HOT SPRINGS CHARACTERISATION AND GEOTHERMAL POTENTIAL STUDY IN PENINSULA MALAYSIA FROM GEOSCIENCES PERSPECTIVES

by

MOHD HARIRI ARIFIN

Thesis submitted in fulfillment of the requirements
for the degree of
Doctor of Philosophy

August 2017

ACKNOWLEDGEMENT

Thanks to the Almighty Allah for granting the opportunity to me to be able to accomplish this level of academic achievements in my lifetime. I am most grateful for the knowledge He bestowed on me. Hence, I could complete this doctoral research work.

My deepest appreciation goes to my main supervisor, Prof. Dr. Mohd Nawawi Bin Mohd Nordin, who stood by me throughout the field data acquisition and guided me strictly through his vast experience and knowledge in the cause of this study. Sharing the knowledge, I was able to acquire from him, most especially in the subject of geophysics, will make me a better and completed geoscientist. I equally want to appreciate the mentorship of my co-supervisor, Assoc. Prof. Dr. Hassan M. Baioumy; I thank you so much for working together with me in the hot water sampling for the geochemical analysis and the geological survey. I equally want to give my profound gratitude to Dr Amin Esmail Khalil and Dr John Stephen Kayode for sharing their vast experience and expertise in the applications of the TEM and MASW methods with me. Also, the later assisted me so much in the compilations and structures of this thesis.

This work would not have been possible to complete in record time without the sponsors I was privileged to enjoyed from the Ministry of Higher Education in Malaysia, for the *Skim Latihan Akademik IPTA* (SLAI) scheme; the Universiti Kebangsaan Malaysia and the geothermal short-term Research Grants, #304/PFIZIK/6313015 by the Universiti Sains Malaysia, (USM), the TNB Research Grants for the Pergau Hot Springs site, the FELDA Sungai Klah, Sungkai Hot

Springs site, Only World Group-OWG, the Pedas Hot Springs site, and the LADA, Langkawi Hot Springs site. All these helped to strengthen the research work and facilitated the advancement of the studies rapidly in the last three years. Special thanks go to the Minerals and Geosciences Department for the provision of data, maps and their support in the literature review.

This journey would not have been possible without the unconditional support I enjoyed from my home front. Therefore, special thanks to my lovely wife, Anis and the children, Adib, Jannah and Affan for their understanding during the fieldwork that took me away for long days and weeks to be able to complete the data acquisition for this research work. This work cannot be accomplished without the efforts and the cooperation of the Staff and student members of the School of Physics, Universiti Sains Malaysia, in particular, the Geophysics Unit who worked resiliently with me during the geophysical field data acquisition.

To me, a PhD degree in geophysics specialising in the geothermal exploration is a great prospect to develop a further plan for the future green energy in Malaysia. Although a lot of efforts, resources and energies are required to cover Peninsula Malaysia, numerous journeys and expenditures for the geophysical and geochemical surveys; are the challenges that I have got to manage. I thank you all for your kind support!

TABLES OF CONTENTS

CHAPTER 1 – INTRODUCTION

CHAPTER 2 - LITERATURE REVIEW

CHAPTER 3 – METHODOLOGY

CHAPTER 4 - RESULTS AND DISCUSSION

CHAPTER 5 - CONCLUSIONS AND RECOMMENDATIONS

LIST OF APPENDICES

LIST OF PUBLICATIONS

LIST OF TABLE

LIST OF FIGURE

LIST OF SYMBOLS

I	Current
V	Potential (volt)
ρ_a	Apparent resistivity
σ	Electric conductivity
k	Geometric factor
R	Configuration resistance
r	Distance between the current electrodes
Ω-m	Ohm-meter
$<$	Less than
$>$	Greater than
Hz	Hertz
mm	Millimeter
cm	Centimeter
m	Meter
km	Kilometer
v	Velocity
v_n	Velocity of n-layer
μ	Poisson's ratio
K	Bulk modulus
G	Rigidity modulus
ε	Elastic coefficient
h	Thickness
h_n	Thickness of n-layer
t	Time
t_i	Intercept time
t_{id}	Intercept time of down-dip
t_{iu}	Intercept time of up-dip
β	Dipping angle
θ_i	Refraction angle
θ_{ic}	Incidence critical angle
θ_{cn}	Critical angle of layer n^{th}
Xc	Critical distance
N	North
E	East

LIST OF ABBREVIATIONS

1-D	One dimensional
2-D	Two dimensional
3-D	Three dimensional
VES	Vertical Electrical Sounding
C	Current electrode
P	Potential electrode
RES2DINV	Resistivity 2-D Inversion software
SAS4000	Signal Averaging System 4000
USM	Universiti Sains Malaysia
UKM	Universiti Kebangsaan Malaysia
KPT	Kementerian Pengajian Tinggi
IP	Induced Polarisation
SP	Self-Potential
m/s	meter per second
DC	Direct current
JMG	Jabatan Mineral dan Geosains
BPT	Bahagian Perkhidmatan Teknikal, JMG
EM	Electromagnetic
TEM	Transient Electromagnetic Method
MASW	Multi-channel Analysis of Surface Waves
MT	Magnetotulleric
Ex	Time-varying electric field on x-axis
Ey	Time-varying electric field on y-axis
Hx	Time-varying magnetic field on x-axis
Hy	Time-varying magnetic field on y-axis
Hz	Time-varying magnetic field on z-axis
TNB	Tenaga Nasional Berhad
TNBR	Tenaga Nasional Berhad (Research) Sdn. Bhd.
GPR	Ground Penetration Radar
CBE	Charge-Balance Error
ASTM	American Society for Testing and Material
APHA	American Public Health Association
PPU	Pencawang Pembahagi Utama
PMU	Pencawang Masuk Utama
MAT	Main Access Tunnel
CVT	Cables and Ventilation Tunnel
SI	Structural Index
FELDA	Federal Land Development Authority

