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PETROLOGY OF THE 2006-2007 TEPHRAS FROM UBINAS VOLCANO, SOUTHERN PERU

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INTRODUCTION

Ubinas volcano (16º 22' S, 70º 54' W) is located in the Quaternary volcanic range in southern Peru, ~60 km east of Arequipa city (Fig. 1). Ubinas is historically the most active volcano in southern Peru with 24 volcanic events (VEI 1-3) recorded since 1550 AD (Hantke and Parodi, 1966; Simkin and Siebert 1994; Rivera et al. 1998). These events are largely intense degassing episodes, with some ashfall and ballistic blocks ($<10.10^6 m^3$) produced by vulcanian and phreatomagmatic explosive activity (Thouret et al. 2005; Rivera et al. 1998). The events caused damage to crops and cattle and affected approximately 3,500 people living in six villages within 12 km from the volcano (Fig. 1).

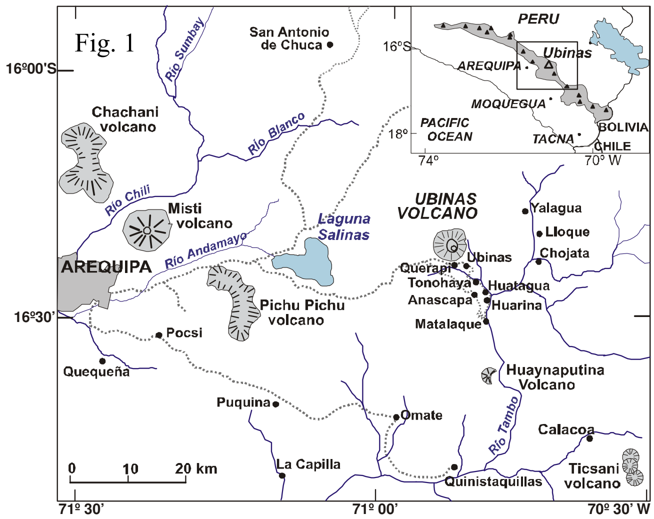


Fig. 1 Location map of the Ubinas volcano. Inset shows its location with respect to the volcanic range in southern Peru. Fig. 2 Ballistic blocks were ejected from the volcano on 24 May 2006. This photograph shows an impact crater created where a 2-m-diameter bomb struck the caldera floor ~200 m from the crater.

The most recent explosive activity began on 27 March 2006 and lasted two years with intermittent eruptive events, while degassing is still ongoing at present. Based on the characteristics of activity and the erupted products the eruptive episode has progressed in four stages: 1) initial phreatic and phreatomagmatic activity (27

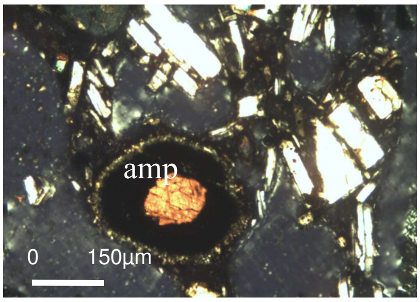
March to ~19 April 2006), including high eruption columns that dispersed ashfall as far as 7 km from the summit; 2) vulcanian explosions (~20 April to 11 June 2006) formed 3 to 4 km-high columns that ejected blocks up to 40 cm in diameter to distances 2 km from the vent (Fig. 2). Fresh lava reached the vent bottom on 20 April; 3) strong degassing interspersed with at least 12 events that produced 2 to 3 km-high columns between mid June 2006 and April 2007, dispersing ash as far as 40 km from the vent; 4) mild degassing produces a permanent 200 to 800 m-high plume and occasional light ashfall around the summit (May 2007 until the present).

Short-lived lasting and slug columns, cannon-like explosions, small amounts of juvenile material, and the andesitic composition of bread-crust bombs indicate a vulcanian style of behaviour at Ubinas. The behaviour is similar to the first phase of the Nevado Sabancaya eruption in 1990-1998 (Gerbe and Thouret, 2004) or to the behaviour of Sakurajima, Japan since 1955 (Morrisey and Mastin, 2000), and to Ngauruhoe, New Zealand in 1974-1975 (Hobden et al. 2002). Petrographical and geochemical characteristics of juvenile blocks and scoriae erupted during the 2006-2007 explosive activity allow for the description of newly erupted magma and therefore leads to a better understanding of the origin of the eruption.

