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Geothermal prospecting in the Semporna Peninsula with emphasis on the Tawau area.

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Abstract: Thermal manifestations in the Semporna Peninsula include hot springs, seepages, mud pools and old steaming ground. Mapping of these thermal features showed that they are structurally controlled.

The chemistry of the thermal waters indicate the presence of two types of waters – near neutral sodium chloride and sulphate waters. Thermal waters from the Apas Kiri area are near-neutral sodium chloride waters and the C1/B and C1/F ratios suggest they have a common source of geothermal fluid. The thermal water from upper Tawau is acid sulphate type and its chemistry suggests it is steam-heated water or ground water mixed with gas (H_2S). The chemistry of thermal waters from Balung and Sungai Jepun areas suggests they are acid sulphate waters which may have come from a far away source and come into contact with and neutralised by cold ground water. The upper Tawau and Balung springs may indicate the perimeter of a field centered on the Maria Volcanic Complex.

The Apas Kiri area is underlain mainly by Quaternary dacitic lava, tuff and agglomerate. The surface thermal manifestations cover an area of 3 km^2. The volcanic rocks are calcitised, chloritised, argillised and pyritised. Around the thermal features, the rocks are strongly argillised and calcitised.

Several characteristics of the Apas Kiri thermal waters e.g. chloride contents, C1/B ratio and geothermometer suggest high subsurface temperature. The C1/B ratio also suggests the reservoir rocks are andesitic.

Total heat loss from the Apas Kiri 2, Apas 5 and Sungai Jepun areas have been tentatively estimated as 28.65, 0.75 and 15.05 MW-Thermal respectively.

INTRODUCTION

During 1989, prospecting for geothermal resources was confined to the sampling and analysis of geothermal waters in the Semporna Peninsula and detailed mapping of the Apas Kiri area, just north of Gunung Andrassy.

With the kind assistance of the Indonesian Government, Mr. Vincent Radja from PLN Indonesia was despatched to Sabah in March 1989 to assist the Malaysian Geothermal Working Group in formulating programs for follow-up geothermal exploration and to advise on short, medium and long term planning and development of geothermal resources. This was followed by the arrival of Mr. Janes Simandjuntak from the Department of Mining and Energy, PLN Indonesia to assist in the sampling and analysis of geothermal waters. The Geological Survey, on its part, carried out 1:10,000

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mapping of 17 km^2 in the Apas Kiri area, north of Mount Andrassy where recent finds indicate this area to have the best potential. Concurrent with this mapping survey, the known occurrences of hot springs in the Balung and upper Tawau areas were relocated and their waters sampled.

This report, therefore, summarises the results of the investigations carried out in 1989. The location of springs sampled and the Apas Kiri area are shown in Figure 1.

GEOLOGIC SETTING

The Semporna volcanic belt is the southwest extension of the volcanic belt of the recently inactivated arc of the Sulu Archipelago which faces northwestwards (Hamilton, 1979). A trench lies at the northwest base of the arc.

The calc-alkaline basalt-andesite-dacite volcanics in the Semporna Peninsula overlies marine sediments and interbedded volcanics of the Oligocene-Miocene Kalumpang Formation (Kirk, 1962; Lim, 1981 & 1988; Lee, 1988). The Kalumpang Formation have been strongly folded and faulted. The major fold structures trend west and southwest although east of the Upper Merotai Besar Valley, they trend southwest.

The volcanic centres which erupted andesitic and dacitic lava and pyroclastics are distributed east-west along the length of the Peninsula. Fission-track dating of zircon grains from hornblende andesite of the Tinagat area on the southern edge of the Semporna Peninsula just east of Tawau gave a Lower Miocene age (Lim, 1988). Whole rock K-Ar determination of Gunung Andrassy andesite gave an Upper Miocene age; extrusion of the andesites, including those of Gunung Magdalena and along the spine of the Semporna Peninsula, could have continued into Lower Pliocene (Lim, 1988). There appears therefore a younging in age of the andesitic rocks from south to north. K/Ar determination of biotite from a sample of dacite from Gunung Maria gave a Lower Pleistocene age.

The basaltic rocks, on the other hand, were erupted along volcanic centres aligned northwest-southeast. This may be due to the fact that the compressive forces acting during the late Tertiary were replaced by tensional forces in the late Quaternary resulting in block faulting and deep fissure formation (Kirk, 1962). This allowed rapid upwelling of the basaltic magma. The basaltic centres in the Tawau area appear to be located within a mini rift (Lim, 1988).

Radiocarbon dating of charcoal from within dacitic breccia which underlies basalt erupted from Gunung Bombalai gave an age of 27,000 + 500 years (Wilford *et al.*, 1967, p. 85) indicating that the youngest dacitic lava and pyroclastics were erupted approximately 27,000 years ago and that volcanic activity, including extrusion of basaltic lavas possibly continued into Recent time.

