HOT SPRINGS CHARACTERIZATION IN PENINSULAR MALAYSIA USING INTEGRATED GEOPHYSICAL METHODS

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by

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LIST OF SYMBOLS

D	Distance between two slopes
I	Current
k	Geometric factor
km	Kilometre
m	Meter
mV	Millivoltage
n	Index of magnetic body ($1.2<n<2.0$)
nT	Nano Tesla
p_a	Apparent resistivity
p	Resistance
R	Resistivity
V	Voltage
Z	Depth, m
Ωm	Ohmmeter
<	Less than
>	More than

LIST OF ABBREVIATIONS

AS	Analytic Signal
E-W	East-West
GPS	Global Positioning System
IP	Induced Polarization
JMG	Jabatan Mineral & Geosains
NE	Northeast
NNW	North-Northwest
NW	Northwest
RMS	Root Mean Square
RTP	Reduce-To-Pole
SE	Southeast
SSE	South-Southeast
SW	Southwest
2-D	Two-dimensional

PENCIRIAN MATA AIR PANAS DI SEMENANJUNG MALAYSIA MENGGUNAKAN KAEDAH GEOFIZIK BERSEPADU

ABSTRAK

Di kawasan yang terkenal dengan aktiviti geoterma, kehadiran dan ciri mata air panas berkait rapat dengan ketakselanjaran geologi yang mendasari, terutamanya sesar, patah dan zon ricih. Kajian ini memanfaatkan kehebatan magnet tanah, pengimejan kerintangan 2-D, dan kaedah polarisasi teraruh untuk membezakan struktur geologi terdalam ini, yang mempengaruhi secara signifikan taburan dan sifat mata air panas. Kaedah-kaedah yang digunakan memberikan cerapan bernuansa ke dalam subpermukaan, memetakan interaksi rumit antara sesar dan manifestasi geoterma yang terhasil. Khususnya, pengimejan kerintangan magnet bumi dan 2-D digunakan untuk mengesan trajektori sesar ini di tengah-tengah zon geoterma, meningkatkan kesetiaan perwakilan geologi sedia ada dan menentukan permukaan geoterma yang berpotensi. Analisis terperinci sedemikian adalah penting, terutamanya apabila menilai kedalaman anomali magnet yang melambangkan asas struktur penting ini. Polarisasi teraruh muncul sebagai alat kritikal, secara berkesan membezakan antara lumpur geoterma (tanah liat) dan air bawah tanah, perbezaan yang sering kabur apabila bergantung semata-mata pada pengimejan kerintangan 2-D. Tiga kawasan panas geoterma menjadi tumpuan kajian ini: Tanah Tinggi Lojing di Kelantan, Manong di Perak, dan Ladang Kombok di Negeri Sembilan. Di Tanah Tinggi Lojing, sisa magnet mendedahkan garis sesar yang mengikut arah aliran NE-SW, ditandai dengan kontras antara 10 nT hingga 120 nT. Fabrik geologi Manong juga mempamerkan sesar arah aliran NE-SW, dengan nuansa magnet menjangkau dari 10 nT hingga 120 nT. Sebaliknya, naratif geologi Ladang Kombok telah dibentuk oleh sesar berorientasikan NW-SE, dikapsulkan oleh kontras nilai magnet dari 10 nT hingga 30 nT. Teknik analisis lanjutan, termasuk isyarat analisis gabungan dan penyahkonvolusi Euler, memainkan peranan penting dalam mengenal pasti batu magnet cetek, mengukuhkan sambungan geologi-ke-geoterma. Kedalaman bawah tanah, yang diperoleh daripada pendekatan penyahkonvolusi Euler, berayun antara 3-11 m, 10-30 m, dan 19-26 m masing-masing merentasi Tanah Tinggi Lojing, Manong, dan Ladang Kombok. Akhir sekali, pengimejan kerintangan 2-D dengan jelas menggambarkan permaidani kerosakan geologi, dengan kontras kerintangan yang berbeza menggariskan tetapan geologi yang berbeza-beza merentasi arena geoterma ini.

HOT SPRINGS CHARACTERIZATION IN PENINSULAR MALAYSIA USING INTEGRATED GEOPHYSICAL METHODS

ABSTRACT

In regions renowned for geothermal activity, the presence and characteristics of hot springs are intricately linked to underlying geological discontinuities, primarily faults, fractures, and shear zones. This study harnesses the prowess of ground magnetic, 2-D resistivity imaging, and induced polarization methods to discern these deep-seated geological structures, which significantly influence the distribution and properties of hot springs. The methods applied provided nuanced insights into the subsurface, mapping the intricate interplay between faults and the resultant geothermal manifestations. Specifically, ground magnetic and 2-D resistivity imaging were employed to trace the trajectory of these faults in the heart of geothermal zones, enhancing the fidelity of existing geological representations and pinpointing potential geothermal surfaces. Such detailed analyses are pivotal, especially when evaluating the depth of magnetic anomalies which symbolize these vital structural underpinnings. Induced polarization emerged as a critical tool, effectively differentiating between geothermal mud (clay) and groundwater, a distinction often blurred when solely relying on 2-D resistivity imaging. Three geothermal hotbeds were the focal points of this research: Lojing Highlands in Kelantan, Manong in Perak, and Ladang Kombok in Negeri Sembilan. In the Lojing Highlands, magnetic residuals unveiled a fault line trending NE-SW, marked by contrasts ranging from 10 nT to 120 nT. Manong's geological fabric similarly exhibited a NE-SW trending fault, with magnetic nuances spanning from 10 nT to 120 nT. In contrast, Ladang Kombok's geological narrative was shaped by a NW-SE oriented fault, encapsulated by magnetic value contrasts from 10 nT to 30 nT. Advanced analytical techniques, including the combined analytical signal and Euler deconvolution, were instrumental in identifying shallow magnetic rocks, reinforcing the geological-to-geothermal connections. Basement depths, derived from the Euler deconvolution approach, oscillated between 3-11 m, 10-30 m, and 19-26 m across the Lojing Highlands, Manong, and Ladang Kombok respectively. Finally, 2-D resistivity imaging vividly portrayed the geological fault tapestries, with distinct resistivity contrasts underscoring the varied geological settings across these geothermal arenas.

