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# Magma transfer and degassing budget: Application to the 2009–2010 eruptive crisis of Mt Garet (Vanuatu arc)

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ABSTRACT

Mt Garet, on Gaua Island, is one of the active volcanoes of the Vanuatu arc. We report here a new dataset on lapilli and lava erupted during Mt Garet unrest in 2009–2010 and on products of the older activity of Gaua composite volcano. The present-day magma of Mt Garet is a trachy-andesite (52 wt.% $SiO_2$) with relatively high Rb/Th (14.6) and Ba/La (41) ratios compared to the Gaua pre- and syn-caldera series, but typical of the central part of Vanuatu arc. Its mineral assemblage is mainly composed of plagioclase ($An_{86–56}$) and clinopyroxene ($Fs_{5–16}$) which display significant chemical variations, patchy zones, surface dissolution, and oscillatory zoning that imply episodes of high undercooling and growth rates. The paragenesis is complemented by Fe–Ti oxides and scarce olivine ($Fo_{72–73}$). The melt inclusions are ubiquitous and their compositions cover a chemical spectrum from basalt to trachy-andesite. Volatile-rich basaltic inclusions ($H_2O$: 2.7 wt.%, S: 0.15 wt.%, and Cl: 0.22 wt.%) are preserved in Mg-rich clinopyroxene whereas the majority of the melt inclusions is volatile poorer with, ≤1.0 wt.% of $H_2O$, ≤0.05 wt.% of S, and 0.25–0.27 wt.% of Cl. At 1100 °C the measured viscosity of anhydrous magma of Mt Garet is $10^{3.5}$ Pa s. Adding 0.8 to 2.5 wt.% of $H_2O$ decreases the melt viscosity by 0.5 to two orders of magnitude. Combining data on bulk rocks, minerals, and their melt inclusions together with the very first published gas fluxes acquired during the same period of activity, we propose that the high sulfur outgassing in 2009–2010 was produced by the degassing of a basaltic magma batch (~0.027 $km^3$) emplaced in a shallow reservoir. This scenario would require temperature and $H_2O$-loss driven resorption/crystallization, magma mixing, and exsolution of an early gas phase rich in $H_2O$, and S.

We suggest here the 2009–2010 activity to be sustained by the existence of thermal convection driven at the bottom of the magma reservoir by cooling, and in which the bubbles are small enough to be stagnant. The most energetic phases are better explained by an additional gas volume, associated to the crystallization of titanomagnetite microcrysts which significantly enhance bubble nucleation. The ultimate step of crystal growth prior to eruption suggests magma ascent within few hours.



## 1. Introduction

The Vanuatu island arc, in the Southwest Pacific, is known for its very active and large volcanoes as those on Ambrym Island (Németh and Cronin, 2008) and for the permanent strombolian/vulcanian activity of Yasur (Tanna island) which was first reported by Captain Cook in 1774 (e.g., Aubert de la Rüe, 1960). Recent airborne measurements of $SO_2$ emission rates, between 2009 and 2012, indicated that the Vanuatu arc is one of the prominent sources of volcanic degassing on Earth (Bani et al., 2012). The very first and only data set presently available for Mt Garet, the active cone of Gaua Island in the central segment of Vanuatu arc, revealed a high $SO_2$ flux of, on average, 2959 t per day in October–December 2009 period of activity (Bani et al., 2012).

Mt Garet is a 460 m high cone that is built up within the summit caldera of a large composite volcano. It was covered by a forest until 1962 when a long period of rest, dated back at least to 1868, ended (Mallick and Ash, 1975). Since 1962, Mt Garet has recurrently produced ash, white steams and gas plumes, and the water of Lake Letas has been periodically discolored (e.g., Mallick and Ash, 1975; Bani et al., in this volume). The last intense explosive activity was documented in 2009–2010, with repeated emissions of several km-high ash-laden plumes, which forced the evacuation of villages located downwind to the trade winds. Since Mallick and Ash (1975), very few data have been published on Gaua volcanic products (e.g., Robin et al., 1995; Peate et al., 1997;

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Beaumais et al. in this volume), and nothing was known about the present-day magmas of Mt Garet.

