GEOCHEMISTRY OF CAYAMBE AND MOJANDA-FUYA FUYA VOLCANIC COMPLEXES: EVIDENCES FOR SLAB MELTS - MANTLE WEDGE INTERACTION?

P. SAMANIEGO[1, 2], H. MARTIN[2], C. ROBIN[3], M. MONZIER[4], J-Ph. EISSEN[5], M.L. HALL[1]

(1) Instituto Geofisico, Escuela Politecnica Nacional (IG-EPN), A.P. 17-01-2759, Quito, Ecuador. (samanieg@opgc.univ-bpclermont.fr; pablosam@hotmail.com).
(2) CNRS, UMR 6524, Université Blaise Pascal, 5 rue Kessler, 63038, Clermont-Ferrand cedex, France. (martin@opgc.univ-bpclermont.fr).
(3) IRD, Université Blaise Pascal, 5 rue Kessler, 63038, Clermont-Ferrand cedex, France. (robin@opgc.univ-bpclermont.fr).
(4) Institut de Recherche pour le Développement (IRD), A.P. 17-12-857, Quito, Ecuador. (michmari@orstom.org.ec).
(5) IRD, UMR 6538, Université de Bretagne Occidentale, B.P. 809, 29285, Brest, France. (eissen@ifremer.fr)

KEY WORDS: Andean NVZ, Ecuador, adakites, mantle wedge processes.

INTRODUCTION

The Northern Andean volcanic zone results from the subduction of the Miocene (12 - 22 Ma) Nazca plate beneath the South-American continental lithosphere. The Quaternary Ecuadorian Volcanic Arc (about 50 edifices) extends from latitude 1°N to 2°S. The main part of this arc has been developed facing the Carnegie Ridge which represents the trace of the Galapagos hotspot across the Nazca Plate. This ridge has been subducting for 6-8 Ma to a position beneath the Andes 300-400 km from the trench (Gutscher *et al.*, accepted). Volcanoes from this arc are distributed following four alignments lying on the Western Cordillera, the Interandean Valley, the Eastern Cordillera and the Back-arc Region (Fig. 1). Recent regional and detailed volcanological works carried out by the Geophysical Institute of the National Polytechnic School at Quito and the IRD show that several large edifices, such as Cayambe and Mojanda-Fuya Fuya, present distinct magmatic series, either with classic calc-alkaline characteristics or with a "adakite-like" feature. The purpose of this paper is to present and discuss these characteristics in order to constrain and understand the petrogenesis process of the Ecuadorian volcanic rocks.

GEOLOGICAL SUMMARY OF THE VOLCANOES

The Mojanda-Fuya Fuya volcanic complex is located in the Interandean Valley, 50 km NNE of Quito. After Robin et al. (1998), the complex consists of an eastern edifice, the Mojanda stratovolcano (MOJ) and a more recent edifice, the Fuya Fuya (FF), built over the western flank of this stratovolcano. Mojanda is formed by lava flows and pyroclastic flow deposits whose composition varies from mafic andesite to dacite (55-67% SiO_2, recalculated as anhydrous). The volcanic units from Fuya Fuya are basal andesite lava flows and subsequent dacitic lava flows, domes and related pyroclastic flow deposits emplaced after a large sector collapse. The whole magmatic FF series is restricted to 61-68% SiO_2. The last domes of this complex are late Pleistocene to Holocene in age.

The Cayambe volcanic complex is located in the Northern Cordillera Real, 30 km E of Mojanda-Fuya Fuya. It mainly consists of a western lavic edifice, the Old Cayambe (VCAY), consisting of former basic andesites to younger dacites (56-68 % SiO_2). Barberi *et al.* (1988) report an K/Ar age of 0.25 ± 0.05 Ma for these dacites which end the volcanic activity of this edifice. The Nevado Cayambe (NCAY) is built upon the eastern remnants of the Old Cayambe structure, probably after a caldera collapse. Nevado Cayambe consists of basal andesitic lava flows (58-63 % SiO_2) overlain by a still active summit dacitic dome complex (63-68 % SiO2) which was the source of several recent pyroclastic flows (Samaniego et al., 1998). Lastly, a small parasitic cone, the " Cono de La Virgen " (CLV) was emplaced on the east flank of NCAY and emitted Holocene andesitic lava flows (59-60 % SiO_2).

MAGMATIC SUITES

As a whole, compared to the Mojanda-Fuya Fuya rocks, the Cayambe volcanics are alkali, LILE, HFSE and LREE enriched (Fig. 2). Such eastward enrichment is classic in the Andean subduction context and has been already noted for Ecuador (Barberi *et al.*, 1988; Barragan *et al.*, 1998).

However, based on major and trace element analyses, two distinct magmatic series can be distinguished in both volcanoes. Whereas the VCAY and MOJ volcanic rocks define a classical calc-alkaline trend, rocks from the young NCAY and FF edifices belong to magmatic suites with distinct geochemical characteristics. They are characterised by the lack of mafic andesites, as well as a HREE and Y depletion with related high La/Yb and Sr/Y ratios (Fig. 2 and 3). In addition, CLV's rocks are high-K andesites, strongly enriched in LREE, LILE and relatively MgO- and HFSE-rich.

