ERUPTIVE STYLES AND INFERENCES ABOUT PETROLOGY OF THE ANDAHUA VOLCANIC GROUP

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INTRODUCTION

The Quaternary scoria cones and lava flows of the Andahua Group are located in the Andean Central Volcanic Zone (CVZ) in the Western Cordillera, NW from Arequipa, on both sides of the Colca Canyon. The Andahua Group is a younge volcanic unit in this part of the CVZ. Its activity started in the middle Pleistocene (Kaneoke & Guevara 1984) and continued up to the present. It is characterized by a large number of eruption centres scattered over an area of 12.000 km^2. Seven clusters of volcanic centres distinguished in the area that include lava domes, lava fields, isolated lava flows and pyroclastic cones (Gałaś 2009). The most prominent volcanic is cluster known as the "Valley of Volcanoes". Several papers on petrology, origin and evolution of magmas of the Andahua group have been published recently. Especially the works of Delacour *et al.* (2007) and others provide a lot of information on chemistry, evolution and genesis of the magmas from the Andahua group.

EXTENT, ERUPTIVE STYLES AND CHARACTERISTIC STRUCTURES

In this work, I collected the rock material also from other cluster then than Valley of Volcanoes and streamed to the limits of occurrence of the Andahua group. Centres of eruption have been distinguished in clusters: the Valley of the Volcanoes, Antapuna, Rio Molloco, Laguna Parihuana, Colca Valley, Pampa Jaran and Huambo-Cabanaconde. They contain lava fields composed of single or sequence lava flows, many centres of lava effusion, including domes and fissures and minor pyroclastic cones (Fig. 1). The 165 individual eruption centres of Andahua Group were distinguished including apparent pyroclastic cones 50-300 metres high, and usually smaller lava domes and fissure vents. There are much more domes, eruptive vents and lava craters - 118, than scoria cones - 47. Most commonly lava flows started from lava domes or craters. A typical centre of eruption is a small lava dome aligned most probably along the feeding fissures. Eruption style was of the Hawaiian type. The scoria cones formed during Strombolian style of eruption.

The Valley of the Volcanoes is the largest cluster from which almost exclusively the petrological analyzes were published. On the contrary Rio Molloco, Laguna Parihuana, Antapuna, Colca Valley and Gloriahuasi Valley in Pampa Jaran weren't described. Results of field works were published in Peru (Gałaś 2009).

For example the largest of the observed lava domes of the Andahua Group, Cerro Coropuna (5180 m a.s.l.), is located in the Rio Molloco cluster, in the bottom of the glacial valley, below Paula gold mine. It attains relative height - 250 m. The dome is exceptionally steep and it is built of dacitic lava entirely fractured in large blocks. It seems an extrusive type dome.

Three broad periods of eruption were distinguished: Pleistocene, Pleistocene/Holocene and Late Holocene (Gałaś & Paulo 2005). The lavas of first period are characterized by varied 0-40% contents of phenocrysts, The majority being amphiboles, plagioclases and pyroxenes. Olivine was found in some sample.

PETROGRAPHY AND ROCK CLASIFICATION

Amphiboles have been identified as oxyhornblende (lamprobolite), up to 4 mm in size. They are distinguished by intensive pleochroism giving dark brown colour. They are automorphic with embayments filled with fine grained matrix.

Pyroxene phenocrysts do not exceed 0.5 mm. They consists mostly of clinopyroxene.

Plagioclases phenocrysts are 1 mm large on the average. Signs of melting and zones rich with volcanic glass inclusions can be found in them.

