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Compositional and petrological variability in central Andean magmas explained by three uniform and ubiquitous magmatic components

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The most mafic compositions of Quaternary magmatism in the Andean Central Volcanic Zone encompass high-K to medium-K calc-alkaline basaltic andesites (52-55 SiO_2 wt%). These baseline compositions are not uniform and characterized by large ranges in major (3.6-9.4 wt% MgO, 4-7 wt% Na_2O+K_2O, 0.8-1.8 wt% TiO_2) and trace element concentrations (9-197 ppm Ni, 501-1944 ppm Sr, 95-257 ppm Zr), as well as trace element ratios (LILE/HFSE: 93>Sr/Y>24; LREE/HREE: 63>La/Yb>8). Such a remarkable variability and the absence of truly primitive lavas in the CVZ reflects distinct petrogenetic processes during ascent and evolution of uniform mantle-derived melts traversing exceptionally thick continental crust (70 km).

Our statistical geochemical modelling (Polytopic Vector Analysis, PVA) of Andean magmas reveals two distinct mafic endmembers and one uniform evolved magma composition that can explain the majority of central Andean magmas. These endmembers are exemplified here by a statistical analysis conducted on hybrid dacites from Taapaca volcano (18˚S) that are involved in the petrogenesis of Taapaca magmas: (1) a low-Mg high-Al calc-alkaline basaltic andesite (BA), (2) an incompatible trace element enriched basalt (EB), and 3) a high-K calc-alkaline rhyodacite (RD). These three endmember magmas also enclose nearly all Quaternary CVZ lavas in a mixing triangle and account for the entire compositional variability of the Quaternary volcanic rocks in the CVZ. A first mixing stage produces hybrid baseline magmas consisting of the EB and BA. The second mixing stage represents shallow crustal magma mixing between the already mixed, mafic (BA+EB) and the silicic RD components. Mixing proportions between these endmembers vary widely and magma compositions of endmembers and/or hybrids are overprinted by different degrees of magmatic differentiation and crustal assimilation.

The availability of the RD magmas in subvolcanic systems determines also the mineralogy of the Fe-Mg phases in the intermediate magmas. Volcanic rocks from neighboring Taapaca and Parinacota volcanoes show that amphibole and titanomagnetite are present in basaltic andesites, andesites and dacites that show geochemical evidence for mixing with a large proportion of the silicic RD magma. Other basaltic andesites and andesites of very similar major element composition have ±olivine, pyroxene, titanomagnetite and ilmenite, while amphibole is absent. During magma mixing, a drop in temperature, an increase in the water content, and changes in the redox conditions of the (BA+EB) component destabilize olivine, pyroxene and ilmenite and promote amphibole + titanomagnetite crystallization in the hybrid magmas. Amphibole-bearing rocks thus form primarily by RD-BA-EB hybridization whereas pyroxene-bearing rocks are differentiation products of dominantly BA-EB hybrids with minor RD admixture. Furthermore, three amphibole species found in the CVZ magmas: tschermakite, magnesiohastingsite, and magnesiohornblende reveal a notable connection to the BA, EB and RD endmembers, respectively. This finding is supported by amphibole compositions synthetized in experimental studies carried out on RD-dominated Taapaca, EB-dominated Parinacota and BA-dominated Lascar volcano (23˚S) lava compositions.

The BA, EB, and RD endmembers represent distinct magma sources: the mantle wedge, enriched lithospheric mantle, and the continental crust, respectively. Therefore, these endmembers are expected to be ubiquitous in the central Andes and have uniform geochemical character.