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Characterization of geothermal activity along the North American–Caribbean Plate boundary in Guatemala: The Joaquina geothermal field

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ABSTRACT

Structural mapping, chemical reconnaissance of thermal manifestations, soil chemistry including CO_2 (soil gas), and shallow temperature measurements were employed in conjunction with petrographic, fluid inclusion, isotopic, and bulk rock chemical analyses of drill cutting samples to identify the characteristics and controls of hydrothermal fluid upwelling and outflow in the Joaquina geothermal system, Guatemala. Evidence is provided for a rapidly-upflowing, meteorically-derived Na-bicarbonate(-sulfate) geothermal fluid (a minority category of geothermal fluid compositions comparable to that found in similar non-volcanic systems). The reservoir temperature, based on the least-diluted samples, is estimated to be 175–185 °C. Carbon isotopic analyses of soil gas and sulfur isotopic analyses of sulfide minerals in drill core and cuttings provide insights into the origin of volatiles in the Joaquina system. These data support the notion of CO_2, CH_4, and sulfur that are products of hydrothermal alteration of organic-rich metasediments of the El Tambor Complex, a unit that likely represents a major component of the stratigraphy in the Joaquina system. Hydrothermal upflow in the region is controlled by interaction between NE-striking sinistral faults and ESE-striking normal faults. Paleo-hydrostatic conditions estimated from fluid inclusion studies indicate a minimum age of 45 ka for the commencement of geothermal activity in the region. The natural thermal output of the Joaquina system is estimated conservatively at 32.2 MW_{th}. This study represents the first detailed field investigation of a non-volcanic geothermal system in Guatemala, and provides insight into the nature and controls of thermal areas inland from the active volcanic arc.

1. Introduction

Guatemala is rich in geothermal energy resources, containing an estimated nation-wide electrical-grade potential of ~1000 MW_e (Lippmann, 2002; Asturias, 2012). Geothermal research in the country has largely focused on the characterization of systems linked to the prominent volcanic centers that constitute the north-western segment of the Central American Volcanic Arc. Despite their relative abundance, however, little effort has been directed to the investigation of thermal areas occurring inland from these volcanic centers. Thus, little is known about the nature of their heat sources, chemistry, and geological controls. One such thermal area, the Joaquina geothermal field (Fig. 1), is the primary focus of this study, the first detailed investigation of a non-volcanic geothermal system in Guatemala.

Much of the modern understanding of geothermal processes stems from early investigations of magmatically-driven convective hydrothermal systems hosted in volcanic and sedimentary stratigraphic units (e.g., Steiner, 1953, 1955; White et al., 1963; Ellis and Mahon, 1964; Elder, 1966; Arnorsson, 1970; Henley and Ellis, 1983). The knowledge gained from studying these systems has proven broadly applicable to geothermal fields that occur in a variety of geologic settings worldwide. It is apparent, however, that certain aspects of this knowledge have limited applicability to geothermal systems that are devoid of magmatic activity. This is illustrated by studies of select fields in the Great Basin (e.g., Cole and Ravinsky, 1984; Edmiston and Benoit, 1985; Henkle and Ronne, 2008; Blackwell et al., 2012; Simmons, 2013), Turkey (e.g., Mutlu and Güleç, 1998; Simsek et al., 2000; Vengosh et al., 2002; Kuyumcu et al., 2011; Özgür, 2013), and Honduras (e.g., Janik et al., 1991; Barberi et al., 2013). In some cases, non-magmatic geothermal systems have been shown to vary drastically from their

