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Geochemistry of thermal springs and geodynamics of the convergent Mexican Pacific margin

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ABSTRACT

Chemical and isotopic composition of waters, helium, carbon and nitrogen isotopes in bubbling and dissolved gases were obtained for 29 groups of thermal springs between 16°N and 21°N, in a ~30 km-wide zone along the Mexican Pacific coast, 60–100 km from the Middle America Trench where Cocos and Rivera oceanic plates subduct under the North America continental Plate. Water isotopic composition of springs generally corresponds to elevations much higher than those of the spring locations indicating high levels of the recharge zones and consequently, high hydraulic gradients and penetration of waters to deep crustal levels, up to 6–8 km taking into account the deep water temperatures estimated by geothermometers and a low thermal gradient (<20°/km) in the coastal zone because of the direct contact of the continental crust and subducting oceanic plates with a cold surface at depths of 15–25 km. The observed $^3He/^4He$ ratios vary from 0.16 Ra to 4.59 Ra (where $Ra = 1.4 \times 10^{-6}$, the air ratio) indicating that some springs discharge gas with a high contribution of mantle helium. High $^3He/^4He$ ratios were measured in springs located within and south of Colima graben, the apparent onshore border between Rivera and Cocos subducting plates, and also within the Rio Ameca graben at the northernmost part of the coastal forearc zone. The permeability of the crust south of Colima graben to the mantle He is interpreted as an evidence for a "slab window" between Cocos and Rivera plates due to different initial dip angles of subduction: a smaller one for the Rivera plate and a steeper one for the Cocos plate, although farther from the trench the Rivera plate subducts much steeper than the Cocos plate. Such geometry of subduction is in agreement with recent data on hypocenter locations of subduction earthquakes within this zone. High $^3He/^4He$ values in gases of the Rio Ameca graben are interpreted as a crustal permeability for mantle He at the Rivera plate margin. The nitrogen isotopic composition is in a good positive correlation with the N_2/Ar ratios. The highest $\delta^{15}N$ of 4–5‰ was measured for gases with $N_2/Ar > 300$ and is associated with the high-salinity springs which are probably originate from the rock–water interaction with the accreted organic-rich sedimentary material.

1. Introduction

Two oceanic plates are subducting beneath the continent along the Mexican Pacific coast: Cocos plate south of Colima graben (~19°N) and Rivera plate to the north of Colima graben (Fig. 1a). Mexican Pacific coast extends along the Mid-America Trench at the distance of 40–70 km from the trench which is very close compared to other continental margins. The Trans-Mexican Volcanic Belt (the volcanic front of the subduction zone) has oblique orientation relative to the coast line and the trench and is situated 200–400 km from the trench, which is a large distance compared to many other subduction zones. The coast line along the trench lies 15–25 km above the interface between the subducting slab and the continental crust. Most of the epicenters of the subduction earthquakes are located within a narrow terrestrial zone, ~30 km along the coast (Pardo and Suarez, 1995). In other words, there is no direct contact of the continental crust with the mantle along the Pacific coast here.

This narrow zone along the Pacific coast (~30 km wide) is a geologically and tectonically complex area composed mostly of granitic batholiths and metamorphic rocks of Cretaceous to Jurassic age. Being a forearc zone adjacent to the trench, this coastal belt is tectonically very active. In addition to great number of subduction earthquakes occurring beneath this zone, several seismogenic deep faults extend parallel to the coast line. This region is also subject to slow tectonic motions, surface uplift and subsidence and has a specific local tectonic pattern governed by strong subducting plate–continental crust dynamic interaction (Kostoglodov et al., 2003; Larson et al., 2004; Manea et al., 2006; Manea and Manea, 2011). The northwest part of the zone is characterized by the most complicated tectonic