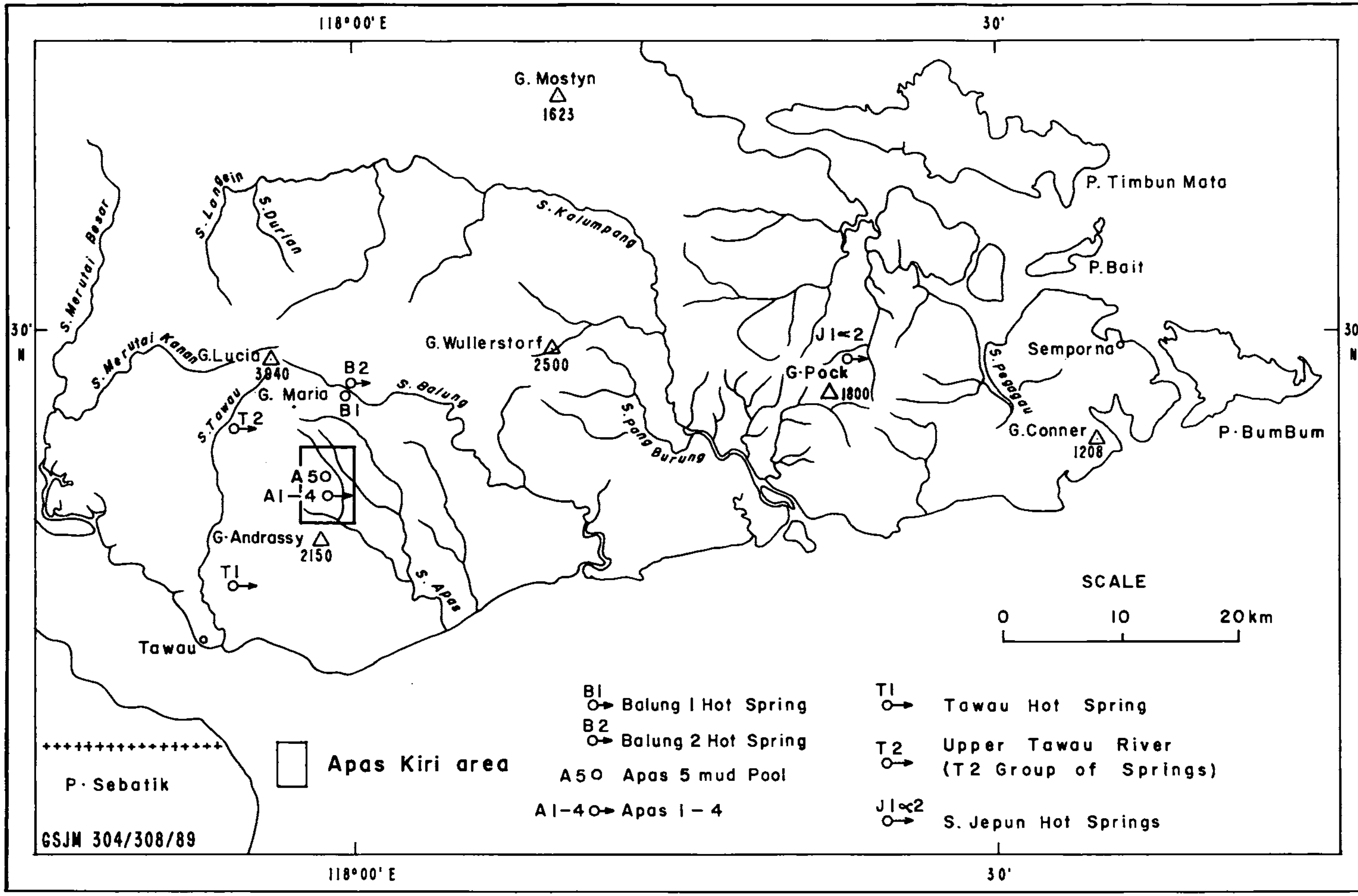

Figure 1. Location of hot springs sampled. Also shown is the Apas Kiri area.

The hot springs, seepages and mud pools are related to major fracture zones (Lim, 1988). Several lineaments 1.3 to 6.5 km long could be recognised from LANDSAT imagery (Hoppe, 1981). The lineaments form a radial pattern around the Magdalena-Maria Volcanic Complex, perhaps indicating fracture zones due to updoming by magmatic pressure. The hot springs are located close to these zones.

Several northeast to north trending faults along the length of the Semporna Peninsula were interpreted from aeromagnetic data. The magnetic basement in the Mount Pock area is about 3 km deep but is around 1.5 km in the Apas Kiri area and is at 0 m level in the basaltic area north of Tawau.

NATURE OF DISCHARGES

The type of discharge features in the Semporna area are hot springs, seepages, mud pools and "old steaming ground". Investigations carried out this year located an old steaming ground and a mud pool, both in the Apas Kiri area and a new hot spring site in the Balung area. A summary of these features are given below.

Upper Tawau River

Eleven warm (25–33.7°C) sulphurous springs occur along a 250 m stretch of the Upper Tawau River (Fig. 2) 5 km west of Gunung Maria. The distribution of the temperatures of the springs is noteworthy; spring waters get hotter to the south. The elevation of this stretch of the river is approximately 370 m above sea level. Several of the outlets are on the river bed or by the bank just below water level. The springs are aligned northeasterly indicating structural control. The close proximity of these springs to major northeasterly trending lineaments observed on LANDSAT imagery had been noted by Lim (1988).

The spring waters are acidic (pH 3.68–4.1). A strong hydrogen sulphide smell could be detected as one approaches this site. The waters of Spring T2A emerge from among boulders of rhyolitic rocks. The boulders surrounding the springs are characteristically coated with sulphur. Pyrite has been noted in several outcrops of andesitic rocks on the banks

It is not possible to obtain a total flow discharge of the area. However, Spring T2B has a flow discharge of 0.15 l/s, a pH of 4.04 and a temperature of 31.5°C. Water from this spring was sampled for analysis. Ten metres downstream from this spring the temperature was 23.6°C and the pH 6.5. Ten metres upstream of the same spring the temperature was 23.1°C and the pH 7.51. The flow rate of the Tawau River here is approximately 1,600 l/s. The temperature downstream of all the springs was 24.3°C and the pH 6.35. Upstream of all the springs the stream temperature was 23.1°C and the pH 7.51.