CHAPTER 1

INTRODUCTION

1.1 Introduction

Hot springs in Peninsular Malaysia predominantly originate from a non-volcanic environment, different from the more tectonically active regions such as Indonesia (Natawidjaja, 2018). Geological studies indicate that Malaysian hot springs arise when groundwater in proximity to granite interacts with the heated substrate, with this heat being internally generated within the Earth (Tan et al., 2016). These springs have diverse utilities, from aquaculture to power generation (Lund et al., 2010). Among these, recreational activities stand out as a primary use. Rich in minerals like sulfur, the springs are believed to offer a plethora of health benefits (Williams et al., 2013). A variety of research domains, encompassing both geological and geophysical approaches, have delved into the genesis mechanisms of these springs. Common geophysical methodologies include ground magnetic, 2-D electrical resistivity, and induced polarization. These techniques skillfully outline subsurface attributes like faults and the depths of geological features (Musa et al., 2014). Differences in magnetic susceptibility, resistivity, and induced polarization values are traceable to tectonic activities that spawn faults and similar features. Consequently, pinpointing faults becomes essential when studying hot springs.

Faults or fractures act as the main channels, facilitating spring water transfer from its origin to the surface (Anderson et al., 2015). The movement of tectonic plates induces stresses at the surface, giving birth to faults. From an economic lens, faults are indicative of potential reserves of groundwater, hydrocarbons, and natural gas (Osborne & Swarbrick, 2010). The resistivity and magnetic methodologies yield contrasting values, earmarking the presence of faults. Conversely, the induced polarization technique distinguishes geothermal waters from muds, preventing the usual confusions arising with resistivity-based assessments (Aizebeokhai et al., 2016). This research, therefore, amalgamates these geophysical surveys to decipher the subsurface dynamics that dictate the flow patterns of hot springs across three prime locations in Peninsular Malaysia.

1.2 Problem Statement

The occurrence of hot spring in Peninsular Malaysia are often said to a distinct pattern that is considered to be structurally controlled by the fault. Based on the geological records and previous studies done by several researcher, the orientation of fault that associated with hot springs in Peninsular Malaysia has two types of trends, which are North-South trend, and East-West trends. Further studies regarding these findings should be conducted to acquire more information regarding these statements. This will give better understanding of the characteristic and orientation of the fault.

Ground magnetic, 2-D resistivity imaging and induced polarization methods are capable in identifying the occurrence of fault or any underlying subsurface bodies. Besides that, the integration of all geophysical surveys is important instead of employing only one method. Those geophysical surveys especially induced polarization methods are crucial when dealing with hot spring environment.

Most of the times, researchers are not making a comparison between the geothermal muds and fresh water as both have the same resistivity indication but, induced polarization method can help to deduce the different between those two elements (Metin et al., 2016; Monahan, 2013). Integration between 2-D resistivity imaging and induced polarization can help to enhance the interpretation.

Last but not least, the current geological map is not up to date in which the tectonic activity movement might change the trend of fault itself. Therefore, a correlation between the geophysical findings with the geological map will helps to produce an updated geology map of the selected study area. Thus, it is essential to employ all these geophysical methods in this research study to solve all the problem statements.

1.3 Research Objectives

The research was conducted at three different areas with the objectives as listed below:

i. To delineate the subsurface features that associated with the occurrence of hot spring in the study area using ground magnetic, 2-D electrical resistivity and induced polarization methods.

ii. To integrate the outcomes from different geophysical findings which are ground magnetic, 2-D electrical resistivity and induced polarization to get better interpretation.

iii. To map the new geological discontinuity observed based on the geophysical findings of ground magnetic, 2-D electrical resistivity, and induced polarization.

1.4 Scopes of study

The ground magnetic, 2-D electrical resistivity and induced polarization were conducted on three different study areas named as Lojing Highlands (Kelantan), Manong (Perak) and Mantin (Negeri Sembilan). This research was conducted with intention to enhance and improvise the current geological findings in recognizing the subsurface features which is fault or fractures that correspond to the occurrence of hot spring in the study area. The survey was performed across the geological fault which was mapped based on the JMG data base map and the data acquisition process was performed in two ways which are regional and detailed geophysical surveys. The regional geophysical survey was conducted using ground magnetic survey for preliminary stage of study in which will help in the delineation of fault/fracture zone in the study area. Based on the result of regional geophysical study, the detailed geophysical study will be performed using the 2-D electrical resistivity and induced polarization (IP) methods in which will help further with precise subsurface information. The next step involving the integration of all of these geophysical surveys which are ground magnetic, 2-D electrical resistivity and induced polarization methods. The integration process will strengthen the geophysical findings.

A correlation between an outcome from the integration of geophysical surveys with the geological map was conducted to validate the occurrence of the subsurface features that present at the study area. Some study area with borehole record will further help in soil lithology mapping which can be used for data interpretation process.

1.5 Significance and novelty of the study

This study involved three types of geophysical methods which are ground magnetic, 2-D electrical resistivity, and induced polarization to delineate the characteristic of subsurface features associated with the presence of hot springs. The novelty and significance of this study are listed below:

i. Integration between geophysical surveys will further validate and mapped the structural remains which are the faults/fractures that are present on the study area rather than conducting a single geophysical survey only.

ii. From this research, an up-to-date geological map of the study area can be produced based on the correlation between the geophysical findings and geological information for further reference since the current geological map is out-to date.

iii. The magnetic and 2-D resistivity response of potential hot spring area were further interpreted by using qualitative analysis to obtain estimated targeted depth.