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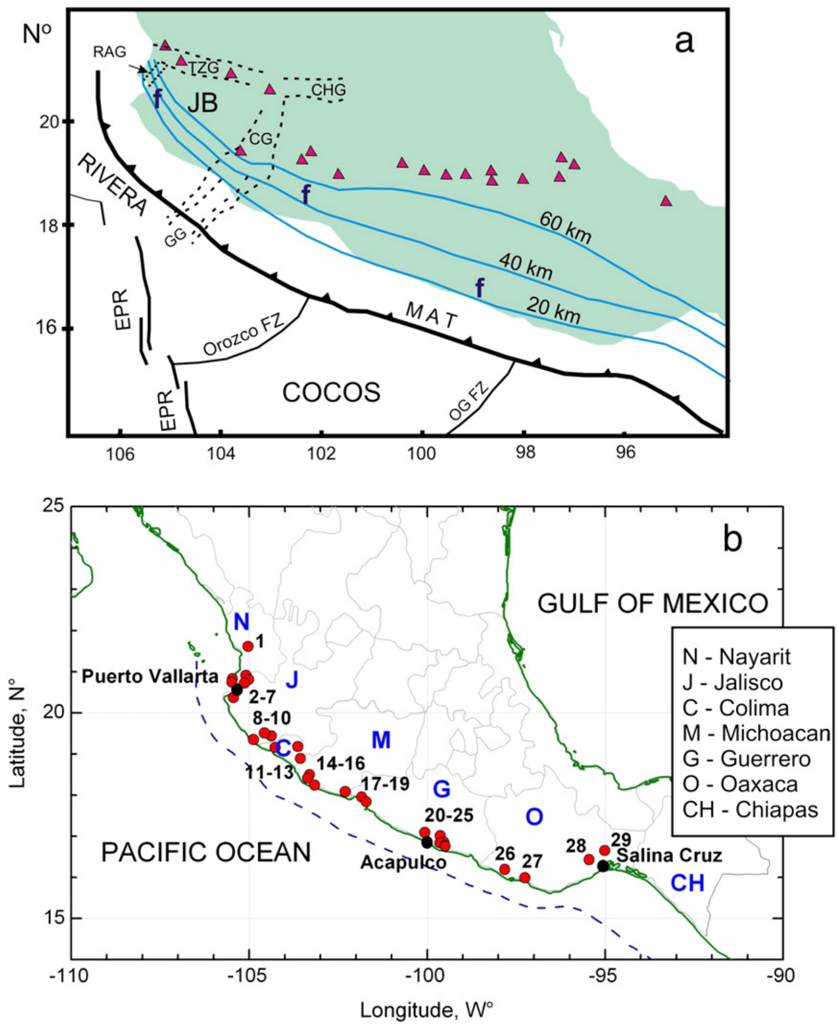

Fig. 1. (a) Sketch map of the plate tectonic setting of Central Mexico. Triangles are active volcanoes of the volcanic front. Izodepth contours (km) of the subducting slab are shown after Pardo and Suarez (1995). Abbreviations: RAG — Rio Ameca graben; TZG — Tepic-Zacoalco graben; CG — Colima graben; CHP — Chapala graben, GG — El Gordo graben; EPR — East pacific Ridge; OFR — Orosco Fracture Zone; OG FZ — O'Gorman fracture zone. f — locations of heat flow wells (Ziagos et al., 1985). See text for more explanations. (b) Location of hot springs along the Mexican Pacific coast. Numbers correspond to numbers, names and coordinates of springs shown in Table 1.

structure. The continental Jalisco Block and two subducting oceanic plates Rivera and Cocos form here a puzzle that still has no unambiguous solution (Ferrari et al., 1994; Kostoglodov and Bandy, 1995; Bandy et al., 2000; Alvarez, 2002; Soto et al., 2009; Yang et al., 2009, among others). Especially, there is a problem of the NW limit of the Jalisco Block that is not well constrained (Alvarez, 2002).

Theoretically, the subduction of the oceanic plate with a cold surface beneath the continental plate should result in a low terrestrial heat flow in the coastal area adjacent to the trench (e.g., Manea et al., 2006). Nevertheless, at least 29 groups of hot and warm springs are known in this zone (Fig. 1b), distributed more or less uniformly from the Tehauntepec isthmus at southeast (~16°N) to Punta Mita at northwest (~21°N). Chemical and isotopic compositions of thermal waters and associated gases can provide unique information about thermal and tectonic regime of a region. Especially, He isotopic composition is a powerful tool for searching crustal permeability to the mantle depth or mantle diapirism (e.g., Polyak and Tolstikhin, 1985; Giggenbach et al., 1993; Dogan et al., 2006; Sano et al., 2006, 2009).

Here we present our data on the chemical and isotopic compositions of waters and gases from 29 groups of thermal springs located within a ~30 km-wide zone along the Mexican Pacific coast. $^3He/^4He$ ratios, water isotopic composition and solute geothermometry of thermal waters are used for the first-order estimations of the thermal regime of this narrow forearc zone close to the trench. We propose also the geometry of the Rivera-Cocos plate boundary (a "slab window") close to the trench on the base of $^3He/^4He$ ratios in coastal springs discharging close to Colima graben. Additionally, we discuss the structure of the northern margin of the Rivera plate, using contrasting $^3He/^4He$ ratios in thermal springs near Rio Ameca graben. N_2/Ar ratios, nitrogen and carbon isotopes are used for the assessment of the apparent accretion complexes composed of organic-rich sediments.

Geochemical data for some springs (gas data for Jalisco Block and water data for the Guerrero coasts) have been already published elsewhere (Prol-Ledesma et al., 2002; Taran et al., 2002a,b; Inguaggiato et al., 2004; Ramirez-Guzman et al., 2004).

2. Subduction and heat flow

The geometry of subduction beneath the Mexican Pacific margin changes significantly from south to north (Fig. 1a). The Cocos plate between ~16°N and 18°N (Oaxaca and Guerrero states, Fig. 1b) has the initial dip angle ~30°, then a flat extension for ~150 km following the continental crust base and finally it steeply immerses beneath the volcanic front (Pardo and Suarez, 1995; Kostoglodov and Bandy, 1995; Manea et al., 2006; Perez-Campos et al., 2008; Skinner and Clayton, 2011). To the north of 18°N, beneath the Michoacan coast, the slab subducts steeper but the entire geometry is still not well constrained. The average dip angle of the hot and young Rivera