NEOGENE IGNIMBRITES AND VOLCANIC EDIFICES IN SOUTHERN PERU: STRATIGRAPHY, TIME-VOLUME-COMPOSITION RELATIONSHIPS, AND RECENT TEPHRA CHRONOLOGY

J.-C. Thouret[1], M. Mamani[2], G. Wörner[2], P. Paquereau-Lebti[1], M.-C. Gerbe[3], A. Delacour[3], E. Juvigné[4], M. Rivera[1,5], J. Mariño[5], L. Cacya[5] , B. Singer[6]

[1] Laboratoire Magmas et Volcans UMR 6524 CNRS, OPGC et IRD, université Blaise Pascal, 5 rue Kessler, 63038 Clermont-Ferrand cedex, France
[2] Abt. Geochemie, GZG, Universität Göttingen, Goldschmidtstrasse 1, 37077 Göttingen, Germany
[3] Laboratoire Magmas et Volcans UMR 6524 CNRS et Université J. Monnet, Saint-Etienne, France.
[4] Laboratoire de Géomorphologie et Quaternaire, Université d'état à Liège, Sart Tilman, 4000, Liège, Belgium
[5] Ingemmet, Instituto Geológico, Minero y Metalúrgico, Avenida Canada 1470, San Borja, Lima, Peru
[6] Department of Geology and Geophysics, University of Wisconsin, Madison, WI 53706, USA.

INTRODUCTION

In the northern Central Andes of southern Peru, four volcanic arcs, termed Tacaza, Lower and Upper Barroso, and Frontal arc, have been active over the past 30 Ma (Fig. 1). They produced five volcanic units between Moquegua and Nazca (14°30–17°15'°S and 70–74°W). The 'Neogene ignimbrites' unit (< 25 Ma) comprises five generations of widespread ignimbrite sheets (>500 km^2 and >20 km^3), representing a major crustal melting event, triggered by thickening and advective heat input from the mantle wedge. Also, four generations of volcanic edifices (i.e shields, composite cones, and dome clusters) and monogenetic fields are intercalated with, and mostly overlie, the ignimbrites based on ages, stratigraphy, and mapping.

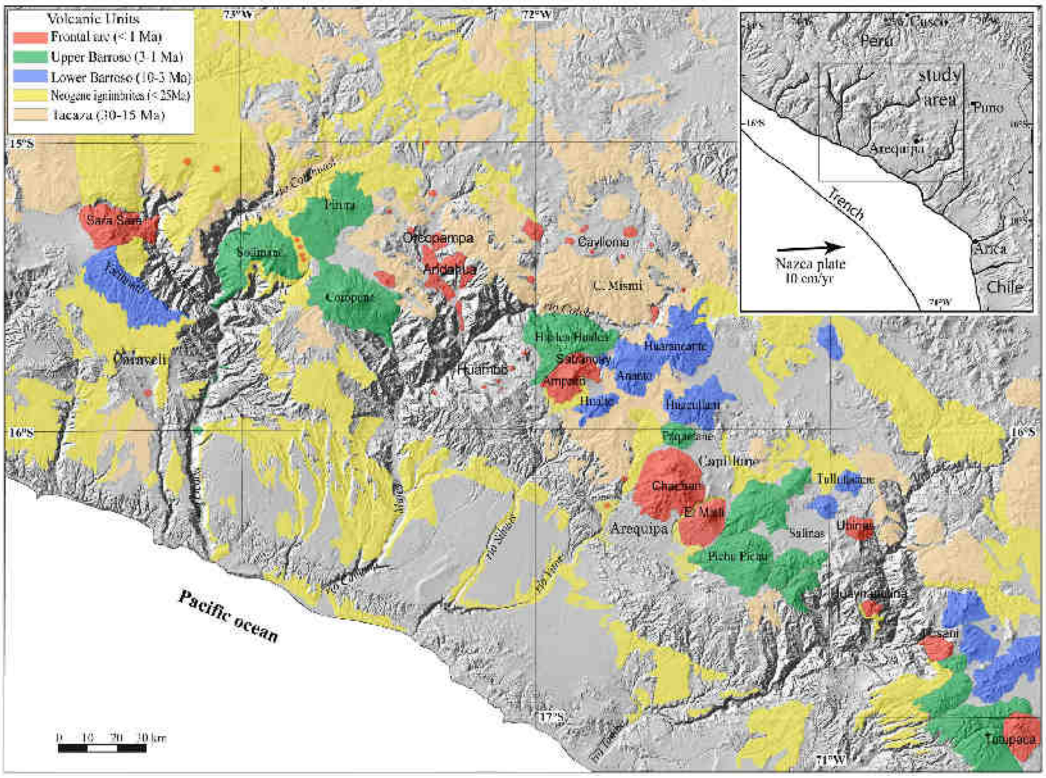

Figure 1. Extent of five volcanic units over the past 30 Ma in southern Peru showing the Neogene ignimbrites and the principal edifices of the four volcanic arcs (Mamani et al., 2008a, and submitted).