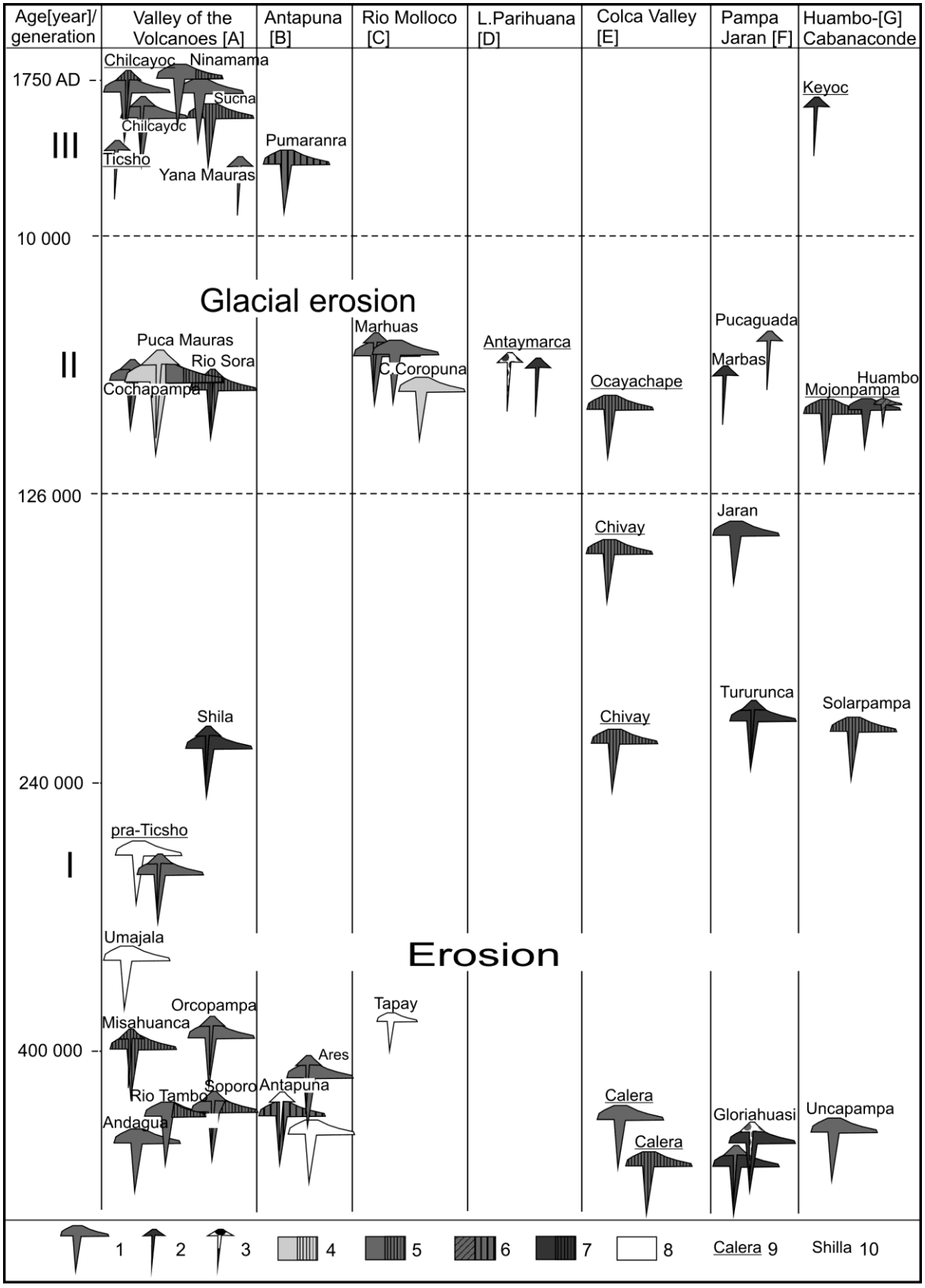

Fig.1. Chronostratygraphic framework showing structures and lithology in all clusters bearing centres of Andahua Group. 1- lava dome, 2 – scoria cone, 3 – stratovolcano, 4 – trachyte, trachydacite, 5 – benmoreite, latite, 6 – andesite, fenoandesite, 7 – mugearite, basalt, 8 – non described, 9 – dated (Kaneoke & Guevara 1984, Eash & Sandor 1995, Cabrera & Thouret 2000, Delacour et al. 2007), 10 – interpreted.

Rock matrix has felsite or hyalopilitic texture. It is mainly built of microlites of plagioclase resembling needles or small laths. The plagioclases are accompanied by unrecognizable opaque minerals and volcanic glass. The contents of glass does not exceed 10%.

The lava flowing down from the Cordillera Chila to the Valley of Volcanoes, near Chachas is quite exceptional. It contains phenocrysts of plagioclase (up to 2 mm) which are often etched or contain melt inclusions. Accompanying pyroxene is represented were by orthopyroxene of the enstatite group. One millimeter quartz grains surrounded by crowns built of clinopyroxene have been also found. Quartzite xenoliths detached from the bed built of Mesozoic formation are also present. The contaminate lava with quartz.

The lava belonging to the second generation contains slightly fewer phenocrysts i.e. 8.5% on the average or it is entirely aphanitic. Plagioclases dominates among phenocrysts accompanied amphibole and pyroxene. Oxyhornblende occurs only in the form of phenocrysts, entirely aphanitic rocks do not contain it. It is similarly shaped as in the old lavas but opacite rims are more pronounced and in some cases replace the whole phenocryst. Some crystals are melted or smoothed and contain melt inclusions.

Otherwise the lava of C. Coropuna dome is distinctly porphyritic. In the C.Coropuna extrusion the content of phenocrysts reaches up to 30% and they comprise oxyhornblende and plagioclase of various sizes. The phenocrysts of plagioclase examined under a scanning microscope show slightly more calcic composition then the plagioclases from the matrix and corresponding to the series of oligoclase-labradorite. Some phenocrysts show signs of zonal melting but no significant change of the chemistry.

Pyroxenes, mostly monoclinic, do not exceed 0.5 mm in size and sometimes they are considerably transformed. They are usually fractured, the fractures being filled with Fe oxides in some of the samples.

Plagioclases reach 1.5 mm in size. Some phenocrysts bear signs of melting on the edges which occur as characteristic inclusions.

The rock matrix is built similarly to older lavas but it contains more opaque minerals and less glass.

The youngest lava flows are usually entirely aphanitic, few samples hypocrystalline-porphyritic laths. The contents of phenocrysts does not exceed a few percent. Small plagioclases are dominating phenocrysts there. Except of lava from Pumaranra dome in Antapuna cluster where oxyhornblende prevails.

