QUATERNARY MINOR VOLCANIC CENTRES IN SOUTHERN PERU: VOLCANOLOGY, PETROLOGY, AND GEOCHEMISTRY

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INTRODUCTION

Several fields of small monogenetic scoria cones and associated lava flows are found throughout the Central Andean Volcanic Zone (CVZ). Some are located in southern Peru on the western Cordillera west of the Colca valley. The Andahua valley located 30 km NE of Nevado Coropuna and currently known as the "Valley of the volcanoes" is certainly the most spectacular (Venturelli, 1978). This field extends north to south over a distance of about 40 km from Orcopampa to Ayo, the youngest centres being concentrated near Andahua. Another field is found near Huambo, 20 km south of Andahua, on the left side of the Rio Colca valley. Their morphologies and a few ^{14}C datations point to of quaternary ages, from late Pleistocene to historic ages. These volcanic fields are located close to the huge quaternary stratovolcanoes (Nevados Coropuna and Sabancaya), and are related to N160 rift structures oblique to the NW-SE-trending Western Cordillera. They mainly consist of basaltic andesite to andesite lavas.

Figure 1: Location map of area of study in Southern Peru.

This study presents volcanological, mineralogical and geochemical data for a set of samples collected from various volcanic cones and lava flows of Pleistocene and Holocene ages. We test the postulate that they represent magmas rather preserved from interactions with crustal materials and consequently that they may reflect more accurately the petrological characters of the source magmas.

VOLCANIC AND STRUCTURAL SETTINGS

The CVZ lies 220-250 km from the Peru-Chile Trench and about 100-130 km above the Benioff zone (Barazangi and Isacks, 1976). The Nazca plate moves towards N80° (Sébrier and Soler, 1991) and the subduction plate is dipping 25-30° beneath the thick continental lithosphere of South America. The minor centres of Andahua – Orcopampa and Huambo are located at the northern edge of the CVZ, where the dip of the Benioff zone is decreasing to 5-15°.

In the Western Cordillera, tensional faulting has prevailed since Cenozoic time and has been associated with an intense brittle tectonic and voluminous calc-alkaline volcanism. On a regional scale, the current tectonic regime is controlled by a N-S stretching related to the collapse of the Andean Cordillera and N80°-trending compression which are thought to be weak since the late Pleistocene (Sébrier and Soler, 1991, Mering and al., 1996). Three groups of active or recently active faults are identified within the studied area on the basis of the analysis of air photographs and satellite scenes (fig. 2). Firstly, the inactive N150-160-trending faults, characterized by dip-slip motions with small sinistral strike-slip component, limit the north and the south zones of the Rio Andahua valley, near Orcopampa and Ayo respectively. They form the overall shape of the rift structures. Secondly, the normal N120-135-trending fractures, characterized by a sinistral strike-slip component best recognized near Andahua, offset the first group of N160 faults. Thirdly, the Huambo area and the south side of the Rio Colca Valley show inactive N130-striking inverse faults, which have been re-activated by the recent extensional regime, and N70-80-striking normal faults, whose southwards dip-slip motion offsets late Pleistocene lava flows.

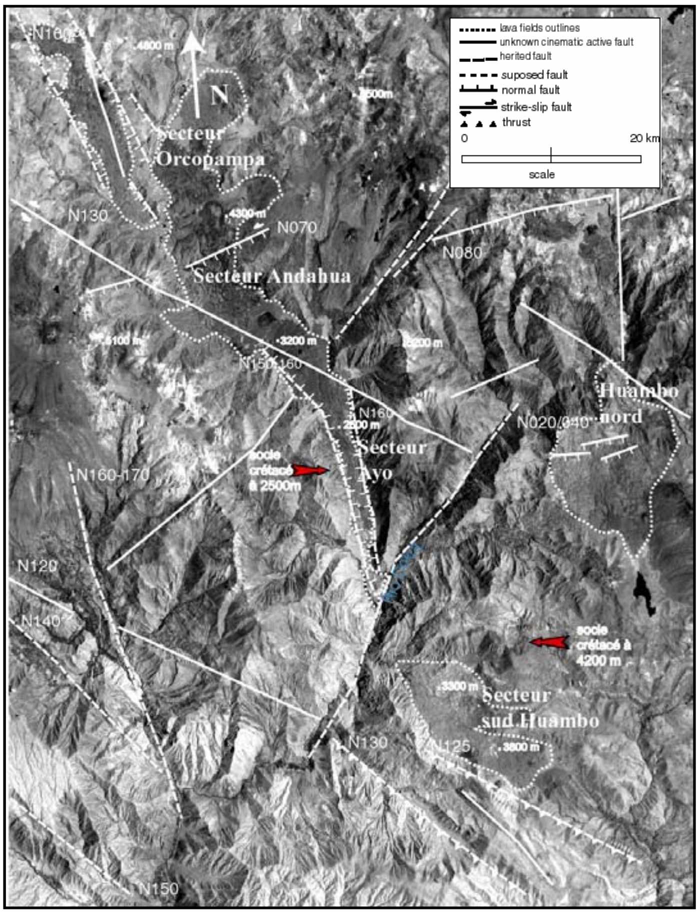

Figure 2: Structural map of Andahua-Orcopampa and Huambo areas.

