-Mg temperatures of thermal waters for sampled hot springs of Tawau area (Giggenbach, 1988)

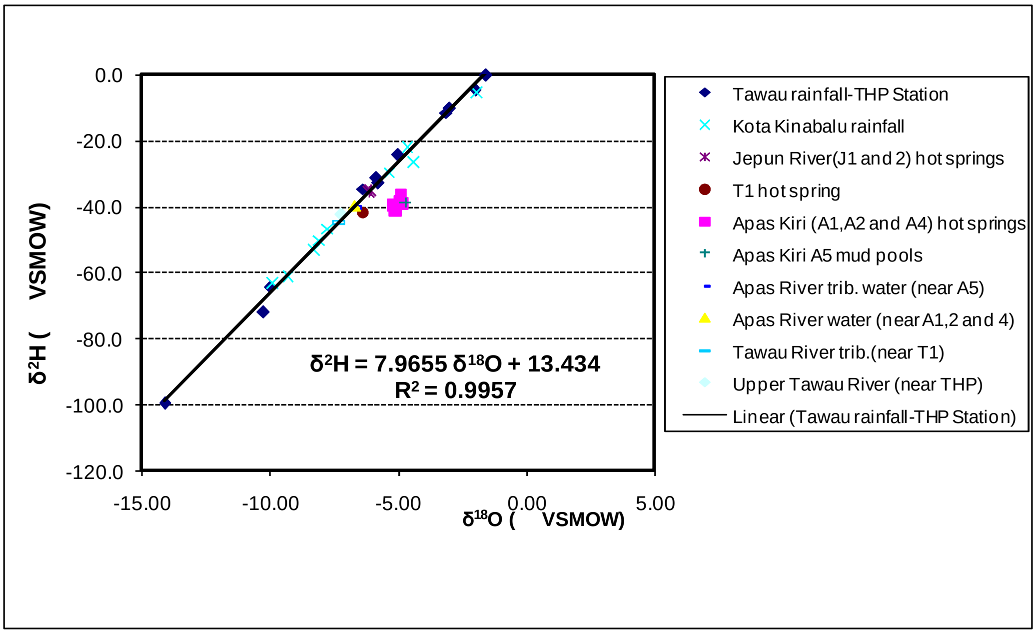

Fig. 14. d18-O vs. d2-H diagram for hot springs, rivers and rainfall of Tawau area

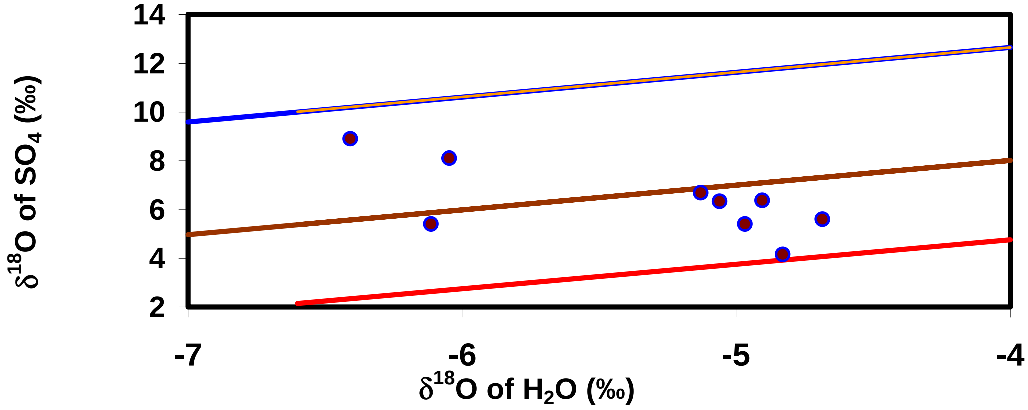

Fig. 15. **$\delta^{18}O(SO_4)$ vs. $\delta^{18}O(H_2O)$ diagram showing reservoir temperatures and relevant isotherms based on the $\delta^{18}O(SO_4$-$H_2O)$ geothermometer.**

Table 6. Reservoir temperatures estimate by O-18 (SO4-H2O) model for hot springs of Tawau area.

Spring Code	Date of sampling	O-18 (water)	O-18 (Sulphate)	Alpha^{18}O	T^{o}C
A1A	7/17/2003	-5.06	6.3	1.0114581	158.0004689
A1B	7/16/2003	-5.13	6.7	1.0118798	152.3146179
A2A	7/17/2003	-4.91	6.4	1.0113306	159.7659507
A2B	7/16/2003	-4.97	5.4	1.0104294	172.8970722
A2C	7/17/2003	-4.83	4.2	1.0090337	195.8514595
A4A	9/26/2002	-5.08			
A5	7/19/2003	-4.69	5.6	1.0103334	174.3684578
J1	7/15/2003	-6.05	8.1	1.0142318	124.3021019
J2	7/19/2003	-6.11	5.4	1.0115839	156.281101
T1	7/20/2003	-6.41	8.9	1.0154059	112.2614528