DOI : https://doi.org/10.7186/wg481202204

What makes a hot spring, hot?

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Abstract: Hot springs naturally are groundwater that emerges to the surface after being heated up by geothermal activities. There are various classifications of hot springs according to the surface temperature. Still, in Malaysia, it is referred to as the spring that is higher than an average body temperature or 40 °C and above. Two types of hot spring origin are volcanic and non-volcanic sources. The Quaternary magmatic intrusion of Maria volcanic complex in Sabah is the only volcanic-related hot spring. Meanwhile, Sungai Klah, Ulu Slim, Gadek, and other hot springs in Malaysia originated from regional granite intrusion that slowly cooled down since the Triassic period. In Peninsular Malaysia, there is a geological trend of hot springs distribution based on three different intrusion and localities of granite batholiths: Eastern, Central and Western belts of granite. Tectonically, most of these hot springs are associated with fault zones related to highly fractured and deep-seated fault areas with high permeability host rock, such as Bok Bak Fault. Later it can conduit meteoric water to seep deep beneath the subsurface and be subjected to a high geothermal gradient zone. High dissolved minerals in the hot springs are beneficial for balneotherapy, while the excess heat and brine can be harnessed into electrical energy. The development of geothermal potential in Malaysia is still unhurried compared to our neighbouring countries, for example, Thailand's Fang Geothermal Power Plant is a non-volcanic hot spring with a sound temperature of 130°C which can generate 300 kW of electricity. Lastly, effort has been made by researchers in gathering the data on hot spring distribution in Malaysia which can be viewed with just a click. A new app is developed for Android user named Malaysia's Hot Springs that can be freely downloaded from the 'Apps Store' in hope that the application can serve as hot springs tourism and publication reference purposes.

Keywords: Hot springs, Malaysia, geothermal

INTRODUCTION

Do you ever wonder why the temperature of groundwater seeping to the surface, commonly called hot springs, can reach up to a boiling point? Where is the source of heat that influenced the temperature of the water? How hot must the water be before it can be classified into the hot spring category? And what is the future of geothermal energy in Malaysia? Hot springs are heated by the geothermal heat which originates from the Earth's interior. Geothermal energy through hot springs is one of the renewable energy sources that could be harnessed to supply electricity and generate heat. Many hot springs have been found in Malaysia and therefore, the need for more research on geothermal energy particularly from hot springs is vital to fully maximise its potential as an energy source that will benefit the economy of this country in a long run.

DEFINITION

In general, a hot spring is a natural occurrence where heated groundwater emerges on Earth's surface. Its temperature is higher than a body temperature and ranges from 40 °C and above. Apart from the high temperature, the water is also filled with very high concentrations of dissolved minerals such as calcium, sodium, sulphate, chloride, and silica.

SOURCE OF HEAT

The formation process of a hot spring can be answered by investigating the source of its occurrence. An increase in temperature happens due to the groundwater being heated up by the intrusion of magmatic bodies. It then rises to the surface through faults and fractures once it has absorbed enough heat to become lighter than the overlying water. This event is related to volcanic eruptions and commonly

0126-5539; 2682-7549 / Published by the Geological Society of Malaysia.

occur near volcanoes. Therefore, this type of hot spring is classified as the volcanic origin. Hot springs of volcanic origin can be found in East Malaysia such as in Apas Kiri, Tawau, Sabah as shown in Figure 1. Current finding of the geochemistry of Sabah and Sarawak hot springs can be accessed in Anuar *et al*. (2021).

On the other hand, hot springs of non-volcanic origin such as the hot spring in Sungai Klah, Perak, shown in Figure 2, can be explained using the cooling magma and geothermal gradient model (Baioumy *et al.*, 2015). By referring to Figure 3, the magmatic intrusions represent the cooling magma that gives rise to the temperature of the surrounding rocks. Over time, these granitic bodies will be embedded in the Earth's crust and continuously distribute the heat after it is solidified due to the thermal gradient. According to this model theory, researchers look into these three components when analysing hot springs of non-volcanic origin: location of the hot spring, the proximity to granitic intrusion and the distance to major faults or fractured zones.

Generally, temperature increases with depth, therefore, at greater depths where the rocks are so hot, the heat will be distributed to the groundwater, which will eventually make its way up to the surface through faults and fractures. Thus, the heated water that forms hot springs comes from the surface water that penetrated the subsurface to a great depth where the temperature is high, or from the groundwater stored in the aquifers.

