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Deep crustal melting in the Peruvian Andes: Felsic magma generation during delamination and uplift

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ABSTRACT

The Miocene-aged Yungay and Fortaleza ignimbrites (YFI), 9° S, Cordillera Blanca, Peru, share geochemical affinities typical of Phanerozoic adakite-like rocks and Archaean tonalite–trondhjemite–granodiorite (TTG) suites. In this contribution, we will investigate the melt source region(s) of the adakitic ignimbrites and their relationship to the dynamic tectonic regime in Peru at the time of eruption. The geochemistry of the YFI differs significantly from spatially related lavas in western Peru, which are characterised by classic calc-alkaline arc signatures. The YFI were erupted along crustal-scale normal faults at the culmination of major tectonic changes affecting the western Peruvian margin, where they represent the last volcanic activity recorded in the area. These regional changes included crustal thickening, shallowing of the Nazca Plate from c. 30° to c. 5°, the arrival and subduction of the Nazca Ridge and rapid crustal uplift and exhumation. The previously unstudied adakitic YFI are examined, then a series of high-pressure piston-cylinder experiments are detailed. Synplutonic mafic-intermediate dyke material is used as an analogous source, and direct experiments are performed on ignimbrite samples. These show that the geochemical signature and mineralogy of the YFI can be produced at pressures >2.2 GPa and temperatures >1025 °C. These data support an origin for both ignimbrites as partial melts of juvenile, garnet-bearing, hydrous, mafic lower crust (granulite to eclogite), modified by ~20% contamination by igneous crust. A slab source is considered highly improbable. Eclogite and granulite at >2 GPa (>65 km depth) are absent within the modern lithospheric architecture of the Peruvian margin, requiring removal of this source region syn- or post-eruption. A likely mechanism for removal is crustal delamination in an east-relative motion, associated with shortening caused by progressive shallowing of the Nazca Plate subducting slab. Due to the restricted mantle flow through the thinned mantle wedge, there have been no further magmatic episodes since the eruption of the Yungay and Fortaleza ignimbrites.

1. Introduction

The Andean orogenic belt is a dynamic, evolving margin, intrinsically linked to the subduction of the oceanic Nazca Plate beneath the South American continental plate. This active arc is a major zone of crustal growth, with geochemically variable magmas produced over only a few tens of kilometres and even at single volcanoes. This pattern is present in most continental arcs (e.g. Japan, New Zealand and west-coast Americas), presenting a problem for geochemists as melt diversity is due to a combination of the source region, mechanisms of melting and subsequent evolution pathways (DePaolo, 1981; Bacon et al., 1997; Hildreth and Moorbath, 1988; Maury et al., 1992; Petford and Gallagher, 2001). Arguments have been made for direct melting of the subducting plate, giving rise to 'adakite' (Defant and Drummond, 1990), or for such melts to metasomatise the mantle wedge (Stern et al., 1989). Although initially thought to be a rare component in magmatic arcs, adakites are now recognised as significant in the geochemical evolution of these arcs (e.g. Chung et al., 2003; Macpherson et al., 2006; Zhang et al., 2005). The change from basalt–andesite–dacite–rhyolite (BADR) magmatism to adakitic magmatism may not be transitional but abrupt, prompted by sudden changes in tectonic conditions including the balance between crustal recycling and juvenile magmatic addition to the continental crust (Hou et al., 2004), the location of the magma source region (e.g. Beate et al., 2001; Bourdon et al., 2002; Maury et al., 1996), and/or the timescales and extent of partial melting in the source region (Jackson et al., 2005). In contrast to older, subduction-related Coastal Batholith magmatism in Peru, the late Miocene Yungay and Fortaleza ignimbrites (YFI), together with the Cordillera Blanca Batholith (CBB; Petford and Atherton, 1996), display adakitic characteristics. These youngest volcanic products reflect a shifting locus of magma generation from the mantle-wedge-related Casma and Coastal Batholith magmas (Pitcher, 1985), through

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progressive movement eastward, represented by Calipuy volcanics, and finally to the Cordillera Blanca region (Fig. 1).

This work presents new geochemical data on the YFI and applies it to the chemical and spatial evolution of the Peruvian margin. Possible magma source constraints are then applied to a set of partial-melting and near-liquidus piston-cylinder experiments, used to probe the physical magma source characteristics and mineral phase relations. Results are combined with existing geophysical data for central Peru, allowing evaluation of potential magma sources in the context of larger-scale tectonic changes occurring at ~5–6 Ma.

1.1. Geology

The YFI were initially mapped in the Rio Santa valley by Wilson et al. (1967) and Myers (1976), and remapped by the Instituto Geológico Minero y Metalúrgico (INGEMMET) in 2000. The Yungay ignimbrite is mainly to the immediate west of the Cordillera Blanca Fault (CBF; Fig. 1). The deposit forms discontinuous hillocks of up to 950 m high, from Huaripampa (8°53′ S, 77°49′ W) to Jancas (9°23′ S, 77°34′ W), with a total outcrop length of 62 km. Based on outcrop thickness, the minimum total volume of the Yungay ignimbrite is 216 km^3 (127.63 km^3 dense rock equivalent). The second major volcaniclastic deposit in the Cordillera Blanca, the Fortaleza ignimbrite, forms massive, columnar-jointed ignimbrite cliffs of up to 800 m high as the north wall to the upper parts of the Rio Fortaleza valley (Fig. 1). Distribution of the Fortaleza ignimbrite indicates that the parent ash flows came down a palaeovalley, from a source near Lake Conococha (10°07′ S, 77°16′ W). The flow has an outcrop length of ~32 km, ending at 10°11′ S, 77°33′ W, and has a minimum volume of 62 km^3 (36.4 km^3 dense rock equivalent). The volume of these deposits is consistent with a caldera-forming event.

