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Metamorphic geothermal reservoir characterisation—A case study in the Jinlun geothermal area, Taitung, Taiwan

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ABSTRACT

There are more than one hundred hot spring outcrops around the island of Taiwan, which implies that Taiwan is rich in geothermal resources; however, no commercial geothermal power plants have been established since 1993, the year of the abandonment of a 3 MW geothermal plant in Chingshui. Situated at the oblique collision zone between Eurasia and Philippine Sea plates, most of Taiwan's hot springs are located in metamorphic terrain rather than volcanic areas. Previous study showed that geothermal resource is also rich in Jinlun area, whereas structural complexity and low permeability pose difficulties to geothermal exploitation. This paper aims to describe a geothermal conceptual model to facilitate the exploitation of the Jinlun geothermal field by integrating results from gravity, temperature surveys, surface geology, and information from recently conducted magnetotellurics survey and a new borehole. Results from the MT survey indicate a deep resistive structure down to 5 km depth. A zone of low resistivity (< 5 ohm-m), which coincides with elevated temperatures observed in the borehole, could be attributed to thrust faulting. Based on ^{14}C dating data, sources of geothermal brine could be connate water or meteoric water that travelled for a long distance. The main reservoir could be located at the fractured regions instead of porous strata.

1. Introduction

Taiwan is located at the oblique collision area between the Philippine Sea plate and the Eurasian plate (Chai, 1972; Biq, 1973; Bowin et al., 1978). The majority of geothermal power plants in most countries such as Japan, the Philippines, New Zealand, Indonesia, and the USA are located in volcanic areas (Hartline et al., 2016; Yamasaki et al., 1979; Takashima and Koshiya, 2008; Koseki, 2015; Datuin and Troncales, 1986; Boedihardi et al., 1992; Wilson and Rowland, 2016), whereas most of the hot springs in Taiwan are located in metamorphic regions (Chang, 2000). In 2015, the total installed geothermal generation capacity worldwide was more than 12,600 MWe (Bertani, 2015); however, none of them were located in Taiwan. In fact, two pilot geothermal power plants were installed in Taiwan in the 1980s, with capacities of 280 kWe and 3 MWe, respectively. The 280 kWe plant was decommissioned due to funding cut by the government, while the 3 MWe was abandoned because of a decline in steam production. The structural complexity and the low permeability of host rocks in metamorphic-type geothermal fields increases the difficulty of geothermal exploration and exploitation. The steep and rugged terrain of eastern Taiwan adds another difficulty for surface geophysical prospection in these metamorphic-type geothermal systems. Consequently, the development of a complete conceptual geothermal model by integrating dataset derived from a wide spectrum of investigating methods is important to understand the potential for metamorphic-type of geothermal systems in Taiwan.

The exploration of the Jinlun geothermal region began in the 1980s. High temperature (98 °C) hot springs that extended over 1000 m upstream and several hundred meters downstream of the Jinlun river indicate the high geothermal potential of the area. From 1982–1984, a total of 11 geothermal exploration boreholes were drilled by Industrial Technology Research Institute (ITRI) and Chinese Petroleum Company (CPC) (Lee et al., 1994; Zhan et al., 1982). Temperature measurements, surface and borehole geology study, borehole flow tests, and geochemical analyses were conducted by previous explorations (Zhan et al., 1982; Huang, 1984; Lo and Lin, 1984). The highest formation temperature, which occurred at a depth of 2000 m, was about 190 °C. The constructed geothermal conceptual model based on these data, however, did not consider a heat source for the system, nor the nature of recharge or size of the reservoir at Jinlun.

The purpose of this paper is to develop a more complete geothermal conceptual model which integrates historical information with newly