PENCIRIAN MATA AIR PANAS DAN KAJIAN POTENSI GEOTERMA DI SEMENANJUNG MALAYSIA DARI PERSPEKTIF GEOSAINS

ABSTRAK

Kajian penyelidikan terhadap tenaga geoterma berasaskan bukan volkanik di Semenanjung Malaysia kurang mendapat perhatian yang sewajarnya. Hal ini, seterusnya, berfungsi sebagai motivasi utama untuk memulakan kajian yang memberi tumpuan kepada kawasan di Semenanjung Malaysia untuk menentukan hubungan antara geologi, geokimia dan kaedah geofizik prospek untuk kesesuaian air panas berasaskan bukan volkanik ini sebagai lokasi berpotensi bagi pembangunan tenaga geoterma. Sebanyak 60 lokasi taburan air panas telah dikenal pasti di Semenanjung Malaysia. Lokasi air panas ini dipecahkan kepada tiga kumpulan utama, dinamakan sebagai; kumpulan Granit Jalur Barat, Granit Jalur Tengah dan Granit Jalur Timur telah diplotkan secara bersama. Pengkelasan air panas berasaskan bukan volkanik ini dibuat berdasarkan taburan pluton granit yang sama dan didapati wujud bersempadanan dengan sentuhan antara jenis batuan lain. Sesar-sesar yang paling ketara di kawasan kajian, seperti (Baubak, Kuala Lumpur, Terengganu, Bukit Tinggi, Lebir, Lepar dan Mersing) memainkan peranan penting dalam sistem kitaran air panas bersama kawasan tadahan air masing-masing. Kajian geokimia sampel air panas, mengesahkan kesemua sampel air panas adalah bukan berasal dari sistem volkanik. Geotermometer dari kuarza dan kalsedoni lebih sesuai digunakan dan julat suhu yang diperolehi adalah lebih konsisten berbanding kaedah geothermometer kation dan anion. Keputusan geokimia Air Panas Tanjung Didih, Air Panas Trong dan Air Panas Gersik didapati tercemar dengan rejahan air masin. Empat lokasi telah dipilih sebagai mewakili taburan air panas di Semenanjung Malaysia bagi kajian lanjutan dengan menggunakan kaedah geofizik; iaitu; Air Panas Ayer Hangat; Air Panas FELDA Sungai Klah, Sungkai; Air Panas Pergau, Jeli dan Air Panas Pedas. Gabungan enam kaedah geofizik (keberintangan geoelektrik, pengkutuban teraruh, elektromagnet fana, graviti, seismos dan radar tusukan bumi) telah menunjukkan bukti kehadiran sesar dan rejahan granit di kawasan lokasi air panas yang menjadi saluran kepada aliran mata air panas ke permukaan. Kaedah graviti menunjukkan kehadiran rejahan jasad granit di kawasan Ayer Hangat malahan kaedah keberintangan dan pengkutuban teraruh juga menunjukkan kawasan tersebut dilaputi oleh lapisan lumpur tebal yang berpunca daripada zon Sesar Kisap. Lima lokasi terbaik untuk pembangunan masa hadapan sumber tenaga geoterma; dengan berasaskan pengiraan entalpi dan beberapa faktor lain seperti yang ditentukan dalam kajian ini; iaitu Ulu Slim; Sungai Klah, Sungkai; Komplek Lojing; Trong, Taiping and Dusun Tua, Hulu Langat seterusnya adalah disyorkan sebagai lokaliti utama untuk mendapatkan tenaga geotherma.

HOT SPRINGS CHARACTERISATION AND GEOTHERMAL POTENTIAL STUDY IN PENINSULA MALAYSIA FROM GEOSCIENCES PERSPECTIVES

ABSTRACT

Research works on the potentials of geothermal energy resources in the non-volcanic hot springs origins within the Peninsula Malaysia have not received the much-needed attention. This, therefore, serves as a major motivation to embark on the studies that focused on the Peninsula Malaysia areas to determine the relationship among the geological, geochemical and geophysical prospection methods for the suitability of these non-volcanic hot springs origins as potential locations for the development of geothermal energy. A total of 60 hot springs locations distributed throughout the Peninsula Malaysia has been identified. These hot springs locations were classified into three major groups, namely; the Western Belt Granite, Central Belt Granite and the Eastern Belt Granite groups were all plotted together. Classifications of these non-volcanic hot springs origin was made by the same distribution pattern of the granites pluton and also close to the contact zones between the different rock types. The most significant faults in the study area; i.e.; (Baubak, Kuala Lumpur, Terengganu, Bukit Tinggi, Lebir, Lepar and Mersing) played a major role in the hot water circulation systems within the water catchment areas respectively. The geochemical analysis of the hot springs waters, confirmed that all the hot springs waters belongs to the non-volcanic origin types. Quartz and chalcedony are the most appropriate geothermometers and consistent with the range of temperatures obtained when compared to the cations and anions geothermometers.