Few and small pyroxene and olivine grains have been observed in two samples. The rock matrix is dominated by plagioclase microlites and Fe oxides. Fluidal and vesicular textures are common.

Projection points of the analysed lavas of the Andahua Group on the TAS diagram concentrate in the lower part of the trachyandesite field, entering also the basaltic trachyandesite or trachyte/trachydacite fields (Gałaś, 2011). Therefore they show slightly alkaline affinity. Single samples are located in the basalt and andesite fields. Taking into consideration additional criteria (Na_2O and K_2O contents), the analysed lavas correspond mainly to three types of rocks: benmoreite, latite and mugearite. The lavas coming from Cerro Coropuna are much more silica and appear on the diagram at the same position as trachydacite, close to dacite and rhyolite fields. The lavas erupted from Chipchane lava dome appear project at the intermediary position between trachyandesite and trachydacite and it is classified as trachyte.

Analysis of spatial variations of lava chemistry carried out by present author gives the following results (Gałaś, 2011):

- latites dominate in the northern and central part of the Valley of Volcanoes including the Rio Sora valley (Yana Mauras, Cochapampa centres),
- benmoreites prevail in the central and southern part of the Valley of the Volcanoes (Ucuya, Jechapita and Chilcayoc Grande), it dominates south of the Colca Canyon in Huambo-Cabanaconde cluster,
- benmoreite (Llajuapampa) and mugearite (Marbas Grande) are present in the cluster of Pampa Jaran,
- latite and benmoreite occur in the Colca Valley,
- andesite of mean potassium content typical for calc-alkali volcanism, appears in crater located on the ridge of Cerro Jajacuchu near Huambo.

INTERPRETATION FOR PETROGENESIS

The most primary contents of Sr and Nd isotopes in the first phase of magmatism took place at least in four regions of occurrence of the Andahua group lavas i.e. in the Valley of Volcanoes, the Colca Valley, Pampa Jaran and Huambo-Cabanaconde. Lavas from Tururunca volcano are the most primitive. Fractional crystallization probably take place only at first phase. At that stage, assimilation took place in the deep crust (Fig.2). The chemical composition of the lava from the Valley of Volcanoes indicates relatively large degree of contamination. This can be also observed in the P.Jaran cluster. Differentiation processes occurring in the shallow zone of the crust had probably more influence there.

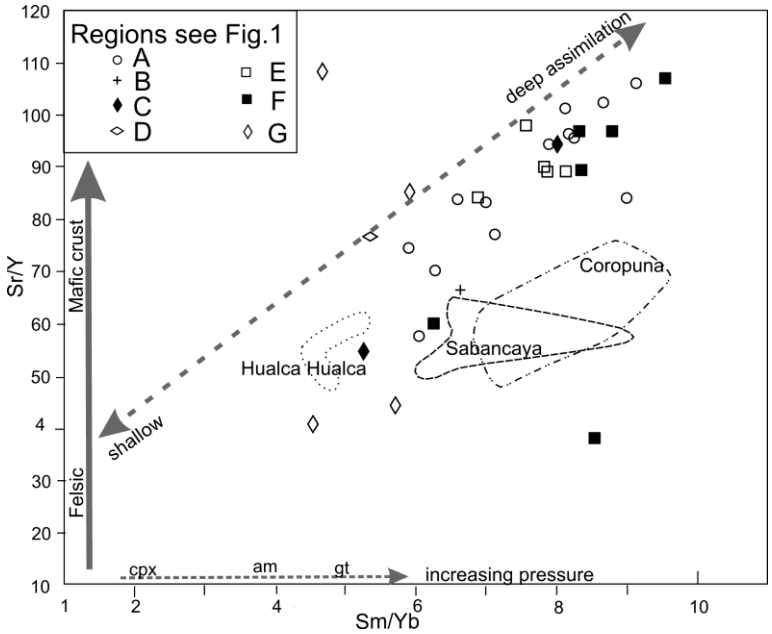

Fig. 2. Sm/Yb versus Sr/Y variations for Andahua Group. Field for the volcanoes Hualca Hualca, Sbancaya and Coropuna (Mamani *et al.* 2010).

The second phase of magmatism had a different nature depending on the region. Assimilation of rocks from the deep crust assumed in the base of Valley of Volcanoes, like during the first phase, and the degree of contamination was very similar. However, assimilation of rocks from the shallow crust had greater importance in the regions of Huambo and Jaran, but the degree of contamination in the Jaran region was small comparing to the Huambo region. It is also very likely that at that stage partial melting of rocks located over the magma chambers and formation of the MASH (Melting, Assimilation, Storage, Homogenization) zone took place. Lava form Cerro Coropuna, could been result of mixing with magma from Sabancaya system.

In the third phase, which concentreted in the Valley of Volcanoes, the magma was contaminated by the deep crust again. In that phase, the degree of contamination was the highest. It seems that if it is assumed that the MASH zone is active the lava composition reflects the processes occurring in the zone.

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