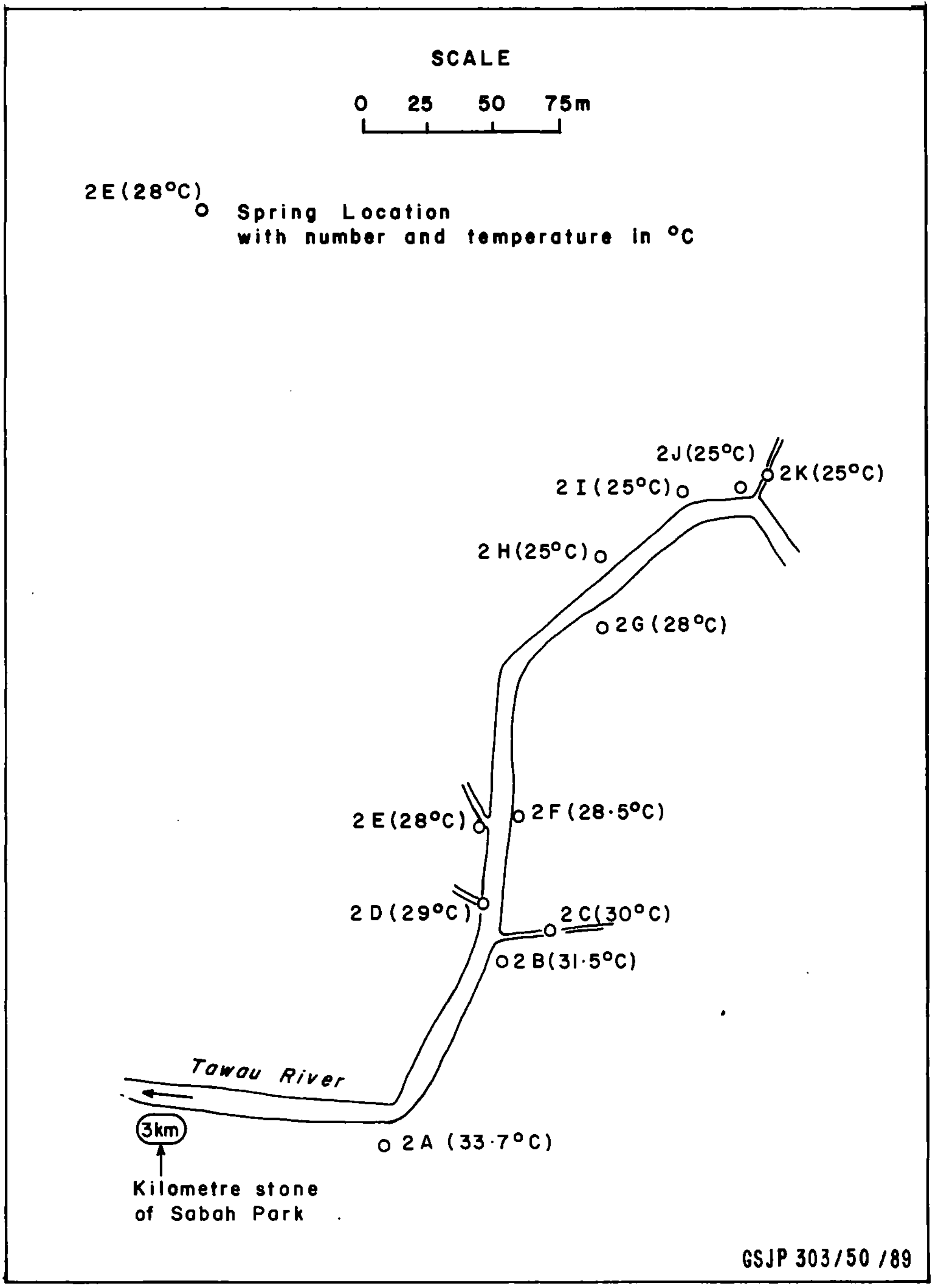

Figure 2. Distribution of warm sulphurous springs in the Upper Tawau (T2) Area.

Apas 1–4

Three hot spring sites occur along a 280 m stretch of the Apas Kiri 2 River (Fig. 3). An "old steaming ground" occurs 100 m away from the river to the north. It is significant that all the thermal activities occur to the north of the river and are aligned northwesterly indicating structural control. The elevation of this stretch of the river is 160–180 m above sea level. These thermal sites have been labelled Apas 1 to 4.

Apas 1 is located 10 m away from the river. The outflow from this spring has resulted in the distinctive brown and green algae-coated 2.5 m travertine cliff-face at the left river bank. There is a slight hydrogen sulphide smell. The pH of the spring water was 6.2 and had a temperature of 64.2°C. The flow discharge was estimated to be 0.05 l/s. The water emerges from the base of a 2 m high travertine terrace. Ten metres upstream was a hot water seepage with a temperature of 39°C and a pH of 6.97.

One hundred and thirty metres upstream is site A2 where four springs (labelled 2A–2D) occur. The left bank of the river is formed of travertine terraces 10–40 cm high where the springs emerge. The springs are at water level or up to 20 cm above water level. The temperatures of the springs range from 41–65.5°C and the pH ranges from 6.06 to 7.6. The flow discharge of B, C and D total 0.4 l/s.

Apas 3 is a mud pool located 20 m inland from the left bank. It is circular in shape and 5 m in diameter. The colour of the water is yellow-brown due to the presence of algae. The water had a pH of 6.9 and the temperature measured at the most active outlet was 62.2°C.

A hot seepage (48°C) occurs 50 m upstream of Apas 3. About 100 m north of Apas 3 is Apas 4, an "old steaming ground". It is liver-shaped, 75 m long northwest-southeast and 30 m at its widest point. There are two main travertine terraces from the bank up to site. At the site itself, there are several mini-terraces 2–10 cm high. Hot water (50–79°C) emerges from several travertine cones/spouts (up to 3.5 m high). Some of the spouts are inactive. Several big and small bubbling pools dot the terrace. The temperature of the pools ranges from 40–60°C. The most active spouts are located at the western edge. The pH of the waters ranges from 7–8. The rate of flow of the most active spouts is approximately 3 l/s. This site is surrounded by ridges up to 40 m high. The fact that there are several inactive cones indicate that this site had been more active in the past. The thermal feature exposed here is similar to that of Kizildere, Turkey and Flores, Indonesia (Radja, personal communication). Two samples of travertine from active cones in the Apas 4 area were analysed and were found to contain high arsenic (2,424–2,625 ppm), 5 ppm of silver, 0.04–0.1 ppm gold, 2,208–2,045 ppm manganese and 0.45–0.5% iron (Lim, 1989).

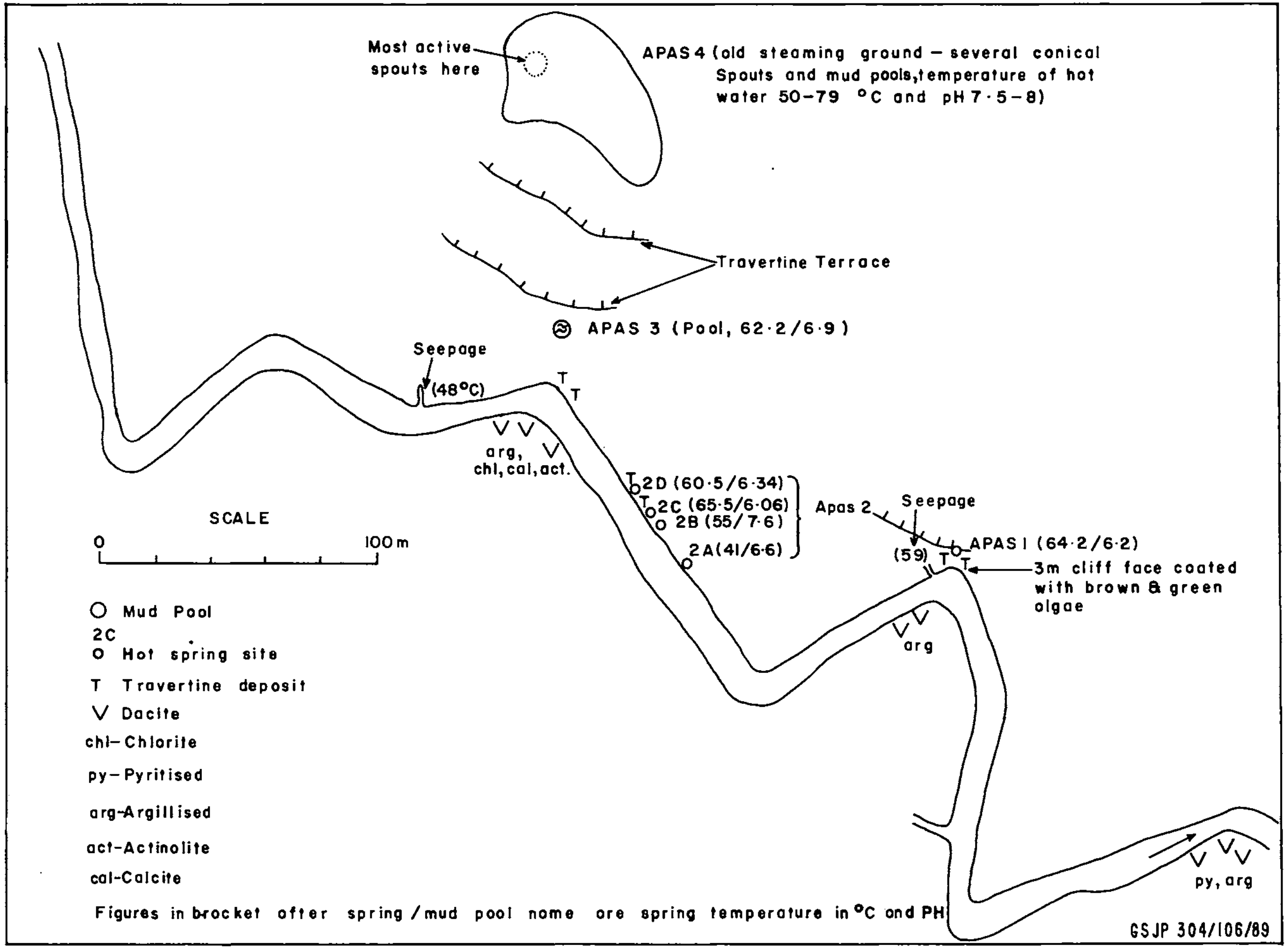

Figure 3. Sketch of hot springs/pool in the Apas Kiri 2 Area.

