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The Los Humeros (Mexico) geothermal field model deduced from new geophysical and geological data

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ABSTRACT

The Los Humeros volcanic complex, a 21 × 15 km diameter caldera edifice nesting volcanic domes and a complex faulting structure, is located at the eastern edge of the Trans-mexican volcanic belt (TMVB). It is a young edifice (< 0.5 Ma) that hosts one of the five main geothermal fields of Mexico with still an important energy production (~65 kW installed capacity). Being one of the more studied producing fields, the geothermal system of the caldera is largely unknown at depths greater than ~2.4 km, which is the approximate penetration range of the available geothermal wells. Here we present the results of a geophysical survey in Los Humeros caldera and surroundings with the aim to provide further insight on the physical characteristics of the geothermal system at depths greater than 2.4 km. The survey comprised 70 broadband magnetotelluric (MT) soundings distributed within and in the periphery of the caldera edifice of which we present here three EW profiles. We also accomplished a mesh of 718 accurately leveled gravity stations. These data sets were complemented with 13 TDEM soundings for static shift control, as well as with the aero-magnetic digital chart of the area (#E14-3, SGM, 2004). The MT data analysis yielded an average electric azimuth of N23W for the central profile where the field production is concentrated, which is quite consistent with the mapped NW-SE geological structure. However, at individual frequency ranges the strike follows the local faulting structures, most of which are apparently controlled by the deeper crater structure. At the production zone, the conductivity model reveals the existence of an eastward dipping resistive body, which follows the isotherms registered at the wells. The inclined conductivity interface above it seems to play an important role in controlling the heat and fluid flow towards shallow depths. Petrographic studies of well samples provide evidence of mineralogical assemblages that suggest magnetite-metasomatose hydrothermal alteration. The production zone coincides with maximum gravity and magnetic gradients, at the western edge of the well-defined circular crater anomaly. At this point the central MT section (profile 1) shows the shallower depth (2–3 km) to the relatively high resistivity (~400–500 ohm-m) and magnetized intrusive-like body. The interpreted geophysical and surface geological data backed by well data support a reservoir and plume model structure consisting of a resistive propylitic core that feds the geothermal field through fractures and deep- seated faults. Surface conductors associated with stratified mineralization produced from lixiviation of geothermal fluids are well differentiated from deeper conductors. The better preserved northern sector of the Humeros caldera yields an anomalous deep conductor at depths of 6–7 km below sea level (profile 5) as well as at the central production sector (profile 1) whereas the anomalous conductivity zone at the southern profile (profile 6) could be as shallow as 5 km below sea level. These anomalous conductivity zones are expected to be associated to the primary energy source of the Los Humeros geothermal system in the form of partial fusion or hypercritical trapped fluids within the upper crust, conditions that have been concluded to prevail along cordilleras of the American continent (e.g. Hyndman, 2017).

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1. Introduction

Being one of the oldest producing geothermal fields in Mexico, Los Humeros geothermal field (Fig. 1) is well known from several perspectives. The large quantity of drilled wells (∼50) has provided abundant sampling for geological, lithological and geochemical analysis mainly in the neighborhood of the production field. Isotopic, fluid inclusion, gas geochemistry, and geochemical modeling publications are available since the early 90 s (Barragán et al., 1991; González-Partida et al., 1991; Martinez and Alibert, 1994). These and further studies have allowed to understand better the behavior of the geothermal reservoir. They include geologic mapping (Pérez-Reynoso, 1978; De la Cruz, 1983; Yáñez and García, 1980; Ferriz and Mahood, 1984; Carrasco-Núñez et al., 2017) subsurface geology (i.e. Viggiano and Robles, 1988; Cedillo, 2000; Cedillo, 1997; Viggiano and Flores-Armenta, 2008; Lorenzo-Pulido, 2008; Gutiérrez-Negrín and Izquierdo-Montalvo, 2010; Carrasco-Núñez et al., 2017), hydrogeological (Cedillo, 1997, 2000) petrological studies (Verma, 1983; Ferriz and Mahood, 1987; Verma, 2000), not to mention the vulcanological (Carrasco-Núñez and Branney, 2005; Wilcox, 2011; Carrasco-Núñez et al., 2012; Dávila-Harris and Carrasco-Núñez, 2014), structural published work of the caldera (Garduño et al., 1985; López-Hernández, 1995; Norini et al., 2015), and the geothermal conceptual model (Arellano et al., 2003; Gutiérrez-Negrín and Izquierdo-Montalvo, 2010). Except for an early phase of prospection (Mena and González-Morán, 1978; Flores-Luna et al., 1978; Álvarez, 1978; Arredondo, 1987; Campos and Garduño, 1987), the geophysical studies focused in the physical modelling of the geothermal system as a whole are practically absent or are too regional (Campos-Enríquez et al., 2005). Until now, the conceptual models of the caldera geothermal field of Humeros have been deduced from geochemical and temperature data (e.g. Castillo-Román et al., 1991; Aragón et al., 2000; Verma et al., 2011) or from two dimensional modelling with drilled wells within the production zone (García et al., 2000), however both models are incompatible to each other. Deep probing geophysical studies (seismic or electromagnetic geophysical techniques) focused in the geological modeling of the caldera structure, heat source distribution, and general configuration of the reservoir was not available until now. Although induced seismicity studies provide very useful information (Ponce and Rodríguez, 1977; Lermo et al., 2008; Rodriguez et al., 2012; Urban and Lermo, 2013) they are not enough in themselves for reservoir modeling. Only recently low intensity seismicity is being applied to constrain the low-velocity heat source distribution of the geothermal system (Lermo J., Pers. comm.).

