



Soil gas geochemistry in relation to eruptive fissures on Timanfaya volcano, Lanzarote Island (Canary Islands, Spain)

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ARTICLE INFO

Article history:

Received 31 March 2012

Accepted 21 October 2012

Available online 2 November 2012

Keywords:

Timanfaya volcano

Soil gas

Radon

Carbon dioxide

Helium

ABSTRACT

We report herein the first results of an extensive soil gas survey performed on Timanfaya volcano on May 2011. Soil gas composition at Timanfaya volcano indicates a main atmospheric source, slightly enriched in CO₂ and He. Soil CO₂ concentration showed a very slight deep contribution of the Timanfaya volcanic system, with no clear relation to the main eruptive fissures of the studied area. The existence of soil helium enrichments in Timanfaya indicates a shallow degassing of crustal helium and other possible deeper sources probably form cooling magma bodies at depth. The main soil helium enrichments were observed in good agreement with the main eruptive fissures of the 1730–36 eruption, with the highest values located at those areas with a higher density of recent eruptive centers, indicating an important structural control for the leakage of helium at Timanfaya volcano. Atmospheric air slightly polluted by deep-seated helium emissions, CO₂ degassed from a cooling magma body, and biogenic CO₂, might be the most plausible explanation for the existence of soil gas. Helium is a deep-seated gas, exhibiting important emission rates along the main eruptive fissure of the 1730–36 eruption of Timanfaya volcano.

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1. Introduction

The presence of soil gas anomalies are related to the preferential release of deep-seated gases along active tectonic structures, and as a consequence, the use of soil gas surveys in earth science studies has become increasingly common in recent years. Such studies have been widely applied to locate active faults and have been used in earthquake and volcanic eruption precursory studies (King et al., 1996; Baubron et al., 2002; Hernández et al., 2004; Walia et al., 2005; Giammanco et al., 2006; Lan et al., 2007). Soil gas surveys are mainly based on the analysis of gases in the soil atmosphere at a usual depth of between 40 cm and 1 m depth from the surface. Studies carried out over active faults and fractures have shown that these geological structures act as preferential pathways for the ascent of gases from different origins toward the surface (King et al., 1996; Padrón et al., 2003; Yang et al., 2003; Walia et al., 2005, 2010; Giammanco et al., 2006; Neri et al., 2011). Studies of soil gas compositions and diffuse degassing surveys in volcanic environments have focused mainly on CO₂. This is because of the fact that, after water vapor, CO₂ is the most abundant gas species dissolved in magma (Stolper and Holloway, 1988). On active or quiescent volcanoes, CO₂

is the main species in soil gas, and is released through tectonic structures (Giammanco et al., 1995, 2006, 2007; Hernández et al., 2000; Dogan et al., 2007; Lombardi and Voltattorni, 2010).

Radon is probably one of the most investigated soil gases emanating from faults (Banwell and Parizek, 1988; Hernández et al., 2004; Walia et al., 2005, 2010; Reddy et al., 2006), and has been also used to monitor volcanic and seismic activity (Zimmer and Erzinger, 2003; Immè et al., 2006; Pérez et al., 2007, 2008). It has three isotopes: ²²²Rn (radon), ²²⁰Rn (thoron), and ²¹⁹Rn (actinon). ²²²Rn is generated from the radioactive decay of ²³⁸U and has a half-life of 3.82 days. Soil gas ²²²Rn measured at the ground level originates from a shallow source unless driving mechanisms such as underground water movements or carrier gas, facilitate the transport from deeper sources to the surface (Etiope and Martinelli, 2002; Yang et al., 2003). Several factors control its concentration in soil gases: the distribution of ²³⁸U in the bedrock, soil porosity and humidity, surface wind speed, and granulation. Thoron is a decay product derived from the ²³²Th decay series and has a relatively half-life of 55 s. Owing to their different half-lives, a ²²²Rn/²²⁰Rn ratio is used to distinguish between gases released from shallower or deeper zones. However, a low ²²²Rn/²²⁰Rn reading can also be found in zones with a very fast soil–gas transport mechanism (Giammanco et al., 2007).