PRE- AND POST-VALLEY INCISION IGNIMBRITE SHEETS AND EVOLUTION OF THE WESTERN CVZ

Our new stratigraphy (Fig. 2) records changing magma composition, uplift and valley incision of the Central Andes, and the rate of growth and degradation of the Early Miocene to Holocene volcanoes.

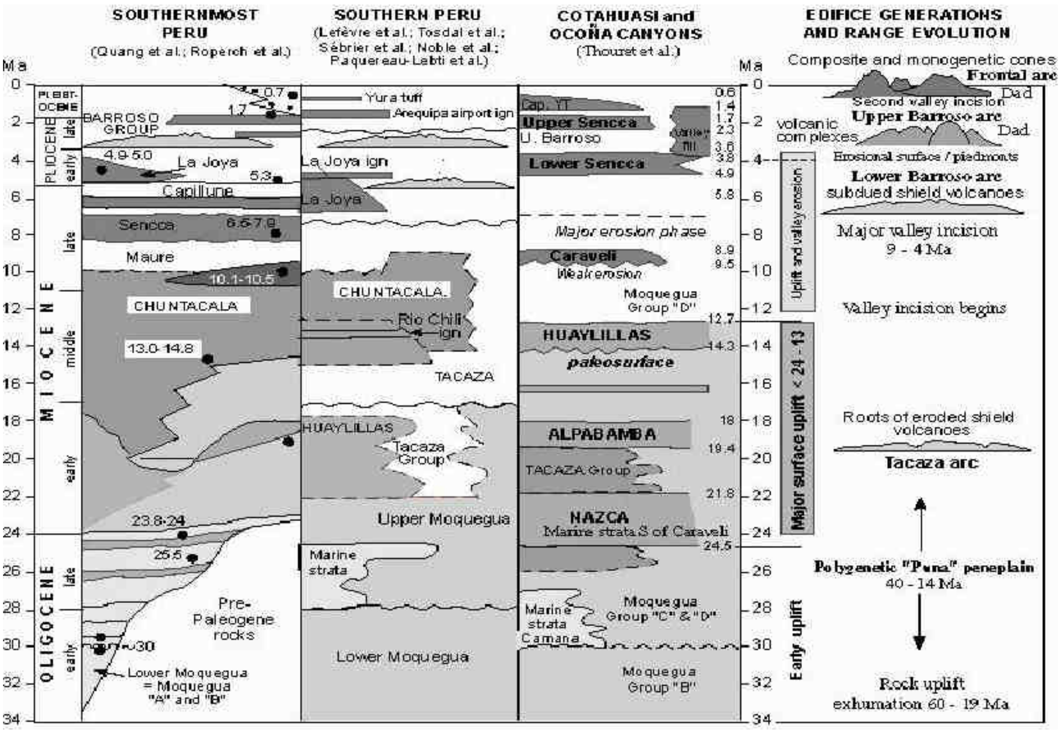

Fig. 2. Stratigraphy and chronology of ignimbrites and lava edifices in southern Peru (Thouret et al., 2007). The evolution of the western Andean range in Peru is also indicated. 'Dad' stands for debris-avalanche deposit.

The older, widespread ignimbrite sheets pre-date valley incision and are intercalated with voluminous conglomerates that reflect major phases of surface uplift as a response to tectonic phases in a crust weakened by massive crustal melting. 1) The 24.6-21.8 Ma-old, welded Nazca ignimbrite sheets within the Tacaza volcanic unit cap extensive plateaus to the N and W of the area as well as further south near Moquegua. 2) The welded, 19.4-18 Ma-old Alpabamba ignimbrites and 3) the 14.3-12.7 Ma-old Huaylillas ignimbrites form extensive plateaus between 4000 and 4500 m asl. S of Nevado Coropuna, N of Cotahuasi and NE of Pausa. They mantle the polygenetic 'Puna' peneplain that formed between >40 Ma and 14 Ma (Gunnell et al., 2008). The ignimbrites erupted from calderas (e.g. N of Alca and NW of Oyolo) during thickening of the Western Cordillera between 24 and 13 Ma. Distal tuff layers of these ignimbrites are interlayered in the fore-arc sediments towards the top of the congomerates of the Moquegua Formation (Roperch et al., 2006) in the Majes, Sihuas and Vitor valleys.

