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# The eruptive history of Morne Jacob volcano (Martinique Island, French West Indies): Geochronology, geomorphology and geochemistry of the earliest volcanism in the recent Lesser Antilles arc

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ABSTRACT

Martinique is the Lesser Antilles Island where the most complete volcanic history of the arc can be found from the Oligocene to the present time. In this study, we focused on the construction of Morne Jacob shield volcano in Martinique, which is the largest volcano of the Lesser Antilles. We have dated twenty representative samples from the Morne Jacob, by K–Ar based on the Cassignol–Gillot technique, used geochemical data and obtained morphological constraints that have helped us to reconstruct better the volcanic history of this shield volcano. Our results and the lack of reliable ages on other Plio-Pleistocene islands show that the Morne Jacob is the oldest volcano of the aerial recent arc that has been dated so far. It has a longer history than previously inferred, with different stages ranging between 5.2 and 1.5 Ma. A large basaltic to andesitic shield volcano was first built between 5.2 and 4.0 Ma (J1) with tholeiitic lavas characterized by an increase of $SiO_2$ content through time. After 800 kyr of repose, calc–alkaline andesites erupted over the first shield from 3.2 to 2.2 Ma (J2a). The accumulation of lavas over a hyaloclastitic basement provoked spreading and northeast creeping of the northern flank of the volcano. The mass movement induced regressive erosion, particularly at the centre of the edifice. Then, between 2.1 and 1.5 Ma (J2b), calc–alkaline lavas, which show a decrease of the $SiO_2$ content through time, erupted at the central vent and from peripheral fissures, over the previous shield and down to the Caribbean coast. Eruptive volumes were reconstructed, permitting estimates of minimum output rates for the volcano's history. Minimum volume erupted during the first stage is $112 \pm 20$ km$^3$ and $33 \pm 25$ km$^3$ during the whole second stage, yielding rates of about 0.107 km$^3$/kyr and 0.019 km$^3$/kyr, respectively. Considering the entire history of Morne Jacob shield volcano, between $5.14 \pm 0.07$ and $1.54 \pm 0.03$ Ma, we obtain a total volume of $145 \pm 32$ km$^3$ above the sea level, and a time-averaged construction rate of $0.040 \pm 0.008$ km$^3$/kyr. With comparison between the reconstructed paleotopographies and the DEM of present topography, we have calculated an eroded volume of 18 km$^3$ over the outcropping 210 km$^2$ that have occurred during the last 1.5 Myr. Finally, our set of twenty K–Ar ages, obtained on groundmass separates, allow us to revise the eruptive chronology of Morne Jacob volcano and to date the earliest subaerial volcanic activity so far identified for the recent Lesser Antilles arc.



## 1. Introduction

Coupled with petrographic and geochemical studies, geochronological investigations can provide valuable insights with regards to the compositional evolution of a volcanic complex. Similarly, determining the growth rate and the evolution of a given volcano is critical to understand timing of magmatic and eruptive processes, to identify any possible periodicity of volcanic episodes, and, to a broader extent, to complete the global database of volcanic output rates.

Martinique, located in the central Lesser Antilles arc (Fig. 1), is a 1100 km$^2$ island built during the last 25 Myr (Germa et al., submitted for publication). Its northern part is made of four Plio-Pleistocene volcanic complexes (Morne Jacob, Pitons du Carbet, Mount Conil and Mount Pelée), built along the recent and internal arc called the Volcanic Caribbees. Previous K–Ar dating of whole-rock samples has indicated a 7 Myr history for this recent arc (Briden et al., 1979), based on the oldest ages obtained on Dominica ($6.65 \pm 1$ Ma; Bellon, 1988), Saint Lucia ($5.94 \pm 0.23$ Ma; Briden et al., 1979) and Carriacou ($6.92 \pm 0.27$ Ma; Briden et al., 1979). However, the ages previously obtained have a questionable reliability. Recent geochronological studies on Basse-Terre de Guadeloupe (Carlut et al., 2000; Samper et al., 2007, 2009), and at Montserrat (Harford et al., 2002) have highlighted large