The present work provides a comprehensive dataset on the geochemistry and mineralogy of the Mt Garet magma, which erupted explosively in 2009–2010, and aims at deciphering the degassing processes that led to high $SO_2$ emissions and ash clouds. We report here also a new sampling of the pre- and syn-caldera activities of Gaua stratovolcano. Our sample set has provided the opportunity to build up a coherent database on geochemistry and mineralogy of the 2009–2010 products, and, for the first time, has shed light on the present-day volcanic activity of Mt Garet in the framework of Gaua volcano.

## 2. Geological background and sampling

Gaua Island, originally called Santa Maria (Mallick and Ash, 1975), is located in the central segment of the Vanuatu arc (Fig. 1), where the D'Entrecasteaux ridge — a 100 km wide Eocene–Oligocene island arc complex on the Australian subducting plate collides with the fore-arc (e.g., Collot et al., 1985) and the sub-marine West Torres Plateau is subducted (Meffre and Crawford, 2001). Arc-ridge collision, facing deep back-arc basins, is thought to be responsible of crustal shortening (Pelletier et al., 1998) and slow down of the convergence rate at the plate boundary (e.g., Baillard et al., 2013). Gaua lies on the northern edge of Aoba back-arc basin, ca. 200 km above the surface of the slab which dips at ca.70° (e.g., Syracuse and Abers, 2006). The island is formed by a large Pleistocene–Holocene composite volcano, of approximately 2400 m in height, with a summit caldera (6 × 9 km; Mallick and Ash, 1975). The pre-caldera activity of Gaua volcano mainly produced basalts and andesites (Mallick and Ash, 1975). The caldera formation has been related to a phreatomagmatic eruption and massive discharge of a chemically layered magma chamber (Robin et al., 1995) or a process of slow, non-explosive subsidence (Mallick and Ash, 1975) as also discussed in the case of Ambrym volcanoes (Németh and Cronin, 2008). Mt Garet emerges from the Lake Letas that fills the volcano summit caldera (Fig. 1).

Lava and pyroclastic rocks representing different periods of activity of Gaua volcano were collected during a field mission in September 2010 (Fig. 1). Following Mallick and Ash (1975), the pre-caldera stage samples were collected from (i) the strombolian scoria fall deposits of Burilan and Devil Rock littoral cones (Gaua 9b, 11, 12a), and (ii) a pyroclastic flow deposit of white pumice (Gaua 14), which was observed for the first time in a ca. 10-m thick succession of ash and scoria layers, cropping out along the sea near Bushman bay, on the west coast. We also sampled blocks of obsidian (Gaua 21) and banded pumice (Gaua 22) at the river mouth at Losolava village, along the northeast coast. Obsidian blocks were first attributed to the syn-caldera plinian phase by Robin et al. (1995). Although the stratigraphic position of these samples is unknown, they come most likely from a fallout deposit in the caldera wall. They differ in texture and composition (as detailed hereafter) from the juvenile fraction of the syn-caldera pyroclastic flow deposits and could instead belong to the pre-caldera stage.

The juvenile components, as well preserved scoriae and bread-crust bombs, of recent pyroclastic flow deposits were sampled (Gaua 17, 24, 25b) along the northern coast at Bushman Bay, where they are well exposed. These deposits were ascribed to the large caldera-forming eruption by Robin et al. (1995).

Ankaramites (Gaua 4), recognized for long time on Gaua (Mallick and Ash, 1975), are emplaced as lava flows on the SW coast. They were not attributed to a precise period of the stratovolcano activity because of the absence of unequivocal stratigraphic relationships between the deposits. Other samples of lava flow (Gaua 2) and associated cone (Gaua 3) near Ontar village on the SW coast, which were previously described as ankaramites, are basaltic trachy-andesites as proved by chemical analyses (Table 1).