Geochemical results from the Tanjung Didih Hot Springs, Trong Hot Springs and the Gersik Hot Springs were discovered to be contaminated with salt water intrusions. Four locations were selected as representatives of the hot springs in Peninsula Malaysia for the detail studies with the applications of the geophysical methods; these are; (i) Ayer Hangat; (ii) Felda Sungai Klah, Sungkai; (iii) Pergau, Jeli and (iv) the Pedas Hot Springs. The combinations of the six geophysical methods, (the geoelectrical resistivity, induced polarisation, transient electromagnet, gravity, seismic and the ground penetration radar) indicates the presence of faults and granitic intrusions in the vacinities through which the hot waters from these hot springs escape to the surface. The gravity method proved the present of granitic rock bodies intrusions in the Ayer Hangat area, whilst resistivity and the induced polarisation methods delineated a thick layer of mud caused by the Kisap Fault zone. The best five hot springs identified sites as potential sites for the future development of geothermal energy resources i.e on the basis of the enthalpy computations coupled with other factors as determined; the Ulu Slim; Sungai Klah, Sungkai; Loging Complex; Trong, Taiping and the Dusun Tua, Hulu Langat are therefore, recommended as the prioritised locations for the harvesing of geothermal energy.

CHAPTER 1

INTRODUCTION

1.1 Background of the study

The year 2020 is fast approaching for Malaysia to be a developed country. Similar to other developed countries, Malaysia need to integrate renewable energy in the form of geothermal energy sources for the electricity power generation. Globally, the increase in the demand for energy usage in most countries has accelerated astronomically such as the America, Iceland, Italy, Germany, Turkey, France and the Netherland (Guo and Wang, 2012). In this regard, Malaysia cannot be left behind as the energy usage demands is in the multiple folds. Several types of renewable energy sources could be a focus in Malaysia for the future need of energy exploitation. These energies from the renewable sources could be divided into; the solar; the wind; hydro, tides, biomass, and the geothermal energy sources (Ommar Ellaben et al., 2014). The critical areas where the renewable energy sources are in utmost demanding are; the electrical power generation sector; the air and water heating /cooling systems, the transportation systems, and the rural (off-grid) energy services (REN21, 2010).

Most of the hot springs in the World have been reported to be located in the volcanic active areas (Vengosh et al., 2002; Moller et al., 2004; Du et al., 2005; Qin et al., 2005; Papp and Nitoi, 2006; Sanada et al., 2006). However, Peninsula Malaysia is not located within the ring of the fire unlike the neighbouring countries like the Indonesia and the Philippines as shown in Figure 1.1. Occurrences of hot springs in the Peninsula Malaysia are related to the non-volcanic activities (JMG, 2013). Limited studies on the non-volcanic hot springs across the Peninsula Malaysia motivated this research work that was carried out and being presented in this thesis. There are numerous hot springs distributed across the Peninsula Malaysia. Samsudin et al. (1997), reported a total of 45 sites of the hot springs for the entire of Malaysia, (i.e., East and West Malaysia). However, contrary to Samsudin et al. (1997) findings, Chow et al. (2010), reported 60 locations of the hot springs in the Peninsula Malaysia only. While in the East Malaysia, (i.e., Sarawak and Sabah), 20 sites 10 of the hot springs are located in each State of Sabah, and Sarawak as reported by the JMG (2010). Only in Tawau, Sabah that detailed studies have been carried out for a geothermal research (Barnett et al., 2015).

Figure 1.1: Active volcanoes, plate tectonics, and the "Ring of Fire" map (after USGS, 2016).

Indonesia and the Philipines utilised about 27% of their geothermal energy generations on electricity supply as reported in (Baioumy et al., 2015). The assessment and utilisation of renewable geothermal resources in Malaysia are yet to be harnessed although more than 60 of the hot springs was previously reported in the Peninsula Malaysia alone. The hot springs characterisation study in Malaysia began by Bott (1980), that covered geochemistry of the water in the states of Selangor, Perak and Negeri Sembilan. Water quality and quantity of flow of the hot springs sources and to apprise their potential for mineral water exploration was reported by (Ho, 1979; Bott, 1980; Enjop, 1990; Abdul Rashid, 1991; Lim, 1991; Chow et al., 2010) and /or Similarly, Leh et al. (2011) reported the recreational uses of the hot springs sources.

Four main hot springs areas was selected for the detailed studies in the Peninsula Malaysia as representatives for the distributions of these hot springs geothermal energy sources. The sites are; (i) Ayer Hangat, in the Langkawi Island, Kedah (in the Northern part of the Peninsula Malaysia); (ii) Pergau, Jeli, Kelantan (in the Eastern part); (iii) FELDA Sungai Klah, Sungkai, Perak (in the Central part) and (iv) Pedas, Negeri Sembilan located in the Southern part of the Peninsula Malaysia. All other hot springs situate in the Peninsula Malaysia was covered by studies of the geochemistry analysis of these hot springs water and the general geological settings.

1.2 Problem statements

There had been limited detail studies of the geothermal potentials of these hot springs in the Peninsula Malaysia. The cost at the exploration stage of a potential site is lower in contrast to the implementation stage, i.e., (the drilling of the wells and installations). The frictional force generated through the plate movement of the Earth Crust could supply enough energy required by man and his environments. If all the geothermal resources in the Peninsula Malaysia could be established and utilised, the present energy dilemma would have been permanently solved because of the resources for this energy is huge and practically inexhaustible. The problem of tapping into these tremendous renewable energy reservoir is not an easy task.

The knowledge transfer about the way to harvesting the geothermal energy for local expert still very low in Malaysia. A research for the development of the potential of geothermal sources for power generation in Peninsular Malaysia is crucial to the right steps towards the actualisation of the needful knowledge on the oringin and occurrences of these hot springs. Since not all these hot springs are capable of yielding adequate hot water temperatures to be viable for the geothermal energy explorations, the issue of ranking them according to the enthalpy values is vital in order to save cost and time required for the detailed studies of all the 60 hot springs locations. Detail geoscientific studies, such as this present research work is a welcome step towards actualising this goal. The extra crucial information for geological and geochemical analysis of all the 60 hot springs water samples are also required.