In Malaysia, there are over 60 known hot spring sites and more to be discovered (Chow *et al.*, 2010).

Figure 1: An example of a hot spring of volcanic type origin is Apas Kiri, Tawau Hot Spring, Sabah.

Figure 2: An example of a hot spring of non-volcanic origin is Sg. Klah Hot Spring, Perak.

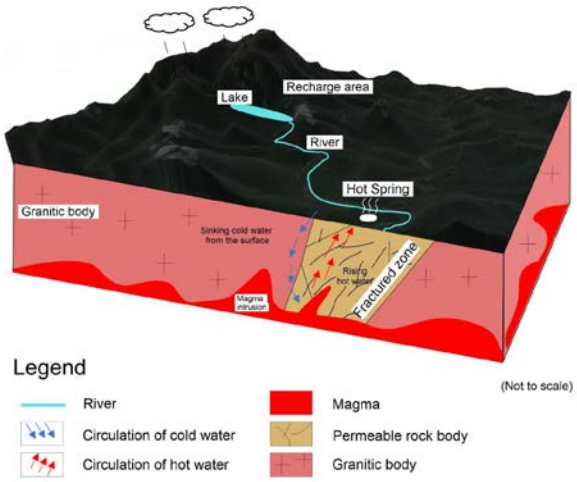


Figure 3: A schematic diagram illustrating the formation of hot spring of non-volcanic origin.

The majority of these hot springs are of non-volcanic origin due to the geographical location of Peninsular Malaysia that is located far from the Ring of Fire and has no active volcanic activities. The highest temperature of hot spring water measured in Peninsular Malaysia is at Sungai Klah Hot Springs, Perak where the temperature can reach 100.2°C. You can even boil eggs in the water.

GEOLOGICAL DISTRIBUTION

The geological distribution of hot springs in Peninsular Malaysia is shown in Figure 4. The distribution of hot springs is concentrated on the west coast of Peninsular Malaysia. It forms a northnorthwest-southsoutheast (NNW-SSE) trend aligned with the main tectonic trend of Peninsular Malaysia.

Researchers have found that most hot spring spots are concentrated near the fault zones. Peninsular Malaysia has numerous major faults, such as Bok Bak Fault, Bukit Tinggi Fault, Kuala Lumpur Fault, Lebir Fault, Seremban Fault, Kisap Fault and Galas Fault. These faults are correlated with hot springs in Peninsular Malaysia within the Eastern and Western belt. Hot springs are usually found in the surrounding area of faults, which are fractured rocks that are permeable, allowing water to flow within the crust. The fluids coming from the highlands are caught by the porous, highly fractured damage zone, which leads them to the surface, explaining the relationship between hot springs and fault occurrence (Taillefer *et al*., 2018).

This is explainable as fractures and faults act as the pathway for meteoric water to flow deep inside the subsurface where the temperature is intense. Hot springs commonly exist in low-lying areas such as swamps, riverbeds, and bedrock surfaces. Given that hot springs occur in these accessible areas, it gives a massive advantage for the developer in planning and utilising the source for the greater good.

BENEFITS AND ADVANTAGES

Continuous efforts have been made in developing hot spring areas into becoming a tourist spot as this heated water has been well known for centuries for its health benefits. One widespread practise in treating illness is balneotherapy, where the body is immersed in mineral-rich water. Hot springs water contains an abundance of dissolved minerals such as sodium, calcium, sulphate, chloride, and silica. This mineral-rich water is believed to have soothing effects on the human body to relieve muscle pain and stressed joints (Erfurt, 2011).