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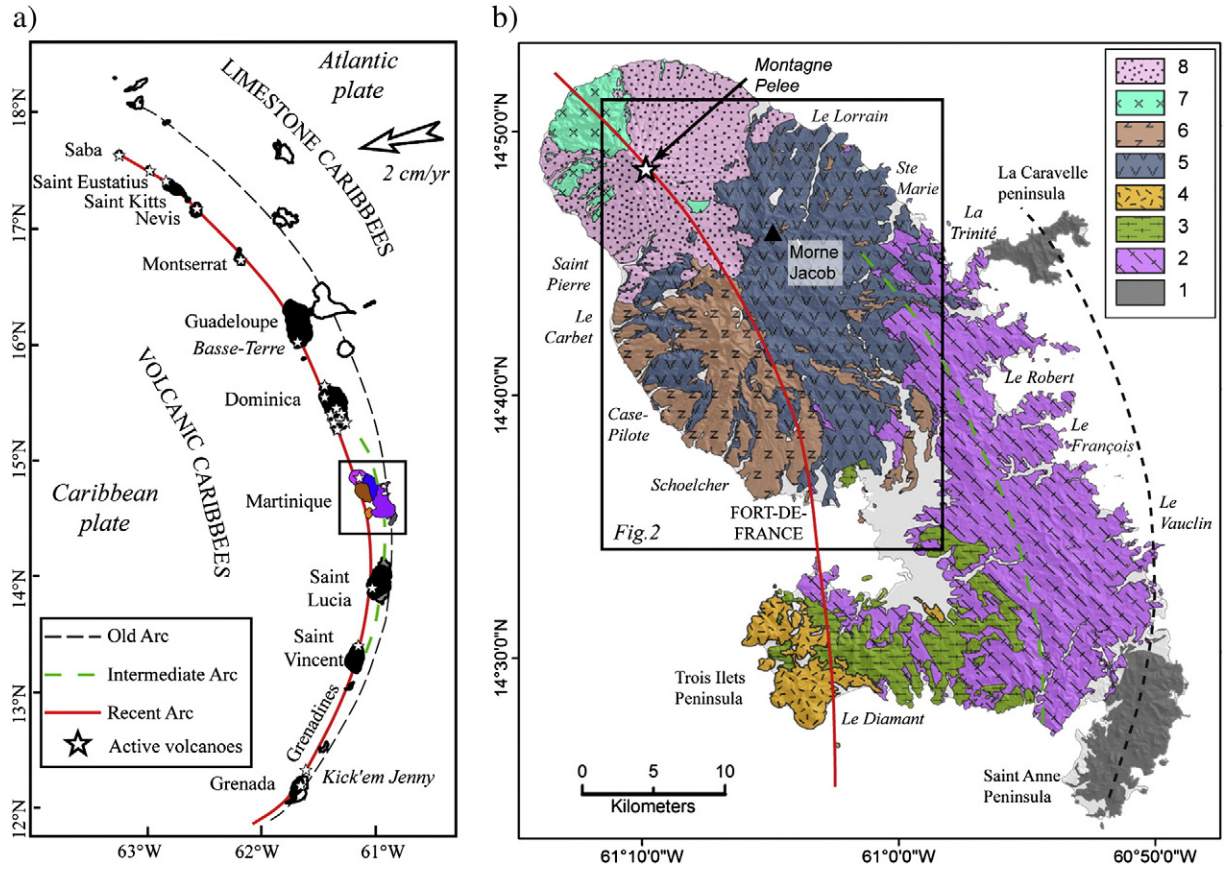


