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A noble gas and $^{87}Sr/^{86}Sr$ study in fluids of the Los Azufres geothermal field, Mexico – Assessing impact of exploitation and constraining heat sources

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ABSTRACT

Thirty geothermal wells and two hot springs were sampled for volume fraction and isotopic measurements of noble gases (He, Ne, Ar, Kr, Xe) and strontium in the Los Azufres Geothermal Field (LAGF), Mexico. The aim of this study was to understand the evolution of fluid circulation following three decades of exploitation and re-injection of used brines and to identify the heat source. The LAGF, divided into the Southern Production Zone (SPZ) and the Northern Production Zone (NPZ), is hosted in a Miocene to Pliocene andesitic volcanic complex covered by Quaternary rhyolitic-dacitic units. Air component corrected $^{3}He/^{4}He$ ratios (Rc) normalized to the atmospheric ratio (Ra = 1.384×10^{-6}), range from 4.21 to 7.93 for most samples pointing to the occurrence of a MORB-type mantle helium component, with contributions of crustal helium up to 53% and 18% in NPZ and SPZ, respectively. Observations based on Rc/Ra and $^{87}Sr/^{86}Sr$ ratios point to mixing of three magmatic sources supplying mantle helium to the LAGF: (1) a pure mantle He (Rc/Ra = 8) and Sr ($^{87}Sr/^{86}Sr$ = 0.7035) source related to mafic magmas; (2) a pure mantle helium component (Rc/Ra = 7) with some radiogenic Sr ($^{87}Sr/^{86}Sr$ = 0.7049) source, possibly related to Quaternary rhyolitic magmas; and (3) a fossil mantle He component (Rc/Ra = 4.0) with some radiogenic Sr ($^{87}Sr/^{86}Sr$ = 0.7038), corresponding possibly to Miocene andesitic magmas. Parental magmas related to sources (1) and (2) emplaced < 50 kyrs ago are likely responsible for the addition of mantle volatiles and heat (Q) to the hydrothermal system of Los Azufres. An observed $^{4}He/^{36}Ar$ vs. $^{3}He/Q$ correlation suggests that heat is transferred by conduction and convection in both NPZ and SPZ. Atmospheric noble gas elemental ratios suggest that geothermal wells located closer to the western re-injection zone are dominated by re-injection of used brines (injectate). The area affected by boiling in LAGF has extended further to the north and west since the last noble gas sampling campaign in 2007–2009 (Pinti et al., 2013).

1. Introduction

Mexico is among the countries with the highest installed geothermal capacity in the world (Flores-Espino et al., 2017). The Los Azufres Geothermal Field (LAGF), with an installed capacity of 247.9 MW (Armenta et al., 2016), is the second most productive geothermal field in Mexico after Cerro Prieto (Fig. 1A). LAGF is located 250 km west of Mexico City, in the central area of the Trans-Mexican Volcanic Belt (Fig. 1A). Its geothermal activity is concentrated in a volcanic complex filled with Miocene andesites and covered by Quaternary dacites and rhyolites. The area is part of the Morelia-Acambay east-west rift zone (Fig. 1B) (Ferrari et al., 1991; Torres-Rodriguez et al., 2005). It is a heavily fractured and faulted volcanic hydrothermal system with the geothermal field being divided into the northern production zone (NPZ) and the southern production zone (SPZ). These reflect different geochemical, production and reservoir characteristics. Their original thermodynamic state is also distinct. Indeed, while the NPZ is found solely in the compressed liquid region, the SPZ encompasses the vapor-dominated, liquid-dominated, and compressed-liquid region, depending on the depth (Torres-Rodriguez et al., 2005). The SPZ yields