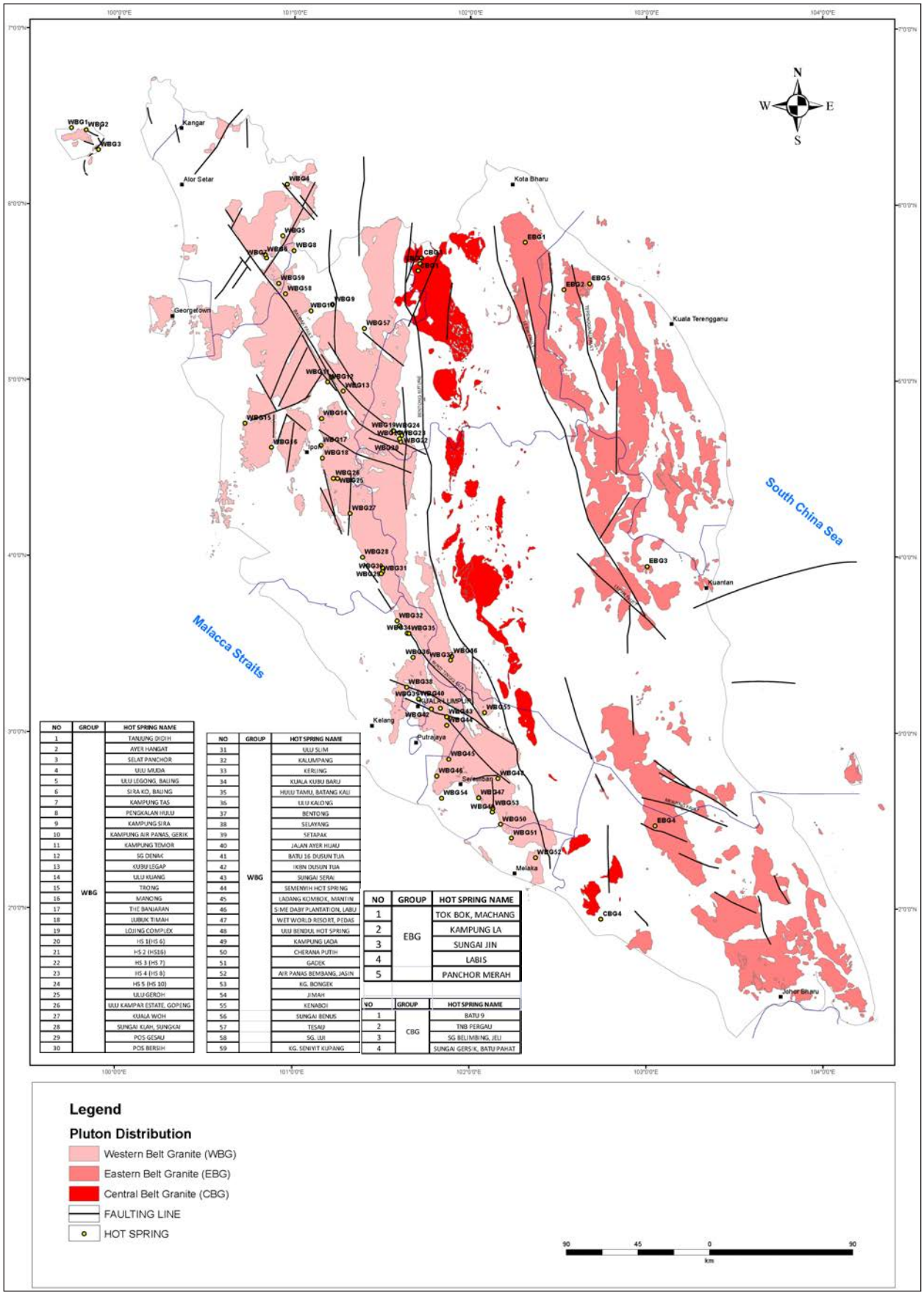
Soaking your body in the warm water of the hot spring is also relaxing and brings tranquillity to your mind. Other than health benefits, hot springs are used to heat spaces, just like an electric heater but it is environmental-friendly and cost-saving. Water from hot springs can also be used for your everyday home purposes such as bathing and washing clothes. On a larger scale, the steam coming out of hot springs is helpful to rotate turbines that could generate electrical energy.

GEOTHERMAL ENERGY

Geothermal is the terrestrial generated heat of the Earth. It is derived from residual energy from Earth's formation and the decay of the radioactive elements in the crust, then transferred to the subsurface by conduction and convection (Tester *et al*., 2006). Throughout the process, water is included as part of a water cycle that comes from rain and snow seeping deep inside the interior portion of the Earth's crust. Upon heating, this groundwater could rise again, emerged with high pressure and temperature to the surface and known as a hot spring. Thus, it is capable of harnessing energy called geothermal energy. For centuries, people have been utilising this energy source for home use, and it has now evolved into the source for generating electricity. As a reference, our neighbour country, Indonesia, has one of the largest geothermal power plants, named Sarulla Geothermal Power Plant, as shown in Figure 6. This fantastic project can supply electricity to 2.1 million households and offset about 1.3 million tonnes (Mt) of carbon dioxide emissions a year (NS Energy, n.d.). Thus, geothermal energy is a renewable energy that is capable of generating a tremendous amount of power supply with lesser pollution to the air!

