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The Exploration of Malaysia's Hot Springs for Geothermal Energy Development

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ABSTRACT

The non-volcanic hot springs' existence in Peninsular Malaysia is hypothetically associated with a series of Triassic intrusions and the manifestation of granite batholiths. The differential age settings that range between 267 to 227 ± 2 Ma for Eastern Belt batholith and 219 to 198 ± 3 Ma for Main Range batholith have influenced the hot springs' surface temperature within these regions. In comparison, the Eastern Belt is I-type granite while the Main Range is unique due to the transitional I-S-type granite. There are forty-five distributions of hot springs in Main Range granite, with surface temperatures ranging from 30˚C – 99˚C at the elongated Northwest and Southeast trends. On the contrary, Eastern Belt granite has a random distribution of eleven hot springs with 38˚C – 72˚C in surface temperature. Recently, there is a cardinal attempt in the harnessing of geothermal energy by using binary technology for small-scale electricity production in rural areas, which shifts from geotourism and balneotheraphy purposes. The target area is known as Lojing in the western part of Kelantan, with a surface temperature of 72 ˚C and geothermometry of 632 kJ/kg. A six-month progress of 300-meter drilling into the nearby granite fracture zone at the hot spring's source has a promising prospect with the rate flow of 90 m^3 /hour. The geophysical details of the conducted nearby-surface study within the area, such as resistivity and induced polarisation, provide the coordinates for drilling a funnel-shaped borehole along the fracture zone. On the other hand, five sulphurous springs and mud pools from Miocene to Quaternary volcanic origins, with surface temperature of 55˚C - 77 ˚C, are discovered in the southeast slope of Mount Maria in Tawau. The Sabah Orogeny of Northwest subduction that faces the Sulu arc has initiated andesitic to dacitic volcanism. The transcurrent and transpressional of Pliocene trending faults at the Northwest have structurally established the Sabah hot springs' existence. The Apas Kiri geothermal field investigation yields up to 14 km^2 of land size with the reservoir temperature up to 200 ˚C, which has the potential of 85 MWe resource capacity. Moreover, there are eight non-volcanic hot springs in Sarawak with surface temperatures ranging from 38 ˚C – 43˚C, along with a new discovery in Merarap, Lawas. There are three stages of concentric igneous intrusions in Kuching, and other randomly disturbed areas in Sarawak that act as the main heat source for hot springs: (1) Triassic to late Tertiary granitoids, (2) Tertiary to Quaternary andesitic and basaltic lava, and (3) Cretaceous to Quaternary dacitic and andesitic lava with pyroclastics. Jurassic to Cretaceous Bau Formation and Pedawan Formation have distinct host rocks for the hot springs at Panchor within the limestone and Paku black shales. Although more than sixty hot springs have been reported in Malaysia since 1960, there is an unclear gap of their sustainability and the nature of its reservoir. Hence, this study aims to investigate the sources of water-rock interaction for Malaysia's hot springs in understanding their potentials and benefits for future geothermal prospects. Two different sources of hot springs have been identified, which are volcanic and non-volcanic in origin. Furthermore, the quartz geothermometry study suggests that the reservoir temperatures of Malaysia's hot springs range from 93˚C - 196˚C. Based on the geochemistry of Peninsular Malaysia's hot springs that indicate low sulphate concentration with Na-bicarbonate as its major minerals, it provides enough evidences for non-volcanic origin. Accordingly, the binary cycle system technology is suitable to develop a potential geothermal electric power plant in the future.

1. INTRODUCTION

Previous studies only focus on the existence and recreational usages of Peninsular Malaysia's hot springs. At the tip of Borneo in Sabah, minimal interests are given towards the potential of geothermal development at Mount Maria. Unfortunately, the progressive effort for the first establishment of geothermal energy development in Malaysia ceased last year. In terms of increasing the local peoples' energy demands, it leaves a gap of highly potential green energy resource around the region, which is unbeneficial towards the community. Malaysia is nourished with geodiversity, especially by the potential geothermal resources that exist as volcanic and non-volcanic in origin. The current investigation has outnumbered the previous studies that identify over 70 recorded hot springs' localities (Baioumy et al., 2015; Samsudin et al., 1997; Sum et al., 2010). Nowadays, most of the hot springs are located deep in the jungles and plantations that emerge along the cracks at low-lying areas near the river, and occasionally in swampy areas. The latest discoveries are usually related to hydrogen sulphide, which has a similar smell to rotten eggs. Rajah Brooke's birdwing butterflies are seen at the hot springs' surroundings, and green algae flourishes within its runoff water. Meanwhile, the well-known hot springs at the urban areas, such as Kuala Lumpur and Ipoh, are well developed as soaking pools for balneotherapy, hot spas, and saunas at the resorts' enclosures.

2. GEOLOGICAL SETTINGS OF HOT SPRINGS IN MALAYSIA

In general, the hot springs' occurrences in Malaysia are related to a series of granite intrusions, but Sabah is related to volcanism (Baioumy et al., 2014; Samsudin et al., 1997). Most of the hot springs' sources are non-volcanic in origin and most likely coexist with the granite batholith belt or faulting due to tectonism. This condition permits the flow of surface water in developing a hydrothermal cycle within the host rock and sustains its existence for decades. Nonetheless, there is only a single record of hydrothermal system which exists in the inactive volcanic regions of Mount Maria at Sabah.