1.3 Research gap and novelty

Less attention was given to the detail geologic and geophysical studies of the hot springs in Peninsula Malaysia to really understand the surface and the subsurface characteristics of these hot springs. In the same vein, the geochemistry and geothermometry of these non-volcanic hot springs is lacking with only few publications available, (e.g. Brugger et al., 2005, Yaguchi et al., 2014). This could be due to their rare occurrences in comparison to the volcanic hot springs been reported globally (Vengosh et al., 2002, Moller et al., 2004, Du et al., 2005, Qin et al., 2005, Papp and Nitoi, 2006, Sanada et al., 2006). One of the major tasks in the exploration of geothermal resources is to estimate the subsurface temperature of the reservoir from the geochemical composition of the thermal springs. The origin of hot springs has historically drawn awareness from water scientists (LaMoreaux, 2001) and several classification schemes have been proposed regarding special features, such as; the average discharge, geological setting, water geochemistry, and water temperature (Pitts and Alfaro, 2001, Kresic, 2010). The origin of these non-volcanic springs remains questionable. Therefore, the goal of this study is to determine the chemistry and deduce the temperature at depth of selected hot springs in order to assess their potential as an alternative source of renewable energy in Malaysia.

Peninsula Malaysia have near surface data and limited to certain geophysical method especially resistivity, Transient Electromagnet (TEM) and gravity method. The distribution of hot springs location not properly recorded using various name makes confusing to find it. This research provides the updated-on locations for newly discovered founded hot springs in Peninsular Malaysia. This will allow other researcher to use the updated map, coordinate, geophysical and geochemical results by refer to the correct place representative from those data.

The depths of previous works were too shallow for exploration of geothermal energy sources as detail geophysical explorations was not done. For better understanding of the subsurface geology for the hot springs, detail application of the geophysical methods for deep target penetrations will provide adequate information on the cap rocks, the reservoir characteristics, and the geological structures that contribute to the circulation of the hot waters.

It was observed that in all the previous studies on the Peninsula Malaysia hot springs, the enthalpy of reservoir waters was not computed in all the previous studies. This important parameter is necessary for the classifications of these hot springs geothermal energy potentials.

The research novelty dwell on the integration of geosciences methods to determine the origin of all the 60 hot springs sited in Peninsula Malaysia, deeper subsurface delineation of the geothermal sources. In addition to the foregoing, the enthalpy of all the reservoir waters was determined. These additional studies enhance the prospect for the harnessing of the geothermal energy resources in the Peninsula Malaysia hot springs.

1.4 Objectives of the research

The objectives of this study;

i. Mapping of the hot springs distributions within the Peninsula Malaysia on the regional geological map.

ii. Characterising of the selected hot springs water using the detail geochemistry and geothermometry studies.

iii. Producing the conceptual model of the selected hot springs and assessing their potentials from geophysical exploration as an alternative source of renewable energy in Malaysia.

1.5 The thesis structure

The layout of this thesis generally organised as follows:

First chapter discusses the introduction to geothermal study at Malaysia with special focus on Peninsula Malaysia. The sub-topics covered the problem statements, research gap and novelty of the research and objectives of study.

The second chapter elaborates the literature review of hot springs and geothermal energy. The hot springs distribution and review of previous studies on the geochemical and geophysical methods.

Chapter three discusses the methodology used in this research work. The way hot springs were plotted in the geological map, water sampling and geochemical analysis and finally geophysical methods were all discussed. The way to create the conceptual model and /or the origin for the selected hot springs was discussed at the end of chapter 3.

Chapter 4 covers the results of the hot springs distributions, their geochemistry and geothermometry results and geophysical data interpretation. This chapter also discusses the newly discovered hot springs and the origin of their hot water explained up to their potential ranking for geothermal energy.

Last chapter show of the conclusions of this research work and some recommendations for future research especially for the geothermal potential of hot springs in the Peninsula Malaysia. Figure 1.2 below summarises the thesis structure in flow chart.

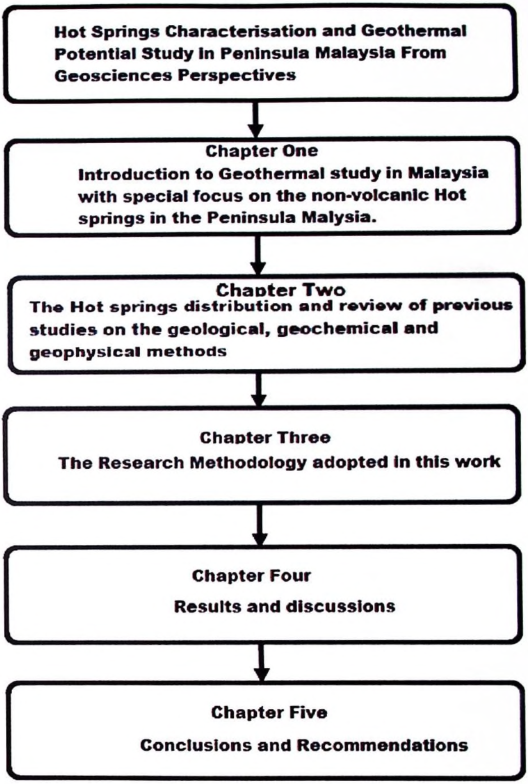

Figure 1.2: Thesis structure flow chart.

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

Chapter two discusses and review the geothermal energy and hot springs. The definition and classification of geothermal systems; their sources, types, and historical background. The hot springs characteristic or features, origin, uses and distributions. Then, the literature focussed on the varieties of studied in Peninsula Malaysia. Role of geochemical and geophysical methods in the geothermal exploration.