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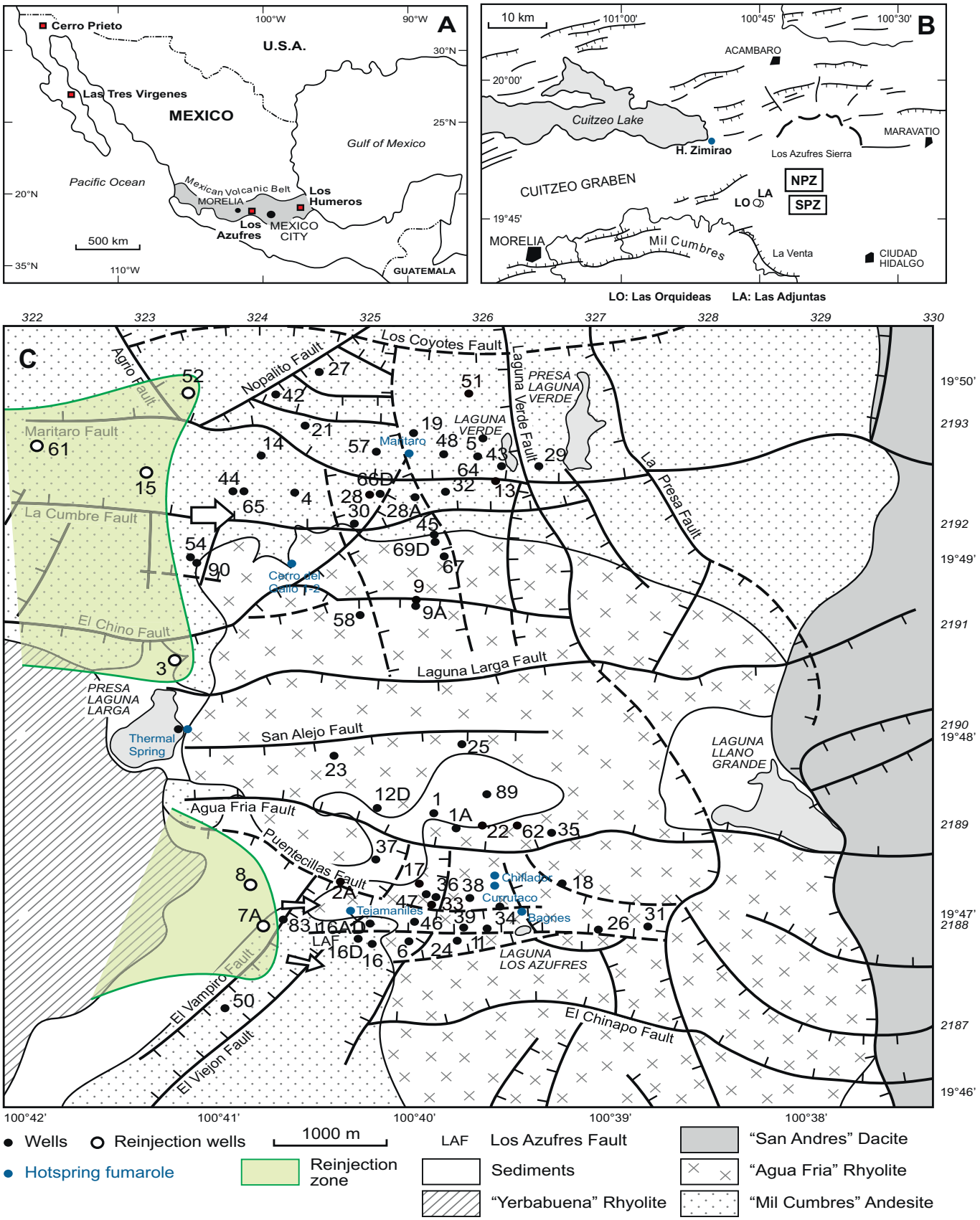

Fig. 1. (A) Simplified map of Mexico with the position of Los Azufres, Cerro Prieto and Los Humeros fields. (B) Simplified tectonic map of the Los Azufres sierra and the E–W rift systems. The location of Araró hot springs on the border of Cuitzeo Lake is also indicated as well as the *H. Zimirao* hot spring. NPZ and SPZ indicate the position of the northern production zone and the southern production zone of Los Azufres geothermal field, respectively (from Pinti et al., 2013). (C) Locations of sampled wells and hot springs sampled in LAGF (this study and Pinti et al., 2013), with tectonic structures and geology. The area of re-injection of used brines (injectate) is reported from Barragán et al. (2005) and Pinti et al. (2013). (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)