In contrast, the younger, less widespread ignimbrites that filled tectonic depressions (Arequipa) or were channeled in deep valleys (Río Ocona and Cotahuasi) post-date valley incision. 1) The 9.4-8.8 Ma-old Caraveli ignimbrites fill an irregular topography cut in the Huaylillas ignimbrites and crown small and low plateaus at 2-2.5 km asl. to the W of the area. They were emplaced in shallow wide valleys cut in the high peneplain, thus indicating that the fluvial incision had already begun by 9 Ma.. 2) The 4.9-3.6 Ma-old non-welded lower Sencca ignimbrites (lower Barroso equivalents) crop out in conglomeratic piedmonts or are preserved on deep valley flanks. The 4.86 Ma-old La Joya ignimbrite (Paquereau-Lebti et al., 2006, 2007) fills the Arequipa tectonic depression. 3) The non-welded 2.3-1.4 Ma-old upper Sencca ignimbrites (upper Barroso equivalents) crop out in similar stratigraphic positions and comprise the non-welded Arequipa Airport ignimbrite (1.63 Ma: Paquereau-Lebti et al.,

2007) at the top of the ignimbrite succession filling the Arequipa depression. Calderas are not clearly identified but magnetic fabric and AMS measurements (Paquereau-Lebti et al., 2007) indicate that Sencca ignimbrites are probably sourced at calderas or crater clusters that are buried beneath younger, Quaternary volcanic complexes such as Nevado Chachani, Coropuna, and Ampato. A second valley incision took place after 2.2 Ma (e.g. the Río Colca valley) or 1.4 Ma, the age of non-welded pumice-flow deposits, which had largely re-filled the canyon of Río Cotahuasi. Younger ignimbrites exist but none exceeds 200 km^2 and 10 km^3. One such example is the Yura Tuff N and W of Nevado Chachani, that may be contemporaneous with the Capillune Formation. Its source is located north of, or beneath, the older, northern part of the Chachani complex.

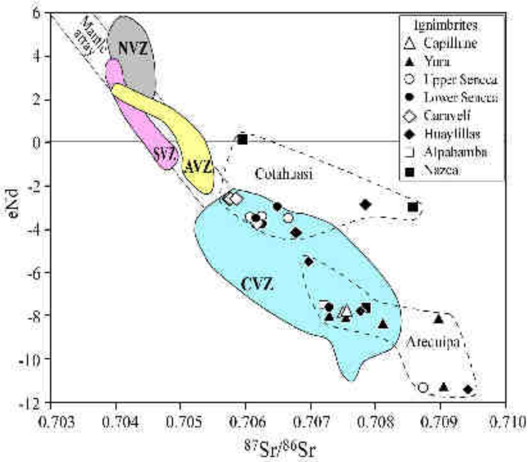

Figure 3.. ℇNd and $^{87}Sr/^{86}Sr$ Plot of ignimbrites of the Cotahuasi and Arequipa areas. Isotope values of igneous rocks support the concept that Andean magmas are controlled by the composition and age of the Andean crust. The Arequipa and the Cotahuasi ignimbrites define a domain that overlaps the average CVZ magma composition domain. The Arequipa ignimbrites eNd is lower than the Cotahuasi ignimbrites eNd. These differences may be the result of the assimilation of crustal materials with different isotopic signatures during magma genesis. Recent geochemical and geophysical data pointed out two distinct crustal domains, termed Cordillera and Arequipa, in southern Peru (Mamani et al., 2008a,b).

