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Evaluating the Chingshui geothermal reservoir in northeast Taiwan with a 3D integrated geophysical visualization model

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ABSTRACT

In the current study, we assess the Chingshui geothermal reservoir with a three-dimensional visualization model that integrates geophysical measurements with well logs. To re-evaluate the geothermal reservoir quantitatively, we reprocessed resistivity measurements from a series of studies conducted nearly 40 years ago, as well as from the magnetotelluric (MT) explorations performed recently in the Chingshui area. We established a three-dimensional (3D) visualization model that integrates these different geophysical survey results as well as the well-logs to better perform the spatial relationships between them. From the orthogonal bipole–bipole resistivity surveys, we have identified several regional conductive structures with resistivity of less than 50 Ohm-m representing the major fault zones of the Dahsi, Xiaonanao, and Chingshuihsi faults. Among them, the Chingshui fault is located along the Chingshuihsi River valley and is associated with hot spring features. The collinear Schlumberger survey along the Chingshuichi Valley identified three relatively conductive regions with resistivity of less than 20 Ohm-m. The MT interpretation shows that the structure associated with the geothermal reservoir extends from these near-surface fractures to a depth of −1500 m toward the south in the fault zone. The identified production zone from the core drilling records is consistent with the conductive structure in the MT inverted image. In addition, the structure seems to consist of two sub-regions: a somewhat shallow one at a depth of between −400 and −800 m in the north and a somewhat deep one at a depth of between −600 and −1500 m in the south. From the 3D model, we estimate that the volume of the Chingshui geothermal reservoir is about 9.54×10^7 m^3. Given a gross porosity of 0.1 and 100% saturation for the fracture zones from the core logs, the inferred Chingshui geothermal reservoir contains about 10 million cubic meters of geothermal fluids.

1. Introduction

The Chingshui geothermal field is located in a 1.3-km^2 area, approximately 13 km southwest of Ilan City in Northeast Taiwan (Fig. 1). Hot springs were found along the Chingshuihsi River and pointed to the possibility that the area was a geothermal region. In the 1970s, the Industrial Technology Research Institute (ITRI) conducted a series of reconnaissance geophysical surveys, including surveys on gravity, electrical resistivity, and spontaneous potential (Lee, 1994), to locate potential drilling sites (Fig. 2). Following the ITRI surveys, Chinese Petroleum Company (CPC) drilled 19 probing wells in the area and later completed seven production wells for power generation (Tong et al., 2008). In 1981, Taiwan's National Science Council funded the construction of a power plant with 3-MW power-generation capacityin Chingshui, Ilan and the power plant was hand over to the Taipower Company for operation. The plant was ceased to function in 1993 owing to scaling problems and decreased fluid production.

In 2008, the Taiwan Government initiated a new campaign for geothermal exploration in the Chingshui area owing to Taiwan's growing need for clean energy. Tong et al. (2008) pointed out that although a few exploration surveys had been conducted the reservoir of the Chingshui geothermal field had yet to be clearly delineated (e.g., Hsiao and Chiang, 1979; Lee, 1994; Su, 1978; Tong

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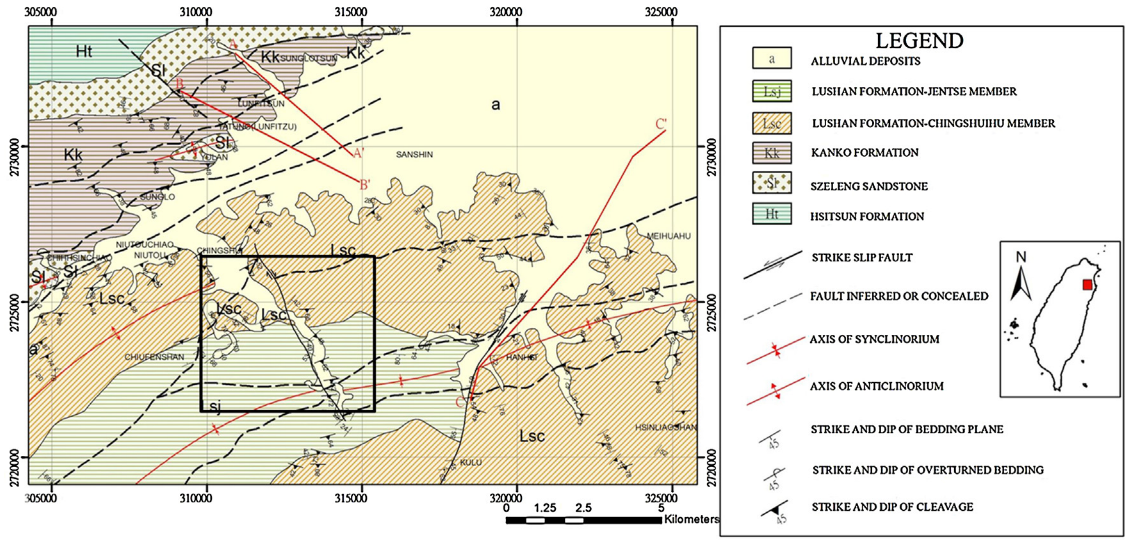

