Journal of South American Earth Sciences 56 (2014) 301–315

Contents lists available at ScienceDirect

Journal of South American Earth Sciences

journal homepage: www.elsevier.com/locate/jsames

Petrology and new data on the geochemistry of the Andahua volcanic group (Central Andes, southern Peru)

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ARTICLE INFO

Article history:
Received 5 December 2013
Accepted 9 September 2014
Available online 28 September 2014

Keywords:
Plagioclases
Phenocrysts
Trachyandesite
Andahua Group
Peruvian Andes

ABSTRACT

The Quaternary Andahua volcanic group is located within the Central Volcanic Zone in Southern Peru. The author presents new data on major and trace elements and $^{87}Sr/^{86}Sr$ and $^{143}Nd/^{144}Nd$ ratios for Andahua rocks from all regions with volcanic centres. The TAS data identify the Andahua lavas as trachyandesites, basaltic trachyandesites and dacites. The phenocrysts are represented mainly by plagioclase, but olivine, clinopyroxene and hornblende are also present. In some cases the trachyandesites show Ca enrichment and their plagioclases have an andesine–bytownite composition. The plagioclase phenocrysts show a slight normal and occasionally reverse zonation. Their basaltic parental magmas were enriched in fluids derived from dehydration of the subducted oceanic crust. The chemical content of the Andahua volcanic rocks shows some similarity to both the slightly older and the contemporaneous and widespread Barroso Group rocks in this region.

1. Introduction

The Quaternary Andahua volcanic group (*sensu* Caldas, 1993) in the Central Andes (southern Peru) was the subject of research. In his earlier works the author described modes of occurrence as well as the regional distribution and time range of these rocks. The products of volcanism occur within the area of 110 by 110 km in the Valley of Volcanoes, on both sides of the Colca Canyon in seven clusters where lava fields, small domes and scoria cones have been distinguished (Fig. 1). Some fields can be classified as monogenetic (Hoempler, 1962; Gałaś, 2011). The presence of abundant eruption centres is a characteristic feature in this region, which prompted the author to classify the group as a large basaltic volcanic field (*sensu* Connor and Convay, 2000). Most of the eruption centres appear as lava domes; 121 of such structures have been documented. Apart from these there are 46 pyroclastic cones, a few of them appear to be culmination domes (Fig. 2). It means that, the cones were built during the last phase of eruptive activity, on the lava dome. They are built of pyroclastic material, except one – Gloriahuasi, which is built of lava and tephra layers and can be classified as a small stratovolcano (Gałaś, 2011). The oldest eruptions occurred in the middle Pleistocene and the youngest ones in historical times, about 300 years ago (Fig. 3) (Cabrera and Thouret, 2000). It should be noted that until now the idea that eruption centres correspond only to pyroclastic and cinder cones (only one lava dome has been identified by Sørensen and Holm, 2008) has been very common in the works concerning the Andahua Group and the number of cones has not been estimated precisely as the figures vary from 25 to 80.

Several papers on petrology, origin and evolution of magmas of the Andahua group have been published recently in different journals (Venturelli et al., 1978; Delacour et al., 2007; Ruprecht and Wörner, 2007; Sørensen and Holm, 2008). Especially the work of Delacour et al. (2007) provides abundant information on the chemistry, evolution and genesis of the magmas of the Andahua Group.

This paper present the results of investigation conducted in all clusters were Andahua Group has been identified. This group has been differentiated from other volcanic groups in the region relatively late and its activity, genesis and structural features are poorly known. This work presents new data on major and trace elements and some isotopic determinations concerning the Andahua Group lavas. Chemical analyses and isotopic determinations of Sr, Nd and Pb in whole rocks samples allowed to infer conclusions on the origin of parental magmas and their evolution. The results of this study enable to develop a better understanding of the magmatic system of the Andahua Group volcanoes. The study is a part of multidisciplinary research oriented to give a scientific background to the project of the Canyon Colca and Valley of the Volcanoes National Park (Paulo and Gałaś, 2006; Paulo et al., 2014).

2. Methodology

The paper is based on field observations and laboratory studies on the form and range of the lava flows. The author collected the