Can hot springs of non-volcanic origin be utilised to generate electricity? The answer is yes. Let us look into one of the famous non-volcanic hot springs in Thailand that can generate 300 kW of electricity, namely Fang Hot Spring, located in the Chiang Mai province. The water temperature can reach up to 130 °C - enough to generate clean energy for distribution for daily use.

The initiative to turn this area into Fang Geothermal Power Plant started in 1989 by the Electricity Generating Authority of Thailand (EGAT) and it is still well-maintained now. According to Richter (2016), the 300 kW geothermal power plant uses binary cycle technology. It distributes 1.2 million kWh per year as it is linked to the local distribution grid system of the Provincial Electricity Authority (PEA). A binary cycle power plant is a type of geothermal power plant that allows cooler geothermal reservoirs. It is a closed system that uses a second working fluid with a much lower boiling point than water. The geothermal fluid in the form of water vapor and working fluid such as hydrocarbon go through a heat exchanger, where the working fluid converts to vapor and drives the turbines. The cooled water vapour is then released back into the underground reservoirs so the new cycle can begin. Over the years, the hot spring area has expanded into multipurpose facilities such as recreational area, spa, bathtub, and bathrooms to attract visitors worldwide. In Figures 7 and 8, our team collaborated with an industrial partner to visit the power plant in 2018. It amazed us that Thailand has been developing these geothermal resources for years and can supply sufficient energy for the country.



NO	GROUP	HOT SPRING NAME
1	WBG	TANJUNG DIDIH
2		AYER HANGAT
3		SELAT PANCHOR
4		ULU MUDA
5		ULU LEGONG, BALING
6		SIRA KO, BALING
7		KAMPUNG TAS
8		PENGKALAN HULU
9		KAMPUNG SIRA
10		KAMPUNG AIR PANAS, GERIK
11		KAMPUNG TEMOR
12		SG DENAK
13		KUBU LEGAP
14		ULU KUANG
15		TRONG
16		MANONG
17		THE BANJARAN
18		LUBUK TIMAH
19		LOJING COMPLEX
20		HS 1(HS 6)
21		HS 2 (HS16)
22		HS 3 (HS 7)
23		HS 4 (HS 8)
24		HS 5 (HS 10)
25		ULU GEROH
26		ULU KAMPAR ESTATE, GOPENG
27		KUALA WOH
28		SUNGAI KUAH, SUNGKAI
29		POS GESAU
30		POS BERSIH

NO	GROUP	HOT SPRING NAME
31	WBG	ULU SUM
32		KALUMPANG
33		KERLING
34		KUALA KUBU BARU
35		HULU TAMU, BATANG KALI
36		ULU KALONG
37		BENTONG
38		SELAYANG
39		SITAPAK
40		JALAN AYER HUJAU
41		BATU 16 DUSUN TUA
42		IKBN DUSUN TUA
43		SUNGAI SERAI
44		SEMENYIH HOT SPRING
45		LADANG KOMBOK, MANTIN
46		SIME DARBY PLANTATION, LABU
47		WET WORLD RESORT, PEDAS
48		ULU BENDUL HOT SPRING
49		KAMPUNG LADA
50		CHERANA PUTIH
51		GADEK
52		AIR PANAS BEMBANG, JASIN
53		KG. BONGEK
54		JIMAH
55		KENABOI
56		SUNGAI BENUS
57		TESAU
58		SG. UJI
59		KG. SENIYIT KUPANG

NO	GROUP	HOT SPRING NAME
1	EBG	TOK BOK, MACHANG
2		KAMPUNG LA
3		SUNGAI JIN
4		LABIS
5		PANCHOR MERAH

NO	GROUP	HOT SPRING NAME
1	CBG	BATU 9
2		TNB PERGAU
3		SG BELIMBING, JELI
4		SUNGAI GERSIK, BATU PAHAT

Figure 4: The distribution map of hot springs in Peninsular Malaysia. Source: Arifin (2017).

Figure 6: An aerial image of the 330 MW Sarulla geothermal power plant located in North Sumatra, Indonesia.
Source: Richter (2018).