An alternative deep probing geophysical technique becoming widely used in geothermal prospecting is the broad-band

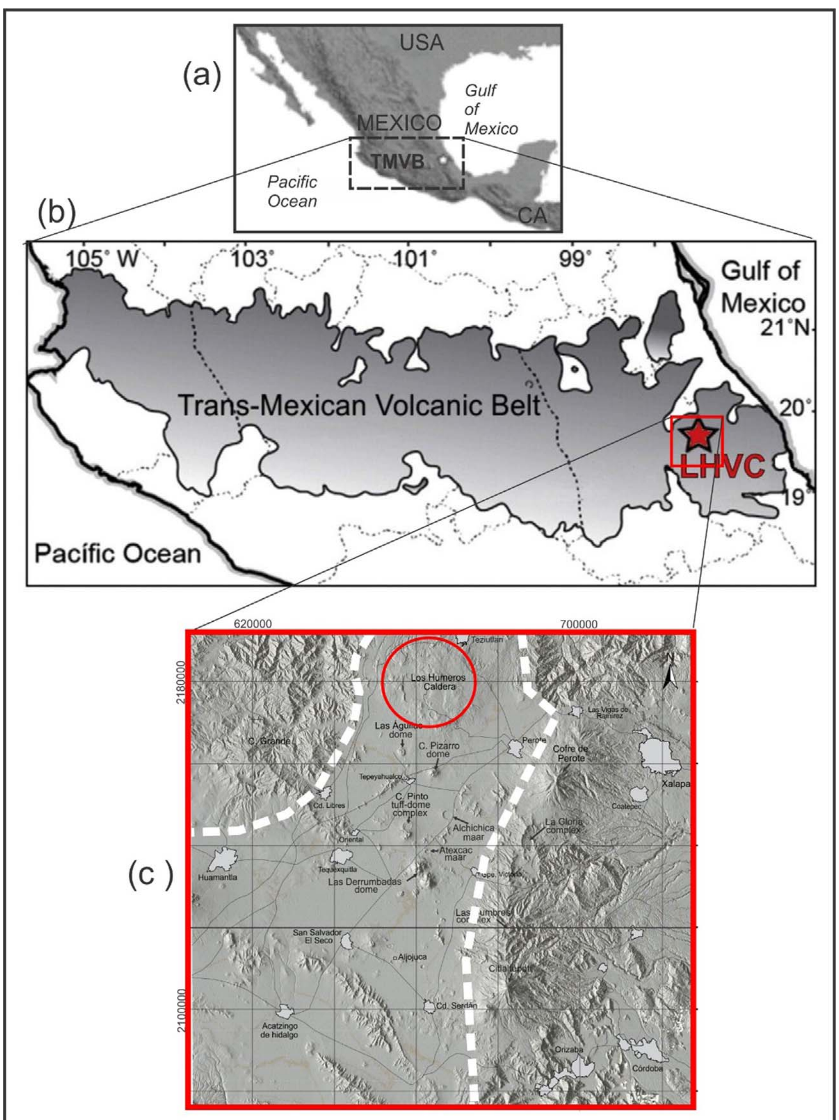

Fig. 1. The Trans-Mexican-Volcanic-Belt (TMBV) extents from the western coast in the Pacific to the eastern end at the Gulf of Mexico (a). The star at the eastern end of the TMVB shows the location of the Los Humeros caldera (LHVC) geothermal field (b). Los Humeros geothermal field (red circle) is located at the northern boundary of the Serdán-Oriental basin, marked with dashed lines (c). (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)