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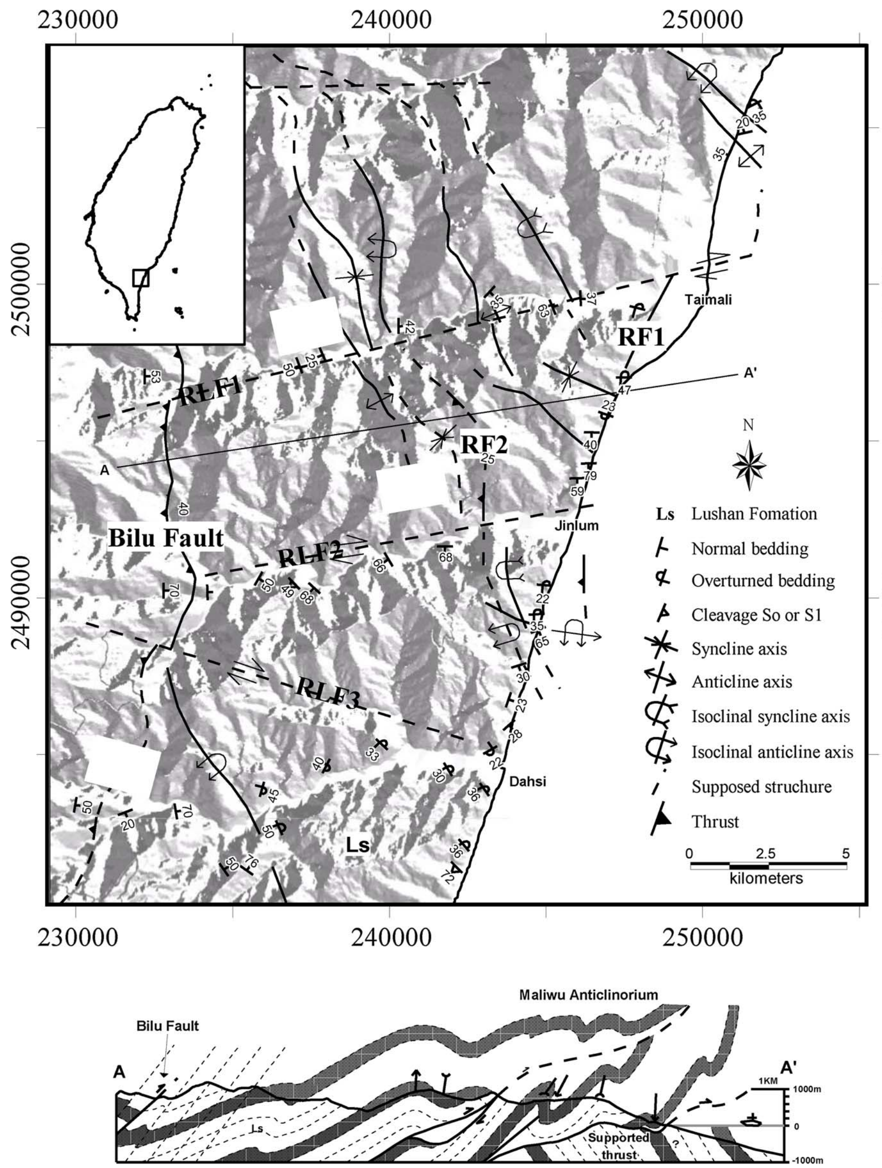

Fig. 1. Simplified structure map and cross-section of the eastern flank of the Backbone Range. The N-S trending structural pattern suggests that most of the deformation resulted from E-W compressional tectonic regime. (After Chang et al., 2009).

conducted magnetotellurics (MT) survey and data from a recently drilled 1000 m deep borehole (TCL9). Additionally, a gravity dataset collected from the Zhiben–Jinlun area (Lee et al., 1994) was re-processed and interpreted.

Results from the MT reveal a deep resistive structure down to 5 km depth. A zone of low resistivity observed is consistent with elevated temperatures in TCL9. A new geothermal conceptual model was developed by combining all the information described above.

2. General geological setting

Taiwan is located at the conjunction zone of the oblique collision between the Eurasian plate and the Philippine Sea plates. This collision started during the late Cenozoic (Chen et al., 1985). In offshore southern Taiwan, the Eurasian plate subducted beneath the Philippine Sea plate, whereas in northeast Taiwan, the Philippine Sea plates subducted into the Eurasian plate. The southern part of Taiwan is a more active collision structure. (Chen, 1982; Ho, 1986; Lee and Cheng, 1986). The Jinlun geothermal field is located at an interesting region where the Eurasian plate has not fully collided with the Philippine Sea plate yet.

From west to east, the Taiwan mountain belt can be subdivided physio-graphically into the Coastal Plain, the Western Foothills and the Hsuehshan Range, the Backbone Range, the Longitudinal Valley and the Coastal Range (Ho, 1986). In general, heat flow and deformation intensity tend to increase from the foreland to the hinterland across the Backbone Range (Ho, 1986; Tsao et al., 1998; Yen, 1967; Lee and Cheng, 1986). The Jinlun geothermal field is located in the south eastern part of Taiwan, which belongs to the southern part of the Backbone Range. From the stratigraphic point of view, the main formations of the southern Backbone Range are composed of metasediments that was interpreted as a very thick deep-sea fan sequence. The clastic material was transported and deposited in the continental slope and ocean basin by turbidity currents (Hu and Tsan, 1984).

Because of the polyphase folding/faulting (Chang et al., 2009) and high topographic reliefs at metamorphic areas, it is difficult to establish a clear geothermal conceptual model with limited resources. Fig. 1 shows the main geologic structures of the southern Backbone Range including Bilu fault, Reverse Faults (RF) including RF1 and RF2, and Right Lateral Faults (RLF) including RLF1 and RLF2 (Chang et al., 2009). The hot spring outcrops of the Jinlun geothermal field are in the cross section of RLF2 and RF2.