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The magmatic feeding system of El Reventador volcano (Sub-Andean zone, Ecuador) constrained by texture, mineralogy and thermobarometry of the 2002 erupted products

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ABSTRACT

After a 26 years long quiescence El Reventador, an active volcano of the rear-arc zone of Ecuador, entered a new eruptive cycle which lasted from 3 November to mid December 2002. The initial sub-Plinian activity (VEI 4 with andesite pyroclastic falls and flows) shifted on 6 and 21 November to an effusive stage characterized by the emission of two lava flows (andesite to low-silica andesite Lava-1 and basaltic andesite Lava-2) containing abundant gabbro cumulates. The erupted products are medium to high-K calc-alkaline and were investigated with respect to major element oxides, mineral chemistry, texture and thermo-barometry. Inferred pre-eruptive magmatic processes are dominated by the intrusion of a high-T mafic magma (possibly up to 1165±15 °C) into an andesite reservoir, acting as magma mixing and trigger for the eruption. Before this refilling, the andesite magma chamber was characterized by water content of 5.3±1.0%, high oxygen fugacity (>NNO+2) and temperatures, in the upper and lower part of the reservoir, of 850 and 952±65 °C respectively. Accurate amphibole-based barometry constrains the magma chamber depth between 8.2 and 11.3 km (±2.2 km). The 6 October 2002 seismic swarm (hypocenters from 10 to 11 km) preceding El Reventador eruption, supports the intrusion of magmas at these depths. The widespread occurrence of disequilibrium features in most of the andesites (e.g. complex mineral zoning and phase overgrowths) indicates that convective self-mixing have been operating together with fractional crystallization (inferred from the cognate gabbro cumulates) before the injection of the basic magma which then gave rise to basaltic andesite and low-silica andesite hybrid layers. Magma mixing in the shallow chamber is inferred from the anomalous SiO_2–Al_2O_3 whole-rock pattern and strong olivine disequilibria. Both lavas show three types of amphibole breakdown rims mainly due to heating (mixing processes) and/or relatively slow syn-eruptive ascent rate (decompression) of the magmas. The lack of any disequilibrium textures in the pumices of the 3 November fall deposit suggest that pre-eruptive mixing did not occur in the roof zone of the chamber. A model of the subvolcanic feeding system of El Reventador, consistent with the intrusion of a low-Al_2O_3 crystal-rich basic magma into an already self-mixed andesite shallow reservoir, is here proposed. It is also inferred that before entering the shallow chamber the “basaltic” magma underwent a polybaric crystallization at deeper crustal levels.

1. Introduction

El Reventador, located on the Ecuadorian Sub-Andean uplift (rear-arc zone), is one of the most active volcanoes of the Northern Andean Volcanic Zone (Hall et al., 2004). It is built upon a 50 km thick continental crust in a relatively low altitude compressional belt situated between the Cordillera Real and the Amazonian foreland (Fig. 1a; Barberi et al., 1988; Guillier et al., 2001). Its lavas and pyroclastics belong to a medium-K calc-alkaline suite which plots in the compositional range of the Plio-Quaternary volcanoes of the Cordillera Real (Aguilera et al., 1988). The present cone (Fig. 1b) has been growing in the last 20 ky within a large amphitheatre and its elevation was 3562 m a.s.l. before the 2002 eruption (Aguilera et al., 1988).

After the pioneer works of Aguilera et al. (1988) and Barberi et al. (1988) on the volcano-tectonic and petrological evolution of El Reventador, recent investigations have focussed on the source region of the magmas (mantle wedge vs. slab melting) and space–time subduction control on lava compositions (Barragan et al., 1998; Bourdon et al., 2003; Andrade et al., 2005). Tibaldi et al. (2005) studied the causes of El Reventador slope failures and the effect of the basement tectonics on the structural evolution of the volcano.

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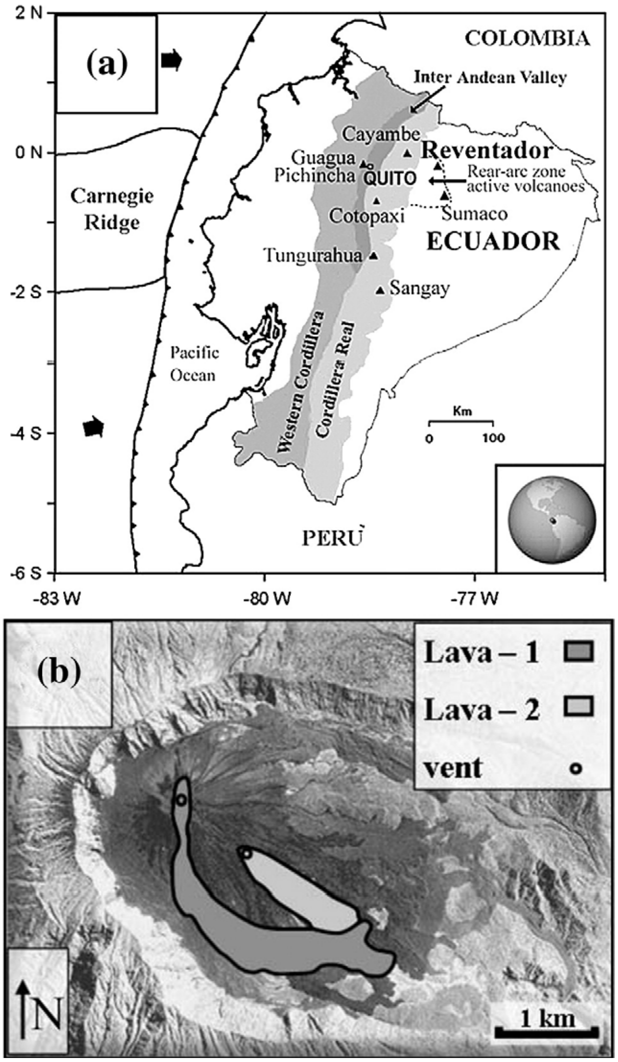

Fig. 1. (a) Location of El Reventador volcano in the Northern Volcanic Zone of the Andes (modified after Molina et al., 2005). (b) Satellite photograph of El Reventador volcano showing the areal distribution of the 2002 lavas (after Hall et al., 2004).