Apas 5 is a pear-shaped mud pool located at the confluence of the Apas Kiri 3 and its tributary (Fig. 4). The site is 1.5 km north of Apas 4. It is 50 m long north-south and 40 m at its widest point. This feature was recognised on aerial photographs due to the fact that it is not vegetated. The site is approximately 270 m above sea level.

The most active part of the pool is in the southwest where several bubbling outlets occur. A few outlets occur at the northern edge. The pH of the water was 6.72 and the temperature ranges from 57.5–60°C. The size and the present localised activity indicate that the site was more active in the past. Thin films of calcium carbonate are deposited on pieces of wood and rocks. The mud is at least 50 cm thick.

It is difficult to obtain an accurate flow discharge since there are seepages into the tributary. Measurements made at the two main outflows in the north gave a discharge rate of 0.2 l/s.

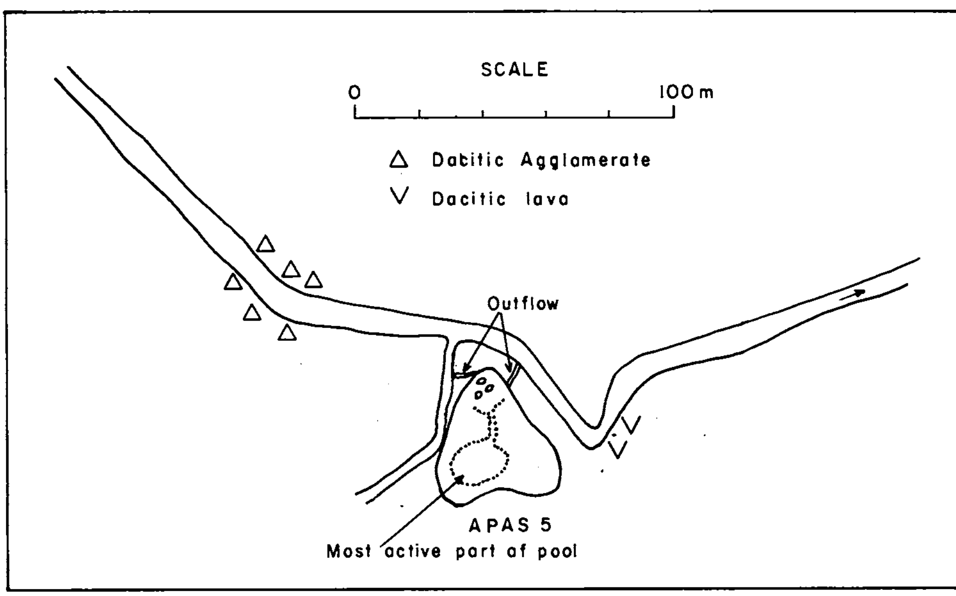

Figure 4. Sketch of Apas 5 Mud Pool, Upper Sungai Apas Kiri 3.

Balung 1

Six outlets occur on both banks and on the stream bed of a tributary of Balung River 200 m above sea level (Fig. 5). The springs on the left bank (5–15 cm above water level) emerges from boulders of silicified rocks. There is a strong hydrogen sulphide smell. Two outlets in weathered dacitic rocks occur on the right bank.

The temperatures of the waters range from 50–56.1°C and the pH from 6–6.2. Flow discharge rates of four of the most active springs total 0.5 l/s. Thin films of silica were being deposited on the boulders. The springs are aligned northeasterly.

Balung 2

Balung 2 is located about 0.5 km northeast of Balung 1 at an elevation of about 200 m above sea level. Hot water (55.6°C) emerges from among boulders of silicified rocks. The outlet itself is a few cm above water level. The discharge rate was 0.5 l/s and the pH was 5.97. There is a strong hydrogen sulphide smell.

A warm pool (39°C) 1.5 m in diameter occurs 30 m northeast of Balung 2 away from the river. The pH of the pool water was 6.05.

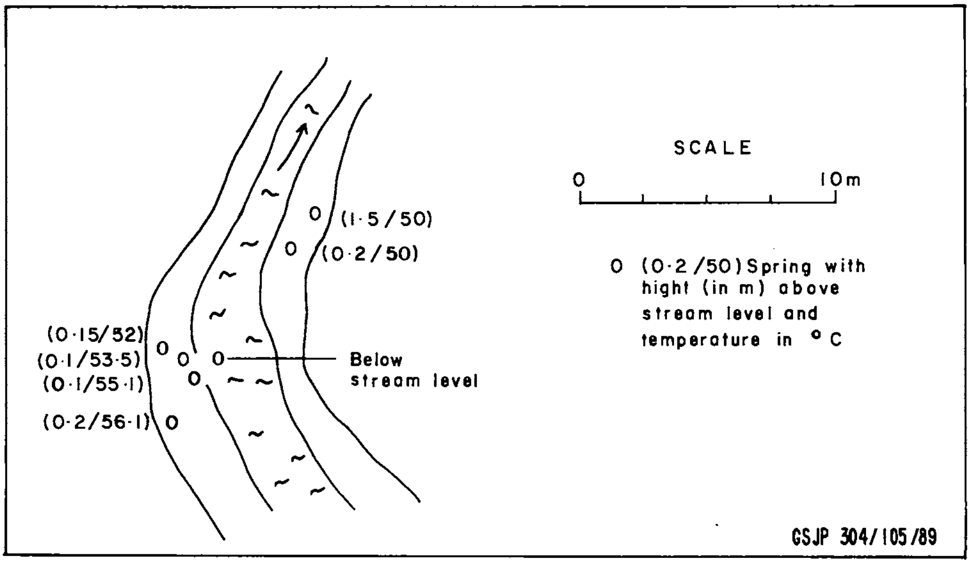

Figure 5. Distribution of hot springs in the Balung 1 Area.

A warm pool (39°C) 1.5 m in diameter occurs 30 m northeast of Balung 2 away from the river. The pH of the pool water was 6.05.