Within the volcanic fields, four main phases of growth may be distinguished on the basis of few ^{14}C datations and the systematic analysis of the stratigraphic relationships of the cinder cones and lava flows (direct field observations, interpretation of aerial and satellite photos and morphometry): late Pleistocene age, early to mid-Holocene age (the ash fall of Cerro Tichso cone is dated at 4060 ± 50 yr B.P., near by the town of Andahua), upper Holocene age (2650 ± 50 B.P. for the Cerro Keyocc near Huambo, and 2860 ± 50 B.P. for a exposed ash fall layer 10 km north of Orcopampa), and historical age (the ash fall of Chilcayoc Grande is dated at 360 ± 50 yr B.P.).

PETROLOGY AND MINERALOGY

A total of 80 samples were collected in the Andahua-Orcopampa and Huambo volcanic fields. Two samples of the small isolated Cerro Nicholson cinder cone, located about 40 kilometres west of Arequipa, were added to the sampling. The lavas consist mainly of basaltic andesites (about 20%), and andesites (about 78%) with few dacites (< 2%).

Basalts and basaltic andesites

The most basic rocks are found in Huambo (52% SiO_2, 6-7 % MgO) and Cerro Nicholsson and are quite scarce. Two groups of basaltic andesite lavas can be distinguished.

The first group consists of lavas, which are similar to basalt in composition and mineralogy. The phenocryst assemblage is normally zoned plagioclase (An_{63-72}), olivine (Fo_{80-86}) and clinopyroxene (Wo_{31-39} En_{32-47} Fe_{3-14}). Olivines are rich in Ni, Cr, and contain small crystals of chrome spinel, suggesting cristallization from a relatively primitive magma. The groundmass consists of laths of plagioclase (An_{53-67}) and Fe-Ti oxides (titano-magnetite). The second group is similar to andesite in composition. These porphyric lavas show phenocrysts of normally zoned plagioclase (An_{53-71}), olivine (Fo_{74-83}), clinopyroxene (Wo_{31-43} En_{37-51} Fe_{4-15}) and Fe-Ti oxides. The groundmass consists of laths of plagioclase (An_{44-64}) and Fe-Ti oxides (titano-magnetite).

Andesites

The andesites are porphyric in the lavas of Andahua and Huambo and microporphyric in the lavas of Orcopampa. The paragenesis consists of plagioclase, rare olivine, pyroxene ± amphibole and Fe-Ti oxides in Andahua and Huambo, whereas the mineral phases in Orcopampa are represented only by plagioclase, clinopyroxene and Fe-Ti oxides. The plagioclase crystals (An_{34-60}) show normal compositional zoning. However reverse compositional zoning are also found ($An_{60-76-56}$), suggesting variations in the conditions of plagioclase crystallization. This disequilibrium is further indicated by the fact that the olivines (Fo_{71-79}) show coronae of clinopyroxene or orthopyroxene. The clinopyroxene crystals are Wo_{31-43} En_{39-48} Fe_{5-15} and the orthopyroxenes are En_{67-75} Fe_{22-30}. The amphibole (magnesio-hastingsite) crystals are sometimes present, often destabilized, and are rimmed by Fe-Ti oxides. The Fe-Ti oxides are represented by titano-magnetites and ilmenites. The groundmass contains mainly plagioclase microlites and microcrystals of the other phases within glass. The glass is dacitic (66 % SiO_2) in composition.

GEOCHEMICAL DATA AND MAGMATIC PROCESSES

The lavas of the Andahua-Orcopampa and the Huambo fields show a more basic SiO_2 range (51,8-64,6 wt%SiO_2), in contrast to the lavas of the Nevado Sabancaya-Ampato stratovolcano massif (57-67 wt%SiO_2) which is located about 50 km of Andahua on the Altiplano (fig. 3A). The geochemical data have suggested the role of two magmatic processes for the evolution of the Andahua-Orcopampa and Huambo lava series.