1.6 Thesis outline

Includes of five chapters. The first chapter basically is an introduction part which gives an overview images and brief ideas of the research workflow which comprise of the problem statements, research objectives, scopes of the study, novelty and significance of the study.

Next chapter, which is chapter 2 will discuss briefly on the theory, fundamental and also the applications of the geophysical survey involved in this study which are ground magnetic, 2-D electrical resistivity and induced polarization of the previous studies done by several researcher. This chapter usually give some idea on what technique shall be used prior to data acquisition phase.

Chapter 3 discusses the methods that will be used based on the input gained from chapter 2. The methodology in this study which are ground magnetic, 2-D electrical resistivity and induced polarization method will be further discusses in this chapter which covers from data acquisition, data processing and interpretation process. In addition, the geological map of the selected study area will also include in this chapter.

Chapter 4 is the most special part in this research as it discusses more details interpretation to answer all the objectives of this study. This chapter will present the results of the ground magnetic, 2-D electrical and induced polarization. The results were focussing on the main objectives of the study which are to identify the difference between the geothermal water and mud, to delineate the subsurface features that associated with the presence of the hot spring and last but least is to integrate all the methods applied. The correlation between the geophysical findings with the geological map will be precisely discusses in this chapter.

Finally, the last chapter is chapter 5 which will be the conclusion of the research study. In this chapter, all the recommendations and suggestions will be included for future improvement of geophysical study.

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

Geophysical studies can be defined in many ways depending on the research that is conducted. It is known as non-invasive technique (direct access to the subsurface or does not require any excavation) used to investigate subsurface conditions in the Earth which can extend to depth of 10's of meter and more through analyzing, measuring and interpreting physical fields at the surface. A wide range of geophysical surveying methods exists for exploration for geothermal energy as well as the monitoring of geothermal reservoirs under exploitation (Ndombi, 1981; Mariita, 1995; Simiyu and Keller, 1997). According to Reynolds (1997) and Sheriff (1982), geophysics is used to study and examine the Earth's internal parts from surface to the inner core by applying physical principles. It encompasses the investigations of the Earth's interior parts in which require taking measurements at or near the Earth's surface that are influenced by the internal distribution of the physical properties (Kearey & Brooks, 1994). The physical properties of the Earth's interior can be discovered by scrutinize these measurements. Geophysical methods are divided into two classes which are passive and active methods. The insertion of the artificial signal into the Earth and the measurements of the Earth's response to the signal itself is involved in active geophysical methods. Passive geophysical methods, on the other hand, involve the measurements of properties of the Earth or naturally occurring fields such as gravity, magnetic and radiometric decay products.

Hence, the subsurface geology can be interpreted by measuring the spatial variations in these naturally occurring fields. Geothermal exploration mostly used geophysical methods since many of the objectives only can be achieved thru conducting these methods, as it is more effective, cost and time saving. It is now ostensible that certain specific physical characteristics of geothermal reservoir and their immediate environments are vulnerable towards detection and mapping by using geophysical methods.

2.2 Theory of magnetic

Ground magnetic method is one of the geophysical methods used to address variations in the Earth's magnetic field, assisting in pinpointing the exact location of geological structures (Joshua et al., 2017). Recognized as a non-destructive method, its applications span various sectors, including environmental and engineering studies. The ground magnetic method can detect voids, near-surface faults, igneous dikes, and buried ferromagnetic materials. Domra et al. (2015) identified two types of rock magnetization: induced magnetization (which aligns with the direction of the ambient earth’s field) and permanent magnetization (common in igneous rocks, contingent on their properties and history). The magnitude of both induced and remnant magnetization is governed by the quantity, composition, and size of magnetic-mineral grains (Domra et al., 2015). Magnetic measurements hold significance in regional exploration as they illuminate the tectonic setting of the study area (Nabighian et al., 2005).

For an example, continental terrane boundaries are commonly recognized by the contrast in magnetic fabric across the line of contact (Finn, 2002). An advantage of applying magnetic methods is that the field varies inversely one power faster with distance to the source. As a result, the magnetic method is more sensitive to source depth which is commonly an important objective in interpretation of the observation (Hinze et al., 2013).

2.3 Theory of 2-D Resistivity Imaging

2-D resistivity imaging method has been widely used since the early 20th century by Frank Wenner and the Schlumberger brothers (Loke & Barker, 2004). Resistivity method is an active geophysical method that utilizes the Voltage that arises because the electric current is injected into the soil. These Voltages provide information about the shape and electrical properties of non- homogeneous stratum (Siregar et al., 2016). The instruments used for this method later improved and increased computational power have become available making this method widely used in the last decades. Modern geoelectrical instruments are used for mineral and oil prospecting, geothermal exploration, pollution mapping at contaminated sites, in construction projects, archaeological prospecting and for various hydrogeological purposes (Loke, 2004; Butler, 2005). Direct current resistivity methods (Onacha, 1993) have been used for reconnaissance mapping, location of faults for drilling targets and to define the boundaries of geothermal reservoirs. The value of geophysics is therefore its ability to acquire information about the subsurface over a substantial area in a reasonable time frame and in a cost-effective manner (Kumar & Bhoi, 2012).

The electrical resistivity value obtained can differentiate the layering of rock, soil and water as the value is distinct from each other. Earth materials factors such as the degree of weathering, type of soil, porosity, grain size, chemical differences, permeability of rocks and volume of rock fracture filled with water (Embi, 2000) greatly influences the differences in electrical resistivity value within the subsurface. Many geological parameters are included in the ground resistivity such as mineral and fluid content, porosity and degree of water saturation within the rock (Loke, 1999). Normally, resistivity is measured by applying current into the ground through two current electrodes known as C1 and C2. In this study pole-dipole array was chosen as it able to provide greater depth of subsurface profiles within limited spaced area during the resistivity data acquisition (Abidin et al., 2017).