GEOLOGY OF THE APAS KIRI AREA

Photogeology

The old steaming ground at Apas 4 could be recognised on aerial photographs due to the fact that it was unvegetated and the cones could be visible. In preparation for the geological mapping, aerial photographs of the Apas Kiri area were studied with a view of delineating features similar to that at Apas 4 and to mark out the lineaments. Several non-vegetated areas similar in appearance to Apas 4 were marked out. However field checks showed that these areas were not related to thermal activities, except for the area where Apas 5 is located. Some are due to the presence of strongly argillised and leached rocks which presumably do not support good vegetation.

Figure 6 shows the lineaments observed on aerial photographs. They have a predominant northwest, north and northeast trend. All the thermal activities in the area are located close to major lineaments.

Lithology

The area is underlain mainly by dacitic lava, tuff and agglomerate (Fig. 6) of Quaternary age. Dacitic agglomerate is dominant in the west, northwest and northeast while dacitic lava and tuff are mainly exposed in the central, south and eastern parts. The agglomerate appears to overlie the dacitic lava and tuff. However, layers of dacitic lava and tuff occur within the main area of agglomerate in the northwest. Likewise, in the southeast there are minor beds of agglomerate interbedded with the lava. In the northeast, the dacitic tuff is interbedded with thin grey laminated mudstone and sandstone. The dacitic tuff shows cross-bedding (dip 53 E).

The dacitic rocks are both mesocratic and melanocratic. The agglomerate consists mainly of angular clasts of dacitic lava and tuff in a fine-grained volcanic matrix. However, in the western part, a significant proportion of the clasts are made up of silicified rocks. The agglomerate is commonly strongly oxidized.

Petrography

The dacitic lava is porphyritic with phenocrysts of hornblende (up to 3.5 mm), plagioclase (up to 3 mm) and embayed anhedral to euhedral quartz in a hyalopilitic to felsitic groundmass of plagioclase laths, hornblende, quartz

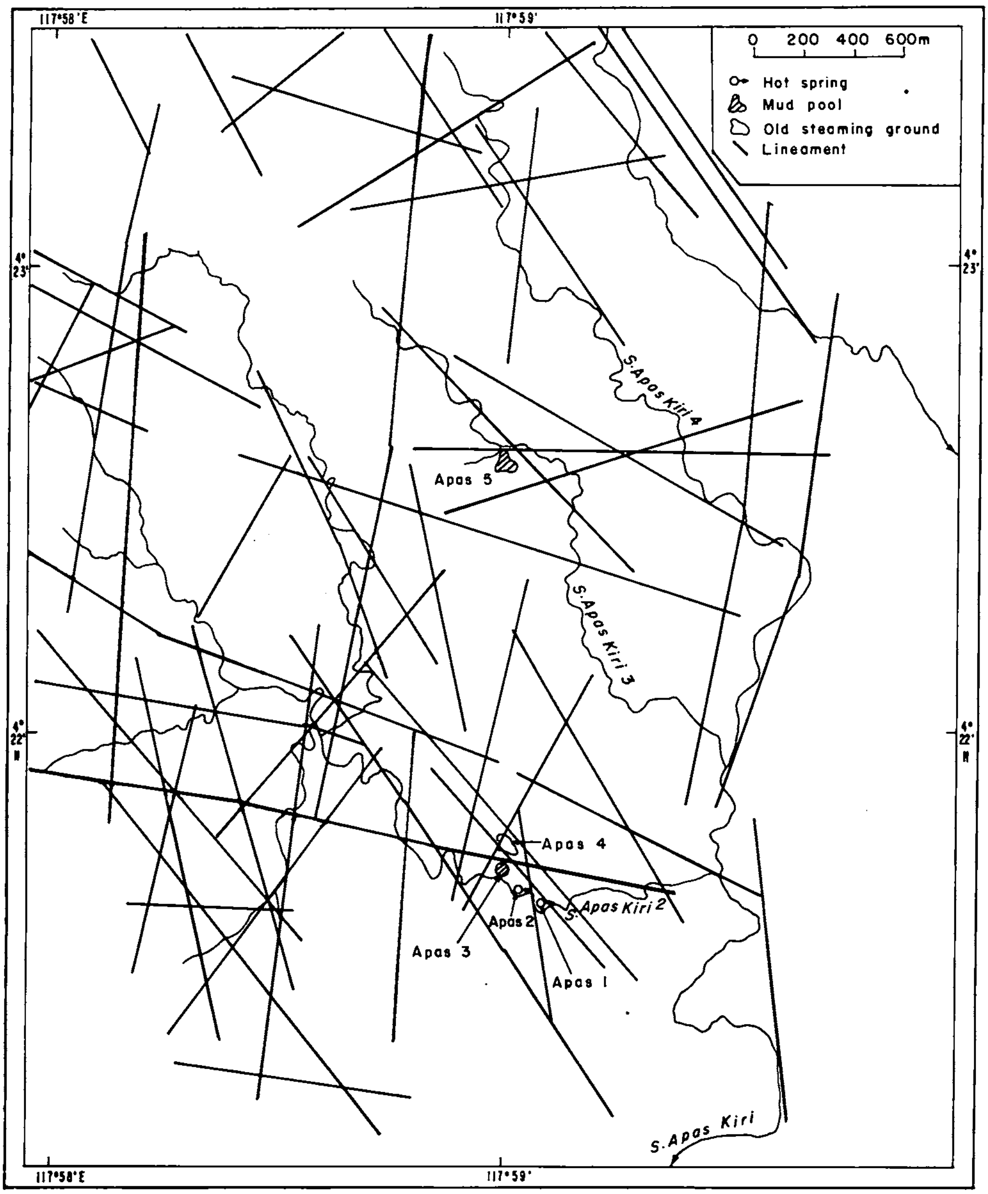

Figure 6. Photolineaments of the Apas Kiri Area.

and opaques. The hornblende, in most cases, is altered to fine, black iron oxide and chlorite. It is commonly bordered by a zone of dusty opaques. The plagioclase is commonly altered, partially or completely, to calcite and in some cases sericite, especially those from the Apas 1–4 area where calcite veins are commonly present. The embayed quartz contains inclusions of groundmass material and are commonly rimmed by a zone of fine quartz.

Structure

The dacitic rocks are well jointed; platy joints are common and columnar joints have been observed at an exposure in the upper Apas Kiri 2. The strikes of the joints are commonly north, northwest and northeast similar to the trend of lineaments indicating that the lineaments observe on aerial photographs are related to major joints/fractures in the rocks.

As mentioned above, the thermal manifestations in the Apas Kiri 2 area are aligned northwest. Apas 5 is located 1.5 km directly north of Apas 4. All this point to the fact that the thermal activities in the area are structurally controlled, perhaps by major deep fracture zones.

Alteration

The alteration of the exposed rocks have been studied and its distribution is shown on Figure 6. The dacitic rocks are mainly calcitised (especially in the Apas 1–4 area), chloritised, argillised. Pyritisation and silicification is more dominant in the northeast (Apas Kiri 4) and in the western edge. Epidote and actinolite have been noted in the rocks from Apas Kiri 3. The agglomerates are commonly oxidised and argillised. The dacitic rocks on the opposite side of the thermal activities at Apas Kiri 2 are strongly argillised and chloritised and at one exposure pyritised.