The lapilli and lava blocks of 2009–2010 explosive activity of Mt Garet were collected during the eruptive crisis which was preceded by strong gas release that caused the complete burning of vegetation on the NW sector of the cone. The first eye-witness accounts, on 29 September 2009, reported strong explosions propelling an ash laden, umbrella-shape plume, which could have reached 3 km in height. In the following two months many explosions associated with ash emissions were recorded by a seismic station installed on the island and observed by the inhabitants (Bulletin of the Global Volcanism Network, 2009). Since mid-December the ash emissions were continuous and ash fallouts significant. In January–February the explosive activity increased culminating in stronger explosions on 27th and 29th of January and 4th of February (Bulletin of the Global Volcanism Network, 2009). Emission of ash plumes is reported until June 2010 (Bulletin of the Global Volcanism Network, 2010). Scoria lapilli emitted early 2010, which were accumulating along shores of Lake Letas (Gaua 27A) and floating on the lake surface (Gaua 27B), were sampled on 4th of

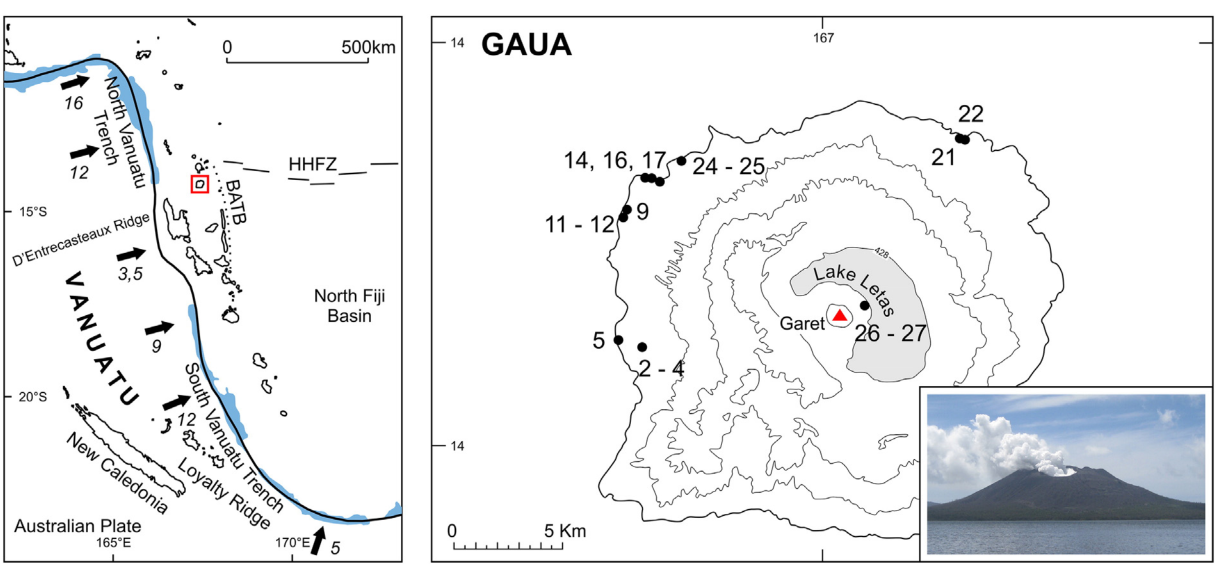


**Fig. 1.** Map showing Vanuatu (previous New Hebrides) arc in southwest Pacific, the convergence rates (indicated by arrows in cm year$^{-1}$), and the location of Gaua volcanic island redrawn from Pelletier et al. (1998), and Calmant et al. (2003), on the left. Schematic map of Gaua Island redrawn from Beaumais et al. (in this volume) with the 2010 sampling sites on the right. The photograph by E. Garaebiti shows Mt Garet and Lake Letas on 30 September 2010.

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