2.1 Peninsular Malaysia

In Peninsular Malaysia, the Indonesian orogeny events of mountain building during the Permian-Triassic era led to the colliding of Sibumasu and Indochina blocks, which formed Peninsular Malaysia. The later formations of Bentong-Raub triggered a granite intrusion and regional metamorphism towards the surrounding sedimentary basin within the area. The several episodes of Triassic granite intrusion are visible as the Eastern, Central and Western belts of granite batholith (Figure 1). The Eastern Belt is approximately emplaced at 220–290 Ma with mainly I-type granite that comprises of gabbro's extended compositional spectrum (±syenites) through granodiorite to monzogranite, forming small batholiths and plutons (Cobbing et al., 1992; Ghani, 2001; Ghani, 2009; Ghani et al., 2013). On the contrary, the Central Belt or Main Range batholith is located at the west of Bentong-Raub Suture within the Sibumasu terrane. It is characterised by a tin-bearing, transitional I- S type granite that originates at 198 to 227 Ma (Ghani et al., 2019). The Western Belt comprises of S-type granites that is emplaced at 200–220 Ma during the establishment of Peninsular Malaysia during the Permo-Triassic era. It resulted from the tectonic geomorphological transformation and formation of Bentong-Raub Suture, Baubak fault, Terengganu fault, Lebir fault, Bukit Tinggi fault and Kuala Lumpur fault (Hutchison, 2014). The Main Range granite at Gadek hot spring in Melaka contains distinct Au-bearing minerals such as pyrite which resulted from the interactions of three different host rocks. The associations of active fault zones and granite batholiths along with the interactions with various host rocks induced most of the hot springs' occurrences. It can be seen within the limestones of Tambun in Perak, while the Sungai Klah and Pedas hot springs occurred from the contact between sedimentary rocks such as phyllite and granite. Thus, it is assumed that Peninsular Malaysia's hot springs originated from a deep-seated fault hydrothermal system.

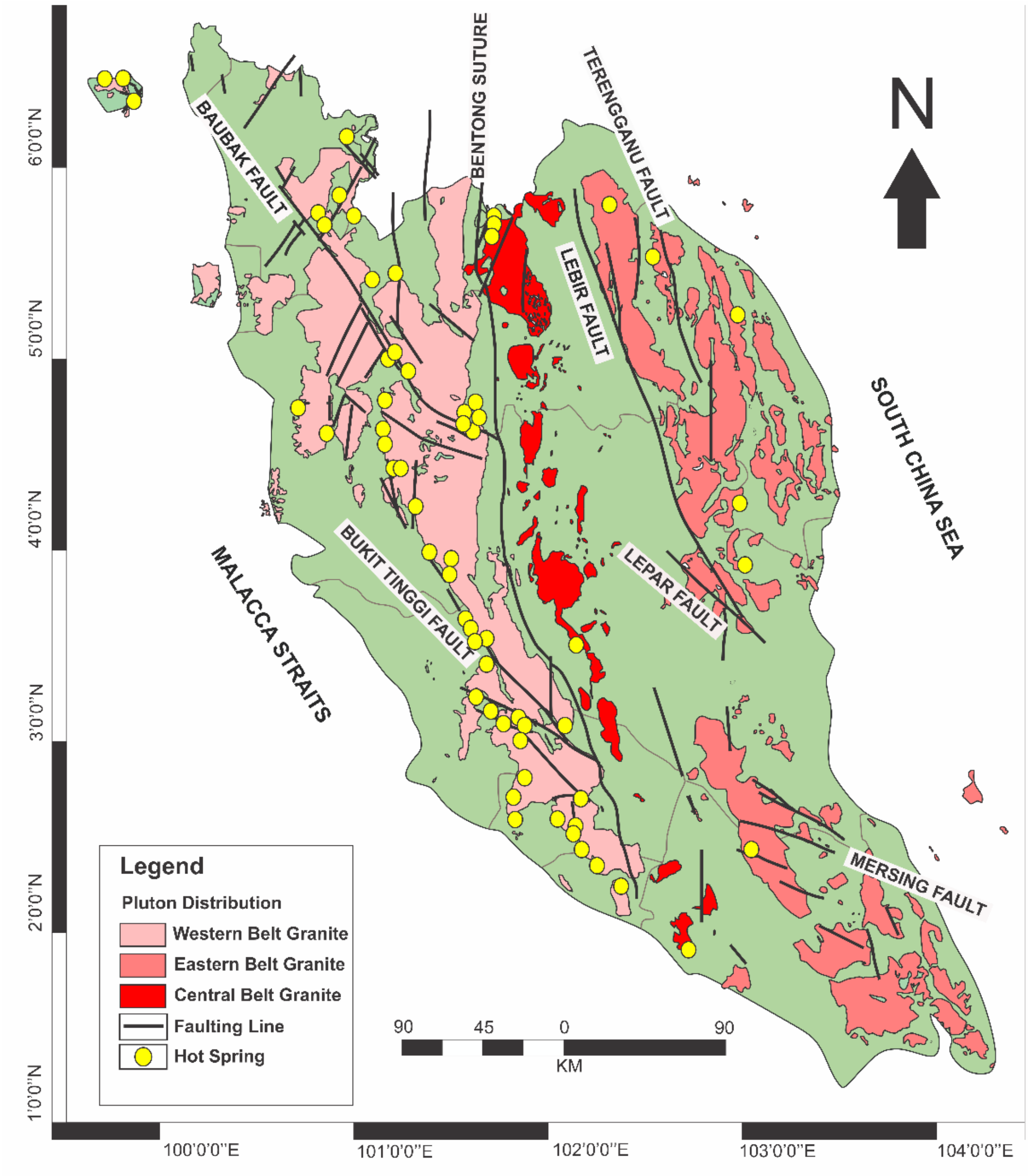

Figure 1: The geological map of granite batholiths and its relationship with hot springs' distribution in Peninsular Malaysia.

2.2 Borneo

In Figure 2 (B), Sabah's five sulphurous springs and mud pools of Miocene to Quaternary volcanic origins are discovered with surface temperatures of 55˚C-77 ˚C in the Southeast slopes of Mount Maria in Tawau. The Sabah Orogeny of Northwest subduction that faces the Sulu arc initiates andesitic to dacitic volcanism. The transcurrent and transpressional of Pliocene trending faults at the Northwest have structurally established the Sabah hot springs' existence (Balaguru et al., 2003; Tongkul & Chang, 2003). The Apas Kiri geothermal field investigation yields up to 14 km^2 of land size with the reservoir temperature up to 200 ˚C, which has the potential of 85 MWe resource capacity (Javino, 2015).