CHEMISTRY OF THE THERMAL WATERS

Altogether ten samples of thermal waters from the various geothermal manifestations in the Semporna Peninsula were analysed. Except for the Sungai Jepun Springs, all the others are in the Tawau area, located at the fringes of the Maria Volcanic Complex. Table 1 shows the results of the chemical analysis. In general the waters are all dilute (Total solids < 7,000 ppm) and contain low silica.

Apas Kiri area

The chemistry (Table 1) of the thermal waters from the springs and mud pool in the Apas Kiri area (samples A1, A4A, A4B & A5) are chemically similar

Table 1. Chemistry of waters from springs in the Tawau, Balung, Apas Kiri and Sungai Jepun areas.

Sample	T1	T2B	A4A	A4B	A1	A5	J1	J2	B1	B2
Site Temp.°C	50.3	31.5	75.6	67.7	60	60	64.9	63.9	55.1	55.6
pH at 25°C	6.9	3.7	6.8	6.7	7.4	6.7	8.6	8.5	6.1	6.0
Dissolved SiO_2	8.0	*	5.0	6.0	6.0	*	3.0	6.0	*	*
Total SiO_2	71	32	88	92	86	75	54	56	37	32
Ca	89.8	138.66	191	179.5	150.9	142.37	317.2	312.4	445.2	447.06
Mg	28.3	14.91	21.4	26.7	24.1	12.9	0.1	0.2	16.4	17.5
K	23.5	3.55	82.5	85	77.5	93.5	3.9	3.8	8.3	9.6
Na	282.7	14	792.5	807.5	760	925	237.5	235	39.25	30.0
Li	1.8	ND	5.6	5.6	5.4	5	0.1	0.1	0.2	0.2
HCO_3	444.08	7.32	810.08	817.4	705.16	544.12	104.92	97.6	89.06	78.08
SO_4	330	500	330	330	312.5	476	900	787.5	1254	1302
Cl	350	6	1350	1400	1250	1410	130	130	10	8
F	1.3	0.23	0.76	0.75	0.65	0.63	1.8	1.8	0.66	0.72
B	20	ND	41	15	21	60	<1	<1	ND	ND
As	0.75	5	200	250	150	250	ND	ND	23.3	17.5
Fe	*	1.4	0.7	1.9	0.3	0.2	ND	ND	0.1	0.3
Mn	0.6	0.4	0.9	1.0	0.3	0.8	ND	ND	1.1	1.1
Total Solids	1350	644	3422	3396	3158	3446	2026	1996	1846	1834
Turbidity	13.4	*	2.75	2.9	2.55	*	0.95	1.15	*	*
Conductivity	2030	835	5310	5330	4910	5320	2440	2446	1853	1822
Na/K	20.5	6.7	16.3	16.2	16.7	16.9	103.6	105.4	6.5	5.2
Na/Ca	5.5	0.18	7.2	7.8	8.78	11.14	1.3	1.3	0.12	0.12
Na/Li	47.5	-	42.6	43.4	42.4	56.1	717.4	730	46.9	45.2
Cl/B	5.3	-	10.05	8.5	10.25	7.17	-	-	-	-
Cl/SO_4	2.87	0.03	11.09	11.5	6.12	8.03	0.39	0.45	0.02	0.02
CL/F	144.3	14.17	952	999.7	581.6	1205	38.6	38.6	8.06	5.95

Note:
1. All cations and anions are expressed in ppm.
2. Total solids are expressed as mg/l, conductivity as umho & turbidity as N.T.U
3. ND - Not detected
4. * Not analysed

Locality:
T1 : Tawau Hot Spring
T2B : Sulphur spring, Upper Tawau River, 3 km from Sabah Parks Office.
A4A : Spout at Andrassy old steaming ground
A4B : Spout at Andrassy old steaming ground
A1 : Outflow of Apas 1 Spring (contaminated with cold water seepage)
A5 : Hot outlet at Apas 5 Mud Pool
J1 : Main spring Sg. Jepun
J2 : Subsidiary spring 10 m upstream from J1, Sg. Jepun
B1 : Balung 1 Spring
B2 : Balung 2 Spring

and the Cl/B and Cl/F ratios suggest that have a common source of geothermal fluid (Fournier, 1981; White, 1980). The waters have the characteristics of neutral pH sodium chloride water; they have high concentrations of chloride, sodium, bicarbonate and near-neutral pH. The geothermal system here is hot water dominated. The Cl/B ratios range from

7.17–10.25 similar to those of the Kawerau geothermal field in New Zealand where the reservoir rocks are andesitic (Mahon, 1970; Ellis & Mahon, 1977). The high bicarbonate concentrations of the waters may be due to the hot water coming into contact with calcitised and calcite-veined volcanic rocks or calcareous beds; mapping has shown that the dacitic rocks in the area are commonly calcitised or calcite-veined. A characteristic feature of the thermal waters from this area is the high content of arsenic. The higher SO_4 content of A5 may be due to the effects of evaporation.

Tawau Spring

The chemistry of the Tawau Spring (sample T1) is similar to that of the Apas Kiri area. The Na/K, Na/Li and Na/Ca ratios of the Tawau Spring and those from Apas Kiri are similar suggesting that they may be related to a common reservoir. However, the water of the Tawau Spring could have travelled a longer distance from the reservoir before emerging.

Upper Tawau and Balung areas

The thermal waters from upper Tawau (T2B) and the Balung areas (B1 & B2) are chemically similar although water from upper Tawau is acidic and contains lower Ca, K, Na, HCO_3 and As but higher Fe. Their similarities are reflected in their similar Na/K, Na/Ca and Cl/SO_4 ratios. The interesting point about the thermal water from upper Tawau is how it has obtained its acidity. Is it because the fluid is a steam condensate or is it ground water mixed with gas (H_2S most likely)? The low concentration of CO_2 does not indicate there is a high gas flow. On the other hand, if the fluid is steam-heated ground water, then the implication is that there is steam somewhere at depth. The waters of both areas are of the acid sulphate type although the waters of the Balung area are near-neutral, perhaps due to their coming into contact with and neutralised by cold underground water. The Balung springs are located at a lower elevation (200 m) compared with those in the upper Tawau area (370 m).

The low Na/Ca ratios of the Balung and upper Tawau springs may indicate that the waters are not supplied directly from the aquifer. Acid sulphate waters are normally at some distance from a major upflow zone or at the perimeter of a field. The waters may reach the surface rapidly along faults or permeable formations.

The low Cl and high SO_4 may indicate steam heating. The high SO_4 may be produced by oxidation of sulphur compounds in the magmatic steam by atmospheric oxygen in solution in groundwater or the waters could have passed through sulphur-rich rocks.