The 3 November 2002 sub-Plinian eruption of El Reventador had a tremendous socio-economic impact in Ecuador including damages to the main oil pipelines, closure of Quito schools and airport for 10 days (Hall et al., 2004). In this work we investigate the magmatic feeding system and related pre-eruptive processes using texture, modal mineralogy, whole-rock geochemistry, microthermometric measurements and available phase equilibria related to the 2002 erupted products of El Reventador. The preliminary calibration of a new amphibole-barometer that works well for medium-K calc-alkaline basic-intermediate magmas is also reported. All the petrological data support the evidence of mixing which resulted from the injection of a basic magma into a shallow, already self-mixed andesite magma chamber. This intrusion may have occurred shortly before the 3 November eruption and possibly was correlated with the unrest of El Reventador volcano (6 October 2002 seismic swarm). The depth of the shallow magma chamber, disequilibria between minerals and melts, and physical–chemical conditions of magma crystallization are evaluated using literature data of experimental petrology on calc-alkaline magmas. A model for the magmatic feeding system of El Reventador during the late-2002 is finally proposed.

2. Structural and magmatic evolution of El Reventador volcano

The three main stage of growth of El Reventador volcano (Aguilera et al., 1988) are represented by: 1) Old Volcanic Edifice (OVE; a K/Ar age of 348 ka is available); 2) Paleo Reventador (PR) and 3) Present Cone (PC). The late Quaternary tectonic around El Reventador volcano is characterized by NS-striking right-lateral reverse faults and NNE-striking right-lateral strike-slip faults (Tibaldi et al., 2005). The eastern flank of the large OVE stratovolcano suffered a major slope failure that gave rise to a huge debris avalanche. PR stratovolcano grew asymmetrically in the caldera amphitheatre and its activity ended with a caldera-forming Plinian eruption. Subsequently, the eastern flank underwent a second collapse that formed another debris avalanche (Almeida and Cruz, 1986). The estimated volumes of the two debris avalanche deposits, are 12.9 ± 1.8 km^3 and 6.7 ± 1.5 km^3 respectively (Tibaldi et al., 2005). The Present Cone (PC) has been forming during the last 20 ka, in the caldera of the second sector collapse, mainly through Strombolian explosions and medium-small volume lavas flowing inside the amphitheatre (Aguilera et al., 1988). Between 1541 and 1976 El Reventador has had at least 16 eruptions mainly characterized by the emplacement of small volume pyroclastic flows, blocky-lavas, debris flows and ash fallouts of limited extension (Hall, 1977, 1980; Hall et al., 2004).

Previous studies on the magmatic system of El Reventador were presented in a report of the Ecuadorian State Agency for Electric Energy (INECEL, 1988) whose results are summarized by Aguilera et al. (1988). These authors have shown that the chemical and mineralogical evolutions of the erupted products indicate a gabbroid-type fractional crystallisation occurring in the middle-lower crust (~8 kbar) within the temperature interval of 910–1118 °C. The PC magmatic evolution was controlled by fractionation and mixing in a shallow feeding reservoir. OVE products are comprised within a medium-K calc-alkaline suite ranging from basalt to dacite whereas the PR and PC magmatic compositions are limited to andesite, basaltic andesite and a few basalts (Fig. 2a).

3. The eruption of November–December 2002

Before 2002, all the historic eruptions of El Reventador volcano were characterized by a Volcanic Explosivity Index (VEI) ≤3 (Simkin and Siebert, 1994). After a dormancy of 26 years, on 3 November 2002,

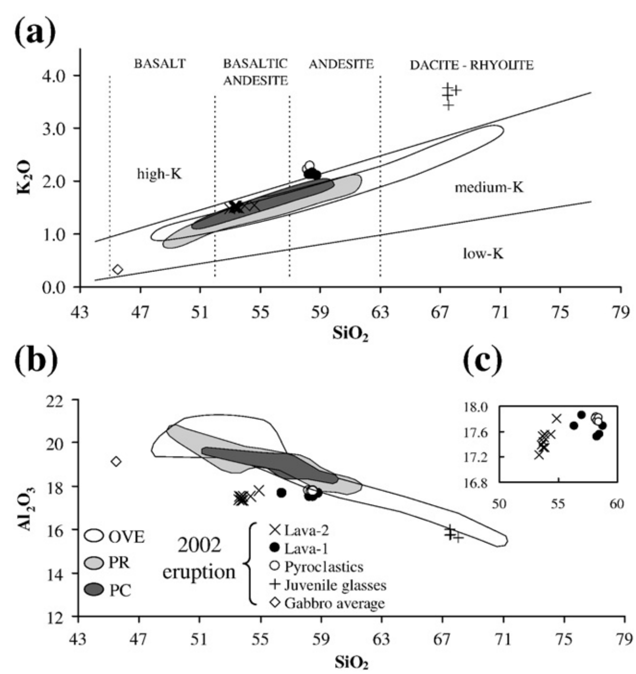

Fig. 2. Representative whole-rock major oxide variations of El Reventador volcanic products. K_2O (a) and Al_2O_3 (b) vs. SiO_2 diagrams; classification fields in (a) are from Le Maitre (2002). (c) enlargement of the basaltic andesite to andesite compositions of the products erupted in 2002.