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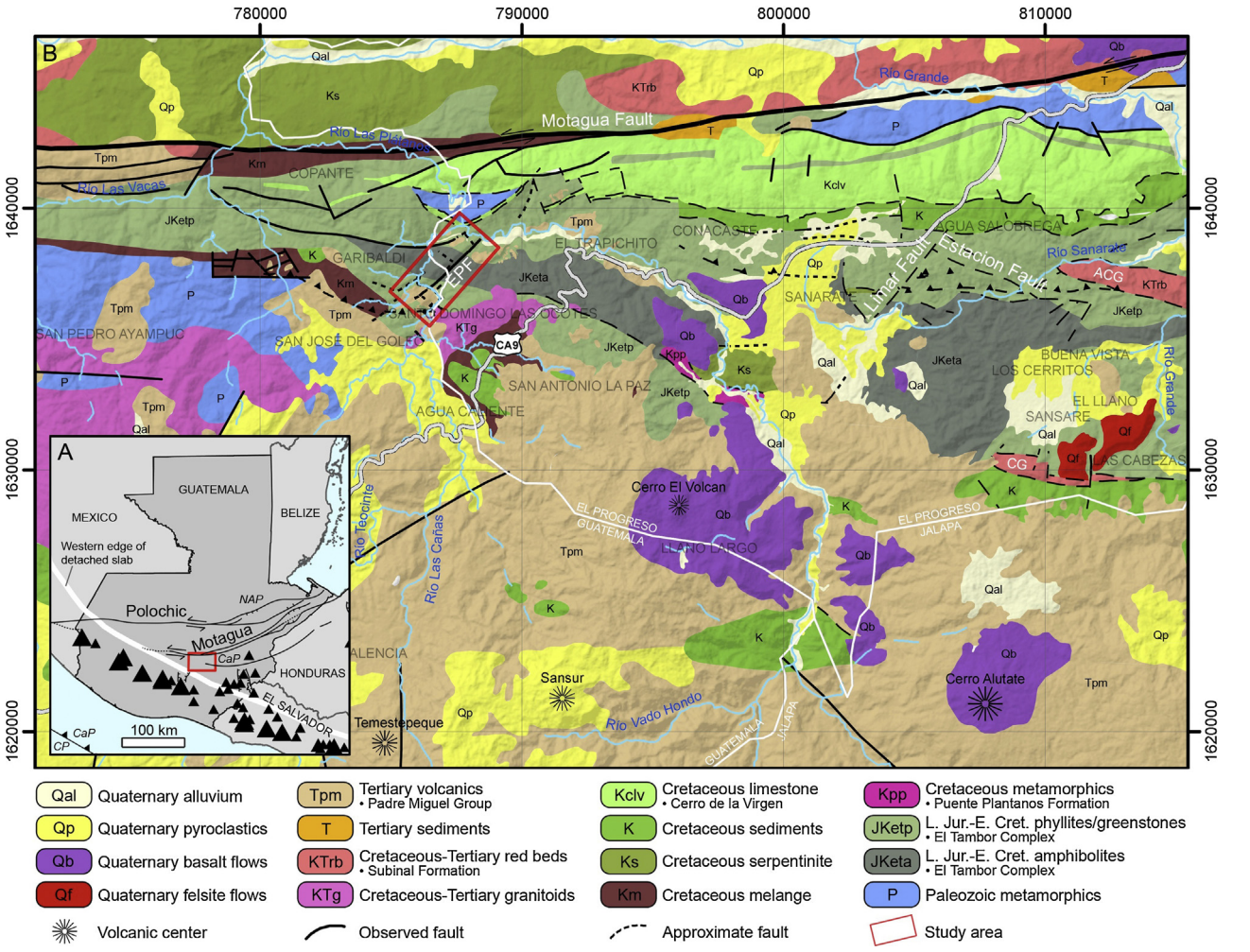

Fig. 1. (a) Generalized tectonic map of Guatemala and surrounding countries showing the location of the Motagua and Polochic fault systems, volcanic centers with recent (large triangles) and Holocene (smaller triangles) activity, the western edge of the detached subducting slab (from Rogers et al., 2002), and the location of map B (red rectangle; fault locations from Walker et al., 2011; locations of volcanic centers provided by the Smithsonian Institution Global Volcanism Program.). NAP = North American Plate; CaP = Caribbean Plate; CP = Cocos Plate. (b) Generalized geological map of the region bordering the Guatemala and El Progreso Departments in Southern Guatemala, showing the main highway, rivers, and department boundaries. Adapted from Montgomery (1973, unpubl.), Lawrence (1980), and Bonis (1993). The Joaquina–Cuajol study region is outlined by the red rectangle. EPF = El Puente Fault; ACG = Agua Caliente Graben; CG = Cujal Graben. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

magmatically-associated counterparts in terms of fluid composition, volatile sources, hydrology, alteration, heat sources, and host rock characteristics. This study of the Joaquina geothermal field was conducted to provide further insight into the nature of these variables in a non-magmatic environment.

Interest in the Joaquina geothermal field developed after mineral exploration boreholes intersected hot water and steam at shallow depths. Core and rock chip samples from these holes, which were drilled to depths from tens of meters to >200 m (between 2001 and 2007), contain abundant evidence of hydrothermal alteration, and although collapsed and inaccessible, many of these boreholes still quiescently vent hot geothermal gases. One of these holes, BRRC-01, discharged a ~10 m-long spray of hot water and steam, known locally as the 'Joaquina Geyser', for an undetermined period of time (Fig. 2b.)

Prior documented geothermal exploration at the Joaquina prospect was limited to a field visit and exploration plan developed by GeothermEx Inc. (2011) for Centram Geothermal Inc., which included a chemical analysis of fluid from the 'Joaquina Geyser'. Exploration and development programs at Joaquina are currently being conducted through a partnership between Adage Geothermal Inc. and Centram Geothermal Inc.

2. Geological setting

The Joaquina geothermal field, Guatemala is located in the northern section of Zone III of the morphotectonic zones of Burkart and Self (1985). This zone is characterized by decompression-induced monogenetic 'behind-the-volcanic-front' (BVF) volcanism related to Neogene–Quaternary east–west extension and rifting (Walker et al., 2011). This east-west extension occurs to the south of the Motagua Fault System at a rate of ~5–10 mm/year (Guzmán-Speziale, 2001; Lyon-Caen et al., 2006; Álvarez-Gómez et al., 2008). The BVF volcanism in Guatemala was initiated after the crustal-scale, left-lateral Motagua Fault system replaced the Polochic system (Fig. 1a) as the main active boundary between the Caribbean and North American plates (the Chortis and Maya Blocks, respectively) at ~4 Ma. This switch to the more arcuate Motagua Fault is thought to have increased transtensional deformation along the western extent of the plate boundary in relation to the counter-clockwise motion of the Maya Block (Rogers and Mann, 2007).

The tectonic and geothermal regime of the BVF region of Zone III shares some similarities with the Western Great Basin region in the United States. In the latter region, the right-lateral Walker Lane Fault System strikes NW-SE and there are a series of extensional