Journal of Volcanology and Geothermal Research 206 (2011) 1–14

Contents lists available at ScienceDirect

Journal of Volcanology and Geothermal Research

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

Gas and water geochemistry of geothermal systems in Dominica, Lesser Antilles island arc

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ARTICLE INFO

Article history:
Received 2 December 2010
Accepted 19 June 2011
Available online 5 July 2011

Keywords:
Geothermal systems
Volcano monitoring
Fluid geochemistry
Dominica
Lesser Antilles

ABSTRACT

Four of the nine potentially active volcanoes on the island of Dominica in the Lesser Antilles volcanic island arc have associated active volcanic-hydrothermal systems. Between 2000 and 2006 the gas and thermal waters from these systems were investigated to geochemically characterise the fluids, gain insight into the temperature and equilibrium state of the underlying reservoirs, and evaluate the feasibility of monitoring geothermal features as a volcano surveillance tool in Dominica. The geothermal gases are typical of those found in arc-type settings, with N_2 excess and low amounts of He and Ar. The dry gas is dominated by CO_2 (ranging from 492 to 993 mmol/mol), and has a hydrothermal signature with hydrogen sulphide as the main sulphurous gas. The waters are predominantly acid-sulphate ($SO_4 = 100$–4200 mg/L, pH ≤ 4), and likely formed as a result of dilution of acidic gases in near surface oxygenated groundwater. Enrichment in both $\delta^{18}O$ and δD with respect to the global meteoric water line (GMWL) confirms that the waters are of primarily meteoric origin, but have been affected by evaporation processes. Quartz geothermometers gave equilibrium temperatures of 83 °C–203 °C. These temperatures contrast with the higher equilibrium temperature ranges (170 °C–350 °C) obtained for the gases using the H_2/Ar^*–CH_4/CO_2 gas ratios plot, suggesting that the quartz geothermometers are affected by non-attainment of equilibrium. This may be a result of precipitation of the dissolved silica and/or dilution by relatively cold shallow aquifers of the thermal fluids. Generally, no significant variations in fluid gas chemistry of the hydrothermal systems were observed during the study period, and we propose that there were no changes in the state of volcanic activity in this period. One exception to this occurred in a feature known as the Boiling Lake, which underwent a month-long period of significant compositional, temperature and water level fluctuations ascribed to a drastic decrease of hydrothermal input related to a perturbation in the lake (probably seismically induced). This geochemical study is part of an ongoing monitoring programme of Dominica geothermal systems, aimed at establishing long-term geochemical observations for the purpose of volcano monitoring.

1. Introduction

The high mobility of magmatic volatiles, much greater than that of magma itself, makes them valuable indicators of change in the state of activity of volcanic systems (Menyailov et al., 1985; Cioni et al., 1989; Giggenbach et al., 1990; Giggenbach, 1997; Brombach et al., 2000; Fischer, 2002). The recording of changes in the chemistry of hot springs and fumaroles associated with volcanic-hydrothermal systems, and its use as a tool for monitoring volcanic activity has been outlined by many authors (Aguilera et al., 2005; Caracausi et al., 2005; Tassi et al., 2005; Lopez et al., 2006; Principe and Marini, 2008; Taran et al., 2008). This technique has been thus far under-utilised in the volcanic islands of the Lesser Antilles, and as a result there is a lack of long-term geochemical surveillance data for the region.

The Lesser Antilles arc includes 21 potentially active volcanoes spread across 11 volcanically active islands (Fig. 1), and volcanic eruptions are one of the main hazards that threaten the eastern Caribbean region. Most of the islands of the Lesser Antilles (e.g. Saba, Statia, Nevis, Montserrat, Guadeloupe, and Saint Vincent) have a single main vent. The other islands are more complicated, and none more so than Dominica, which has nine young volcanic centres resulting in an exceptionally high level of volcanic risk (Lindsay et al., 2005). Many of these islands have active geothermal systems associated with the young volcanic activity, and in the French islands (Guadeloupe and Martinique) geothermal monitoring is part of routine volcano surveillance (Bigot and Hammouya, 1987; Bigot et al., 1994; Komorowski et al., 2002).

Robson and Willmore (1955) performed the first investigations of geothermal systems in the Lesser Antilles. Their studies involved the measurement of thermal outputs of several geothermal areas in the

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0377-0273/$ – see front matter
doi:10.1016/j.jvolgeores.2011.06.007