The resulting voltage difference is measured at two potential electrodes known as P1 and P2. Apparent resistivity (p_a) value can be calculated from the current (I) and the voltage (V) values, whereas k depends on the arrangement of the four electrodes, as shown in the equation 2.1.

$$p_a = \frac{kV}{I} \tag{2.1}$$

Where,

p_a : Apparent resistivity

k : Geometric factor

V : Voltage

I : Current

Usually, resistivity meters give a resistance value (2.2),

$$R = \frac{V}{I} \tag{2.2}$$

Where,

R : Resistance

V : Voltage

I : Current

Hence, the apparent resistivity value is calculated as shown in equation 2.3

$$p_a = kR \tag{2.3}$$

Where,

p_a : Apparent resistivity

k : Geometric factor

R : Resistance

Resistivity survey is chosen for this project as it is the most efficient technique as it provides a better information on evaluating large areas of the subsurface rapidly.

2.4 Induced Polarization

Induced polarization (IP) is known as capacity of the Earth to grasp charge of electric over time and is one of a famous geophysical imaging technique that used to detect the electrical chargeability for certain subsurface materials, for an example ore. Conrad Schlumberger was the one patented the induced polarization (IP) method in 1912 and this method is basically an adjunct of electrical resistivity method (Schlumberger, 1920). Induced polarization (IP) offers a broad information of formations that is unavailable and underground features by just conducting resistivity or seismic survey. (IP) Induced polarization (IP) employs the similar methods as resistivity in which involve injecting current into the ground by using two metal electrodes, but induced polarization (IP) surveys give an additional parameter known as chargeability in time-domain (Zonge et al., 2005). Induced polarization (IP) requires stronger currents compared to resistivity surveying due to its higher sensitivity towards noise but the use of it has seen increase because of the improved instruments and its potential to detect certain contaminants and minerals that resistivity measurement cannot performed (Loke, 2004). This method has been mainly used for mineral exploration since the first half of the 20th century and recently it has been implemented for extensive range of uses such as mapping groundwater contamination plumes, landslides & structurally sensitive clays and the recognition of buried landfills, (Butler, 2005; Dahlin et al., 2010). There are wide range of materials that capable to generate effect of induced polarization (IP) in disparate situations. According to Zonge et al. (2005), some of the large, induced polarization (IP) responses was measured in metallic lustre minerals as shown in Table 2.1.

The uses of induced polarization (IP) become more extensive especially in minerals industry due to the magnitude of these responses. The effect of induced polarization (IP) is a surface of property when the character of mineralization of sulphide turn into massive, the magnitude of the response become decrease. Corresponding large responses can also be generated from layered silicates, clays and other alteration products (Zonge et al., 2005). Loke (2004) find out that clays are normally in the range of 10-50 mV/V as shown in Figure 2.1.

Table 2.1 Summary of induced polarization (IP) response (Zonge et al., 2005)

Physical properties	**Effect on IP measurements**
Increasing metallic or metallic lustre sulphide content (disseminated)	Increasing chargeability
Increasing clay content (less than ~10%)	Increasing chargeability
Decreasing fluid resistivity	Reduces clay response

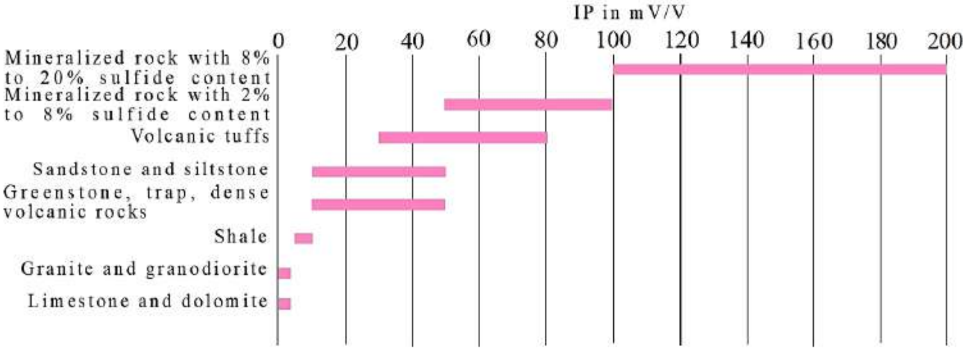

Figure 2.1 Ranges of chargeability in common polarizable geological materials. IP effects show high values due to *the* presence of conductive minerals (modified from Loke, 2004).

2.5 Overview of major geological fault in Peninsular Malaysia

The locality of Peninsular Malaysia is generally sited on Sundaland in the southern part of the Eurasian Plate. Sundaland itself is a large region that included Peninsular Malaysia and Maritime Southern Asia Islands of Sumatra, Borneo, Java and all the surrounding small islands. Generally, Sundaland was recognized as tectonically stable region based on the low seismicity profile since Cenozoic time. The occurrence of major fault in peninsular Malaysia are categorized as inactive fault. Nevertheless, a series of large earthquake events over the years had reformed the scenario of tectonic in the region of Southeast Asian region in which involving Peninsular Malaysia (Shuib et al., 2017). Peninsular Malaysia has experienced earthquakes originated from local such as Kuala Pilah earthquake, Manjung earthquake and Terengganu earthquake.

Reactivation of major faults in Peninsular Malaysia is indicated by the active series of earthquake activity. Rahimi et al. (2015) identified active faults such as Lepar Fault and Seremban Fault based on the active seismic activity which further confirmed the reactivation of major faults in Peninsular Malaysia.

The major fault in Peninsular Malaysia can be divided into three types which are terrain-bounding fault, terrain parallel fault and terrain-crossing fault (Yin, 1988). Three types of prominent faults system were identified by Mineral and Geoscience Department of Malaysia (JMG) which area northwest to southeast, north to south and east west direction of fault system. A total of seven major fault in Peninsular Malaysia were recognized which are Bok Bak Fault, Bukit Tinggi Fault, Kuala Lumpur Fault, Lebir Fault, Lepar Fault, Mersing Fault and Terengganu Fault (JMG, 2014). Burton (1965) identified Bok Bak Fault in which striking to the northwest in Baling, Kedah as a major strike slip fault.