Figure 7: An image of our team in front of the 300 kW Fang Geothermal Power Plant in Thailand.

DATA WITHIN REACH

This is an era where every piece of information is attainable with just a touch. 'Malaysia Hot Springs' is a mobile app that contains data on every hot spring in Malaysia such as its location, temperature and the distribution of hot springs in Peninsula Malaysia as shown in Figure 5. This app is beneficial and convenient for researchers to collect first-hand data of their study area such as its water temperature and location. A user can easily access the information by downloading the app, and it is free!

CONCLUSION

Hot springs are a natural occurrence where groundwater is heated up at great depths and brought to the surface through cracks, fractures, and faults. The heated water has a temperature higher than our body and is filled with remarkably high concentrations of dissolved minerals. These properties make hot springs famously known to have healing and soothing effects on the human body, thus contributing to hot springs development as one of the geo-tourism attractions. With about 60 hot springs of low to medium temperatures in Malaysia, geothermal energy can be explored and utilised as a renewable energy source. Therefore, further geoscientific investigations should be considered and carried out in supporting the development plans of geothermal energy. It is hoped that Malaysia will fully utilise and generate electricity from it in the future.

ACKNOWLEDGEMENTS

The authors would like to thank Universiti Teknologi PETRONAS for allowing the internship program with Universiti Kebangsaan Malaysia. Special thanks to the Geology program, Department of Earth Sciences and Environment, Universiti Kebangsaan Malaysia management for encouraging us to publish our research work, and to the reviewers for providing helpful comments.

Figure 8: An image of our team observing and learning briefly about the geothermal power plant.

AUTHOR CONTRIBUTIONS

NAR wrote the original draft and served as an intern. MNAA was responsible for data curation, investigation and conceptualization of model. MHM and NSIAR reviewed hot springs distribution map and the application/map/figures preparation. MHA administred and supervised the overall project, handled data acquisition and curation, investigation, software, formal analysis, funding acquisition, resources and also as corresponding author.

CONFLICT OF INTEREST

The authors declare that we have no conflict of interest in this paper.

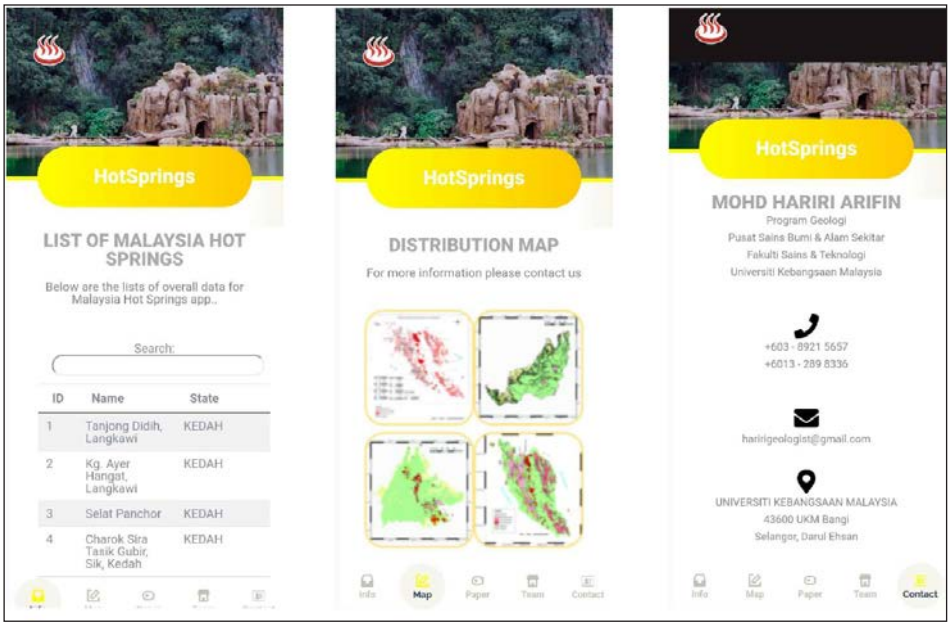


Figure 8: Features that are available in the app are shown. The 'Malaysia Hot Springs' app is downloadable in Androids. For further information, contact Dr. Mohd Hariri Arifin through phone or email.

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Manuscript received 7 June 2021;
Received in revised form 27 January 2022;
Accepted 28 January 2022
Available online 26 April 2022