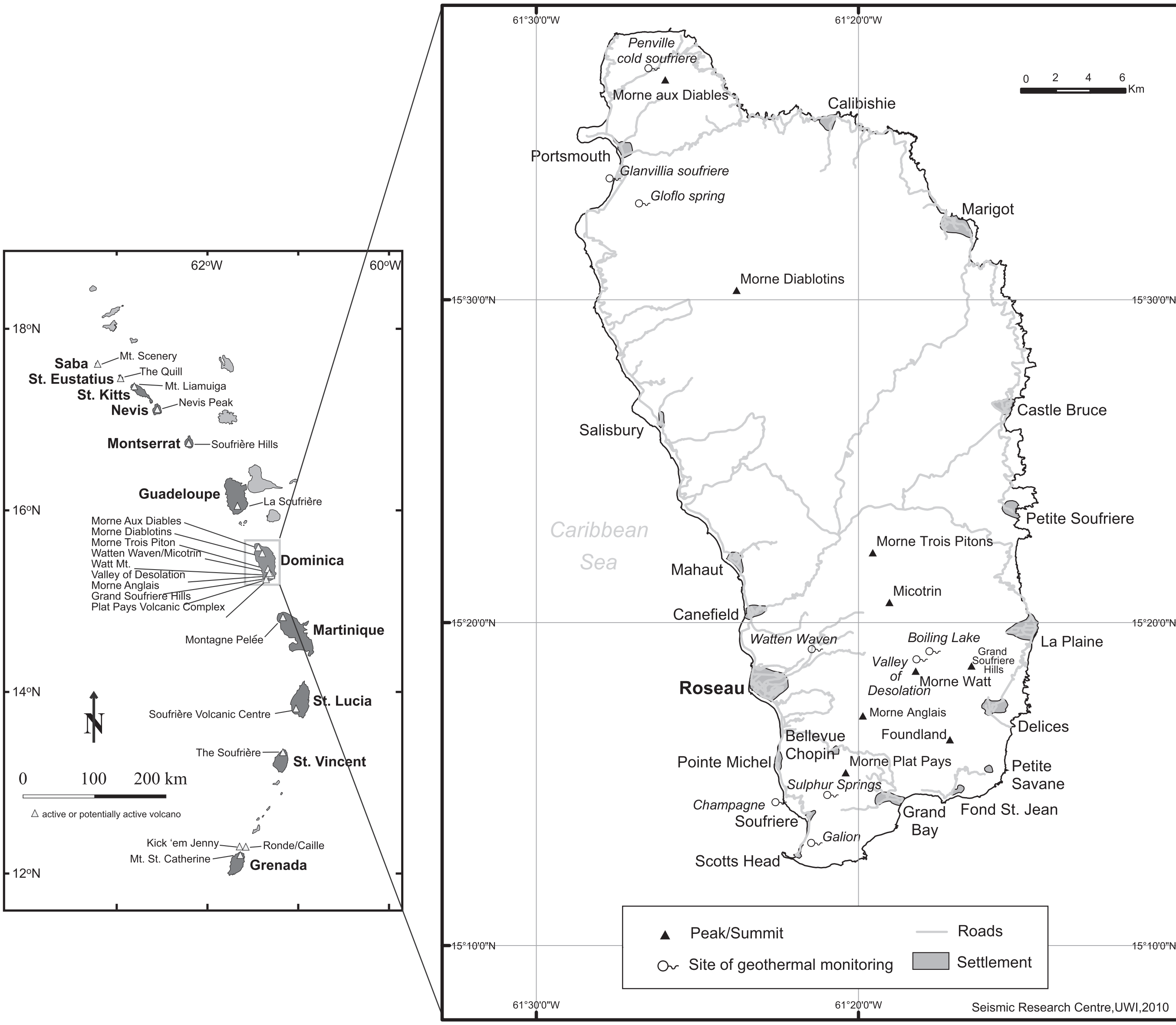

Fig. 1. Map of the Lesser Antilles showing the location of Dominica (left) and a map of Dominica showing sites of geothermal activity and monitoring (right).

Lesser Antilles, including Dominica, and their contribution to the overall heat balance of the Earth. Research into He, Ne, Sr, Ar and C isotopes of hydrothermal fluids in the Lesser Antilles was later carried out by Pedroni et al. (1999) and Van Soest et al., (1998). These studies focused on the use of these isotopes to trace the recycling of subducted terrigenous sediments in arc magmas, through volatile provenance at summit fumaroles. Oxygen and hydrogen isotopic composition of hydrothermal brines from Dominica reported by Pedroni et al. (1999) showed an essentially meteoric-hydrothermal origin, while isotope compositions, element ratios, and concentrations of Ne and Ar suggested that these noble gases were almost wholly derived from the atmosphere.

More recently, Herlihy et al. (2005) conducted studies relating the geology of Dominica with the geochemistry of associated hot springs. They categorised most of the hot springs studied as Ca–Mg–SO_4 type in chemistry, and stable isotopic analyses of $\delta^{18}O$ and δD suggested that water–rock interaction and alteration had occurred. A more specific study of the geothermal springs in northern Dominica was conducted by Harrell et al. (2008). They analysed $\delta^{18}O$ and δD isotopes of these springs compared to Vienna Standard Mean Ocean Water (VSMOW) and found that they lie on a trend between the meteoric water line (MWL) and a magmatic source, in contrast to other studies which showed a meteoric origin affected by water–rock interaction. Furthermore, the chemical composition of the springs was interpreted to represent mixing of variable amounts of freshwater or seawater with a magmatic source that appeared to be constant for the northern springs. Four of the nine young volcanic centres in Dominica have associated geothermal activity in the form of hot and cold springs, fumaroles, mud pools, and steaming ground. A complete data set of chemical and isotopic compositions of the geothermal gas and waters from these features may improve our understanding of the dynamics of the island's volcanic systems, complement the existing routine seismic monitoring programme; as well as contribute to a more long-term geochemical surveillance of these volcanic systems.

In this paper we describe and report on the chemical composition of fumarolic and hydrothermal spring discharges of Dominica based on gas and water samples collected during the period 2000 to 2006. We discuss the origin of the discharged fluids, and we propose an evaluation of the hydrothermal reservoir temperatures on the basis of fluid geochemistry. This information is then used to make recommendations on the usefulness of long-term geochemical observation as part of the overall volcano monitoring efforts on the island.