Journal of Volcanology and Geothermal Research 283 (2014) 66–72

Contents lists available at ScienceDirect

Journal of Volcanology and Geothermal Research

journal homepage: www.elsevier.com/locate/jvolgeores

# Helium isotope systematics of volcanic gases and thermal waters of Guadeloupe Island, Lesser Antilles

P. Jean-Baptiste [a,*], P. Allard [b], E. Fourré [a], F. Parello [c], A. Aiuppa [c]

[a] Laboratoire des Sciences du Climat et de l'Environnement, CEA-Saclay, Gif-sur-Yvette, France
[b] IPGP, UMR7154 CNRS, Sorbonne Cité, Paris, France
[c] DiSTEM, Università di Palermo, Palermo, Italy

ARTICLE INFO

*Article history:*
Received 19 April 2014
Accepted 4 July 2014
Available online 12 July 2014

*Keywords:*
Volcanic gases
Helium isotope
Carbon isotope
Guadeloupe

ABSTRACT

The island of Guadeloupe is located in the middle of the 850 km long Lesser Antilles island arc. Present-day volcanic and geothermal activity is concentrated in two systems both located in the southwestern part of the island (Basse Terre): the La Soufrière volcanic complex and the Bouillante hydrothermal system, some 20 km to the northwest of the volcano. We report here the largest isotopic data set for helium isotopes in hydrothermal gases and waters from both systems, acquired between 1980 and 2012. $^3He/^4He$ ratios in the fumarolic gases of La Soufrière volcano have been quite homogeneous and stable over the last thirty years. The average ratio of $8.2 \pm 0.2\ R_a$ confirms that the volcano is tapping a MORB-like mantle source. In contrast, the nearby Bouillante geothermal system displays a much lower $^3He/^4He$ ratio ($4.5 \pm 0.1\ R_a$). He–C elemental and isotopic relationships show that both systems are actually fed by the same magmatic source, and that their marked difference in $^3He/^4He$ results from the $^4He$ contamination of the Bouillante deep aquifer by the surrounding wallrock. This conclusion is strengthened by the spatial distribution of $^3He/^4He$ ratios which shows that La Soufrière fumaroles and the Bouillante geothermal system are the two end-members of a spatial trend of decreasing $^3He/^4He$ ratio with distance from La Soufrière summit dome, implying an increasing addition of radiogenic $^4He$ from the host rocks away from the present-day active volcanic edifice.

## 1. Introduction

Guadeloupe island belongs to the Lesser Antilles island arc, the active volcanic chain generated by the subduction of the Atlantic seafloor beneath the Caribbean plate (MacDonald et al., 2000). It is located in the middle of the arc, just south of the island of Montserrat. Present-day volcanism in Guadeloupe is active in Basse-Terre, the western part of the territory (Fig. 1). There, volcanic activity started some 3 million years ago (Briden et al., 1979; Samper et al., 2007). It migrated southward over time to give birth, some 200,000 years ago, to the Grande Découverte–La Soufrière volcanic complex (Boudon et al., 1989). The last eruption, in 1530 AD (Boudon et al., 2008), built the 0.05 $km^3$ andesitic lava dome of La Soufrière volcano, the highest landmark (1430 m asl) in Guadeloupe. Since then, intense hydrothermal activity has persisted at La Soufrière, including six phreatic eruptive phases. Volcanic gases are persistently released as fumaroles on and around the lava dome (Brombach et al., 2000; Ruzié et al., 2012) and as dissolved and/or bubbling gases in thermal springs around the volcanic edifice (Villemant et al., 2005; Ruzié et al., 2013).