Figure 2 (A) portrays eight non-volcanic hot springs in Sarawak with surface temperatures ranging from 38 ˚C–43˚C. There is also a new discovery in Merarap, Lawas. There are three stages of concentric igneous intrusions in Kuching and other randomly disturbed areas in Sarawak that act as the main heat source for hot springs: (1) Triassic to late Tertiary granitoids, (2) Tertiary to Quaternary andesitic and basaltic lava, and (3) Cretaceous to Quaternary dacitic and andesitic lava with pyroclastics. Jurassic to Cretaceous Bau Formation and Pedawan Formation have distinct host rocks for the hot springs at Panchor within the limestone and Paku black shales (Pubellier & Morley, 2014; Zin, 1997).

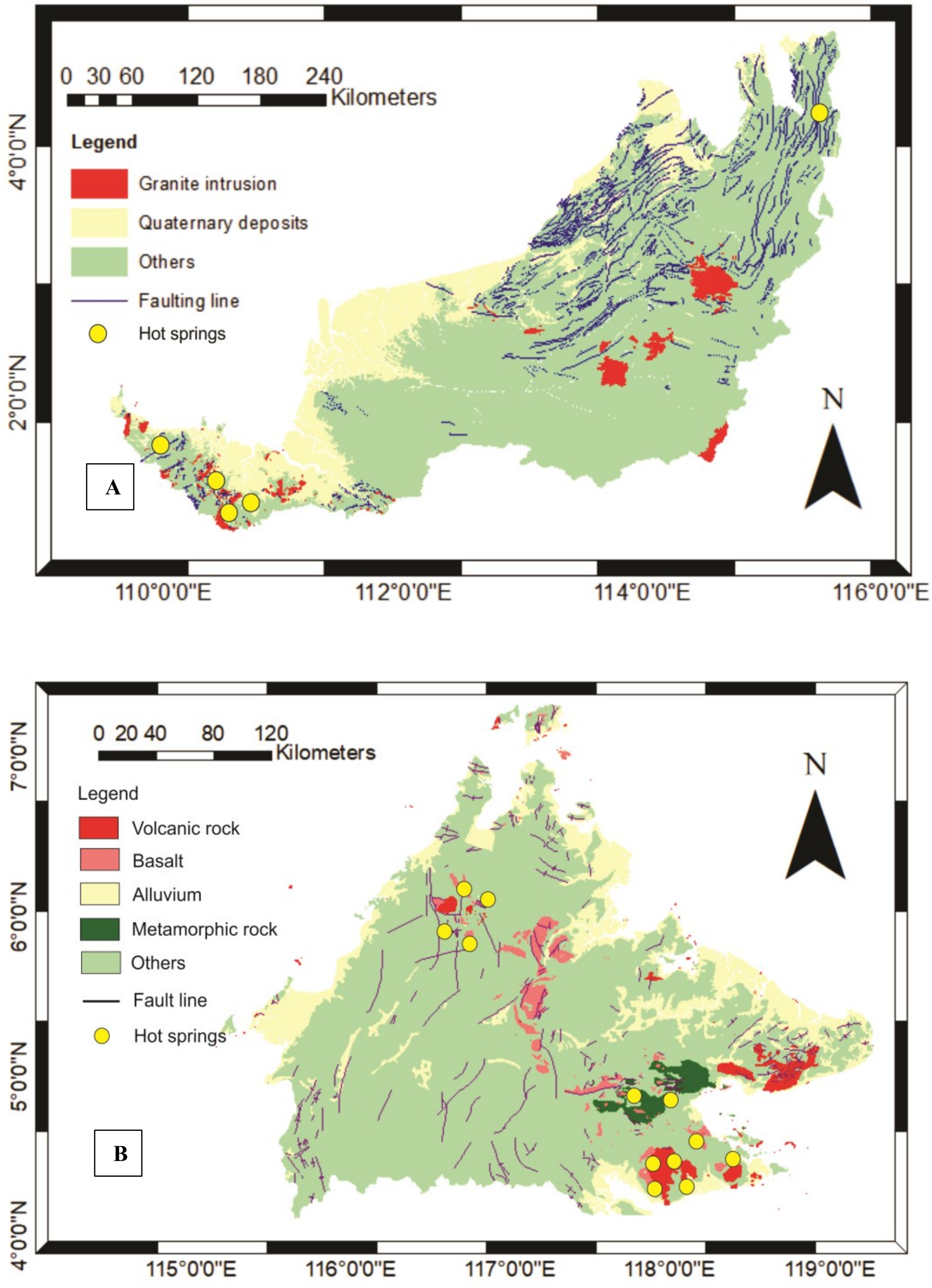

Figure 2: The simplified geological map of hot springs' distribution within granite batholith and volcanic rock in Sabah. (A) refers to Sarawak and (B) portrays the Sabah region.

3. SAMPLES AND ANALYTICAL METHODS

3.1 Hydrogeochemistry

Six water samples were randomly collected from Malaysia's hot springs that represent different geological settings and surface temperatures. The surface temperature and pH values for each hot spring were measured in-situ where the investigated localities are presented in Table 2 and Table 3. In the sampling process, the outflows of the hot springs' water were collected and tightly sealed in polyethylene-filled bottles. Table 2 shows the water samples based on their localities, along with the reading of surface temperature and pH values that were measured by using a multimeters during each sampling point (the in-situ method was used to measure the pH values regardless of the varying temperature from various hot springs' sources). The water samples were taken to the Environmental Science (ES) Laboratories (M) Sdn. Bhd. at Kuala Lumpur for tracing its major elements of SiO_2, Mg, Ca, Na, F, Fe, SO_4, HO_3, Cl and F. The elements of SiO_2, Ca, Mg, K, Na and Fe were analysed by applying inductively coupled plasma (ICP) while the dissolved Cl and F were analysed by using a UV spectrophotometer. The applied method analysis and detection limits for this study are summarised in Table 1.

Table 2: The applied methods and detection limits of the cations and anions analysis for Malaysia's hot springs.

