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A pilot magnetotelluric survey for geothermal exploration in Mae Chan region, northern Thailand

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ABSTRACT

There are many potential sites for geothermal power plants in Thailand. After many years of geological and geophysical surveys, a pilot magnetotelluric (MT) survey was made to assess the reservoir of the Mae Chan geothermal area, northern Thailand, which is one of the key areas for geothermal development. Seven MT sites were deployed in a 3 km × 4 km area around the Mae Chan district covering the Mae Chan hot springs. The MT data were acquired at low and high frequency ranges and were inverted using a 3-D MT inversion to yield the 3-D resistivity structure of the area. The results show that there are two conductive zones near the surface associated with the hot fluid of the Mae Chan hydrothermal system. The hot fluid reservoir mostly resides at less than 500 m below the surface in weathered and fractured granite and in the overlying sedimentary deposits. Its source rock is imaged as a resistive zone corresponding to the hot granite batholith below it. The hot fluid rises up along the Mae Chan fault. The fault is clearly observed as a resistivity contrast extending from the surface to depth. It dips at a moderate angle. From the measured temperature of the fluid from a drill hole and the estimated temperature of the granite rock from the resistivity structure we conclude that the Mae Chan geothermal area is likely to be suitable for immediate development of a small-scale geothermal power plant.

1. Introduction

To reduce Thailand's growing dependence on fossil fuels, finding alternative sources of energy is vital for the Thai economy. Geothermal energy has become a choice for many countries around the world during the past few decades because of its low cost and low emissions. Northern Thailand is one of the areas where the potential for geothermal power plants is very high (Barr et al., 1979; Chuaviroj, 1988; Owens, 2012; Singharajwarapan et al., 2012). Many of the hot springs in northern Thailand (Fig. 1a) have a temperature exceeding 80 °C (Chuaviroj, 1988; Singharajwarapan et al., 2012; Subtavewung et al., 2005). These hot springs are commonly associated with strike-slip fault zones (Fig. 1a) such as the Mae Chan Fault (MCF), the Mae Hong Son Fault (MHF), and the Pha Yoa Fault. These faults formed as the Indian plate subducted beneath the Eurasian plate. Currently, only one geothermal power plant is operating in Thailand. It is a 0.3 MW Ormat binary power plant installed in 1989 in the Fang district of Chiang Mai province in northern Thailand (Fig. 1). The plant utilizes 130 °C water encountered in fractured granite at depths of 250–400 m (Ramingwong et al., 2000).

Another prominent area classified by the Thailand Department of Alternative Energy Development and Efficiency (DEDE) is the Mae Chan geothermal field (Raksaskulwong, 2008; Ramingwong et al., 2000), located about 30 km to the north of Chiang Rai province (Fig. 1b). The Mae Chan area along with the survey sites is shown in Fig. 2. The hot springs at Mae Chan are associated with the almost east-west left-lateral strike-slip Mae Chan Fault (Figs. 1b and 2), which extends from the northernmost part of Thailand near the Thailand–Myanmar border through the Mae Chan region to the Mekong River into Laos, a distance of 140 km. The thermal waters at Mae Chan seep into the base of the Mae Chan creek, which is only exposed during the dry season (shown as Y1 and Y4 in Fig. 2). They also form hot pools at Y3a and Y3b (Fig. 2) in which the measured temperatures can reach 99.5 °C (Singharajwarapan et al., 2012). In addition, hot springs have been reported near MCH3 (Fig. 2).

