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# Chemical and isotopic characteristics of geothermal fluids from Sulphur Springs, Saint Lucia

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ABSTRACT

Sulphur Springs is a vigorous, geothermal field associated with the active Soufrière Volcanic Centre in southern Saint Lucia, Lesser Antilles island arc. The 'Sulphur Springs Park' is an important tourist attraction (touted as the 'world's only drive-through volcano') with some of the hot pools being developed into recreational pools. Some 200,000 people visit the park each year. Since 2001, the hydrothermal fluids of Sulphur Springs have been sampled as part of an integrated volcanic monitoring programme for the island. Gas and water samples were analysed to characterise the geochemistry of the hydrothermal system, and to assess the equilibrium state and subsurface temperatures of the reservoir. This has also enabled us, for the first time, to establish baseline data for future geochemical monitoring.

The gases are of typical arc-type composition, with $N_2$ excess and low He and Ar content. The dry gas composition is dominated by $CO_2$ (ranging from 601–993 mmol/mol), with deeper magmatic sourced $H_2S$-rich vapour undergoing boiling and redox changes in the geothermal reservoir to emerge with a hydrothermal signature in the fumarolic gases. Fluid contributions from magmatic degassing are also evident, mainly from the moderate to high contents of HCl and deeply-sourced $H_2S$ gas, respectively. Sulphur Springs hydrothermal waters have acid-sulphate type compositions ($SO_4$ = 78–4008 mg/L; pH = 3–7), and are of primarily meteoric origin which have been affected by evaporation processes based on the enrichment in both $\delta^{18}O$ and $\delta D$ ($\delta^{18}O = -1$ to 15‰ and $\delta D = -9$ to 14‰ respectively) in relation to the global meteoric water line (GMWL). These waters are steam-heated water typically formed by absorption of $H_2S$-rich gases in the near surface oxygenated groundwaters. Reservoir temperatures calculated from the evaluation of gas equilibria in the $CO_2$–$CH_4$–$H_2$ system reveal higher temperatures (190 to 300 °C) than those derived from quartz geothermometry (95 to 169 °C), which appeared to be affected by dilution with meteoric waters. Generally, no significant variations in fluid geochemistry of the hydrothermal system were observed between 2001 and 2006, and we propose that there were no changes in the state of volcanic activity during this period.



## 1. Introduction

While geochemical monitoring of volcanic-hydrothermal systems is commonly practiced at many volcanoes around the world, it is only recently that it was implemented as part of the ongoing volcanic surveillance programme of the University of the West Indies (UWI) Seismic Research Centre (SRC) for the English-speaking islands of the Lesser Antilles. This has, in general, primarily been due to a lack of financial and human resources in the region. In the French islands, geothermal monitoring of the volcanic-hydrothermal systems of La Soufrière (Guadeloupe) and Mt. Pelée (Martinique) has proven to be an important tool in volcanic surveillance and geothermal exploration (Bigot and Hammouya, 1987; Bigot et al., 1994; Brombach et al., 2000; Komorowski et al., 2002). The need to improve the understanding of, and provide baseline geochemical data for other poorly studied volcanoes in the Lesser Antilles was clearly recognised, and in November 2000 a geochemical monitoring programme in Dominica was initiated by the SRC. The data obtained from that study provided the first time-series observations used for the purpose of volcano monitoring, and permitted the characterisation of the geothermal fluids associated with volcanoes of Dominica (Joseph et al., 2011). The use of geochemical monitoring of springs, fumaroles, and bubbling gases in providing information about the hydrology of a geothermal system and conditions of the reservoir, has been recognised by many other researchers. This is especially important in the context of establishing baseline studies for future monitoring and understanding of the hydrothermal system during periods of quiescence (Rouwet et al., 2009b).

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In Latin America, several pioneering studies related to baseline geochemical monitoring of the fluids associated with volcanoes have been conducted. Amongst them are Giggenbach et al. (1990), who commenced a chemical surveillance programme of Nevado del Ruiz, Colombia in September 1985, three months prior to the major eruption that led to heavy loss of life. Their research revealed that the fumarolic discharges in September were essentially magmatic in composition with an increasing hydrothermal component up until the eruption. Fischer et al. (1997), began a sampling programme of fumarolic gases and spring discharges at Galeras volcano, Colombia over the period 1988 to 1995 when it had reactivated. Their study indicated that sampling of thermal springs for the evaluation of the extent, maturity and duration of hydrothermal activity at active volcanoes provided a good indicator for the possibility of sector collapse, unrelated to changes in actual magmatic activity. It also demonstrated how long-term chemical surveillance of springs and fumaroles makes a significant contribution to understanding volcanic activity, magma degassing and the sources of magmatic and hydrothermal volatiles. Initial geochemical studies of magmatic hydrothermal systems for use in volcanic surveillance have been conducted at Rincon de la Vieja volcano, Costa Rica, and in Northern Chile at the Arica-Parinacota, Tarapacá and Antofagasta regions, and Lascar volcano (Tassi et al., 2005, 2009, 2010); at Tacaná volcano, Mexico-Guatemala and El Chichón, Mexico (Rouwet et al., 2009a, 2009b; Tassi et al., 2003); at Puracé volcano and Cumbal volcano in Colombia (Sturchio et al., 1993; Lewicki et al., 2000); and San Vincente, El Salvador (Aiuppa et al., 1997).

