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Review article

Petro-geochemical constraints on the source and evolution of magmas at El Misti volcano (Peru)

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A B S T R A C T

El Misti volcano, a large and hazardous edifice of the Andean Central Volcanic Zone (CVZ) of southern Peru, consists of four main growth stages. Misti 1 (>112 ka) is an old stratovolcano partly concealed by two younger stratocones (Misti 2, 112–40 ka; Misti 3, 38–11 ka), capped in turn by a recent summit cone (Misti 4, <11 ka). In order to gain insights into magma composition controls on eruptive behaviour through time at El Misti, we have conducted a petrological and geochemical study of selected rock samples from the main growth stages of the volcano. Whole rock compositions range from andesite to rhyolite and belong to a medium to high-K calk-alkaline magmatic suite. El Misti samples are characterised by high large-ion lithophile elements, but low concentrations of high field strength elements, and heavy rare earth elements, consistent with a subduction zone setting. The $^{87}Sr/^{86}Sr$ (0.70715–0.70882) and $^{143}Nd/^{144}Nd$ (0.511983–0.512277) isotope ratios suggest that magma composition is significantly affected by contamination and/or assimilation processes during their evolution, likely due to the presence of thick (65–70 km) continental crust beneath the CVZ in southern Peru. Geochemical evidence indicates that magmatic evolution is mostly controlled by Assimilation–Fractional Crystallisation (AFC) mechanisms. Modelling reveals a mass-assimilated/mass-fractionated ratio (ρ) ≤ 2.2, which suggests an assimilated crust fraction below 14 wt.% on average. Our isotopic data clearly identify the Proterozoic "Charcani gneiss" basement as the main contaminant. Both contamination and assimilation processes peaked at ~30 wt.%, during the Misti 3 stage when rhyolites were generated. We ascribe the general depletion in HREE and Y and elevated La/Yb and Sr/Y ratios in El Misti samples to the enrichment of the mantle wedge source of the parental magmas by a felsic melt of adakitic composition and hydrous fluids. Our work highlights that El Misti's magmatic system has remained relatively homogeneous since at least 0.12 Ma, with a marked influence of the contaminating crust in the Late Pleistocene Misti 3 stage, which resulted in highly explosive eruptions. Andesitic-dacitic compositions are dominant in the Holocene and historical Misti 4 stage, and are expected for future volcanic events at El Misti.

Contents

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1. Introduction

Since the Jurassic, widespread magmatism has developed along the Andean margin as a result of the Nazca Plate subducting beneath the South American continent. Throughout the Cenozoic, the segmentation of the subduction regime has led to the formation of four volcanic provinces known as the Northern, Central, Southern and Austral Volcanic Zones of the Andes (Thorpe et al., 1982; Fig. 1a). Offshore from southern Peru, the 44 Ma-old oceanic Nazca Plate (anomaly 20 according to Herron, 1972) converges with the South American plate at N80° and an average velocity of 5–7 cm/yr (Norabuena et al., 1998). The Central Volcanic Zone (CVZ), which extends from 16° S (Southern Peru) to 28° S (Northern Chile), consists primarily of large silicic systems and andesitic-dacitic composite volcanoes, with some subsidiary monogenetic fields (de Silva and Francis, 1991; Delacour et al., 2007; Stern, 2004; Wörner et al., 2000).

Quaternary erupted lavas in the CVZ are characterised by high $^{87}Sr/^{86}Sr$ and $\delta^{18}O$ ratios (typically >0.70534 and 8–12‰, respectively) and low $^{207}Pb/^{204}Pb$ (15.55–15.65) and ε_{Nd} (−2 to −12), in conjunction with low heavy rare earth elements (HREE) and Y contents (Davidson et al., 1991; de Silva et al., 2006; Delacour et al., 2007; Feeley and Davidson, 1994; Haschke et al., 2006; Kay et al., 2010; Kiebala, 2008; Mamani et al., 2010; Thouret et al., 2005; Wörner et al., 1988).

Previous work on magma genesis and evolution in the CVZ have revealed complex processes that combine initial melt production with tranfers of metasomatic fluids and/or felsic melts into the mantle wedge, and subsequent differentiation through mechanisms such as MASH (melting, assimilation, storage and homogenisation), fractional crystallisation, AFC (Assimilation–Fractional Crystallisation) and magma mixing at different depths in both the mantle and continental crust (e.g., Aitcheson and Forrest, 1994; Davidson et al., 1991; Delacour et al., 2007; Gerbe and Thouret, 2004; Godoy et al., 2014; Hildreth and Moorbath, 1988; Mamani et al., 2010; Sørensen and Holm, 2008; Tepley et al., 2013; Thorpe et al., 1984; Thouret et al., 2005; Wilson, 1989).

Most current petrogenetic models for CVZ magmas consider that the primary calk-alkaline Plio-Quaternary magmas of southern Peru are derived from partial melting of a mantle wedge previously metasomatised by hydrous fluids released through dehydration of the subducted lithosphere, with subsequent crustal contamination during magma storage and ascent through the thick continental crust (65–70 km in southern Peru, Barazangi and Isacks, 1976). Some authors (e.g., Feeley and Davidson, 1994; Hildreth and Moorbath, 1988; Kay, 2002) assume that both mantle-derived and crustal magmas may have mixed and/or mingled at deep levels in a high-pressure MASH zone, thereby producing large volumes of contaminated andesitic magmas. Little to no sediments, however, are present on the subducting oceanic crust at the Peru–Chile trench (Thornburg and Kulm, 1987) and their subsequent role in crustal contamination of magmas can be precluded. Other studies suggest that tectonic shortening in the northern part of the CVZ resulted in significant crustal thickening, leading to a temperature increase in the lower crust, which promoted partial melting of local granulitic crust (Kay et al., 1999; Whitman et al., 1996). Additionally, low pressure assimilation and fractional crystallisation (AFC) processes, as well as magma mixing and/or crustal anatexis at higher crustal levels beneath large composite volcanic complexes may also impact the erupted magma compositions (e.g., Barreiro and Clark, 1984; Davidson and de Silva, 1995; Davidson et al., 1991; Godoy et al., 2014; Harmon et al., 1984; James, 1982; Tepley et al., 2013; Thorpe et al., 1984).

Such a combination of complex mechanisms that gradually modify the composition of different magma batches makes petrogenetic reconstructions difficult, yet a limited number of processes may have played a dominant role in the generation and evolution of these magmas, while others may be subordinate. Previous investigations, for example, suggested that the magma reservoir beneath El Misti volcano was several km^3 in volume and recurrently filled and homogenised prior to eruption (Ruprecht and Wörner, 2007). In addition, Tepley et al. (2013) proposed the existence of a temporary, shallow (~3 km deep), small-volume rhyolitic reservoir, most notably immediately