2.2 Geothermal energy

Geothermal energy and hot springs are one system established together. The word 'geothermal' refers to the thermal energy of the planetary interior and it is a large reservoir of heat with enough high temperature to encompass as an energy sources (IGA Service GmbH, 2014). The heat (geothermal energy), initiated from the decay process of radioactive material in the core mantel of the earth. It is enhanced by the continued generation of heat due to radioactive decay of uranium, thorium and potassium within the earth crust (Bowen, 1989). The heat travel to the surface through conduction and convection processes produced as the hot water at the surface (hot springs). The degree of temperature gradient is more often than not around about 30°C per kilometre (km) and up to about 150°C/km in a great geothermal area. Reducing the burning of fossil fuels makes sense on both economic and environmental point of view. Geothermal energy offers the alternative renewable energy resources, especially for the developing countries like Malaysia.

Geothermal exploration is necessary in order to identify potential geothermal field that are commercially significance in the identification of related anomalies in connection with anomalies upwards movement of the magma. Of course, factors such as temperature and enthalpy distribution of permeability, and the depth of a suitable aquifer acting as a reservoir, play a significant role in producing a spectrum of geothermal systems including both convective and conductive varieties (IGA Service GmbH, 2013).

2.2.1 Terminology and classification

Geothermal systems can be defined and classified on the basis of their geological, hydrological and heat transfer characteristics (IGA Service GmbH, 2014). Active geothermal systems consist of hot fluid and hot rock within the upper part of the Earth's crust (IGA Service GmbH, 2014). The fluid is, for the most part or solely, meteoric water or seawater by origin, or a mixture thereof. Since the thermal energy of the earth crust is stored in large rock masses, a working fluid (water) is needed to transport and transfer this heat to the surface (IGA Service GmbH, 2014).

Five categories of geothermal system can be recognised base on the nature of the geological system from which they originate (ESMAP, 2012). The first is volcanic geothermal system that is related to volcanic activity. The heat sources for such systems are hot intrusions or magma (ESMAP, 2012). This class often situated within or close to volcanic complexes, such as calderas (ESMAP, 2012). In volcanic systems, it is mostly permeable fractures and fault zones that control the flow of the water (ESMAP, 2012). The second type is convective fracture controlled systems. This system is the heat source of the hot crust at a depth in tectonically active areas (ESMAP, 2012). The third type is the sedimentary geothermal systems that are located in many of the world's major sedimentary basins (ESMAP, 2012). These systems are conductive in nature rather than convective, even though fractured faults play a role in some cases (ESMAP, 2012). Geo-pressured system is a type of analogous to geo-pressured oil and gas reservoirs in which fluid caught in stratigraphic traps may have pressure close to lithostatic values (ESMAP, 2012). The last type is the hot dry rock (HDR) that consist of volumes of rock that have been heated by volcanism or abnormally high heat flow (ESMAP, 2012).

Generally, geothermal systems develop by deep density-driven convention of ground water, yet, in some systems of relatively low temperature, the convection may be driven by hydraulic head only (IGA Service GmbH, 2014). The water convection transports heat from the deeper source to the shallower parts of the geothermal systems. The heat source may be a magma intrusion (in volcanic geothermal systems), or the hot rock at the roots of the convection cycle (in non-volcanic geothermal systems) (IGA Service GmbH, 2014).

The term for geothermal reservoir indicates the hot and permeable part of a geothermal system that may be directly exploited. For a geothermal reservoir to be exploitable, it needs to have sufficient natural heat that transforms to pressure and brings the steam to the surface. Meanwhile, the term for geothermal field is a geographical definition that indicating an area of geothermal activity at the Earth's surface. In the case without surface activity, this term may be used to indicate the area at the surface corresponding to the geothermal reservoir below (IGA Service GmbH, 2014).

2.2.2 Type of geothermal field classification

A primitive classification of geothermal field types, regarded as mining enterprises, distinguishes three broad classes (hot water fields, wet steam fields and dry steam fields) (Facca, 1977). First, a hot water field contains water reservoir at temperatures ranging from 60 to 100°C (Gupta, 1980). Such fields could be useful for space heating, agricultural and various industrial purposes. The geology of hot water fields is much the same as for cold ground water systems. System suitable for commercial exploration may be confined (artesian) or open that is without a cap rock. This class may be worth to be invested in, if large water reservoir is believed to exist at temperature of about 60°C and at less than 2km depth with heat flow of at least $2.2\mu cal/cm^2s$ while the yield per well is large.

Second, wet steam fields contained a pressurised water reservoir at temperatures exceeding 100°C. This is the commonest type of economically exploitable geothermal field (Facca, 1977). When hot water is brought up to the surface through a well, and its pressure is sufficiently reduced, some quantity of the water will be flushed into steam under saturated conditions with water usually predominating. A productive well in this type of field will continue to flow after the process has been initiated.

The third class, dry steam fields which is the dry yield or superheated steam at the wellhead, at pressure above atmospheric pressure. The degree of superheated may vary from 0 to 50°C. Geologically, wet steam and dry steam fields are generally similar, as emphasised by the fact that in some cases wells have produced wet steam for a period and dry steam late.

Bowen (1989), classified geothermal into two main widely accepted systems. The convective geothermal systems are characterised by natural circulation of the working fluid. The convective geothermal systems can be subdivided into hydrothermal and circulation systems. For hydrothermal systems, they are characterised by both high porosity and high permeability. Almost all geothermal systems which have been developed to generate commercial electric power fall into this group (Garg and Kassoy, 1981). Obviously, this is possible where the systems are shallow (less than 3km deep) and hence can be tapped by drilling. Under the hydrothermal systems, there are two classes of hydrothermal systems namely; vapour- and liquid-dominated. Both vapour- and liquid-dominated systems can coexist in a reservoir and hence the distinction between them is really significant only in terms of utilising the resources. For the circulation systems, it occurs in low porosity- low fracture permeability environments in areas of high to normal regional heat flow. It could develop in areas free of young igneous intrusions, arising from the deep circulation of meteoric water in the thermal regime of conductive and regional heat flow. Obviously, in order for such systems to prevail, the related rocks must possess significant fractures and fault zones of adequate permeability that permit water circulation.