Both ignimbrites are pumice-poor, unwelded to incipiently welded, stratigraphically homogeneous and crystal-rich. Deposits show a characteristic lack of associated Plinian deposits. They display a massive, non-graded structure, weak lateral fabric variations, common lithic clasts, and are lapilli-poor. These petrographic features are consistent with deposition from a pyroclastic flow rather than a surge. The Yungay ignimbrite is composed of: 30% quartz, 25% plagioclase (dominantly oligoclase), 3% biotite, 2% Fe–Ti oxides and 40% groundmass (ash and small fragments) including pumice. The Fortaleza ignimbrite differs slightly, at: 25% quartz, 20% plagioclase (dominantly oligoclase), 4% biotite, 2% Fe–Ti oxides, and 48% groundmass. Phenocryst phases in both

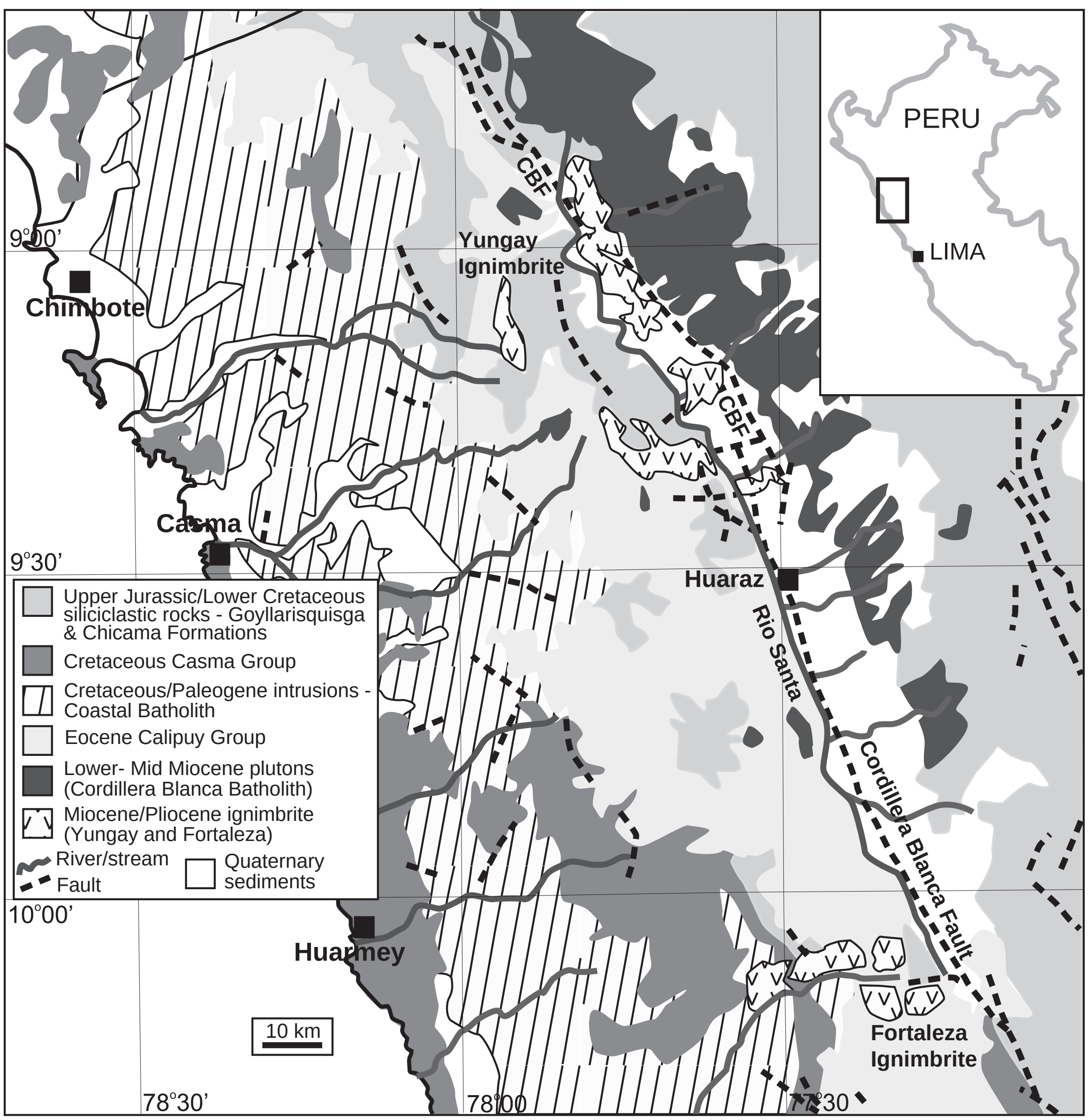

Fig. 1. Geology of the Ancash region, Peru, showing the location of the YFI deposits within the Rio Santa valley. Map compiled from INGEMMET (2000) map sources.