Major faults of Peninsular Malaysia are said to have an orientation of NNW-SSE, NW-SE, E-W, and NE-SW in which have undergone repeated complex movement involving movement of sinistral and dextral across the strike slip-fault (Shuib, 2009). The earliest fault trending that has been identified was N-S fault trends based on the dating process. The N-S fault was associated with the process of amalgamation of Sibumasu and Sukhotai Arc which takes place in the or Permian-Triassic. The major fault trend NNW-SSE which is also known as dextral faults was recognized to occur during the age of Late Triassic-Jurassic then give rise to the development of continental pull-apart basins during Jurassic-Cretaceous time.

Shuib (2009) also stated that the reactivation process of major faults takes place during Cenozoic time. Some researchers suggested that faulting events in Peninsular Malaysia during the Cenozoic time were associated with the “Extrusion Model” due to the plate tectonic collision between India and Eurasia. The collision event has resulted in extrude of major fault towards the eastwards direction (Tapponnier et al., 1986; Leloup et al., 2001; Replumaz and Tapponnier, 2003). Figure 2.2 shows the regional tectonic setting of Peninsular Malaysia.

Determination of geological faults can be done by various geophysical methods. The most preferred and cost-effective method in the determination of faults can be ground magnetic and 2-D resistivity imaging methods. The ground magnetic method is known as a non-destructive geophysical method that measures the Earth’s magnetic intensity. These methods measure magnetic material properties caused by the induced remanent magnetization. This method is used to obtain an overview imagine of subsurface geological features such as faults, fractures, and rock contacts (Adagunodo and Sunmonu, 2012).

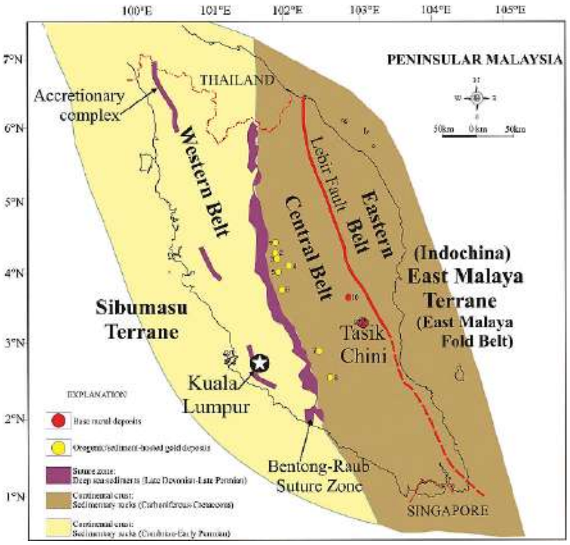

Figure 2.2 Tectonic belt of Peninsular Malaysia (Basori et al., 2016)

2-D resistivity imaging is used widely for detailed geophysical study as it offers a precise view of the geological subsurface. In this method, electrical output will be used to measure the electrical resistance of certain Earth's materials. Suski et al., (2011) stated that the 2-D resistivity imaging is capable in delineating the location of shallow faults thus, will be the most proper method to deploy in regard to fault determination.

2.6 Distribution of hot springs in Peninsular Malaysia

Hot springs are generated from the geothermal heat that originated from the Earth's interior. Hot springs in volcanic areas usually getting heated by the rocks that has closed contact with magma. For a non-volcanic environment, the water that percolates deeply into the Earth's crust will have enough heat supply to flow to the surface and become hot springs as the temperature of the rock increase with depth. However, not all hot springs are necessarily associated with volcanism; some tend to occur in flat zones or close to sedimentary contacts (Baioumy et al., 2014; 2015).

The occurrence of hot spring in Peninsular Malaysia are genetically associated with the tectonic activities. Most of the heat sources of hot spring are sited at the western flank of the Main Range Granite (Figure 2.3) and distributed along the fault zones. More than a number of 60 hot springs has been identified and few of it were sited within sedimentary rocks in which have close relation to granitic bedrock or granite sedimentary rock (Sum, Irawan & Fathaddin, 2010). The hot spring in Peninsular Malaysia are often related to geothermal gradient in which the temperature of rock increasing with the increasing of depth.

The geothermal system usually consists of the heat sources, geothermal cap and fluid that carries and transfer heat from the surrounding rocks (Zira, 2013).

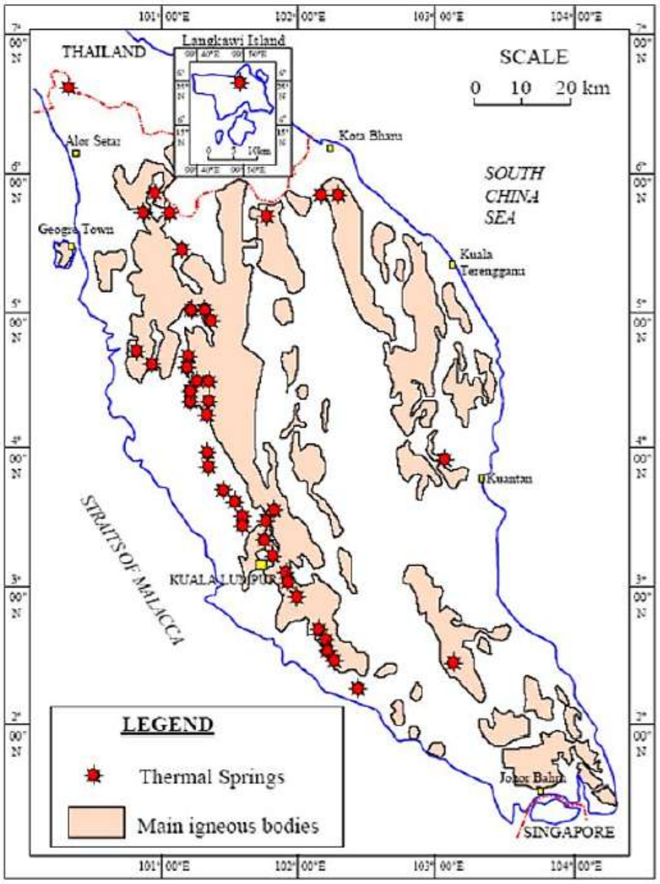

Figure 2.3 Hot spring locations in Malay Peninsular (Source: Renewable Energy in ASEAN, 2005)

