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# The 2013 eruption of Chaparrastique volcano (El Salvador): Effects of magma storage, mixing, and decompression

Piergiorgio Scarlato [a], Silvio Mollo [a,b,*], Elisabetta Del Bello [a], Albrecht von Quadt [c], Richard J. Brown [d], Eduardo Gutierrez [e], Bettina Martinez-Hackert [f], Paolo Papale [a]

[a] Istituto Nazionale di Geofisica e Vulcanologia, Via di Vigna Murata 605, 00143 Rome, Italy
[b] Dipartimento di Scienze della Terra, Sapienza-Università di Roma, P.le Aldo Moro 5, 00185 Roma, Italy
[c] Department of Earth Sciences, Institute of Geochemistry and Petrology, ETH, 8092 Zurich, Switzerland
[d] Department of Earth Sciences, Durham University, Science Site, DH1 3LE, UK
[e] Observatorio ambiental, Ministerio de Medio Ambiente y Recursos Naturales, El Salvador
[f] SUNY Buffalo State, Department of Earth Sciences and Science Education, Buffalo, USA,

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ABSTRACT

On December 29, 2013, an isolated vulcanian-type eruption occurred at Chaparrastique volcano (El Salvador) after 12 years of inactivity. The eruption was classified as VEI 2 and produced an ash plume with a maximum height of ~9 km. Textural and compositional data from phenocrysts from the erupted products have been integrated with geochemical and isotopic information from bulk rocks to elucidate the magmatic processes responsible for the reawakening of volcanic activity.

Phenocrysts consist of Fo-rich poikilitic olivines hosting high-Mg titanomagnetites, and Fo-poor olivines coexisting with low-Mg titanomagnetites. Mineral-melt equilibria suggest an origin for the distinct phenocryst populations by mixing between a high-*T* (~1130–1150 °C), basaltic magma with $fO_2$ (NNO buffer) typical of the lower crust in arc systems and a low-*T* (~1060–1080 °C), basaltic andesitic magma with $fO_2$ (NNO + 1 buffer) commonly encountered in shallower, more oxidized crustal reservoirs. Thermobarometry based on Fe-Mg exchange between orthopyroxene and clinopyroxene constrains the crystallization before eruption at relative low-*P* (~150–250 MPa) and low-*T* (~1000–1050 °C). Mixing between two chemically distinct magmas is also evidenced by the occurrence of reverse zoned plagioclase phenocrysts with resorbed sodic cores and re-growth of sieve-textured calcic mantles. Conversely, plagioclase rims exhibit disequilibrium compositions addressed to decompression kinetics (~$10^{-3}$ MPa/s) driven by rapid magma ascent to the surface (~0.03 m/s).

Major and trace element modelling excludes fractional crystallization as the primary mechanism controlling the bulk rock variability, whereas geochemical data align along a mixing trend between two end-members representative of the primitive basalt and the differentiated basaltic andesite. Trace element and isotope data indicate that the primary source of magmatism is an enriched MORB-like mantle with the contribution of fluxes of metasomatic fluids and/or melts produced by the subducted slab. The role played by slab-fluid inputs of carbonate origin and slab-melts from the hemipelagic sediments seems to be minimal. Assimilation/contamination processes of magmas by crustal rocks are also negligible. In contrast, the geochemical signature of magmas is greatly influenced by slab-derived aqueous fluids produced prevalently by progressive dehydration of marine sediments and altered basaltic crust.



## 1. Introduction

El Salvador is one of the most seismically-active regions on Earth (Fig. 1a), being located along the Central American volcanic front that is defined by ~50 major volcanic centers, including composite or clustered volcanoes, distributed nearly continuously along 1200 km from western Guatemala to central Panama (e.g., Carr et al., 1979; Carr, 1984; MacMillan et al., 2004). The Volcanic Cordillera in El Salvador is a line of volcanoes parallel to the coast and the offshore subduction zone. El Salvador has 23 volcanoes and 5 volcanic fields. At present, only a few volcanoes are active (outgassing and rarely ash emissions) such as the Santa Ana, San Salvador, San Miguel and Izalco volcanoes (e.g., Agostini et al., 2006 and references therein).

Chaparrastique volcano, also known as San Miguel, is a composite volcano in central-eastern El Salvador, ~15 km southwest of the city of San Miguel. A rural population of ~70,000 people lives within 10 km of the summit crater of Chaparrastique, and San Miguel is the second

* Corresponding author.
*E-mail address:* silvio.mollo@uniroma1.it (S. Mollo).

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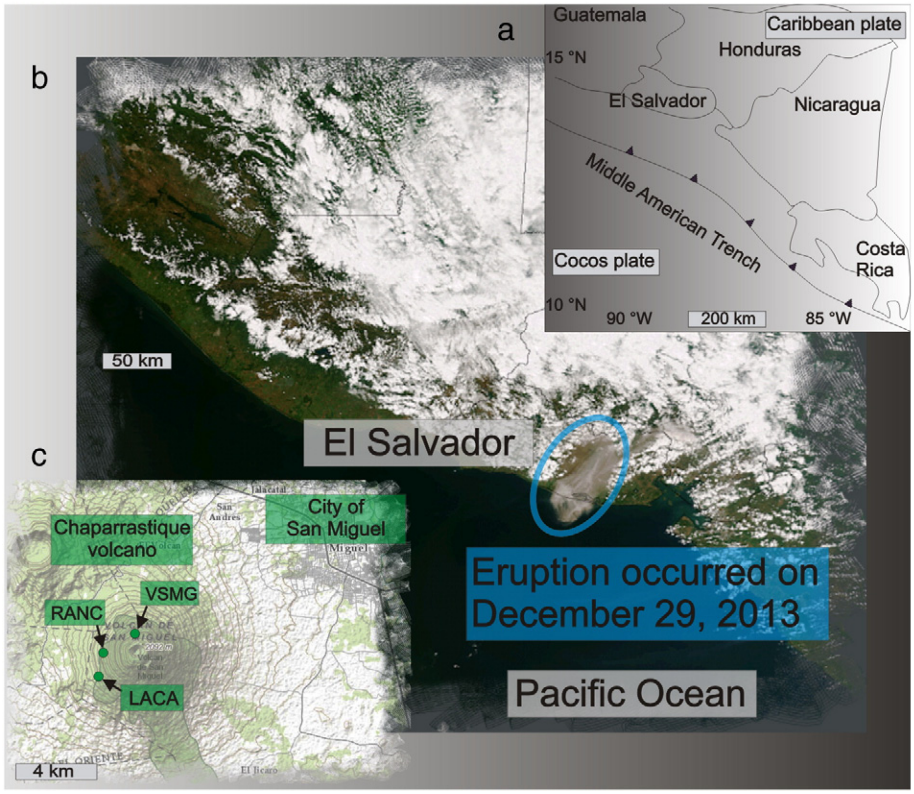


