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Construction and destruction rates of volcanoes within tropical environment: Examples from the Basse-Terre Island (Guadeloupe, Lesser Antilles)

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ABSTRACT

In order to better constrain the construction and the erosion rate affecting the volcanic island of Basse-Terre Island (Guadeloupe, F.W.I.), an enlarged K–Ar age dataset has been combined with reconstruction of the paleo-topography. Two different methods of interpolation of the present topography have been cross-checked to better support the erosion rates obtained and their associated uncertainties. The present study focusses on the Monts-Caraïbes volcanoes and on the main geomorphic feature of the Piton de Bouillante volcano, the Beaugendre Valley. The Monts-Caraïbes volcanoes were constructed in 83 kyr at a rate of 0.12 ± 0.04 km^3/kyr. During the last 450 kyr, they have experienced an erosion rate of 610 ± 550 t/km^2/yr. In the Piton de Bouillante volcano eleven new K–Ar ages have been obtained, constraining the duration of its volcanic activity between 880 ± 14 and 712 ± 12 ka, and involving a construction rate of 0.70 ± 0.20 km^3/kyr. For this volcano, an erosion rate of 1220 ± 700 t/km^2/yr has been obtained for the last 700 kyr. Our study also shows, based on the contemporaneity of the ages in the entire Beaugendre Valley added to the mean erosion rate of 1350 ± 550 t/km^2/yr, that the flank collapse hypothesis cannot explain the formation of this valley. Finally, the similarity of the erosion rates computed for different locations of the Basse-Terre Island shows that the time-integrated erosion appears independent to the trade wind effect and suggests that the barrier effect due to the relief is not present here.

1. Introduction

The current geomorphology of volcanic islands results from both constructive and destructive (slow erosion to giant flank collapse) processes (e.g. Thouret, 1999). Although instantaneous flank collapses can occur repeatedly on volcanic islands (e.g. McGuire, 1996; Deplus et al., 2001; Hildenbrand et al., 2004; Boudon et al., 2007), long-term erosion remains often the dominant factor for dismantling volcanic massifs, especially when they are located within a tropical climate (e.g. Salvany et al., 2012). Even through the erosion processes and the factors controlling them (e.g. water discharge, relief and slope angle, chemistry and hardness of the material) are relatively well known, the erosion rates, especially over the long term, are still poorly documented. Several studies proposing erosion rates have been conducted across the globe but they are mainly based on the present-day chemical erosion budget, hence determined over a short time interval (e.g. Louvat and Allègre, 1997; Louvat and Allègre, 1998; Rad et al., 2006). Only a few studies have aimed to constrain the mechanical and/or total erosion affecting volcanic surfaces over a long time interval (Le Friant et al., 2004; Samper et al., 2007; Hildenbrand et al., 2008; Germa et al., 2010; Karátson et al., 2012; Salvany et al., 2012).

Located in a tropical climate, involving high average annual temperature and heavy rainfall (1500–3000 mm/yr) with a torrential hydrologic regime, combined with a relatively homogeneous andesitic lithology inducing sharp reliefs, Basse-Terre Island (Guadeloupe archipelago) undergoes significant erosion. This makes this island an especially suitable place to quantify long-term erosion processes. On this island, estimation of total erosion rate has been previously proposed based on determination of only the present-day chemical erosion rate (Rad et al., 2006; Rad, 2007; Rad et al., 2013). However, in addition to the surprisingly wide range of erosion rates obtained, such an approach constrains the erosion rate only over a very short time interval (on the order of a few years) and does not take into account extreme climatic events like storms and hurricanes regularly affecting Basse-Terre Island, and which, most probably, contribute significantly to the erosion budget. Furthermore, the decrease of the erosion rate through time, with rivers reaching their equilibrium profile, is also not considered with such approach.

In the present study, we propose to combine accurate K–Ar geochronological data obtained using the Cassignol–Gillot technique, which is particularly suitable for Quaternary volcanoes and/or low-K lavas (e.g. Gillot et al., 2006), with DEM geomorphological analyses. It allows the evolution of paleo-surfaces through time to be computed in order to

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better constrain the volumes dismantled and the erosion rates associated with long time intervals, including all the geodynamic, structural and climatic factors.

In order to test the topographic effect in controlling rainfalls and resulting erosion, we focus on two different locations within Basse-Terre Island: the Monts-Caraïbes and the Piton de Bouillante volcanoes, two geomorphologically distinct volcanic massifs, located on the southernmost part and on the southwestern coast of the island, respectively.

2. Geological setting

The Lesser Antilles volcanic arc results from the intra-oceanic subduction of the North and South American plates beneath the Caribbean plate with a convergence rate of about 2 cm/yr (e.g., DeMets et al., 2000). This 800 km-long volcanic arc, made of twenty main islands, consists of two distinct branches merging in the southern part. To the east, the old arc (external arc), which was active from the Eocene to the Oligocene, is now covered by Miocene to Pleistocene-Quaternary limestones. To the west, the recent arc (inner arc) has been active since the early Pliocene (Bouysse and Garrabe, 1984; Wadge and Shepherd, 1984; Fig. 1A).

Located in the northern part of the recent arc within the Guadeloupe archipelago, Basse-Terre Island results from the activity of six main volcanic massifs, showing an overall southward migration. In the northern half of the island, the Basal Complex (2.79 ± 0.04–2.68 ± 0.04 Ma) and the Septentrional Chain (1.81 ± 0.03–1.15 ± 0.02 Ma), made of eroded composite volcanoes following a NNW–SSE trending lineament, are located within the extension of the Eperon of Bertrand–Falmouth faults system (Feuillet et al., 2001; Samper et al., 2007; Figs. 1B, 2A).