Integration of geophysical methods used in geothermal studies will imply a good correlation result between geophysical findings. Several studies (Óladóttir and Friðriksson, 2015; Maucourant et al., 2014; Byrdina et al., 2009; Finizola et al., 2003) have been conducted using a range of geophysical methods in the geothermal study. In geothermal studies, the employment of geophysical methods is important for delineating subsurface features that are related to geothermal systems. Neawsuparp et al., (2010) identified that resistivity increases with increasing depth. The electrical resistivity of rocks reflects the geothermal properties will be measured using 2-D resistivity imaging methods. Resistivity are very sensitive to high temperature and rock alteration process (Hersir and Flovenz, 2013).

The ground magnetic method is capable in estimating the location and depth of magnetic sources or even tracing buried dykes, pipes or underneath geological features. It also capable of discovering area of reduced magnetization caused by thermal activity (Georgsson, 2009). In a geothermal environment, heated rock usually will be caused changes or loss in magnetization and will reacquire when the rock cools down (Kayyode et al., 2017). The magnetic method is very sensitive to heat and magnetic measurement is used to measure the variation of magnetic intensity that has been affected by geothermal activity. Basically, the variation of magnetic occurs was influenced by the process of magnetic induction which resulted in magnetic anomalies consisting of positive and negative (Syukri et al., 2014).

2.7 Previous study

The previous study for this research was divided into two sections focussing on fault delineation and potential geothermal identification studies.

2.7.1 Fault delineation using a geophysical method

Many research studies have employed the geophysical method to delineate geological faults. Khalil et al. (2015) performed a study using the magnetic method, and the study area sited at El-Bahariya Oasis which is located at a distance of approximately 370 km southwest of Cairo, in the heart of the Western Desert. The main objective of this research is to classify the shallow and deep subsurface structures of the region under investigation.

In a mesh-like field with a 500 m spacing interval, a total of 53 magnetic stations have been tested. The required corrections have been made regarding daily variation, regional gradient, and time variations. Then the total magnetic intensity map (TMI) was generated and reduced to the magnetic map of the pole (RTP). Based on the result obtained, The RTP land magnetic map (Figure 2.4) showed that two lines of small folds are formed along the main anticline's east and west sides. Two mechanisms for fault (NE–SW) trending fault mechanism and another (NW–SE) trending fault mechanism is also identified in Bahariya Oasis.

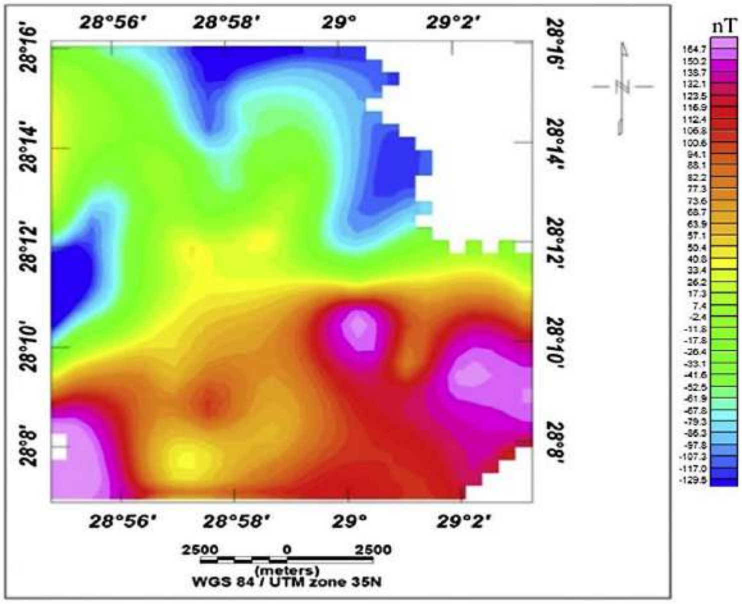

Figure 2.4 Reduced to pole (RTP) of total magnetic anomaly map of the study area (Khalil et al., 2015).

Metin et al., (2016) conducted an integrated geophysical study using ground magnetic and 2-D resistivity imaging method to determine the location of deep fault in North Anatolian Fault system. The Wenner arrays with different electrode spacing was employed to different locations in order to attain a shallower depth of continental crust.

The ground magnetic was used to investigate the location of the deep-seated fault in the continental crust by using 20 m interval spacing for each magnetic station. Based on the research studies, result from the 2-D resistivity imaging suggested that at distance of 15-78 m the indication of fault obtained based on the geophysical parameters and having orientation towards north direction. The result from ground magnetic survey indicated the presence of deeper fault plane of the crust having a dipping at 70 – 90 strike-slip faulting. The integration between these two geophysical methods suggested the fault occurred at distance of 15 -78 m and dipping towards a compression area due to the presence of trans-tensional stresses in deeper part of continental crust area.

The study of Sumatran fault was conducted using 2-D resistivity imaging by Syukri et al., (2014). A pole-dipole array was used with electrode spacing of 10 m during the survey and the processing of data involved the deployment of Res2Dinv software to generate 2-D inversion model. The outcome from this survey suggested that the depth of bedrock obtained was 30 -120 m depth and the occurrence of fault at depth of 150 m at distance of 57 – 620 m based on the highly contrast in resistivity value as shown in Figure 2.5.