Parameters	Method Used	Detection Limit (ppm)
pH	APHA 3120B, 2005	
SiO_2	APHA 3120B, 2005	1
Ca	APHA 3120B, 2005	0.01
Mg	APHA 3120B, 2005	0.01
K	APHA 3120B, 2005	0.01
Na	APHA 3120B, 2005	0.005
Fe	APHA 3120B, 2005	0.005
HO_3	APHA 3120B, 2005	1
SO_4^{2-}	APHA 4500 SO_4^{2-}E, 2005	1
Cl	ASTM D 512, 1981	0.1
F	APHA 3120B, 2005	0.1

3.2 Geothermometry

The specification of the hot springs' water temperature and components were calculated by using dissolved silica. This method is relevant for hot springs' water that has either lost its heat by steam separation or retains it before the mixing process. Truesdell and Fournier (1977) outlined the analytical and graphical estimations of the temperature from the mixed components of the hot water with the cold water. Using the formulas by Fournier (1977) and Arnorsson et al. (1983), the reservoir's temperature was estimated by using silica geothermometers.

$$T = \frac{1309}{5.19 - \log[SiO_2]} - 273.12\ (quartz) \tag{1}$$

$$T = \frac{1112}{4.19 - \log[SiO_2]} - 273.12\ (chalcedony) \tag{2}$$

3.3 Geophysical Survey

The Electrical Resistivity Tomography (ERT) and Induced Polarization (IP) surveys were conducted at Lojing geothermal complex. The resistivity and chargeability data were obtained by using the pole-dipole protocol from SAS4000 resistivity meter and ABEM LUND ES10-64C electrode selector system. A total of 15 survey lines from 400 metres to 800 metres with the respective electrode spacings of 5 metres and 10 metres were implemented. The measured resistivity survey data was interpreted by using RES2DINV inversion software. It is based on the smoothness of the constrained least-squares method, known as the Gauss-Newton method. The ERT and IP modelling were optimised by an iterative method, which reflects good geological correlation based on the obtained results that had a low root mean square error.

4. RESULTS AND DISCUSSIONS

4.1 Hydrogeochemistry

The variations of physicochemical analysis from Malaysia's hot springs are shown in Table 2. The temperature of the hot springs varies from 76 to 45 ˚C. The highest recorded surface temperature of the samples is located at Poring in Sabah, followed by Apas Kiri, Sungai Ber, Gadek and Kampung La. Annah Rais in Sarawak holds the lowest surface temperature. In addition, the pH values range from slightly acidic in Apas Kiri's volcanic hot spring to neutral at Annah Rais and Kampung La, followed by basic to highly alkaline in Sungai Ber.

Table 2 presents the cation and anion contents from different geological settings of Malaysia's hot springs which indicate a relatively high concentration range. According to Baioumy et al. (2015), Apas Kiri's volcanic hot spring has a high concentration of Ca (332 ppm), Mg (23.9 ppm), Na (963 ppm), K (114 ppm), HCO_3 (268 ppm), Cl (1214 ppm) and SO_4 (272 ppm). On the other hand, other non-volcanic hot springs have the average concentrations of Ca (3.6ppm), Mg (0.36ppm), Na (75.18ppm), K (5.13ppm), HCO_3 (71ppm), Cl (17.1ppm) and SO_4 (6.2ppm). The high difference in SO_4 concentration with 261 ppm indicates the difference in origins of Malaysia's hot springs. The values of SiO_2 for all samples range from the highest at Sungai Ber hot spring, with 135 ppm, to the lowest at 40 ppm in Annah Rais. The average is 90.2 ppm. In contrast, a relatively high anion content of HCO_3 at 156 ppm was obtained from Gadek hot spring, which is similar to other non-volcanic hot springs except for Apas Kiri's volcanic hot spring with 112 ppm.

Table 2: Tabulation of surface temperature, pH values (*in-situ method*) and the concentrations of cations and anions (ppm) for the selected hot springs' water samples in Malaysia.

Hot springs	Geological setting	Surf.T (°C)	pH	Ca	Mg	Na	K	Fe	HCO_3	Cl	SO_4	F	SiO_2
Sungai Ber	Central belt	71	9.23	1.97	0.1	25.9	2.88	<0.005	42	3.4	9	3.5	135
Kampung La	Eastern belt	50	7.2	2.49	0.09	42.6	1.18	<0.001	42	7	2	8.7	94
Gadek	Western belt	59	8.3	4.3	1	66	3.2	0.1	156	3	4	10.4	58
Annah Rais	Sarawak	45	7.1	3.53	0.46	33.1	1.12	-	34	7.1	5	1.3	40
Poring	Sabah	76	8.3	5.72	0.16	208	17.3	-	81	65	11	9.4	91
Apas Kiri	Sabah (volcanic)	75	6.4	332	23.9	963	114	-	268	1214	272	2.6	123

Based on the table, the non-volcanic hot springs of Sungai Ber, Kampung La, Gadek, Annas Rais and Poring show high Na and HCO_3 concentrations. In conjunction with the tectonic block of mountain formation and granitic intrusion after the plate collisions, most of Malaysia's hot springs exist on major fault lines and shear zones, which classify the hot springs as non-volcanic with Na-carbonate rather than Na–SO4, Na–SO4–Cl bicarbonate and Ca–SO4 (Baioumy et al., 2015; Yaguchi et al., 2014). The Na bicarbonate from the granitic rocks was plausibly formed by the montmorillonisation of plagioclase, the exchange in the cation's reaction of Na–montmorillonite and the precipitation of calcite. It affects the residual concentration of calcite as relatively high within the five samples of non-volcanic hot springs. The odour similar to rotten eggs is related to the small amount of $SO_4{}^{2-}$ ions that derive from the oxidation of sulphide and H^{+}. It is released by the oxidation process that is consumed by the interaction with plagioclase (Yaguchi et al., 2014). Comparatively, Hamzah et al. (2013) analysed the prospect of balneotherapy where certain hot springs in Peninsular Malaysia that contain Na-bicarbonate are only suitable for bathing activities while inappropriate for drinking purposes.

4.2 Geophysical Survey

There are two representatives with ongoing developmental progress of geothermal power plant and recreational areas which have been subjected to subsurface mapping. The first representative is Sungai Ber at Lojing in Kelantan. Four survey lines were paralleled with each other at the northeast to southwest direction.