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http://dx.doi.org/10.1016/j.jsames.2014.09.012
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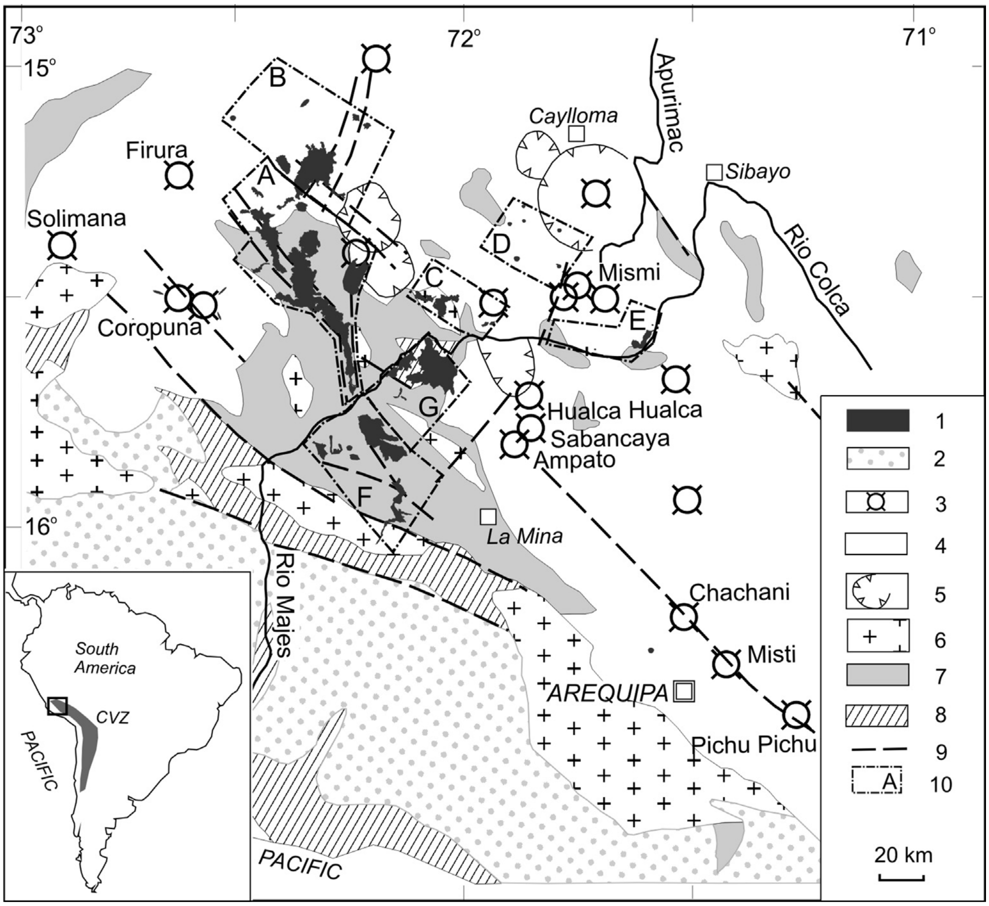

Fig. 1. Geological map of Río Colca region (from Paulo, 2008). 1 – Quaternary: Andahua Group, 2 – Pleistocene: alluvial gravels, 3 – Pliocene–Quaternary: stratovolcanoes of Barroso Group, 4 – Neogene–Quaternary: pyroclastic and lacustrine deposits, slopewash sediments, 5 – Neogene: caldera complexes, 6 – Jurassic, Cretaceous, Palaeogene: plutons, 7 – Jurassic, Cretaceous: sedimentary formations, 8 – Proterozoic: Arequipa massif gneisses, 9 – major faults, 10 – Andahua Group occurrence area: A – Valley of Volcanoes, B – Antapuna, C – Río Molloco, D – Laguna Pariuhuana, E – Río Colca Valley, F – Jarán, G – Huambo.

rock material also outside the Valley of Volcanoes and reached the limits of the occurrence of the Andahua Group. A total of 130 rock samples gathered from seven regions, in which the Andahua Group formations occur, were used for analyses (previously scientists focused their investigations on the Valley of Volcanoes and some parts of two other regions). Fifty thin sections for transmitting light were prepared and analysed, ICP analyses of 34 samples were performed at ACTLABS Activation Laboratories Ltd. (Canada). The ratios of $^{87}Sr/^{86}Sr$ and $^{143}Nd/^{144}Nd$ isotopes were determined for seven samples. The isotope analysis was performed using a Triton multi-collector mass spectrometer in the static mode. SEM–EDS examinations of 13 selected samples were carried out by means of a scanning electron microscope Quanta 200 FEG and NOVA NANO SEM 200. Selected analyses published in the works of Delacour et al. (2007) and Sørensen and Holm (2008) were also added to the analysis.

3. Geological setting

The convergent zone between oceanic Nazca and continental South America plates is supposed to have been active since the Palaeozoic (Golonka and Ford, 2000). The Mochica, Peruvian and Inca phases (Cretaceous/Paleogene) were the main compressional events in the Central Andes (Sempere and Jacay, 2008). Numerous folds, thrusts and faults trending NW–SE were formed then. The NE–SW faults present in the region were formed as the result of the next compressional phases. Stress regime in that part of the Andes is as follows: N–S stretching and E–W compression associated with the convergence of the oceanic Nazca plate (Sebrier and Soler, 1991). Extension in the Arequipa region is NE–SW (Mering et al., 1996). In the study area, there are three differently oriented systems of tectonic grabens (Soulas, 1977; Anatayhua et al., 2002; Żaba et al., 2012): NW–SE, WSW–ENE and NNW–SSE.

Orogeny has been active since late Palaeozoic and noted in Neogene times; volcanic eruptions culminated in the Miocene forming several calderas (Fig. 1) within the long lasting Tacaza volcanic arc (Thorpe et al., 1984; Trumbull et al., 1999). Hydrothermal activity around these calderas resulted in formation of ore veins (Noble et al., 2003; Paulo, 2008). This subduction related active magmatism is characterized by rapid crustal thickening since mid-Oligocene until present day (Mamani et al., 2010). The Coastal Batholith, which consists of several plutonic bodies, is partly the result of this magmatic activity. The crust reaches a thickness of up to 70 km in this area. Two domains have been differentiated in the basement of the study area: the Paracas (in the north) and Arequipa (in the south) domains (Pitcher et al., 1985). The magmatic arc was transformed and emplaced several times. The main arc system shifted in different time to northeastward or southwestward (Charrier et al., 2007; Mamani et al., 2010). The active Central Volcanic Zone (CVZ) is now 230 km long and located 115 km above the Benioff–Wadati plane (England et al., 2004).

In this part of the CVZ, the Coropuna (6425 m a.s.l, Fig. 2) is the largest volcano, rising about 3000 m above its surroundings (De Silva and Francis, 1991). The nearby situated Sabancaya (5976 m