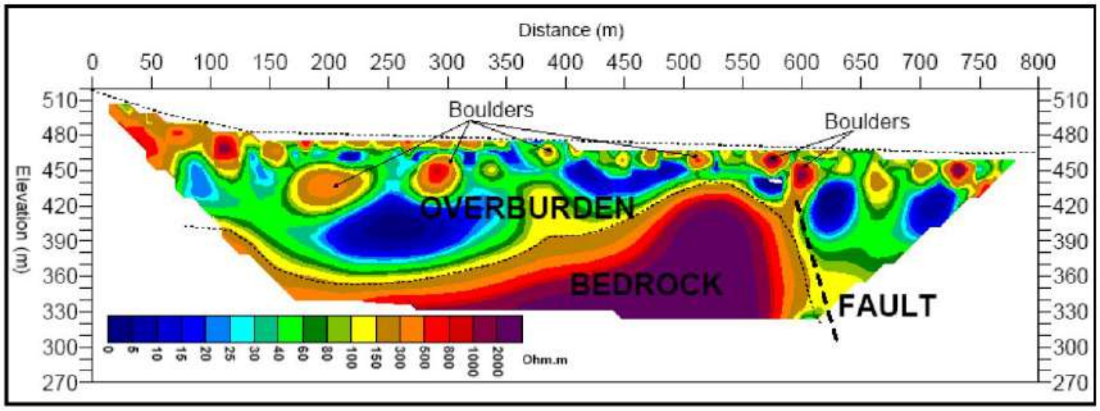

Figure 2.5 2-D inversion model of resistivity imaging (Syukri et al., 2014).

Monahan (2013) conducted a resistivity survey in at Lost Osos Fault zone to study the occurrence of shallow fault. The study was performed using a SYSCAL KID Switch 24 resistivity meter and the data obtained was further processed using Prosys II and Res2Dinv to produce 2-D inversion resistivity model. A 60 m long of survey line was conducted along the Lost Osos Fault zone with 12 with 12 electrode that were spaced regularly. Based on the result obtained from the resistivity survey, it can be confirmed that at distance of 22 m the resistivity value shows a highly contrast value of 7Ωm – 10Ωm at the southwest part to 20 Ωm to the northeast part which indicate the fault emplacement due to the presence of alluvium deposit and melange hanging wall as shown in Figure 2.6.

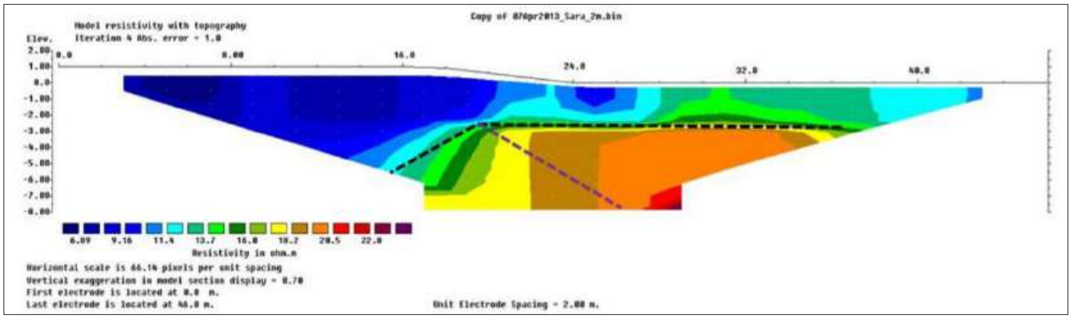

Figure 2.6 2-D inversion result of in Lost Osos Fault zone (Monahan, 2013).

Weicht et al. (2013) conducted ground magnetic and 2-D resistivity imaging survey to delineate the Light Street Fault. The ground magnetic method was performed using proton precision magnetometer devices with a total of 168 magnetic stations. For the 2-D resistivity imaging, the SYSCAL KID resistivity meter was used with spacing of electrode 3.5 m using Wenner configuration. The resulted obtained from the ground magnetic suggested that, the magnetic intensity reading was not consistent across the fault which was high magnetic and steep gradient at the same time.

The 2-D resistivity result suggested that the abrupt increase in resistivity value is due to the high fracturing and presence of vern-filling calcite based on the correlation with borehole data.

Kamarudin et al. (2015) employed ground magnetic and 2-D resistivity imaging method to study the Seulimeum fault in Northern Sumatra. A total of three survey lines of 2-D resistivity imaging and random magnetic station were conducted at Krueng district. The result obtained from both ground magnetic and 2-D resistivity were then used for correlation purposes to study the fault and depth of magnetic source in the study area. The result implies that there was a presence of fault zone based on the highly contrast value in both ground magnetic and 2-D resistivity as shown in Figure 2.7. Thus, the study managed to successfully correlate the geophysical methods with Seulimeum fault.

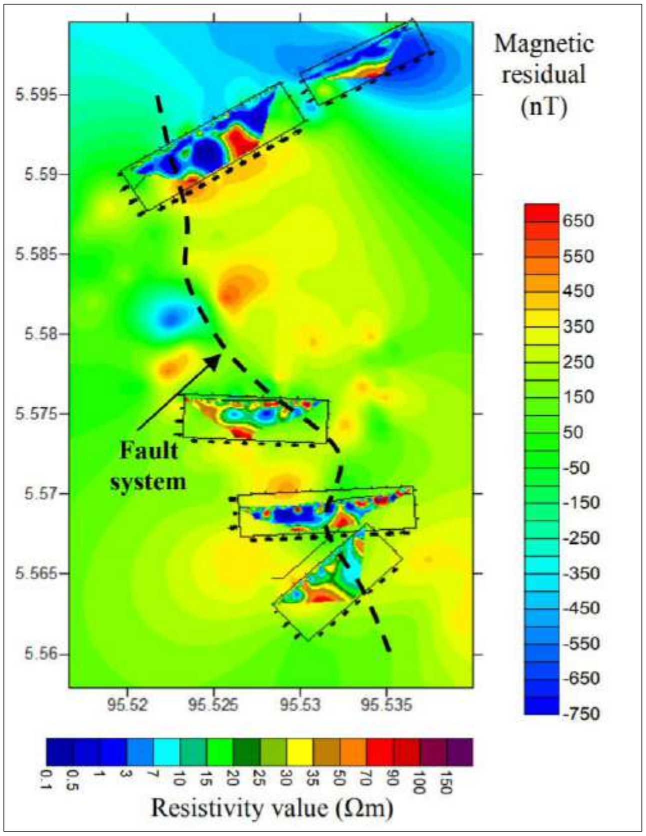

Figure 2.7 Correlation result between 2-D resistivity and ground magnetic (Kamarudin et al., 2015)