PETROGRAPHY AND MINERALOGY OF THE 2006 TEPHRA

The juvenile dense and poorly vesicular blocks erupted on 27 April (Ub-04), 7 May (Ub-13), 24 May (Ub-14) and 28 October 2006 (Ub-18) are porphyritic (Fig. 3a, 3b) and contain phenocrysts (250µm-1.6mm in size, 2-5 vol.%) and microphenocrysts (80-250µm in size and 30 to 40 vol.%) of subhedral to euhedral plagioclase (An_{41-68}) and a small amount of amphiboles and clinopyroxenes. The plagioclase phenocrysts are variably zoned. Some display reverse zonations, low-An cores (An_{33-56}) surrounded by relatively high-An “dusty”rims (An_{47-68}) containing abundant small (1-20µm) melt inclusions (Fig. 3b). Other plagioclase phenocrysts lack the “dusty”rims, being normally zoned with high-An (An_{47-66}) cores and An_{41-59} rims.

a)



b)

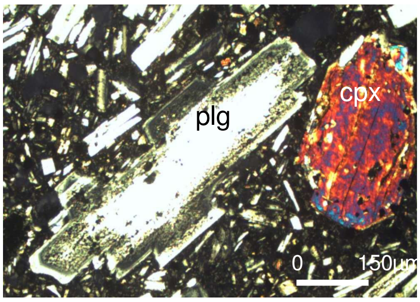


Fig. 3. Photomicrographs of thin sections in scoriae and dense blocks: a) “dusty-rimmed” plagioclase phenocryst and clinopyroxene phenocryst. b) Amphibole phenocryst showing reaction rims.

In addition, some tephra samples (Ub-04, 13, 14) contain scattered phenocrysts of subhedral and anhedral amphibole, namely pargasite with Mg# 66-70, and 200 to 300µm in size. They show reaction rims (20 to 150µm in width) suggesting resorption or dissolution surfaces, probably due to decompression effect during magma ascent. Clinopyroxene, specifically augite (En_{39-48} Wo_{38-49} Fs_{14-19}), are either phenocrysts up to 800 µm in size or microphenocrysts; some showing reverse zonation (Mg# 68-74). Phenocrysts of orthopyroxene, i.e enstatite (En_{65-71} Wo_{2-7} Fs_{23-32}) are up to 600µm in size and sometimes show slight reverse zonation (Mg# 71-73).

Numerous glomerophenocrysts of plagioclase, clinopyroxene, orthopyroxene, and Fe-Ti oxydes are in reaction. In all blocks and scoriaes, Fe-Ti oxydes (<200 µm and <2-4 vol. %) are euhedral and dispersed in the groundmass, and also appear as inclusions in the phenocrysts (orthopyroxene, clinopyroxene, amphibole, and olivine).

Blocks that were sampled in April and May 2006 include scattered, subhedral and anhedral olivine phenocrysts (<200 µm and 1-2 vol. %), which display normal zonation (Fo_{72-76} cores and Fo_{63-71} rims). They are usually surrounded by a fine microlite aggregate, while resorbed shapes suggest that they may be xenocrysts. The groundmass (<80 µm) consists of plagioclase, ortho- and clinopyroxene, and dacitic glass (67-68 wt% SiO_2). Both olivine and amphibole are missing in lavas erupted in October 2006, and contrast to lavas erupted earlier in April and May 2006. However, the mineral assemblage does not display any significant variation in mineral composition throughout the eruptive episode. On the other hand, pre-eruption temperatures have been estimated using different calibrations of the two pyroxenes (Wood and Banno 1973; Wells 1977). Pre-eruption temperature is estimated to range between 1000 and 1090 ºC.

GEOCHEMISTRY OF JUVENILE 2006 LAVAS

The juvenile magma, represented by lava blocks and scoriae, comprise high-K calc-alkaline andesite showing a restricted range of composition (56.7-57.6% SiO_2; 2.0-2.3% K_2O: Fig. 4) compared to historical lavas. In addition, trace element compositions are characterised by a high LILE (K, Rb, Ba, Th) and LREE contents with respect to HREE (Fig. 5). The trace element composition of the juvenile tephra is similar to the average composition of the erupted andesites over the last 1500 years (Thouret et al. 2005; Fig. 5). Depleted Y and HREE is attributed to mixing and assimilation processes of magmas near the base of the >60-km-thick continental crust (Thouret et al. 2005).