The inversion model shows a high resistance anomaly with resistivity values more than 800 Ωm. It indicates the average depth of the granite bedrock ranges from 10 metres to 20 metres. On the contrary, a low resistivity zone has the average values less than 250 Ωm with an average depth of 50 metres to 125 metres. It reflects the presence of highly conductive material which in this case is the presence of hot water in the fracture zone. The fracture zone is suggested to align in the Northeast–Southeast direction based on structural correlation. Figure 3 portrays a fence diagram to determine the correlation of fracture zone at each survey line. The location of the hot spring's aquifer within the fracture zone and is dimensionally wider between 80 metres to 130 metres eastward (Figure 3). In correspondence to several exploration wells such as PDL 1, the borehole data of the tube well at 270 metres has confirmed the presence of unconsolidated sediments in the area's lithology. The sediments are made from loose to dense silty sand up to 14 metres, followed by the moderately fractured granite up to 138 metres. Based on the geophysical surveys, a 300-metre-deep exploration well at PDL 2 was not completed due to technical issues. The highly pressurised water-bearing fracture underneath the well with 138 metres in depth as well as the rate of water flow Q=15241.82 Gal/h have minimised the drilling force for a deeper penetration. The obtained geothermal gradient within the 138-metre well averages 0.228 ˚C/m. It is expected to successfully generate enough electricity with 114 ˚C by using geothermal binary plant at a 500-metre-deep exploration well (Fukuda et al., 2014).

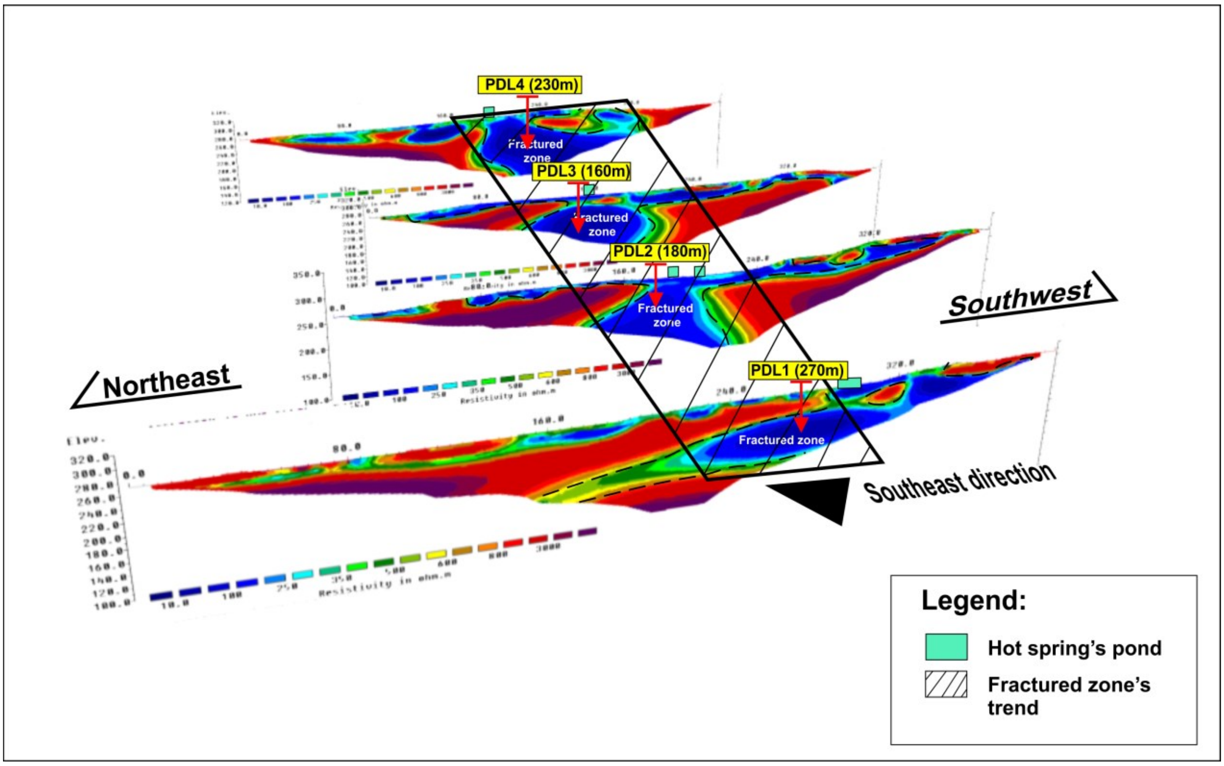

Figure 3: A fence diagram of four perpendicular resistivity survey lines at Sungai Ber hot spring. The black square label shows the connection between southward trending fracture zones in the hot spring area.

In the search of potential hot springs' sources via the drilling method, Gadek hot spring in Melaka stands as the second representative that establishes as a part of geotourism attractions. Figure 4 shows the aerial photo of the recreational area at Gadek. Five resistivity survey lines were deployed in the direction of Northeast to Southwest.