The Mae Chan region is located at the boundary between a valley filled with Quaternary alluvium to the east and a Triassic granitic batholith to the west (Fig. 1b). Permian–Triassic rhyolite and ash-flow tuff can be found in the northeastern part of the Mae Chan area, and low-grade metamorphic rocks consisting of phyllite, quartzite, and schist formed during Devonian–Carboniferous time occur in the northwestern part of the area (Fig. 1b). It has been suggested

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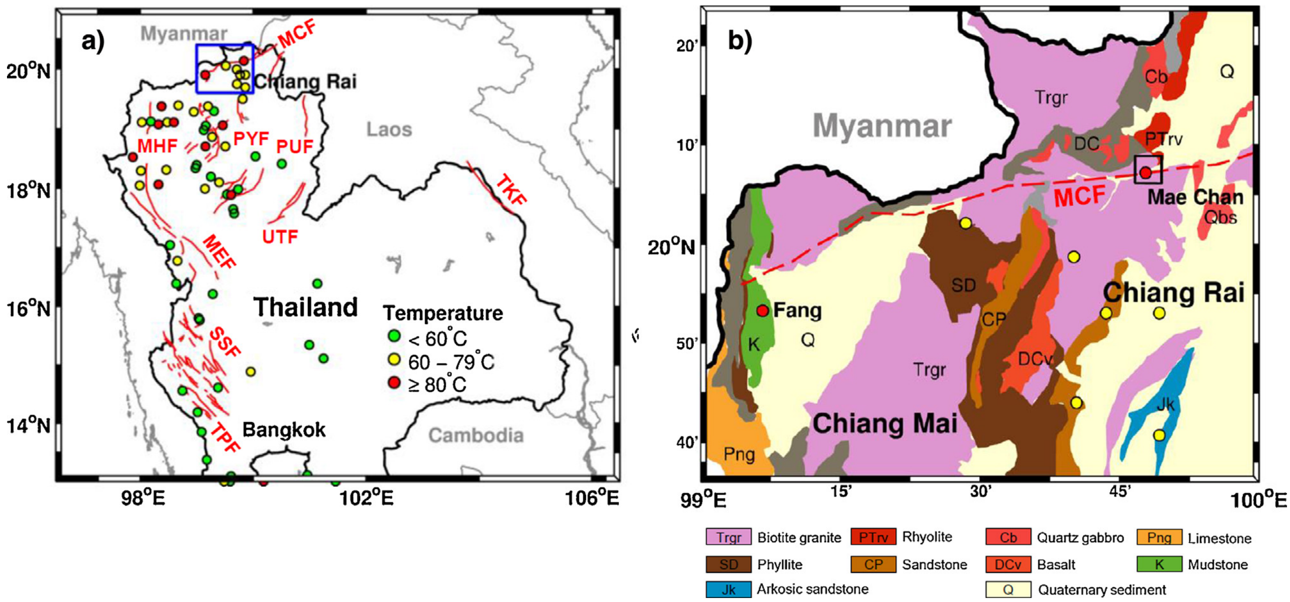

Fig. 1. (a) Locations of hot springs in northern Thailand in which red circles indicate the hot springs whose temperature exceeds 80 °C, yellow circles for temperature between 60 °C and 79 °C, and green for lower than 60 °C (Subtavewung et al., 2005). MCF, MHF, PYF, PUF, UTF, MEF, SSF, TPF, and TKF are for Mae Chan Fault, Mae Hong Son Fault, Pha Yoa Fault, Pua Fault, Uttaradit Fault, Moei Fault, Sri Sawat Fault, Three Pagoda Fault and Tha Khaek, respectively (after Kosuwan et al., 2006). (b) The detailed regional geological map of the blue rectangular block shown in (a). MCF is drawn according to Kosuwan and Lumjuan (1998). The "black" rectangular block indicates the area of the Mae Chan survey of this paper and is shown in detail in Fig. 2. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

that the thermal water forms a shallow reservoir within the weathered, fractured granite and in the sedimentary basin and seeps to the surface through the Mae Chan Fault (Fig. 2). To further investigate the reservoir, vertical electrical sounding (VES) (DEDE, 2005; Thienprasert and Raksaskulwong, 1997; Thienprasert, 1980) and seismic refraction surveys (Thienprasert, 1980) including drilled holes (DEDE, 2005; Geotermica Italiana SRI, 1984; Owens, 2012; Thienprasert and Raksaskulwong, 1997) were conducted in the Mae Chan valley just near the hot springs (Y2 of Fig. 2). These studies indicated that the subsurface geology near Y2 consisted of a 10–20 m thick clay and sand layer above a 100 m thick weathered and fractured granite layer. At greater depths granite bedrock was encountered.