Conductive geothermal systems are included in low-temperature, low enthalpy aquifers, including geopressurised reservoir and hot dry rocks. The low-temperature and low enthalpy aquifers are located in high-porosity and high-permeability sedimentary sequences. The conduction which is solely responsible for the geothermal regime is frequently in a steady state and the working fluid is either available in sedimentary basins. For the geopressurised reservoirs, it comprises a rather unusual category of geothermal resource. In fact, it was a special case of sedimentary aquifer in which the pore fluid sustained pressure exceeding hydrostatic pressure, thus bearing a large part of the total overburden. The last conductive geothermal system is hot dry system. The hot dry rocks in a high-temperature, low-permeability environment is particularly interesting for its potential in areas not normally considered geothermally promising.

2.2.3 Utilisation as reported

Geothermal energy has been widely used to be in use by mankind as far back as the third century (WIKIPDIA, 2016). The first usage as a source of heat energy was reported to be in China, but subsequent used became popular during the Roman Empire. However, France made the first attempt to use the thermometers to measure geothermal heat in 1740. But in the year 1870, a modern scientific method was devised to study the Earth's thermal administration. In 1892, the United States invented the first geothermal district heating system at Idaho. Italy made the first attempt to use the geothermal system to generate electricity in the year 1904. By the year 1942, 127MWe was installed globally (Dickson and Fanelli, 2016).

Geothermal energy technology has evolved in the course of the nineteenth century. The Renewable Energy Technical Assessment Guide published in 2004, gave a worldwide installation of the geothermal energy at over a 9,400MWe as presented in Figure 2.1. A critical examination of the Figure 2.1 presents neighbouring countries such as the Philippines, Indonesia and Thailand have their geothermal energy sources harnessed to cater for the increase in their energy demand. Malaysia is yet to exploits this great potential among the ASEAN region, though efforts are ongoing at Sabah in the East Malaysia, but it is of a volcanic origin.

Source | Based on Bertani 2010

Figure 2.1: Geothermal power installed capacity worldwide (after Bertrani, 2010).

2.3 Hot springs; definition and origin

The hot springs, also termed thermal springs, could be defined as groundwater originating from a source at temperatures significantly higher than the surrounding temperatures (Baioumy et. al, 2014). The groundwater get heated up by the intrusions from the Magmatic bodies thereby causes an upward movement of the waters to the ground surface through the fractures or faulted planes. These activities are usually related to the volcanic eruptions during large plates movement. However, some of the thermal springs are not always products of these volcanic activities. The groundwater get heated at a greater depth of several metres to kilometres where the temperature of the rocks as the source of the heat is higher as a result of the temperature gradients of the Earth's crust.

Generally, the hot springs water of an area contains large concentrations of dissolved minerals, such as sodium, calcium, sulphate, chloride, or silica higher than that of the local non-hot springs ground water (IGA Service GmbH, 2014). The water warms as it descends, possibly along fault zones that overlain the magma chamber, until it absorbs enough heat to become lighter than the overlying water. The warm water hen rises to the surface. The mechanism for the circulation of the water is the same, regardless of whether the water becomes heated by the geothermal gradient or by the buried, cooling magma (IGA Service GmbH, 2014).

2.3.1 Application

Until a century ago, geothermal energy was known mostly as a source of heat for spa and bathing purpose (ESMAP, 2012). The use of geothermal resources is strongly influenced by the nature of the system that produces them. The resources of hot volcanic system are utilized mostly for space heating and direct uses. Apart from power production and district heating, two major fields are for industry and agriculture. There are also the balneological and recreation fields. The most interesting and important role of geothermal energy is in the field of mining and upgrading minerals (Lindal, 1977). The use of geothermal water for animal husbandry and other farm uses were discussed by Boldizsar (1970), Komagata et al. (1970) and Boersma, (1970). Usage of hot springs can be classified up to eight groups as shown in Table 2.1.

Those other things, the application of geothermal energy has both its problems and its rewards. Yet, experience shows that the problems have a way of disappearing as research and development advances in any specific application. Any widespread use of geothermal energy is very different on research and process development (IGA Service GmbH, 2014).

Table 2.1: Hot springs and their usage (ESMAP, 2012).

Group	Usage
Living use	People supply water by handling with a dipper, turning on a faucet or drawing from a well to wash clothes & dishes and clean up.
Public bath	It is not only for tourists, but also for citizens to get relaxed and communicate with each other.
Gardening	Cyclamen and Orchid flowers are cultivated in a house heated by thermal steam (Dragone and Rumi, 1970). Processing the pulp and paper (wood processing). Cooke, (1970) describes for growing mushrooms in New Zealand.
Sinter	A crystal of mineral spring gushed out and capable of been easily make as an instant hot spring with these special bathing powders to enjoy a sulphur bath.

Group	Usage
Cooking	Fresh food, such as eggs, vegetables and rice are steamed instantly in the hot vapour and retaining the nutrients.
Heating	Functioned like an electric heater, but is a hot spring heater which makes the room warmth from the spring without polluting the air. The floor heated by thermal steam is nice & warm to make us feel comfortable.
Fish breeding	The fry of carps is raised in thermal water under a strict temperature control good for ornamental fish pond operators.
Geothermal energy	The energy generated from turbine for electrical power supply.