**Fig. 1.** Schematic map showing the Central American volcanic arc (CAVA), where volcanism occurs above the plate boundary between the subducting Cocos plate and the overriding Caribbean plate (a). The ash plume of the Chaparrastique vulcanian-type eruption captured by the Suomi NPP satellite (b). Seismic monitoring stations of VSMG, RANC, and LACA located, respectively, at 1 km north, 2 km east, and 3 km south-east to the volcanic crater where twelve rock samples were collected (c).

largest city in El Salvador. On December 29, 2013, after 12 years of inactivity, Chaparrastique volcano erupted at 10:30 local time (16.30 GMT), prompting the evacuation of more than ~5000 people living in ~3 km radius around the volcano (Martinez-Hackert et al., 2015). The eruption was a vulcanian-type explosion that lasted 2.5 h (Fig. 1b). The explosion was classified as VEI 2 and produced an ash plume with a maximum height of ~9 km (Martinez-Hackert et al., 2015). The eruption column generated heavy ash fall in nearby areas downwind, especially in the towns of Chinameca and San Jorge. A short lived pyroclastic density current generated from an early Vulcanian explosion travelled ~500 m down the flanks of the volcano and entered coffee plantations.

On January 2014, in response to a request of support by the government of El Salvador, the INGV (Istituto Nazionale di Geofisica e Vulcanologia, Italy) organized a task force in close collaboration with volcanologists from MARN (Ministerio de Medio Ambiente y Recursos Naturales, El Salvador). A campaign survey was conducted over a period of ten days, with the aim to install a monitoring network on the flanks of the volcano (Bonforte et al., 2015; Granieri et al., 2015; Scarlato et al., 2014). At the same time, a suite of twelve eruptive products (i.e., fallout tephra) was collected in correspondence of the seismic monitoring stations of VSMG, RANC, and LACA located, respectively, at 1 km north, 2 km east, and 3 km south-east to the crater (Fig. 1c).

Here we present textural and mineral chemistry data from phenocrysts integrated with bulk rock geochemical and isotopic data, with the aim to elucidate magmatic processes that triggered the 2013 eruption. Mineral-melt equilibria, and major and trace element modelling define the pre-eruptive crystallization conditions of the system and indicate that magma mixing and magma decompression were the most important mechanisms for triggering the eruption. The magma source has been also constrained by trace element and isotope systematic. Magmas were generated by partial melting of an enriched MORB-like mantle wedge with a dominant contribution of aqueous fluids derived from the subducted slab.

## 2. Geological setting

The Pacific coastline of much of Central America is marked by a line of active and quiescent volcanoes known as the Central American Volcanic Arc (CAVA) (e.g., Aubouin et al., 1982; Carr et al., 1990, 2004; Leeman et al., 1994; Protti et al., 1995). To the south of Central America the Cocos Plate, which underlies an area of the east Pacific, is being subducted beneath the Caribbean Plate along the Middle American trench. The volcanoes result from the upward movement of magma generated along the subduction zone between the Cocos and Caribbean tectonic plates. El Salvador, and neighbouring Central American states, lies on the Caribbean Plate. Frequent earthquakes also occur along the plate boundary. From Guatemala to northern Costa Rica, ~25 Ma old crust (formed at the East Pacific Rise) is subducted at an angle varying from 55° in Guatemala and El Salvador to 65° in Nicaragua and northern Costa Rica (Protti et al., 1995; Syracuse and Abers, 2006). The crustal thickness, angle of subduction, and convergence rate contribute to the thermal structure of the subduction zone, which is a major control on the generation of magmas in Central America (Davies and Stevenson, 1992). The sediment input consists of a ~200-m-thick layer of hemipelagic clay overlying a ~250-m-thick layer of carbonate ooze (Aubouin et al., 1982; Plank and Langmuir, 1998). The calc-alkaline compositions of volcanic rocks from CAVA record systematic along-strike variations in many geochemical tracers of the slab, including Ba/La (Carr et al., 1990), U/Th (Patino et al., 2000), B/Be (Leeman et al., 1994), and $\delta^{18}O$ (Eiler et al., 2005). For most of these tracers, the peak in inferred slab flux occurs in the central portion of the CAVA, in Nicaragua, and falls to nearly the global minimum to the southeast, at the terminal sector of volcanoes of Costa Rica. Where the crust is thinner, high-Mg basalts are more abundant (e.g., Nicaragua). Conversely, in correspondence of a thick and old continental crust, low-Mg basaltic lavas occur and are less abundant (e.g., central and western Guatemala). Moreover, the continental crust of southern Central America is