Thermal manifestations are also widespread in the Bouillante area located on the coast some 20 km to the northwest of La Soufrière, including hot springs, fluids from geothermal wells, gas bubbling at sea (off the coastal area of Pointe Lézarde) and a deep submarine hot spring (−23 m) at the base of Ilet Pigeon (Fig. 1). The chemical composition of the thermal springs indicates a marked difference between both systems: the thermal springs of La Soufrière edifice are characteristics of young and shallow groundwaters of meteoric origin interacting with high temperature volcanic rocks and gases (Brombach et al., 2000). In contrast, Bouillante thermal waters, which have been studied intensively for their geothermal potential (Cormy et al., 1970; Demians D'Archambaud and Surcin, 1972, 1976; Sanjuan et al., 1999; Brombach et al., 2000), originate from a deeper, more mature aquifer with a marked Na–Cl composition showing the influence of marine waters. This deep aquifer is exploited for generating electricity by a geothermal power plant located on the coast and plans for future extension are being considered.

Helium isotopes are a powerful indicator of the extent of the mantle-derived contribution to crustal fluids (Ballentine et al., 2002). Their ratio varies by more than three orders of magnitude in terrestrial samples. This results from the distinct origins of $^3He$ (essentially primordial) and $^4He$ (produced by the radioactive decay of U and Th) and their contrasted proportions in the Earth's reservoirs. When referred to the

---

[*] Corresponding author.
*E-mail address:* pjb@lsce.ipsl.fr (P. Jean-Baptiste).

http://dx.doi.org/10.1016/j.jvolgeores.2014.07.003

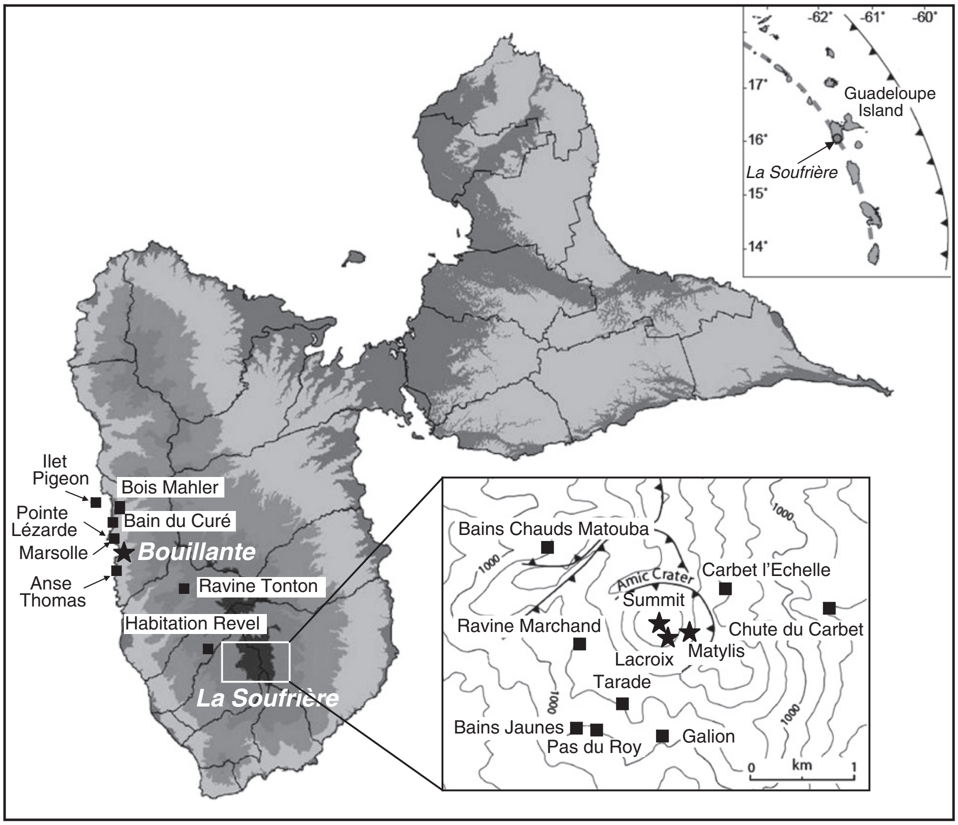

**Fig. 1.** Location map of the sampling points.

atmospheric ratio ($R_a = 1.38 \times 10^{-6}$), typical $^3He/^4He$ ratios vary from $<0.05\ R_a$ in the continental crust to $8 \pm 1\ R_a$ on average in MORB-type upper mantle, and up to ~ 40–50 $R_a$ in products of plume-related ocean islands, such as Hawaii and Iceland (Ballentine and Burnard, 2002; Graham, 2002; Stuart et al., 2003). Furthermore, helium closely follows carbon dioxide during magma degassing and the $CO_2/^3He$ ratio of volcanic gases is one important complementary indicator of their origin (Sano and Marty, 1995; Allard et al., 1997; Marty and Tolstikhin, 1998).