2.3.2 Distributions of hot spring in Peninsula Malaysia

Samsudin, et al., (1997), reported that most of the thermal springs are located either inside granitic structures or close to granites rocks or along the major fault or shear zones. It is believed that the granite batholiths that have become embedded in the earth crust continue to give off heat after solidification. Their residual temperature is probably in the order of 700 to 1200°C, (Biro Rundingan dan Kembangan, 1994). Some of the heat is probably generated by radioactive decay of minerals contained in these rocks.

Other thermal springs occur at the granitic-sedimentary contacts or within sedimentary rocks near the granite contacts. It is possible that the deep-layering groundwater contained in the aquifers of the crust, which occur mainly in sedimentary rocks is moved towards the surface sometimes as a result of magmatic and volcanic heat and under the influence of pressure and it brings about a redistribution of the heat along the various pathways that it follows. Water seeping through the fractures and crevices in the earth's crust is heated by contact with the hot granitic base rock and emerges as hot springs (Baioumy et al., 2015).

Some of the hot springs are occurs within the low lying and topography of the hot springs commonly occur at low lying areas in various geographic setting including within swampy areas, river beds and bedrock surfaces. The setting and occurrences of most hot springs is in alignment with main tectonic belt of the Peninsula Malaysia (Baioumy et al. 2014). Major concentration of the hot springs typically concentrated along major fault zones, within the western main range granitoid that offer rapid penetration of meteoric water to depths where the rocks are warm enough to generate a convective up flow of the hot water.

According to Malaysian Tourism Bulletin (1991), quoting the Geological Survey Department, there are 45 known hot springs in Malaysia. However, hot springs in Kg. Mata Air, Padang Besar, Perlis and Kg, Sira Ko, Baling, Kedah were found out to be cold springs. Hot springs in Kg. Sg. Bersih, Hulu Slim, Perak and Kg. Lada and Kg. Cengkau in Rembau, Negeri Sembilan are found located very closed to each other and regard as similar source. Table 2.2 shows the distribution of hot springs in Peninsula Malaysia.

Table 2.2: List of the hot springs distribution in Peninsula Malaysia after Samsudin, et al. (1997).

No.	Location	State	Surface Temperatures (°C)
1	Batu 9, Trong, Taiping	Perak	48
2	Air Panas, Keroh	Perak	44
3	Kg. Ayer Panas, Gerik	Perak	45
4	Kg. Sira, Gerik	Perak	65
5	Kuala Woh, Batu 7, Tapah	Perak	71
6	Kg. Air Panas, Ulu Selim	Perak	92
7	Pos Bersih, Ulu Selim	Perak	36
8	Batu 15, Tapah	Perak	44

9	Hulu Kampar Estate, Gopeng	Perak	43
10	Kg. Ulu Geroh, Gopeng	Perak	38
11	Kg. Kubu Legap, Lasah	Perak	29
12	Kg. Temor, Lasah	Perak	46
13	Sg. Danak, Lasah	Perak	60
14	Kg. Ara Panjang, Manong	Perak	47
15	Lian Seng Tong, Chinese Tample, Ipoh	Perak	29
16	FELDA Sungai Klah, Sungkai	Perak	98
17	Ulu Sungai Periah, Sg. Siput South, Ipoh	Perak	51
18	The Banjaran hot spring, Tambun	Perak	65
19	Kg. Ayer Hangat, Langkawi	Kedah	45
20	Kg. Legong, Baling	Kedah	55
21	Kg. Sira Ko, Baling	Kedah	30
22	Mata Ayer, Padang Besar	Perlis	27
23	Kg. Mata Ayer, Machang	Kelantan	27
24	Kg. Labok, Machang	Kelantan	41
25	Batu Melintang, Jeli	Kelantan	52
26	Sg. Ber (HS 10)	Kelantan	72
27	Sg. Berok (HS 6)	Kelantan	63
28	Sg. Mering (HS7)	Kelantan	50
29	Sg. Mering (HS8)	Kelantan	50
30	Sg. Mering (HS16)	Kelantan	57
31	Air Panas, Setapak	Kuala Lumpur	46
32	Batu 16, Dusun Tua, Hulu Langat	Selangor	71
33	IKBN, Hulu Langat	Selangor	78
34	Sungai Serai, Hulu Langat	Selangor	47
35	Sg. Tekala, Semenyih	Selangor	41
36	Pusat Latihan Polis, Kuala Kubu Bharu	Selangor	45
37	Kerling	Selangor	45
38	Selayang, Batu 9, Gombak	Selangor	56
39	Air Panas, Ulu Yam	Selangor	56
40	Ulu Tamu, Batang Kali	Selangor	45
41	Pedas Wet World	Negeri Sembilan	58
42	Kg. Lada, Rembau	Negeri Sembilan	46
43	Kg. Cherana Puteh, Alor Gajah	Melaka	46
44	Kg. Ganun, Gadek, Alor Gajah	Melaka	59
45	Kg. Air Panas, Labis	Johor	46
46	Parit, Gerisek, Batu Pahat	Johor	46
47	Sg. Jin, Sungai Lembing, Kuantan	Pahang	41
48	Sg. Bujang, Bentong	Pahang	41
49	Batu 77, Bentong	Pahang	45

There were limited study done to access the geothermal potential in Peninsula Malaysia for power generation (Ho, 1979) that covered only geothermometric measurements of hot springs in Perak and Kedah. Ho (1979), conducted preliminary work on geothermometric in parts of the states of Perak and Kedah. The determination of the sub-surface temperatures of hot springs water was conducted based on silica content. He discovered the temperatures ranged 125°C to 166°C. The reports from this researcher is not only outdated, but it was not detail enough to be considered as a representative of the Peninsula Malaysian's hot springs for the geothermal energy exploration.