In the southern part of the island, the Axial Chain, dated to 1.023 ± 0.025 to 0.435 ± 0.008 Ma, was shaped by NW–SE striking alignment of composite volcanoes guided by the Montserrat–Bouillante strike–slip fault zone (Blanc, 1983; Carlut et al., 2000; Feuillet, 2000; Samper et al., 2007; Figs. 1B, 2A). In its northwestern part, the Bouillante province, which was active between 1.2 and 0.6 Ma, is composed of a succession of small submarine and sub-aerial monogenetic vents displaying a wide range of petrological compositions from basalt to rhyolite (Briden et al., 1979; Blanc, 1983; Carlut et al., 2000; Fig. 2A). Furthermore, this volcanic province is cross-cut by numerous local faults (Feuillet et al., 2002; Mathieu et al., 2011; Calcagno et al., 2012). Within the Axial Chain, the Piton de Bouillante volcano is located at the junction of three regional fault systems, the NNW–SSE Montserrat–Bouillante sinistral strike–slip fault system to the north, the E–W to ESE–WNW Bouillante–Capesterre normal fault zone to the east, and the western termination of the WNW–ESE volcano-tectonic depression of the Marie-Galante graben system to the south (Feuillet et al., 2002; Thinon et al., 2010; Calcagno et al., 2012). This volcanic massif, particularly studied with regard to its geothermal potential, is incised to the west by the deep Beaugendre Valley (Fig. 2). Its origin is currently debated, and attributed either to a caldera collapse (Westercamp and Tazieff, 1980; Dagain, 1981) a flank collapse (e.g. Boudon, 1987; Feuillet, 2000; Boudon et al., 2007; Mathieu et al., 2011), a structural deformation (normal or strike–slip faulting), or to long-term erosion processes (Samper et al., 2007; Fig. 2). Therefore, the Beaugendre Valley represents an interesting morphological structure which is worth concentrating on in order to study erosional processes.

The southernmost part of Basse-Terre Island is constituted of the Monts-Caraïbes volcanoes. In this massif, only two ages of 555 ± 26 and 472 ± 16 ka are available (Blanc, 1983) showing that their activity is coeval with the terminal phase of the Axial Chain (Blanc, 1983). Out of the migration trend of volcanic activity, their activity was principally submarine and phreatomagmatic, with a terminal phase characterized by explosive subaerial eruptions including plinian deposits of dacitic composition intercalated with effusive lava flow (Westercamp and Tazieff, 1980; Boudon et al., 1988). Finally, located between the Monts-Caraïbes and the Axial Chain, the Grande-Découverte volcanic complex (GDVC) has been active since at least 200 ka, and includes

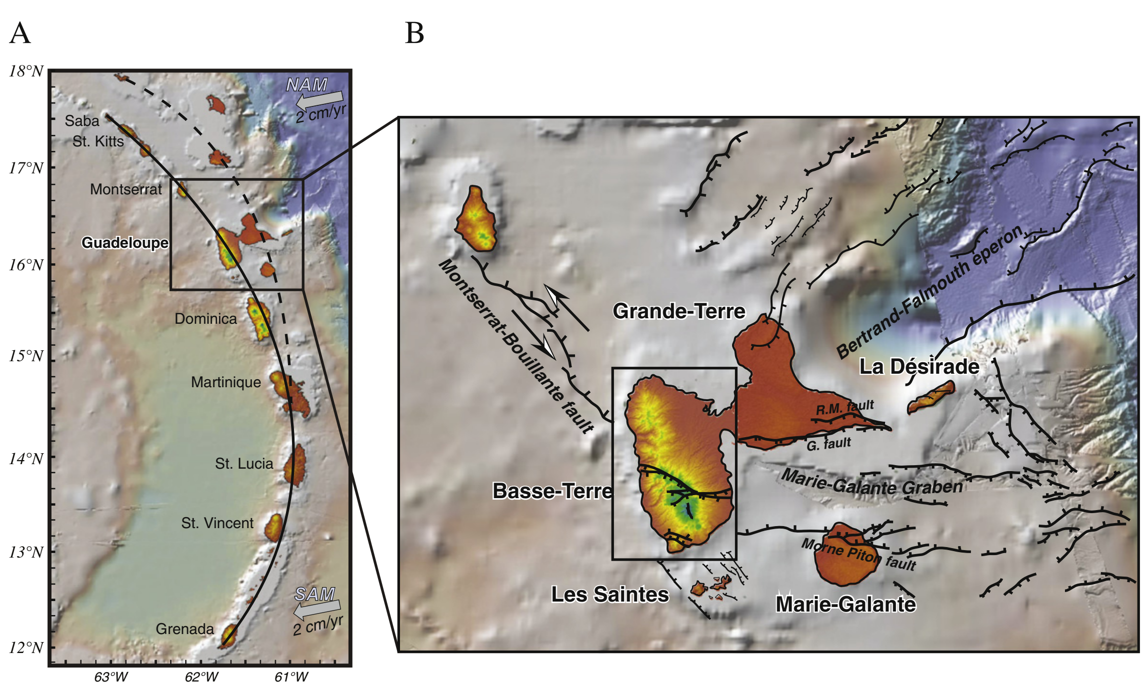

Fig. 1. (A) Regional setting of the Lesser Antilles arc. Continuous line: recent arc; dashed line: old arc. Gray arrows: plate motion vector (after DeMets et al., 2000). Black square: location of Basse-Terre Island. M–B: Montserrat–Bouillante fault; Ep. B–F: Eperon of Bertrand–Falmouth faults system; M-G: Marie-Galante graben system (see text). (B) Shaded Digital Elevation Model (illumination from NW, data from the IGN) of Basse-Terre Island, with the main volcanic massif and schematic main geodynamic structures.