Table 2. Chemistry of waters from streams in the Tawau, Balung, Apas Kiri and Jepun areas.

Sample	UT2B	DT2B	UA4	DA4	UA5	DA5	UJ	DJ	UB1	DB1	UB2	DB2
Site Temp.°C	23.3	23.6	29.3	31.8	26.3	27.6	29.9	31.9	24.1	28.5	26.5	36.3
pH at 25°C	6.7	6.6	7.5	7.3	6.8	6.7	8.4	8.3	7.1	6.8	6.6	6.1
Dissolved SiO_2	*	*	4.1	*	*	*	*	*	*	*	*	*
Total SiO_2	37	49	41	*	*	43	*	*	75	45	54	32
Ca	11	17.16	10.12	20.7	6.96	19.72	21.6	51.8	10.2	65.6	49.62	173.91
Mg	2.58	2.12	1.5	4.7	2.53	2.57	*	*	3.94	4.55	9.85	18.05
K	1.9	1.8	2.1	6.8	2.8	11.4	*	*	3.45	3.5	4.35	4
Na	4.7	4.5	8.1	37.5	4.55	104	10.8	19.3	10.35	8.9	12.25	12.5
Li	ND	ND	*	*	ND	0.5	*	*	ND	ND	ND	ND
HCO_3	31.72	31.72	75.64	126.88	19.52	65.88	163.48	151.28	58.56	64.66	23.18	28.55
SO_4	23.5	38.9	14.3	*	21.5	49	*	*	13.2	116.5	203.5	280
Cl	4.4	3.2	2.0	84	9.9	165	6.4	12.8	9.8	5	5	5.2
F	0.07	0.07	0.065	0.098	0.07	0.11	0.11	0.2	0.08	0.14	0.14	0.31
B	ND	ND	*	*	ND	8	*	*	ND	ND	ND	ND
As	*	*	1.0	*	*	*	*	*	*	*	*	*
Fe	0.03	0.4	0.6	0.5	0.3	0.5	0.9	0.7	0.2	0.8	0.3	2.3
Mn	ND	ND	ND	ND	ND	0.1	ND	ND	ND	0.4	0.1	0.7
Total Solids	128	158	86	*	132	474	*	*	152	424	286	1178
Turbidity	*	*	2.95	3.77	*	*	8.3	3.6	*	*	*	*
Conductivity	107.6	127.5	79.2	440	63.9	684	196	336	161.8	441	349	899

Note:
1. All cations and anions are expressed in ppm.
2. Total solids are expressed as mg/l, conductivity as umho & turbidity as N.T.U
3. ND - Not detected
4. * Not analysed

Locality:
UT2B : Tawau River, 10 m upstream of Spring T2B
DT2B : Tawau River, 10 m downstream of Spring T2B
UA4 : Apas Kiri 2 upstream of old steaming ground
DA4 : Apas Kiri 2, downstream of old steaming ground
UA5 : 10 m upstream of Apas 5.
DA5 : 10 m downstream of Apas 5
UJ : Upstream of Sg. Jepun springs
DJ : Downstream of Sg. Jepun springs
UB1 : 10 m upstream of Spring Balung 1
DB1 : 12 m downstream of Spring Balung 1
UB2 : 12 m upstream of Spring Balung 2
DB2 : 10 m downstream of Spring Balung 2

Sungai Jepun area

The thermal waters of the Sungai Jepun area contain high concentrations of sulphate and relatively high concentrations of Ca, Na and bicarbonate which are characteristics of acid sulphate waters. However the pH is near-neutral and the springs are located at low elevations (Sahat *et al.*, 1988). As in the case of the upper Tawau and Balung areas, the waters could have reach the surface rapidly along faults or permeable formations from an aquifer that is some distance away and come into contact with and neutralised by cold ground water before emerging on the surface. The Mg contents are very low.

Table 3. Subsurface temperatures calculated from chemical geothermometers.

Sample	Location	Spring Temperature	Subsurface Temperature				
			Silica geothermometer		Na/K geothermometer		Na-K-Ca geothermometer
		°C	Truesdell (1975) °C	Fournier (1971) °C	Truesdell (1975) °C	Fournier (1971) °C	Truesdell (1975) °C
T1	5 km NE Tawau	50.3	118.4	118.9	168.4	201.6	166.5
T2B	Upper S. Tawau	31.5	86.6	82.1	315.6	312.3	15.1
A4A	Apas Kiri 2	75.6	127.9	130.2	191.9	220.5	190.3
A4B	Apas Kiri 2	72.2	129.9	132.6	193.1	221.4	191.9
A1	Apas Kiri 2	69.0	126.9	128.9	189.6	218.7	190.6
A5	Apas Kiri 3	60.0	120.8	121.7	188.7	217.9	194.4
J1	S. Jepun	64.9	106.8	105.7	50.7	99.3	26.2
J2	S. Jepun	64.1	108.3	107.2	49.9	98.5	25.7
B1	S. Balung	55.1	92.0	88.3	285.3	290.9	24.5
B2	S. Balung	55.6	86.6	82.1	359.6	342.2	25.7

CHEMICAL GEOTHERMOMETRY

The subsurface temperatures of the various areas have been estimated using different chemical parameters as shown on Table 3. The silica geothermometer gave low subsurface temperatures for all the waters. The silica geothermometer is not applicable for the Balung, Sungai Jepun and in particular the upper Tawau waters as these are acid sulphate waters in which silica is expected to be low. Applied to the waters from the Apas Kiri area, the silica geothermometer also gave low subsurface temperatures. The silica concentrations in the Apas Kiri waters are low; there may be silica dilution during the upwelling of hot water to the surface.

The Na/K and Na-K-Ca geothermometers are not applicable for the Sungai Jepun, upper Tawau and Balung springs. Anomalously high Na/K and low Na-K-Ca temperatures were obtained for the three areas. The waters from these three areas are of acidic sulphate type and would not be in equilibrium with feldspar. On the other hand, the Na/K and Na-K-Ca geothermometers gave closely similar high subsurface temperatures for the waters from Apas Kiri.

ESTIMATION OF HEAT LOSS

By estimating the total seepages and flow rates of hot springs and using the chloride concentrations of the springs, river water upstream and downstream of the discharges and the temperatures of discharges, an attempt has been made to estimate the total heat loss. This method assumes heat loss by evaporation and convection is minimal and is not taken into consideration.

Apas Kiri 2 area (Apas 1–4)

Using the following parameters, the total heat loss is calculated (Janes *et al.*, 1989):

Chloride concentration upstream (Cl_u) = 2 ppm

Average chloride concentration of springs (Cl_s) = 1375 ppm

Chloride concentration downstream (Cl_d) = 84 ppm

Flow rate of Apas Kiri 2 (Fr) = 2500 l/s

Average temperature of seepages and springs (T_s) = 73.9°C

Average air temperature (T_a) = 28.0°C

$$\text{Mass flow rate (MFR)} = \frac{Cl_d - Cl_u}{Cl_s} \times Fr$$

$= \frac{84 - 2}{1375} \times 2500$ l/s

= 149.1 l/s

Total heat loss = $(T_s - T_a)$ x MFR x Specific heat capacity of water

= °C x l/s x kJ/kg °C

= (73.9 – 28.0) x 149.1 x 4.1868 kJ/s

= 28651 kJ/s

= 28.65 MW Thermal

It should be emphasized that the above is only an approximate estimation; the flow rate of the stream should be properly measured and the downstream sample taken below the first spring (A1) to get a better picture of the total heat loss.