Previous studies of helium isotopes in Guadeloupe (van Soest et al., 1998; Pedroni et al., 1999; Ruzié et al., 2012, 2013) have concentrated mostly on La Soufrière system and have shown that the volcano is tapping a MORB-like source with $^3He/^4He$ values around 8 $R_a$. In contrast, two results from the Bouillante geothermal power plant (van Soest et al., 1998; Pedroni et al., 1999) indicate a much lower $^3He/^4He$ value (4.5 $R_a$), raising interrogations as to whether the Bouillante hydrothermal system is fed by a magmatic source distinct from that of La Soufrière. Here, we report the results of a study conducted from 1980 to 2012, covering the two systems of La Soufrière and Bouillante and comprising a total of 92 samples from 20 sites, including both free gases (fumaroles, gas bubbles, geothermal wells) and dissolved gases in hot springs. Some of the gas samples were also analysed for their carbon isotope ratio. The aim of this study was to investigate the helium isotope composition of the main geothermal manifestations of Basse-Terre (Guadeloupe), to map their spatial distribution, to study their temporal variability and to gain deeper insight into the source of the volcanic gases.

## 2. Sampling and methods

Our data set goes back to 1980 when the Lacroix fumaroles (now extinct) were sampled for the first time for helium isotopes (Allard, 1983; Allard et al., 1983). Our first extensive survey of the helium isotopic composition of the gases and hot springs was performed in 1995. The following campaigns took place in 1996, 1999, 2006 and 2012. Water samples for helium isotopes were collected in standard refrigeration grade 3/8" copper tubes equipped with metal clamps at both ends. The tubes were flushed with the water prior to closure using either the natural water flow or a peristaltic pump connected with Tygon tubing. Fumarolic gases where collected in copper tubes or pre-evacuated glass flasked with stopcocks. When present, gas bubbles in water were also collected in the same way using an inverted funnel. Prior to 2000, He analyses were performed at LSCE-Saclay using a VG-3000 mass spectrometer (Jean-Baptiste et al., 1992) and on a MAP-215-50 mass spectrometer with simultaneous helium and neon isotope determination afterwards (Jean-Baptiste et al., 2010). Gas samples were directly connected to the high-vacuum inlet system of the mass spectrometer. Helium and neon dissolved in the water samples were first extracted under vacuum into sealed glass tubes. Typical $^4He$ and $^{20}Ne$ blanks are $5 \times 10^{-10}$ and $3 \times 10^{-10}$ $cm^3$ STP for the mass spectrometer inlet, and $2 \times 10^{-9}$ and $1 \times 10^{-9}$ $cm^3$ STP for the extraction system, respectively. For gases, analytical uncertainties on $R/R_a$ and helium mixing ratio are $\pm 0.08$ and 0.1 ppm, respectively. Analytical precision on helium and neon concentrations and on $^3He/^4He$ ratios in water samples is better than 0.8%. Helium concentrations and isotopic ratios were corrected for the atmospheric air component using the measured $^{20}Ne/^4He$ ratio (when available) assuming a pure atmospheric origin for neon (Hilton, 1996). For the earlier samples for which no neon data were available, the helium volcanic component dissolved in water was obtained by subtracting the atmospheric air component at the solubility equilibrium (Weiss, 1971; Jean-Baptiste et al., 2009), and, for gas samples, from the measured co-amount of uncondensable gases assumed to be entirely atmospheric in origin. Comparison of the results given by both methods for waters (Table 2) shows that using the solubility