Helium, owing to its special geochemical properties, is considered by geochemists to be an almost ideal indicator of geochemical processes (Pogorski and Quirt, 1981). It is highly mobile, chemically

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inert, physically stable, nonbiogenic, sparingly soluble in water under ambient conditions, almost non-adsorbable, and highly diffusive with a diffusion coefficient about 10 times that of CO_2 . These properties minimize the interactions of this noble gas during its movement toward the earth's surface and its concentration is not modified by subsequent chemical reactions. An excess of ^4He (hereafter simply referred to as helium) in soil gases compared to atmospheric values has been reported by several authors, and is found mainly near fractures (Lombardi et al., 1984; D'Alessandro and Parello, 1997; Padrón et al., 2003; Padrón et al., 2012; Hong et al., 2010; Lombardi and Voltattorni, 2010).

In May 2011, we performed a soil gas survey on Timanfaya volcanic system (Lanzarote, Canary Islands, Spain), which focused mainly on CO_2 , ^{222}Rn , ^{220}Rn and He concentrations, to investigate the relationship between soil gas concentrations and the volcano-tectonic structures of Timanfaya volcano. Since the active fractures at Timanfaya volcano are evident from the surface geology, the main aim of this study is to investigate whether these geological structures are actively releasing deep gases. At present there is no surface evidence of gas emissions at Timanfaya volcano, and therefore the study of the spatial distribution of CO_2 , ^{222}Rn , ^{220}Rn and He concentrations in soil gases becomes an ideal geochemical tool to identify sites with an anomalous emission of deep-seated gases, which could then be used for volcano monitoring.

2. Geological settings

The Canary Archipelago is located in the eastern Central Atlantic off the Moroccan coast, and consists of seven major islands and several islets extending about 450 km from east to west (Fig. 1). There is a recognized east-to-west age progression of the oldest subaerial volcanism, from about 20 Ma for the eastern islands of Lanzarote and Fuerteventura (Dañoheitia and Canales, 2000) to 2 Ma for the westernmost islands of La Palma and El Hierro (Ancochea et al., 1994; Guillou et al., 1996). This apparent east to west progression of the oldest subaerial volcanism and its agreement with the increase of $^3\text{He}/^4\text{He}$ ratio measured in terrestrial fluids from Lanzarote to La Palma and El Hierro Islands (Pérez et al., 1994), seem to be compatible with the hotspot trace proposed for the Canaries by Morgan (1971) and Pérez et al. (1994). Lanzarote Island (795 km², Fig. 1) is an emerged part of the East Canary Ridge (ECR), which is a ca.

70-km-long, 65-km-wide, NNE–SSW linear volcanic structure offshore Morocco (Marinoni and Pasquaré, 1994). It is the easternmost island in the Canary Islands and it is situated approximately 100 km from the NW coast of Morocco, Africa. The ECR consists of a number of uplifted blocks of oceanic basement covered by a thick sedimentary sequence (10 km) mantled by 5 km of volcanic rocks, with an intrusive complex between the two layers (Banda et al., 1981). The emergent part of the island is essentially formed of volcanic rocks, mainly basaltic in composition (Marinoni and Pasquaré, 1994). The island is elongated in NNE–SSW direction reflecting the trend of the ECR, and most of the emission centers in the central part of the island indicate concentration of vents with a ENE–WSW trend (Fig. 2). From 1730 to 1736 Lanzarote suffered the longest eruption in historical times in the Canary Islands, a basaltic-type eruption with tholeiitic composition, with more than 30 volcanic cones formed in different eruptive phases which covered 23% of the island (Carracedo et al., 1992). The eruptive vents are aligned along a fracture more than 14 km in length (Fig. 2). The main fissure that fed the 1730 eruption is related to the general trend (N70°E) of alignment of recent emission centers that shows the path of the central structural rift-type zone (Carracedo et al., 1992). The last eruption at Lanzarote Island occurred during 1824 at Tinguaton volcano, and produced a small lava flow that reached the SW coast.