Akinlalu et al. (2016) conducted 2-D resistivity imaging and ground magnetic survey to delineate the basement structure of Precambrian Basement Complex of Iwaraja area including geological fault and boundaries of different geologic units. A total of sixteen traverse was mapped having an orientation of N-E to NE-SW directions. Ground magnetic was performed on the sixteen traverses and 2-D resistivity method was performed on three traverse having orientation of N-E directions. Dipole-dipole arrays was employed in 2-D resistivity method. Based on the geophysical findings, ground magnetic survey managed to revealed delineated fractures (Figure 2.8) and 2-D resistivity outcomes compliment the ground magnetic result by locating the major fault

(Figure 2.9). The fault determined in both ground magnetic and 2-D resistivity reveal the faults is trending almost to NE-SW direction.

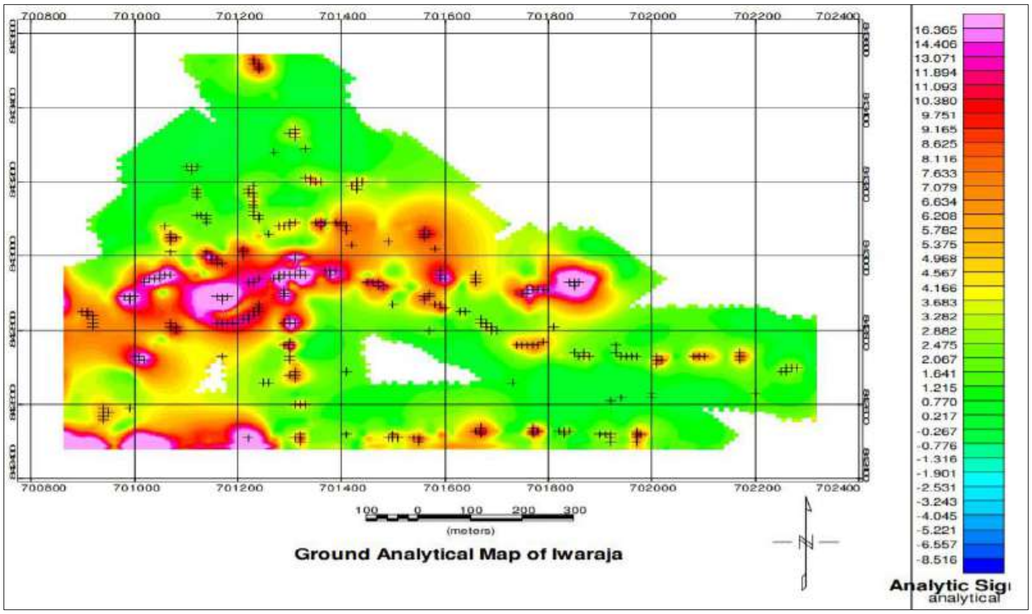

Figure 2.8 Analytical signal of Iwaraja (Akinlalu et al., 2016).

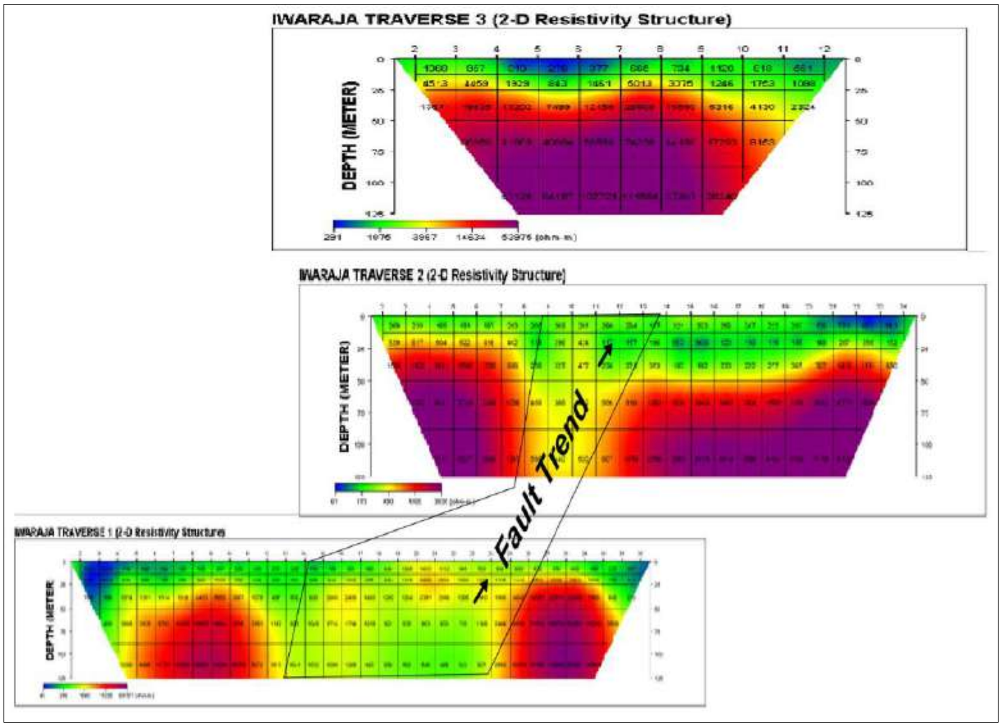

Figure 2.9 2-D stacking of resistivity imaging (Akinlalu et al., 2016).