**Fig. 1.** a) Geodynamic setting of the Lesser Antilles arc. White arrow shows the direction of the subduction of the Atlantic plate under the Caribbean plate. The black dashed line locates the front of the Old arc, the green dashed line locates the intermediate arc, and the red bold line locates the volcanic front of the Recent arc. b) Schematic geological map of Martinique Island, simplified after Westercamp et al. (1989) and using ages of Germa (2008). 1: Basal Complex and Sainte Anne Series (24.8 ± 0.4 to 20.8 ± 0.4 Ma, Germa et al., submitted for publication), 2: Vauclin–Pitault submarine chain (16.12 ± 0.23–8.48 ± 0.14 Ma), 3: South-Western Volcanism (9.89 ± 0.14–7.09 ± 0.10 Ma), 4: Trois Ilets Volcanism (2.358 ± 0.034–0.346 ± 0.027 Ma), 5: Morne Jacob Shield Volcano, 6: Carbet Complex (0.998 ± 0.014–0.322 ± 0.006 Ma), 7: Conil Complex (0.543 ± 0.008–0.126 ± 0.002 Ma), 8: Mount Pelée (0.126 ± 0.002 Ma–present). Extent of Fig. 2 is located with the square.

discrepancies, regarding both magnetic polarity and geological evolution, with the earlier results obtained by whole-rock K–Ar (Bellon et al., 1974; Andreieff et al., 1976; Nagle et al., 1976; Briden et al., 1979; Andreieff et al., 1988) due, most probably, to the use of whole-rock dating and, in some cases, of weathered samples. These recent papers highlight the importance of using current geochronological methods to obtain reliable chronologies.

Except for Guadeloupe Island, no exact data about areas and volumes of individual edifices exist for the main volcanically active islands. Whereas northern islands are small, with areas less than 115 km$^2$, central and southern islands are larger with areas between 300 and 900 km$^2$. The largest island is Basse-Terre, Guadeloupe (~850 km$^2$), constituted by two old massifs to the north, and by the Axial Chain to the south (~450 km$^2$), which is made of four imbricate edifices with a total volume of 180 km$^3$ (Samper et al., 2007). In northern Martinique, Morne Jacob volcano is a large single shield volcano, with lavas ranging from basalts to andesites. It covers an area of more than 350 km$^2$, and thus can be considered as the largest volcano of the Lesser Antilles. Its north-eastern flank exhibits a U-shaped structure, open to the northeast, in which lies the main summit of the complex. Previous whole-rock K–Ar dating indicated a 3 Myr history for this volcano, divided into two main stages (1) between 5.5 and 4 Ma, and (2) between 2.8 and 2.2 Ma (Westercamp et al., 1989).

Although the evolution of the main active volcanoes from the Lesser Antilles Island arc is relatively well documented, only a few reliable age and volume data allowing eruptive rates calculations are available (Montserrat: Harford et al., 2002; Guadeloupe: Samper et al., 2007). However, such approaches have been recently conducted, for other arc stratovolcanoes built on oceanic crust (Seguam Island: Jicha and Singer, 2006) as well as in continental setting (Mount Adams: Hildreth and Lanphere, 1994; Tatara–San Pedro: Singer et al., 1997; Mount Baker: Hildreth et al., 2003a; Katmai cluster: Hildreth et al., 2003b; Ceboruco-San Pedro: Frey et al., 2004; Tequila Volcanic field: Lewis-Kenedi et al., 2005; Parinacota: Hora et al., 2007). These studies have shown that eruptive rates are highly variable in subduction zones, with peak rates during cone building ranging from 0.02 to 0.79 km$^3$/kyr for volcanism younger than 1 Ma. The estimates for Morne Jacob volcano construction rates obtained here for the first time will contribute to Lesser Antilles and global compilations of magmatic output rates in various geodynamic contexts (e.g., Crisp, 1984; White et al., 2006).

The main purposes of this study are to use high-precision groundmass K–Ar geochronology, Geographical Information System (GIS) modelling, and geochemical analyses to recover the full volcanic history and constrain better the duration of activity of each building stage of the Morne Jacob shield volcano, as well as to quantify their volume and eruptive rates.

## 2. Geological setting

Martinique is located in the central part of the Lesser Antilles Island arc, which results from the westward subduction of the Atlantic plate under the Caribbean plate (Fig. 1). Whereas in the southern part of the arc, volcanic activity occurred along a single SW–NE axis, the northern part experienced a westward jump of the volcanic front and