One of the most prominent phenomena at Timanfaya volcanic field is the high maintained superficial temperatures occurring in the area since the 1730–1736 volcanic eruption. Thermal anomalies are confined either in fracture-related alignments or along the rims of craters (Araña et al., 1984). The maximum temperature recorded in this zone is 605 °C, measured inside a slightly inclined 13 m deep well. The main thermal anomalies are located in the area known as Islote de Hilario, 0.6 km to the north-west of the Timanfaya cinder cone. Other areas with superficial temperatures of 125–200 °C occur along one of the main crater rim (Araña et al., 1984). Ortiz et al. (1986) inferred a shallow magma chamber that fed the 1730–1736 eruptions located at approximately 4 km depth with temperatures in the range 900–1100 °C. Araña et al. (1984) suggested that thermal energy would be transported through fractures by magmatic volatiles and/or by water vapor coming from a deep-seated 3–4 km water table.

3. Sampling and analytical methods – May 2011

In order to study the relationship between soil gas composition and volcano-tectonic structures at Timanfaya volcano, we collected 366 soil gas samples following a homogeneous pattern in a distribution of sampling sites along the surface environment of Timanfaya volcano (Fig. 3). We took into consideration the local geology, the location of the volcano-tectonic structures and their accessibility. Owing to the low degree of soil development, soil gas sampling was not possible on large surfaces of the Timanfaya volcanic system that has been covered by very recent lava flows (non studied area in Fig. 3). A higher sampling density was used at those areas where surface temperature anomalies were present. At each sampling site, soil gas samples were collected at a depth of 40 cm depth using a stainless steel probe. Samples were then stored in glass vials. He, N_2 , O_2 , ^{40}Ar , ^{36}Ar and CO_2 concentrations were analyzed within 24 h by means of a Quadrupole Mass Spectrometer (QMS; Pfeiffer Omnistar 422). Atmospheric gas was used to calibrate the instrument for the He, N_2 , O_2 , ^{40}Ar and ^{36}Ar , while specific gas-standards were used for CO_2 . The accuracy of the gas contents determined by the instrument was estimated to be ± 300 ppb, for helium, $\pm 1\%$, for N_2 and O_2 , ± 50 ppm for ^{40}Ar and ± 5 ppm for ^{36}Ar . ^{222}Rn and ^{220}Rn concentrations in soil gases were measured in-situ at each sampling site by means of a SARAD Rn monitor, model RTM-2010-2. The instrument was connected to the metallic probe and inserted into the soil at a depth of 40 cm. Soil gas was pumped through the measurement

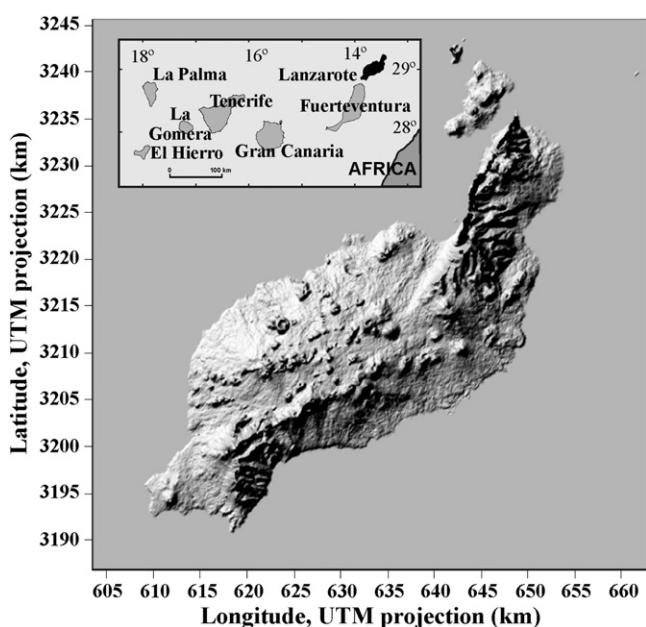


Fig. 1. Geographic location of Lanzarote Island, Canarian archipelago.

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