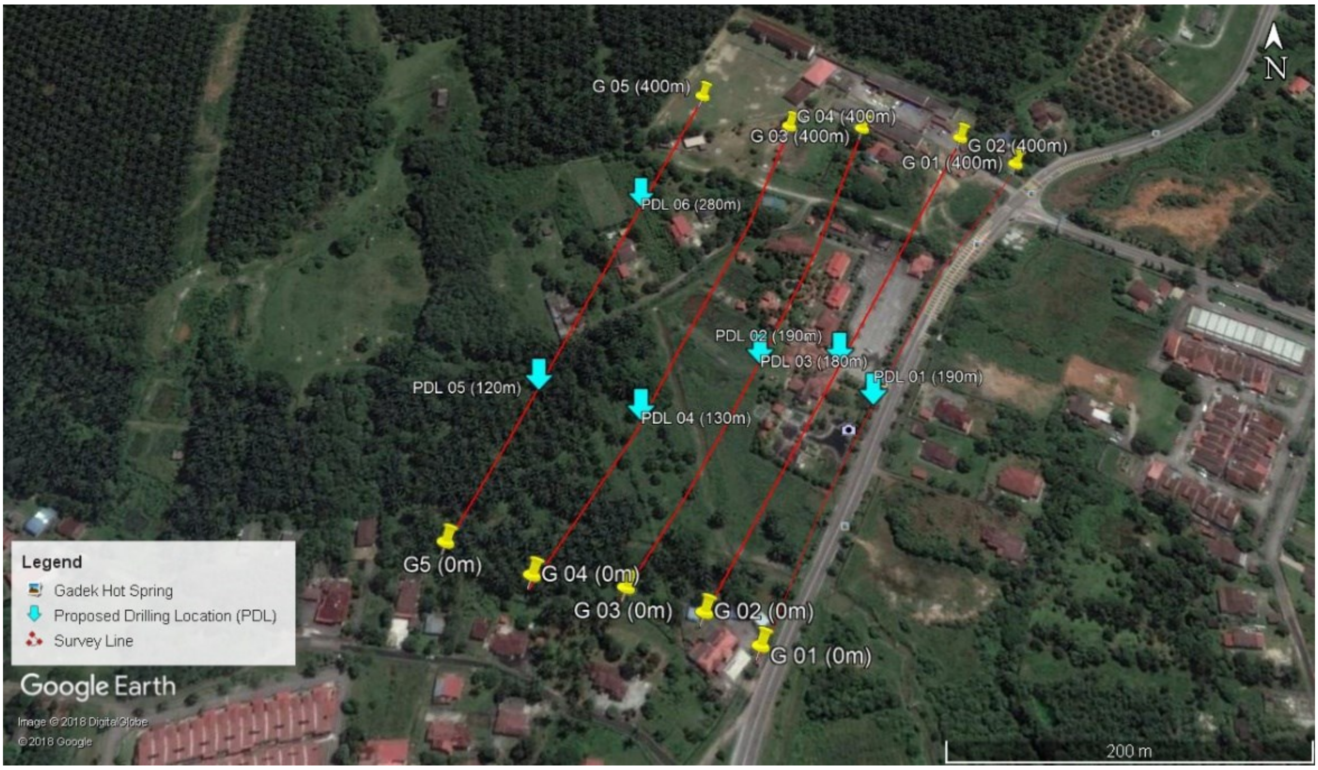

Figure 4: The aerial photo of resistivity survey lines' arrangement at Gadek hot spring.

From the profile, the low resistivity values that range from 5 Ωm – 80 Ωm are interpreted as a water-bearing zones with the estimated layer's depth of 75 metres from the surface. Based on Induced Polarization, the soft layer also has low chargeability values that range from 2.0 ms – 15.0 ms. The trend of the fracture zone is suggested to be at the Northeast–Southwest direction. The moderate resistivity values from 150 Ωm - 500 Ωm are interpreted as a weathered granite where the layer is unevenly distributed near the surface that extends to 70 metres in depth. Contrastingly, the highest resistivity values that range from 500 Ωm – 1000 Ωm are interpreted as a shallow granite bedrock towards the northeast direction of the survey line. It can be found at 235 metres to 400 metres near the surface of the survey line. From the resistivity model in Figure 5, the water-bearing zone can be discovered at the depth of 120 metres. There is no significant geological feature in the model.

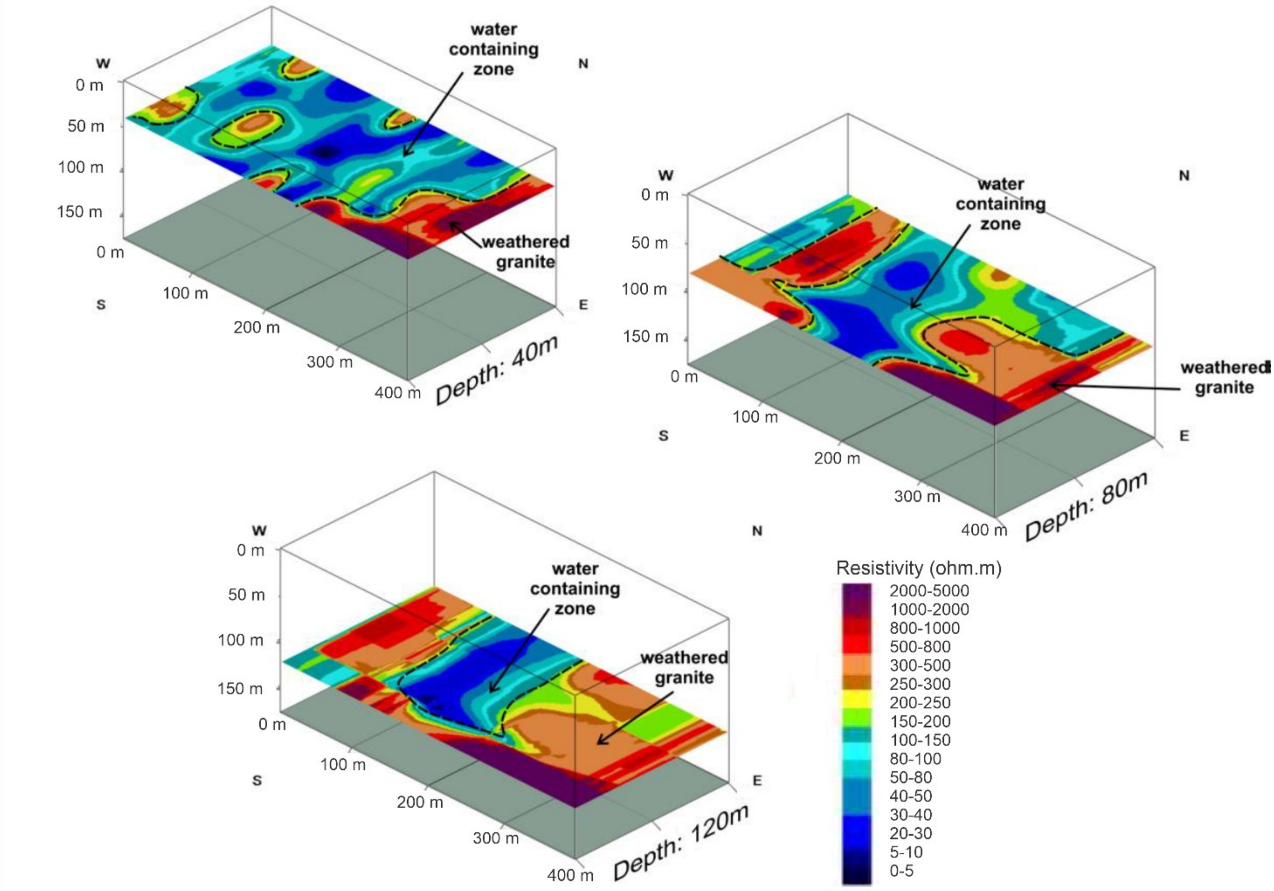

Figure 5: A resistivity model of sliced depths at 40 metres, 80 metres and 120 metres after the integration of five survey lines at Gadek hot spring.