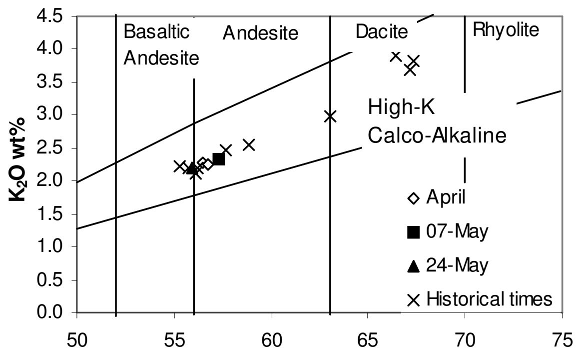


Fig. 4

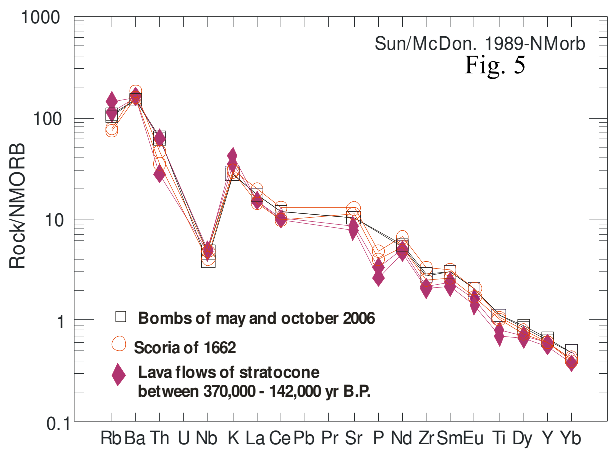


Fig. 5

Fig. 4. Alkali-silica diagram showing that the composition of erupted lavas in 2006 at Ubinas. Fig. 5. Spiderdiagram of the 2006 - 2007 tephras for the purpose of comparison with Ubinas lavas prior to 2006 (Thouret et al. 2005). Both figures show that the composition of the 2006 erupted lavas is similar to the average composition of historically erupted lavas

DISCUSSION AND CONCLUSION

Over the past 1500 years Ubinas has erupted magma ranging from basaltic andesites to dacites, with andesites being most common. Chemical characteristics of the magmas mainly result from fractional crystallisation processes in a shallow magma chamber and assimilation at various crustal levels (Thouret et al. 2005). In addition few erupted pyroclastic products show evidence of magma mixing as mineralogical disequilibrium, in combination with shallow aquifers of the hydrothermal system, which may have contributed to the triggering of eruptions (e.g., the AD 1677 scoria and ash flow deposits of basaltic andesite composition. On the other hand, the 980 yr BP-old plinian event produced a voluminous dacitic pumice fall deposit that does not contain evidence for magma mixing. Thus, recent Ubinas magma has displayed a large range in compositions and the magma chamber may have been periodically and partially emptied during the historical eruptions.

The geochemical composition of the juvenile magma erupted at Ubinas between April and October 2006 is similar to that erupted during the last 1500 years, suggesting that all magmas have the same mantle source. However, some petrographic textures and chemical zoning pattern of phenocrysts suggest that part of the mineral assemblage was not in equilibrium with the melt prior to, or during the eruptive activity. The juvenile tephra erupted at Ubinas between April and October 2006 exhibit plagioclase phenocrysts (some “dusty-rimmed”, with reverse zonation), orthopyroxene, clinopyroxene with reverse zonation, amphibole with disequilibrium features as reaction rims, and olivine xenocrysts. Based on the types of textures and mineral geochemistry two hypotheses can be considered for the triggering mechanism of the most recent eruptive activity: 1) re-supply of mafic magma into the conduit or a shallow magma chamber containing cooler andesitic magma, which has triggered the eruption through the addition of heat and/or volatiles to the resident magma; or 2) repeated and continuous ascent of small batches of new magma, which incorporated xenocrysts of magma erupted previously. Both processes may have led to over pressurisation of the magma chamber and probably triggered the mild eruptive episode.

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