The Sulphur Springs geothermal field, located in the Soufrière Volcanic Centre (SVC) in the south of Saint Lucia (Fig. 1), is one site that was chosen to initiate the geochemical monitoring programme in Saint Lucia in 2001. Sulphur Springs has been incorporated into a Park that is managed by the Soufrière Foundation and visited by locals and tourists all year round, with an average of 200,000 visitors per year. The physical dangers associated with the geothermal activity at Sulphur Springs have been demonstrated by historical occurrences of landslides, small phreatic and hydrothermal eruptions that eject ash into the surrounding atmosphere and by people falling into boiling mud pools. Several thermal pools at the site have been developed for recreational use including bathing, and the application of mud masques, as well as for therapeutic applications.

With the exception of geochemical data obtained from geothermal feasibility studies at Sulphur Springs, limited data is available on the evolution over time of the fluid composition of the hydrothermal system. This study presents an extensive description of the present-day manifestations and provides a data set to define the baseline for future geochemical monitoring, through the undertaking of time series monitoring of gas and water chemistry over the period 2001 to 2006. In this paper we (a) describe the chemical and isotopic compositional features of the hydrothermal fluids of Sulphur Springs; (b) revaluate the reservoir temperatures and state of equilibrium on the basis of gas and solute geothermometry; and (c) and look at the implications of geochemical surveillance on the overall volcano monitoring efforts in Saint Lucia.

## 2. Geological setting

### 2.1. Geology

The island of Saint Lucia, located in the southern region of the Lesser Antilles, is one of the larger islands of the arc, with an area of approximately 610 km$^2$. The most pronounced topographic feature is the N–S trending axial range with the highest mountain, Mount Gimie (950 m), located in the south-western part of the range (Fig. 1). Saint Lucia is made up almost entirely of volcanic rocks, but only one volcano, the Soufrière Volcanic Centre (SVC) in the southwest of the island, is considered to be potentially active (Lindsay et al., 2005). The youngest age dates available for large pyroclastic eruptions at the SVC are 20,000 years B.P. (Schmitt et al., 2010). Several lava domes and explosion craters have, however, formed since then

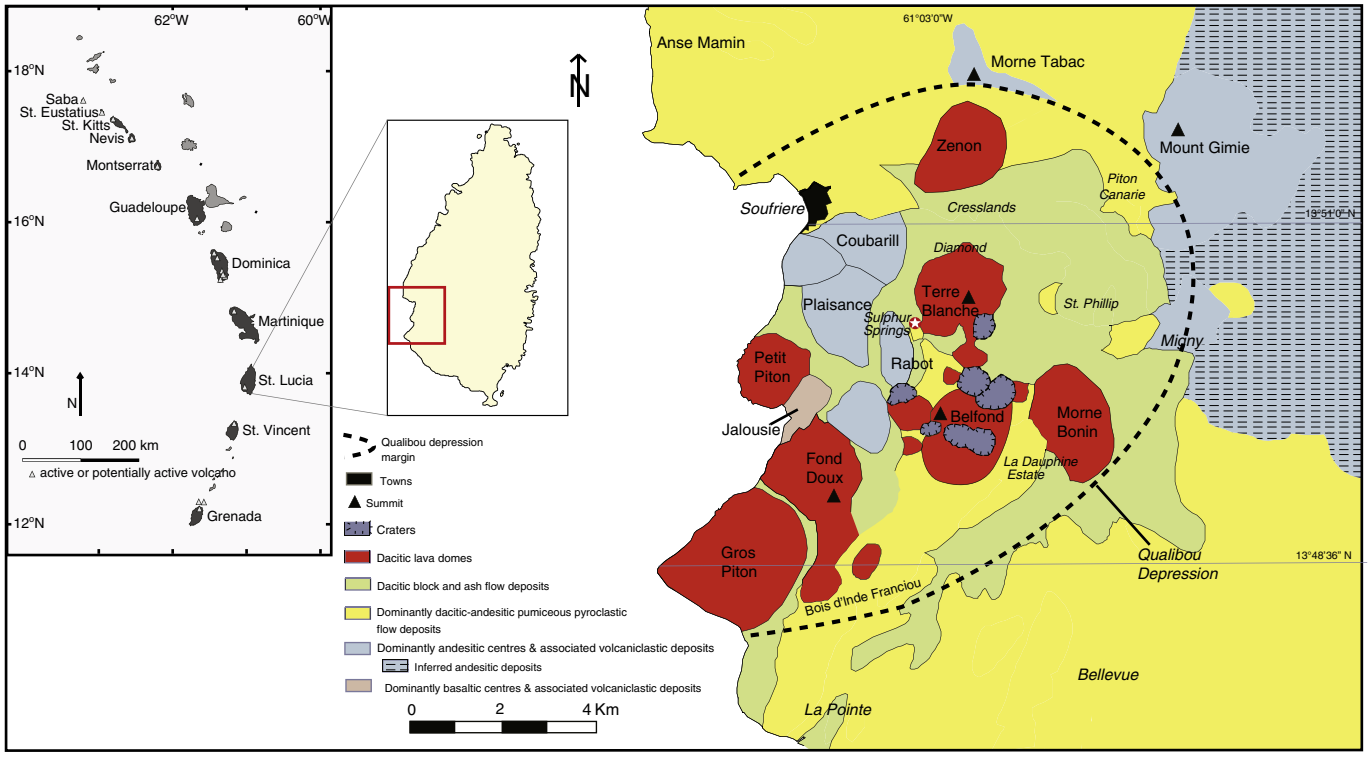


**Fig. 1.** Map of Lesser Antilles showing the location of Saint Lucia (left), and map of Saint Lucia showing an outline of the Qualibou Depression and main vents of the Soufriere Volcanic Centre (right).