As discussed by Baioumy et al. (2015), the cooling down of the molten magma's dry rock system provides its residual heat towards the host rocks from Triassic granite intrusion in Peninsular Malaysia. It is adequate to characterise the geothermal system of Malaysia's hot springs as convective hydrothermal resources. As shown in Table 3, the resources with lower temperature due to the mixed surface water result from the water circulation along deep-seated fractures (Mao et al., 2015; Ruggero & Lund, 2013). The geothermometry data of dissolved silica content infers Sungai Ber with the highest temperature of 154 ˚C, which generally classifies as low-enthalpy geothermal systems according to its silica conductivity (Kumara & Dharmagunawardhane, 2017; Wishart, 2015). Table 3 also displays the potential of Malaysia's geothermal resources are applicable for the agricultural, manufacturing and daily life purposes (Nguyen, Arason, Gissurarson & Pálsson, 2015; Porowski, 2018; Sircar, Yadav & Sahajpal, 2016). For example, Cameron Highlands has one of the largest agricultural activities in Malaysia, especially in producing tea leaves. The tea industry requires a huge consumption of electrical power despite the humidity and surrounding temperature of less than 20 ˚C on average. Hence, it can be generated by the nearby Sungai Ber hot spring with the surface temperature of 74 ˚C which is just 30 minutes away from the plantation area.

Table 3: The tabulation of Malaysia’s hot spring localities and resources for the possible economic prospect in the future.

No.	Locality	Coordinates	Surf. Temp (˚C)	T (Quartz) (˚C)	T (Chalcedony) (˚C)	Suitable Usage (Nguyen et al., 2015; Porowski, 2018; Sircar et al., 2016)
1.	FELDA Sungai Klah, Sungkai	3˚ 59’52’’N, 101˚23’31’’E	99	132.24	104.28	Binary cycle electric energy, food processing, preheating and heating, evaporation and distillation, lumber drying.
2.	Kampung Air Panas, Ulu Slim	3˚ 53’57’’N, 101˚29’48’’E	92	132.83	104.89	
3.	IKBN, Hulu Langat	3˚ 08’20’’N, 101˚50’09’’E	78	130.44	102.45	Fruits and vegetable drying (coming prospect for tea leaves drying especially in Sg. Ber Lojing highland) Beet sugar extraction Pasteurisation Whey condensing Beeswax melting Washing Fish drying
4.	Apas Kiri, Tawau, Sabah	4˚ 17’58’’N, 117˚54’23’’E	77	129.0	101.0	
5.	Poring, Sabah	6° 2; 54.0"N 116° 42' 20.2"E	76	nil	nil	
6.	Sungai Ber (HS 10), Lojing	4˚42’35’’N, 101˚34’05’’E	74	153.87	126.43	
7.	Charok Sira, Ulu Muda	6˚07’15’’N, 100˚51’36’’E	73	128.59	100.57	
8.	Sungai Ber (HS 70), Lojing	4°42'25.5"N 101°34'02.0"E	71	154.32	126.89	
9.	Batu 16, Hulu Langat	3˚ 08’20’’N, 101˚50’09’’E	71	124.75	96.66	
10.	Kuala Woh, Batu 7, Tapah	4˚14’30’’N, 101˚19’24’’E	71	105.00	76.71	
11.	The Banjaran hot spring, Tambun	4˚37’51’’N, 101˚09’22’’E	65	114.87	86.67	
12.	Kampung Sira, Gerik	5˚23’43’’N, 101˚06’10’’E	65	83.79	55.49	
13.	Sungai Ber, Lojing (HS 6)	4˚42’35’’N, 101˚34’05’’E	63	149.70	122.14	
14.	Pos Kesau, Ulu Slim	3°55' 58"N 101°30'78.0"E	60	114.11	85.90	Washing Mushroom culture Pickling Personal hygiene Laundry and meat processing
15.	Sungai Danak, Lasah	4˚57’37’’N, 101˚07’13’’E	60	115.63	87.43	
16.	Mount Maria, Tawau (5 hot springs)	4˚26’08’’N, 117˚56’47’’E	60	122.0	93.0	
17.	SunGAI Jepun, Semporna	4˚26’11’’N, 118˚26’53’’E	60	nil	nil	
18.	Poring, Kinabalu	6˚02’44’’N, 116˚42’12’’E	60	nil	nil	
19.	Pos Rasau, Ulu Slim	3°52'67"N 101°28'03"E	59	115.63	87.43	
20.	Kampung Ganun, Gadek, Alor Gajah	2˚24’30’’N, 102˚14’19’’E	59	108.51	80.25	
21.	Pedas Wet World	2˚37’56’’N, 102˚03’16’’E	58	119.99	91.84	
22.	Batu 9 Gombak	3˚15’15’’N, 101˚43’24’’E	58	110.97	82.73	
23.	Sungai Jin, Sungai Lembing, Kuantan	3°56'58.2"N 103°00'55.2"E	58	109.34	81.09	
24.	Ladang Kombok, Negeri Sembilan	2˚50’20’’N, 101˚53’20’’E	57	126.69	98.64	
25.	Sungai Mering (HS16)	4˚38’53’’N, 101˚36’11’’E	57	107.67	79.40	
26.	Kampung Tok Bok, Machang	5°50'16.3"N 102°14'32.8"E	56	129.21	101.20	
27.	Air Panas, Ulu Yam	3°27'50.1"N 101°41’48.9"E	56	101.46	73.16	
28.	Ulu Kalong	3°25'35.05"N 101°40'51.07"E	56	110.16	81.91	
29.	Kampung Legong, Baling	5˚49’00’’N, 100˚56’08’’E	55	120.41	92.26	
30.	Kampung Sira, Gerik Perak	5˚06’36’’N, 100˚58’04’’E	55	nil	nil	
31.	Air Panas Bembang, Jasin	2˚17’27’’N, 102˚22’35’’E	55	135.72	107.83	
32.	Jalan Air Hijau, Setapak	3°11'26.3"N 101°42'49.7"E	55	105.09	76.80	
33.	Janakuasa TNB Pergau (tunnel)	5˚37’23’’N, 101˚42’21’’E	53	118.56	90.40	
34.	Batu Melintang, Jeli	5˚42’14’’N, 101˚43’59’’E	52	97.61	69.29	