FOUR GENERATIONS OF VOLCANIC EDIFICES AND TIME-VOLUME-COMPOSITION RELATIONSHIPS

Dated lava flows and pyroclastic deposits indicate that four generations of composite and monogenetic edifices have crowned the Western Cordillera and are intercalated with, or mostly overlie, the ignimbrites (Fig. 2). 1) Although the Tacaza arc is deeply eroded, roots of hydrothermally-altered edifices remain in the Caylloma area 60 km N of the Frontal arc. 2) The 9 to 4 Ma-old Lower Barroso edifices are moderately eroded, subdued shields with a core of 6-4 Ma-old basaltic andesite and andesite lava flows (e.g. near Cora Cora and around the Laguna Salinas). 3) The 3-1 Ma-old Upper Barroso stratovolcanoes and dome complexes, with a wider range of composition from mafic andesites to rhyolites, have been carved by glacial erosion and abundant scars of flank failures in hydrothermal systems (e.g. Pichu Pichu and Chachani). 4) The Pleistocene – Holocene volcanoes are composite cones such as El Misti, Ubinas, and domes on caldera edges such as Ticsani. Most of these composite cones are younger than 0.8-0.6 Ma (Thouret et al., 2001, 2005; Gerbe and Thouret, 2004). The Frontal arc includes coeval monogenetic fields like the Andahua-Orcopampa-Huambo field, where strombolian cones and lava flows formed between 0.5 Ma and historic times (Delacour, 2007).

The $^{40}Ar/^{39}Ar$ chronology, combined with volumes of composite cones, allow eruption rate estimates, which are minimums because glacier erosion and explosive events have carried material away from the edifices. Eruption rate is apparently lower during the first phase of the growth of the stratovolcanoes over a long period (400 – 800 ka) and apparently accelerates during maturation and growth of the summit cones: 0.6 km^3/ky at Misti over 110 ka and 0.22 km^3/ky at Ubinas over 250 ka. Eruption rates fluctuate between 0.1 and 1 km^3/ky according on the time span considered and with respect to magma composition and eruptive style (mafic effusive vs. evolved and pyroclastic). The morphology of composite cones has changed between Plinian eruptions that formed summit calderas (Misti 13–11 ka; Ubinas 25−9 ka). Large debris avalanches occurred at composite cones and domes complexes during the last 0.5 Ma. The largest collapse at Ticsani produced a 20 km^3 debris-avalanche deposit (Mariño y Thouret, 2003) but smaller, recurring debris avalanches as young as Middle-Late Holocene have also occurred at the Ubinas cone and the Tutupaca dome.

The $^{40}Ar/^{39}Ar$ chronology and petrology of the lava flows and pyroclastic deposits allow us to estimate the magmatic evolution through time (Fig. 3). Andesite and mafic andesite magmatism forms the base of stratovolcanoes beneath summit cones and are present in monogenetic compound lava flow fields throughout the region, mostly along deep-seated, normal N80-trending faults (e.g. Ichupampa Fault). The monogenetic field of Andahua-Orcopampa-Huambo has 25-50 km^3 of lava, with an eruption rate of 0.09-0.18 km^3/ky. The ascent of magma producing coeval compound lava fields has bypassed the reservoirs of composite cones in the upper crust: the magma genesis is attributed to partial melts of the lowermost part of the thick Andean continental crust added to mantle-derived arc magmas in a high pressure MASH zone (Delacour et al., 2007).

RECENT (50 KA) TEPHRA-CHRONOLOGY AND ERUPTION FREQUENCY

Table 1 displays a 50 ka-long record of identified and dated tephras, lava flows and lava domes linked to one of the ten active or subactive composite cones, domes and monogenetic fields between Nevado Sara Sara to the N and the Yucumane volcano to the S of the CVZ in southern Peru. This segment of the Frontal arc has registered at least 50 events, i.e 1 eruption every 1 kyr over the past 50 ka, and at least 12 large Plinian eruptions producing >1 km^3 of tephra. On a cautionary note, tephras older than 15 ka have not been dated yet, the existence of tephra not yet recognized cannot be precluded, and other tephras have been removed away and lost from the record. If the well established 15 ka-old tephra record is taken at face value, the eruption frequency increases to 3 events per kyr (e.g., Juvigné et al., 2008), comprising two moderate-sized ash fall every kyr and one voluminous Plinian pumice fall on a 2400 – 3600 yr interval.