Even though spring temperatures can reach 99.5 °C (Singharajwarapan et al., 2012), the maximum temperature reached at a depth of 100 m was 122 °C (Owens, 2012). In 2004, the area (Y2 of Fig. 2) was again drilled to a depth of 56 m to extract the hot fluid. Its temperature at that depth is around 94 °C (DEDE, 2005). The hot water is currently used for spas and drying agricultural products. In the initial assessments of the Mae Chan region, Owens (2012) concluded that the shallow fluids are not hot enough to generate electricity and drilling to depths of 1 km in the granite was not cost-effective. To assess the size of the reservoir without costly drilling, a magnetotelluric (MT) survey was conducted. The MT surveys are widely used in the past decades in geothermal exploration to reveal hydrothermal systems beneath the surface and to help define the drilling locations for the production wells (Heise et al., 2008; Newman et al., 2008). This is because of its major advantage as it is the only method that can directly sense a geothermal reservoir from its electrical resistivity from the surface down to depths of several kilometers (Árnason et al., 2010; Sinharay et al., 2010; Yu and Strack, 2010; Heise et al., 2008; Garg et al., 2007; Santos et al., 2007; Harinarayana et al., 2006; Uchida et al., 2005; Volpi et al., 2003; Lugão et al., 2002; Cumming et al., 2000; Bibby et al., 1995; Sandberg and Hohmann, 1982).

In this paper, we report on the analysis of a pilot MT survey in the Mae Chan area. The objectives of the experiment are to determine the source of the hot fluid and its location, and the size and depth of the reservoir. This information will be used to help determine the potential of the Mae Chan region for geothermal power production. We first describe the acquisition of the magnetotelluric data. Data processing, inversion and interpretation are then discussed.

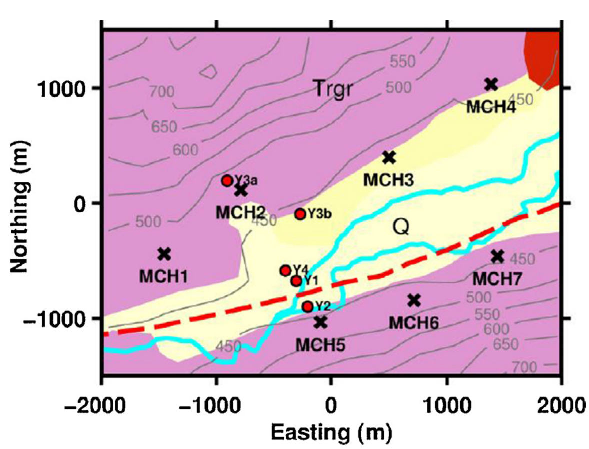

Fig. 2. Locations of seven MT sites (crosses sign) covering an area of 3 km × 4 km in Mae Chan district, Chiang Rai province, Thailand. Geological rock units and topography are plotted as the background on this map. Y1 and Y4 are the hot spring locations found at the river bed. Y2 is the drilled hole (DEDE, 2005), and Y3a and Y3b are the hot springs found at the surface. Additional hot springs are also found around the north of MCH3 but are not shown.

2. Magnetotelluric survey: data acquisition, data processing and 3-D inversion

In July 2013, high frequency and broadband MT data were acquired at seven sites in a 3 km × 4 km area in the Mae Chan region which included many of the hot springs (Fig. 2). All sites used a KMS-820 data acquisition unit and coils and electrodes from KMS Technologies – KJT Enterprises Inc., Houston, TX, USA. Only the