35.	Ulu Sungai Periah, Ipoh	4°49'08''N, 101°04'25''E	51	nil	nil		
36.	Kampung Bongek, Rembau	2°34'10.2"N 102°08'05.1"E	51	nil	nil		
37.	Sungai Mering (HS7)	4°38'53''N, 101°36'11''E	50	112.56	84.33		Greenhouse farming Washing Concrete building curing Soft drink and carbonates Soil sterilisation Fruit and vegetable drying
38.	Sungai Mering (HS8)	4°38'53''N, 101°36'11''E	50	117.84	89.67		
39.	Air Panas La, Besut	5°31'05''N, 102°32'04''E	50	133.42	105.48		
40.	Batu 9, Trong, Taiping	4°45'09''N, 100°43'15''E	48	132.00	104.04		
41.	Sungai Serai, Hulu Langat	3°05'26.8"N 101°47'40.6"E	48	120.69	92.55		
42.	Kampung Ara Panjang, Manong	4°37'08''N, 100°53'07''E	47	113.34	85.12		
43.	Pos Gesau	3°57'05''N, 101°28'17''E	47	115.63	87.43		
44.	Ladang Kombok, Mantin	2°50'20.6"N 101°53'20.9"E	47	126.69	98.64		
45.	Spring Resources Apartment, Kuala Lumpur	3°11'27''N, 101°42'46''E	46	nil	nil	Suitable for balneotherapy (Sircar et al., 2016)	
46.	Kampung Temor, Lasah	4°57'37''N, 101°07'13''E	46	107.67	79.40		
47.	Kampung Cherana Puteh, Alor Gajah	2°26'42''N, 102°12'31''E	46	117.84	89.67		
48.	Kampung Lada, Rembau	2°32'38''N, 102°07'40''E	46	103.30	75.00		
49.	Kampung Air Panas, Labis Johor	2°28'21''N, 103°02'59''E	46	124.75	96.66		
50.	Parit, Gerisek, Batu Pahat	2°12'37''N, 102°08'44''E	46	122.75	94.63		
51.	Ulu Bendul, Terachi	2°44'27.72"N 102°9'44.07"E	46	113.34	85.12		
52.	Batu 77, Bentong, Pahang	3°24'34''N, 101°53'28''E	45	103.48	75.18		
53.	Kerling, Selangor	3°36'40''N, 101°36'41''E	45	102.57	74.27		
54.	Pusat Latihan Polis, Kuala Kubu Bharu	3°33'47''N, 101°39'00''E	45	nil	nil		
55.	Ulu Tamu, Batang Kali	3°27'50''N, 101°41'49''E	45	101.46	73.16		
56.	Kg. Ayer Panas, Gerik	5°23'37''N, 101°05'51''E	45	nil	nil		
57.	Kampung Ayer Hangat, Langkawi	6°25'24''N, 99°48'47''E	45	93.50	65.18		
58.	Air Panas Kroh, Pengkalan Hulu	5°43'29.1"N 101°00'53.6"E	45	nil	nil		
59.	Lubuk Timah Hot spring ipoh	4°33'34''N, 101°09'43''E	45	124.09	95.99		
60.	Batu 15, Tapah	4°12'31.2"N 101°17'43.9"E	44	nil	nil		
61.	Hulu Kampar Estate, Gopeng	3° 15' 1"N 102° 25' 12"E	43	106.82	78.55		
62.	Annah Rais, Kuching	1°08'03''N, 110°15'59''E	43	nil	nil		
63.	Panchor Hot Spring, Serian.	1°15'16.9"N,110°26'50.7" E	42	nil	nil		
64.	Sungai Bujang, Bentong	3° 55' 19"N 101°24' 50"E	41	nil	nil		
65.	Sime Darby Plantation, Labu	2°45'18.4"N 101°48'31.9"E	40	nil	nil		Low temperature resources Aquaculture Soil warming
66.	Paku, Sarawak	1°25'12''N, 110°11'53''E	38	nil	nil		
67.	Kampung Ulu Geroh, Gopeng	3° 16' 22"N 102° 25' 5"E	38	102.39	74.09		
68.	Panchor Merah, Terengganu		38	nil	nil		
69.	Kalumpang Hot Spring	3°37'59.2"N 101°35'25.3"E	36	nil	nil		
70.	Tanjong Didih, Langkawi	4°57'37''N, 101°07'13''E	31	nil	nil	Relatively warm, can be used for daily care	
71.	Sungai Sawa, Ulu Slim	3°52'54"N 101°29'02"E	31	nil	nil		
72.	Kampung Sirako, Baling	5°40'17.3"N 100°51'31.0"E	31	nil	nil		

5. CONCLUSION

Malaysia's geothermal system is characterised as low enthalpy. Based on the geochemistry results, there are two types of geothermal origins for Malaysia's hot springs: 69 hot springs are non-volcanic, while another two at Apas Kiri and Tawau are volcanic in origin. The non-volcanic hot springs are due to a convective hydrothermal system. The water cycle infiltrates throughout the highly fractured and tectonically altered host rocks into areas with deep-seated faults. The hot springs emerge throughout its weak spots at various locations.

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