Firstly, the fractional crystallization process is dominant and is indicated by the evolution of major elements. Most of the element contents decrease with increasing SiO_2 content and may be related to the fractionation of plagioclase, olivine, pyroxene, amphibole and Fe-Ti oxides. Several stages of fractionation are evidenced by the behaviour of some elements such as Na_2O and Al_2O_3. They show a positive correlation with SiO_2 content during a first step (< 58% SiO_2), which may be consistent with a predominant role of mafic minerals (olivine, pyroxene), and a slight decrease for higher SiO_2 content (>58% SiO_2) suggesting the main role of plagioclase during the end of the fractionation process. The influence of the fractional crystallization process is reinforced by a similar evolution of trace elements. The Ni, Cr, Sr, and V contents decreasing with increasing SiO_2 content are

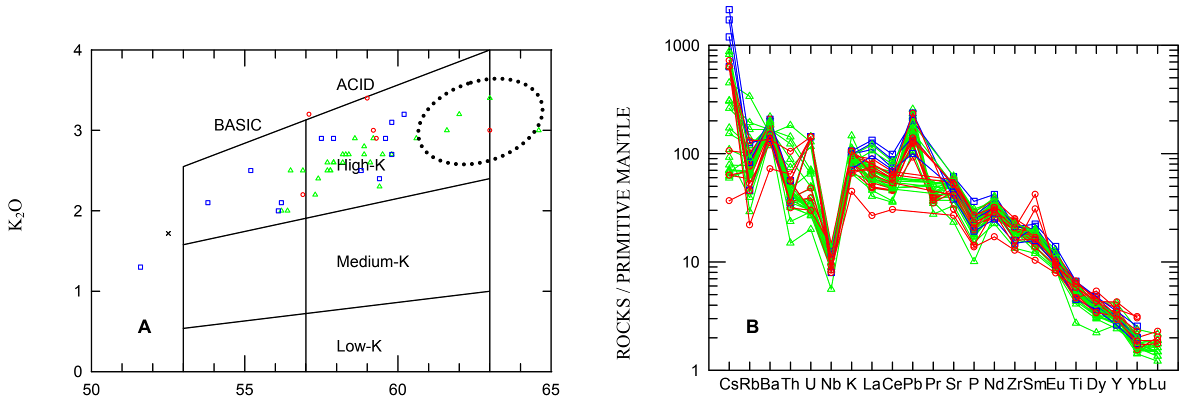

Figure 3: A: K_2O vs SiO_2 (Gill, 1981); B: REE patterns normalized to chondrites (Sun and Mc Donough, 1989). Square: Huambo; circle: Orcopampa; triangle: Andahua; cross: Cerro Nicholsson. The big circle represents the field of Nevado Sabancaya compositions

probably related to crystal fractionation, as well as the parallel patterns of REE normalized to chondrites. The role of crustal contamination in magma evolution is inferred by the scattered trends of elements such as Ba, Zr, Nb and by the relative enrichment of LILE (as Rb and Th). Further the O, Sr, Nd isotopic data ($^{87}Sr/^{86}Sr$= 0,7063-0,7067, $^{143}Nd/^{144}Nd$= 0,5123-0,5124, and $\delta^{18}O$=7,07-8,45 ‰ SMOW) exclude a direct mantle source origin and suggest also a crustal component. Secondly, concerning the source of these magmas, the REE patterns normalized to primitive mantle show positive anomalies of Sr, Ba, Th and negative anomalies in HFSE (Rb, Nb), which are typical features of continental arc magmas (fig. 3B). The "peaks" of Sr, Ba and Th reflect the participation of enriched fluids in subduction zone and (or) a crustal component. The relative depletion of HREE in Spider diagrams suggests a residual phase in source material (as amphibole or garnet), which concentrates the HREE.

CONCLUSIONS

The Andahua-Orcopampa and Huambo lavas were formed by fractional crystallization from a primitive magma, which is possibly enriched by fluids from dehydration of the subducted lithosphere. The crustal contamination also plays a role in the magma evolution. Variable rates of contamination affect the lavas whether they are stored within the crust or rapidly erupted from their deep reservoir. The less evolved lavas are found in the Huambo area and may be related to deeper faults, which have promoted the basic magma ascent. In that respect, the Huambo "basalts" may represent the best witness of source magmas within this part of the Central Volcanic Zone.

REFERENCES

BARAZANGI M. and ISACKS B. (1976). Spatial distributions of earthquakes of the Nazca plate beneath South America, v 4, pp. 686-692

MERING C. and *al.* (1996). New data on the geodynamics of southern Peru from computerized analysis of SPOT and SAR ERS-1 images, Tectonophysics, n°259, pp.153-169

SEBRIER M. and SOLER P. (1991). Tectonics and magmatism in the Peruvian Andes from late Oligocene time to Present, Geological Society of America, Special Paper 265

VENTURELLI and *al.* (1978). Trace element distribution in the Cainozoic lavas of Nevado Coropuna and Andagua Valley, Central Andes of Southern Peru, Bulletin Volcanologique, vol 41-3