Apas 5

Using the above method and with the following parameters the total heat loss from Apas 5 was similarly calculated:

Chloride concentration upstream = 9.9 ppm

Chloride concentration of pool = 1,410 ppm

Chloride concentration downstream = 165 ppm

Flow rate of Apas Kiri 3 = 50 l/s

Average temperature of pool = 58.75°C

Average air temperature = 26.3°C

Mass Flow Rate = 5.5 l/s

Total Heat Loss = 747.2 kJ/s

= 0.75 MW Thermal

Sungai Jepun

The total heat loss of the Sungai Jepun area was similarly calculated to be 15.05 MW Thermal-hour using the following parameters:

Chloride concentration upstream = 6.4 ppm

Chloride concentration downstream = 12 ppm

Average chloride concentration of springs = 130 ppm

Flow rate of Sungai Jepun = 2,000 l/s

Average temperature of springs = 64.5°C

Average air temperature = 28°C

Upper Tawau and Balung

No heat loss calculation was made because the stream waters were sampled too close to the discharge features and the chloride concentration upstream could have been affected by seepages.

CONCLUSIONS

The thermal manifestations in the Semporna Peninsula include hot springs, seepages, mud pools and old steaming ground. Mapping of these features showed that they are structurally controlled.

The chemistry of the thermal waters indicate that two types of waters are present. The geothermal system in the Apas Kiri area is neutral sodium chloride water whereas in the upper Tawau it is acid sulphate water. The chemistry of the upper Tawau Spring also suggests it is steam-heated water implying there is steam somewhere at depth or it is ground water mixed with gas. The chemistry of the waters from the Balung and Sungai Jepun areas suggest acid sulphate waters that may have been derived from a far away source and mixed with cold ground water before emerging as springs. The distribution of the Balung, Apas Kiri, and upper Tawau thermal features around the Maria Volcanic Complex is noteworthy suggesting they may be related to a common heat source. The upper Tawau and Balung areas may indicate the perimeter of the field.

The Apas Kiri area is underlain mainly by Quaternary dacitic lava, tuff and agglomerate. The thermal manifestations cover an area of 3 km^2. The volcanic rocks there have undergone various alteration - calcitization, chloritization, argillization and pyritization. Around the thermal features the rocks are strongly argillized and calcitised.

The best geothermal prospect so far located is the Apas Kiri area where several characteristics of the thermal waters e.g. chloride, Cl/B ratio and geothermometer suggest high subsurface temperature. The Cl/B and Cl/F ratios of the thermal waters of the Apas Kiri area suggest they have a common source of geothermal fluid. The C1/B ratios also suggest that the reservoir rocks are andesitic.

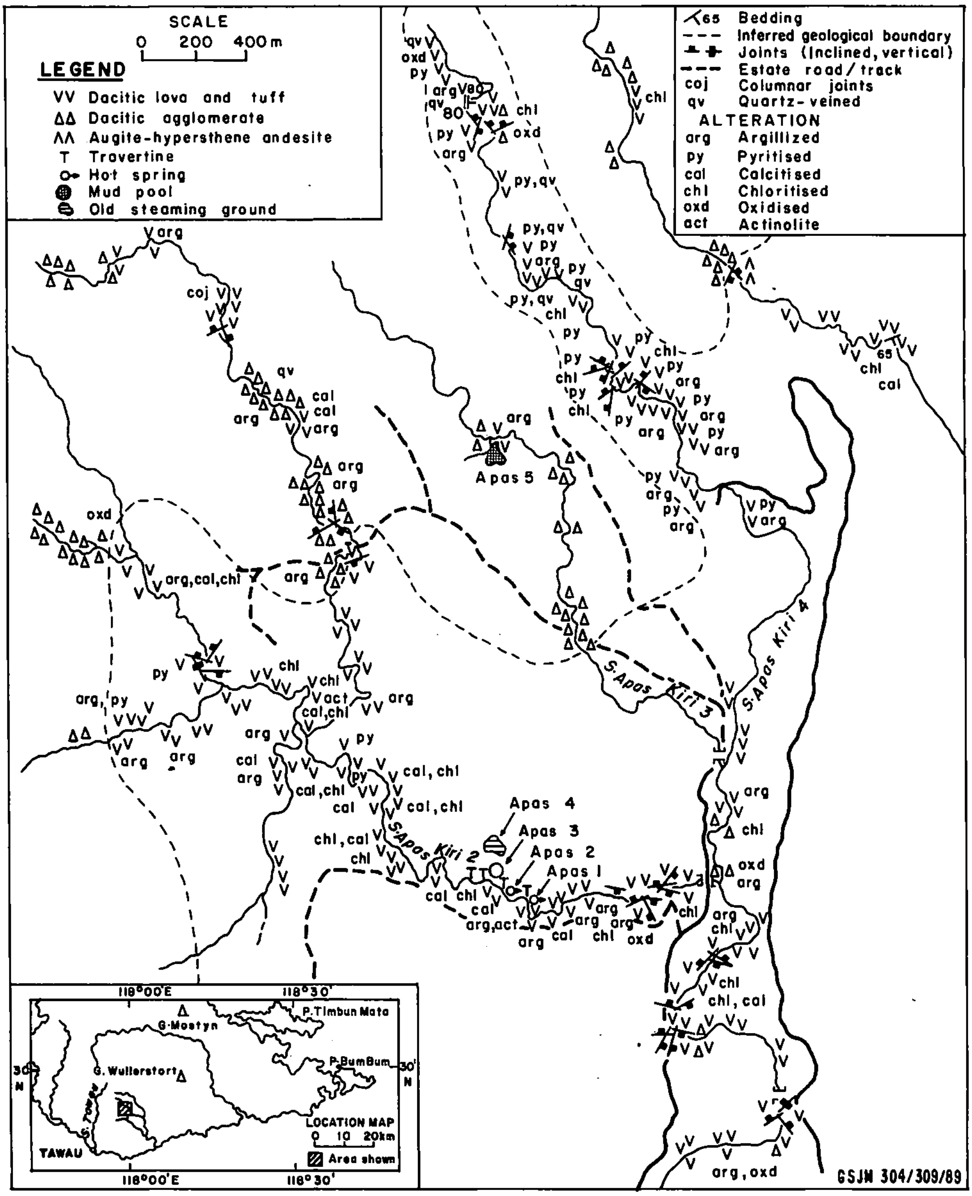

Figure 7. Geology of the Apas Kiri Area.

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