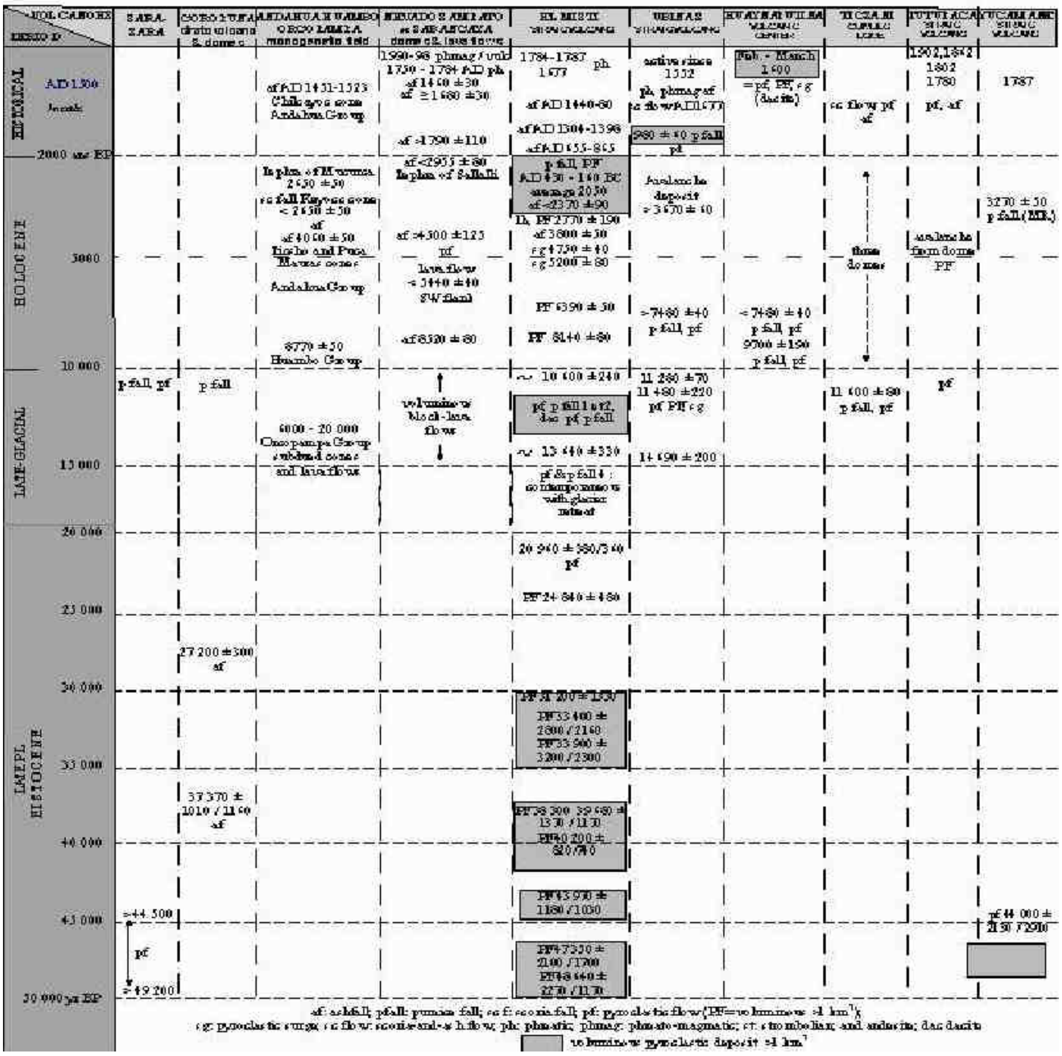

Table 1. A 50 ka-long tephra and lava stratigraphical record of the Fontal arc between the Nevado Sara Sara and Yucamane volcanoes.

CONCLUSION

From the chronostratigraphy, large-scale ignimbrite sheets (>20 km^3) have erupted on intervals of 5 Ma but many individual smaller ignimbrites have also occurred. The last large-scale ignimbrite erupted 1.6 Ma ago and the last small ignimbrite erupted 1 Ma ago. Each of the four generations of composite and shield volcanoes has lasted about 1 to 4 My but this belies the rapid growth of short-lived (<0.8 Ma) composite cones, which have erupted at a rate of 0.2–1 km^3/kyr on average over the past 250 ka.

Based on Table 1, the tephra record of the Frontal arc displays at least 50 events, i.e one eruption every kyr over the past 50 ka, including 12 large Plinian eruptions with >1 km^3 of tephra. Very large eruptions (VEI 6; Thouret et al., 2002) such as the Huaynaputina AD1600 event would potentially have a severe effect on southern Peru, western Bolivia, and northernmost Chile. The global climatic effect of the Huaynaputina eruption is currently highlighted (EOS, 2008). Such eruption could occur in the area comprised between Huaynaputina, Ticsani, and Tutupaca in the department of Moquegua: a long volcanic history and recent eruptions of silicic magma suggest that similar vigorous eruptions may occur in the near geological future. In addition, debris avalanches and landslides from ignimbrite cliffs in deep canyons and from hydrothermally-altered composite cones, even without any eruption, and subsequent debris flows pose serious threats to the population.

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