Fig. 1. The regional geology map of the study area; modified from Tseng (1978) and Lin and Lin (1995). The square area indicates the geophysical survey region for the Chingshui geothermal field.

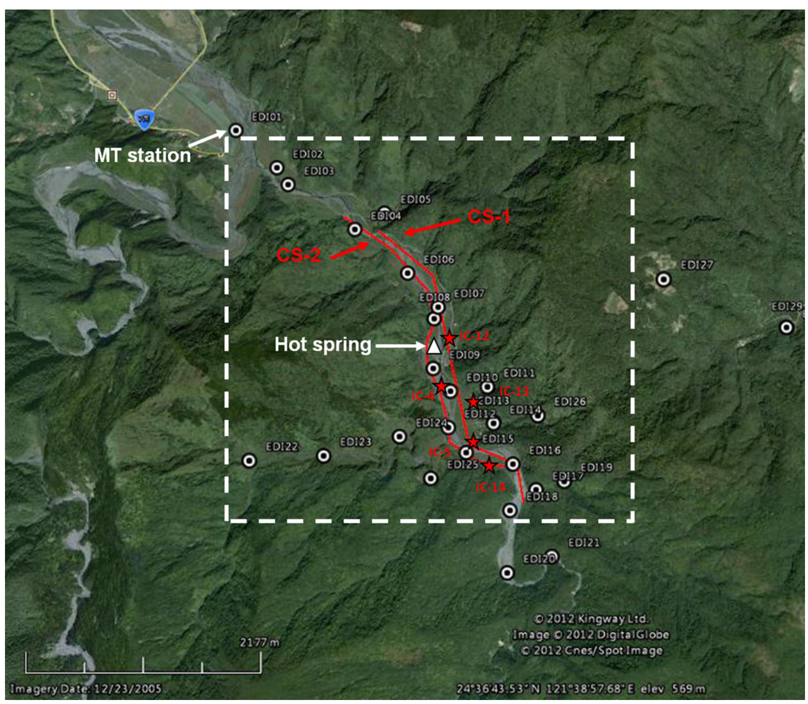

Fig. 2. The satellite image showing the enlarged square area in Fig. 1 and the locations of the hot spring outcrop (the red triangle), the electrical resistivity surveys along the Chingshui river (the two red lines), production wells (the red stars), and the MT stations (the small white circles). Dashed-line square indicates the area of the 3D visualization model shown in Fig. 7. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

et al., 2008; Tseng, 1978). The team collected data from gravity, magnetic, and MT measurements and tried to interpret the structure of geothermal reservoirs (Tong et al., 2008). They relied mainly on the MT inversion results to delineate the geothermal reservoir structures because the magnetic and gravity data could not provide as good a resolution as the EM and resistivity measurements. However, the locations of surface hot springs are inconsistent with the locations of low resistivity regions in MT inverted images. Neither the fracture zones nor their orientations, as indicated in well logs, can be well correlated to the low resistivity regions in the MT inverted images. The inconsistency raises questions about the appropriateness of the MT inverted images, leaving the reservoir structures in the Chingshui area an unknown variable.

In this study, we have tried to review and reprocess the resistivity and MT measurements with new processing and inversion strategies. The electrical resistivity data derive from surveys conducted by ITRI from 1973 to 1975 (Lee, 1994). These resistivity surveys feature two configurations: the orthogonal bipole–bipole method and the collinear Schlumberger method. The ITRI team used the orthogonal bipole–bipole method while fixing both transmitter and receiver dipole lengths at 500-m. The receiver dipole was moved across the Chingshui area while the dipole direction was kept normal in relation to the source dipole. The collinear Schlumberger method was utilized along the two sides of the Chingshuihsi River. The MT raw data were the same as those in Tong et al. (2008) and were reprocessed with both one- and two-dimensional