Then the studies were only focused on the occurrence of hot springs, the hot springs water quality and their suitability for tourism industry. Bott (1980), reported the brief descriptions of the occurrences, chemical analysis and gaseous discharge of these thermal springs. A preliminary study on the thermal springs of Peninsula Malaysia was conducted and reported by Abdul Rashid Bachik (1991). The objective of the study was to determine the quality, quantity of flow and to assess their potential uses particularly as possible source for mineral water. Umar Hamzah et al. (1990), carried out geological and geophysical investigations on most of the thermal spring sites investigated. The study aims at determining the geophysical properties of the rock mass in the vicinity of the hot spring areas. The occurrence of thermal springs in West Malaysia showed a distinct pattern that is considered to be structurally controlled and probably genetically related to granitic intrusions and post magmatic activities (Abdul Rashid Bachik, 1991).

Department of Minerals and Geosciences Malaysia, (JMG) conducted several geological, geochemical and geophysical studies of the hot springs in Peninsula

Malaysia. The selection of hot springs sites for the geothermal energy ranking, depends on the hot springs temperatures with the hottest as the priority. Applications of the Time Domain Electromagnetic (TEM) geophysical method in the hot springs study was introduced by (Harun, 1996) at Ladang Sg. Lalang, Hulu Langat, Selangor. TEM method also was used to study hot springs at Ulu Selim by Mohd Rais Ramli (2003). The hot springs study at Lojing, Gua Musang were conducted from the qualitative studies, (Azmi Ismail and Mohd Azmer Ashari, 1998) followed by Azmi Ismail et al. (2002). Geophysical survey using the TEM was carried out by Mohd Rais Razali and Ho Choon Seng (2002) and Mohd Rais & Abd. Rahim Harun (2003). The study of Lojing hot springs by Azmi Ismail, (2004) further added value to the none geothermal energy usage of these hot springs. Early mapping and potential of Lojing hot springs as a tourism destination were conducted by Kamal Roslan Mohamed et al. (2001 & 2002).

The general geological study was conducted by Malaysians university lecturers and researchers. Preliminary mapping of geological heritage resources in Kelantan by Che Abdul Rahman and Kamal Roslan Mohamed (2001) reported and identified 23 localities as potential geosites including that of Lojing hot springs. Another research for the geological heritage conducted at Lojing hot springs and Tok Bok, Machang by Tanot Unjah et al. (2001). No focus for geothermal energy potential study in Peninsula Malaysia because all these previous works were not aligned with the geothermal energy resources in this area.

2.4 Geological study

The geological information such as type of rock and structural setting (i.e main faults and fractures system) are very important input to understand geothermal system. The geological settings indicate the occurrence of hot springs in two main trends (Baioumy et al., 2014). The West–East trend extends from the Ayer Hangat hot springs at Langkawi Island in the West, to the Kampung Labok hot spring, Machang, Kelantan and Kampung La hot spring, Hulu Besut, Terengganu in the East. The North–South trend extends from the Pengkalan Hulu hot spring, Kedah in the North to the Gerisek hot spring, Johor in the South. Majority of the hot springs in Peninsula Malaysia are found along the Main Range Granite batholith of the Peninsula Malaysia (Samsudin et al., 1997). However, few of these hot springs are found situated within the area of sedimentary rock and close to the granite body. The geographic distribution of the hot springs as illustrated by the map appears to follow a NNW–SSE alignment that represents the main tectonic trend of the Malay Peninsula. A large number of these hot springs are prominent at localities of the major fault zones (Harun, 1991). All the hot springs from Peninsula Malaysia are non-volcanic origin base on type of rock. Only hot springs from Semporna-Tawau area reported consist of Quaternary volcanic rocks type (Yunus et at., 2010).

2.5 Geochemical analysis

Geochemistry plays relatively crucial role in the exploration of geothermal resources and subsequent utilization. Its major contributions in geothermal resource assessment includes; estimation of subsurface temperatures, determination of the origin of the waters and flow patterns within the reservoir. The major tools used in geochemical mapping are water and gas. Geothermal waters have been classified with respect to their anion and cation constituents into alkali-chloride water, acid sulphate water, acid sulphate-chloride water and bicarbonate water (Jeremiah and Isaack, 2012). Over the last decades, geochemical methods have been increasingly applied in geothermal resource development (Gupta, 1980). They are relatively much less expensive as compared to geophysical methods and subsurface investigation using drilling method and made them more popular.

It has proved difficult to obtain a genetic classification of subsurface waters (Armannsson and Fridriksson, 2009), since water tends to flow away from its point of origin and undergo water-rock interaction during its movements making it increasingly difficult to decipher its origins. According to White (1986) subsurface waters can be classified as follows based on their origin: meteoric water, which circulates or has recently been circulating in the atmosphere, co-existing with near-surface. Uncemented sediments can circulated in subsurface rocks and dissolve constituents; ocean water, which is partly evaporated products of meteoric water; evolved connate water, which forms in young marine sediments; metamorphic water, which is contained in or driven from rocks undergoing metamorphic dehydration reactions; magmatic water is derived from oceanic and evolved connate waters subducted along with oceanic crust into the mantle, and; juvenile water, which is classified as water that has never circulated in the atmosphere.

The origin of the geothermal fluids has been debated for a long time. However, this problem was convincingly solved by Craig et al. (1956) and Craig (1963) through detailed studies of the isotope ratios H/D and $^{16}O/^{18}O$ of geothermal fluids. The H/D ratio in the meteoric and geothermal waters was found to be same