In addition, the whole suites of both volcanic complexes show a significant MgO, Ni and Cr enrichment compared to "normal" andesitic suites. Their Sr and Nd isotopic ratios are similar and close to the MORB values, suggesting no contamination by the highly radiogenic upper continental crust.

On the other hand, the two series are mineralogically different: in the NCAY and FF suites, amphibole is omnipresent, whereas in VCAY and MOJ it is in subordinate amounts and only in the more evolved laves (>63 % SiO_2).

GEOCHEMICAL MODELLING AND DISCUSSION

Modelling based on both major and trace element behaviour has been performed on these suites. This procedure shows that the fractional crystallisation in the upper crust can account for the geochemical diversity of the volcanics (line 1a and 1b, Fig. 3). For both low-Y (or adakite-like) NCAY and FF series, the fractionation of amphibole, plagioclase, clinopyroxene and magnetite explains the whole compositional variations. In the same way, the fractionation of plagioclase, ortho- and clino-pyroxene and magnetite accounts for some characteristics of the VCAY and MOJ suites. In addition, geochemical modelling shows that it is impossible to relate low-Y and classic calc alkaline rocks by fractional crystallisation.

In order to understand the HREE and Y depletion of the subduction-related volcanic rocks, two models have been proposed: (1) partial melting of the basaltic oceanic crust leaving an eclogitic residue (the adakitic model); or (2) assimilation of lower crustal silica-rich melts. In fact, geochemical modelling shows that partial melting of an enriched MORB source leaving an eclogitic residue (cpx + gt +/- hb) may explain low HREE and Y contents (line 2a and 2b, Fig3). On the other hand, the volcanic arc is located too far from the trench (250-300 km), the slab is apparently too deep under the volcanoes (> 100 km) and the arc is built over a thick continental crust. This argues against the adakitic model and suggest a explanation by lower crustal assimilation. Thus, the two hypotheses (slab melting or lower crustal assimilation) are currently debated.

The anomalous high MgO, Ni and Cr concentrations; as well as the anomalous geochemical characteristics of the CLV volcanics (strongly incompatible elements enriched and weakly enriched in MgO) may be explained by interaction between slab-derived silica-rich partial melts and the mantle wedge. This model for magnesian andesite generation was proposed by Kay *et al.* (1993) and Yogodzinsky *et al.* (1995). The enrichment in transition elements as well as "magmatic" metasomatism of the mantle wedge could result from the mixing between hypothetical slab-derived melts (aprox. 5-15 % partial melting) and the depleted mantle wedge (line 4, Fig. 3). Therefore, a different degree of mixing between a "low-Y end-member" and a "mantellic end-member" (line 5, Fig. 3) could account for the parental magmas of each series. Such a model has been proposed by Yogodzinski *et al.* (1998) to explain the genesis of Aleutian high-magnesian andesites.

Whatever the correct hypothesis, the genesis of these magmas implies an anomalous thermal regime either in the subduction plane or in the mantle wedge and lower crust. The high density of volcanoes in Ecuador, the large width of the volcanic arc (120-150 km) and the intermediate seismicity gap (70-220 km) along the Benioff plane that caracterizes the Ecuadorian subduction system (Gutscher *et al.*, accepted) argue for the presence of an anomalous high thermal regime, and may be due to the subduction of the Carnegie Ridge. This ridge is younger and thus hotter than the Nazca lithosphere, and its subduction could be responsible for additional stress heating in the subduction zone.

CONCLUSION

On the basis of available data, the low-Y and HREE contents of the NCAY and FF suite, show that there is a intervention of silica-rich basaltic melts via slab partial melting or infra-crustal assimilation. On the other hand, the enrichment in MgO, Ni and Cr for all rocks and the peculiar chemical compositions of CLV volcanics are evidence for a small degree of slab partial melting and an intense interaction between slab-derived silica-rich melts and the mantle wedge. In addition, the slab melting hypothesis is supported by recent geophysical data corroborating the subduction of a hot and young oceanic slab. Detailed petrological studies in those two volcanic complexes arc in progress, in order to decide between the two hypotheses.

REFERENCES

Barberi F., Coltelli M., Ferrara G., Innocenti F., Navarro J.M., ct Santacroce R. (1988) Plio-Quaternary volcanism in Ecuador; *Geol. Mag.*, 125,1, pp. 1-14.

Barragan R., Geist D., Hall M.L., Larson P. and Kurz M. (1998) Subduction controls on the compositions of the lavas from Ecuadorian Andes. *Earth Planet. Sci. Lett.* 154, 153-166.

Gutscher M.A., Malavielle J., Lallemand S. and Collot J.Y. (accepted) seismotectonics of the North Andean margin: Impact of the Carnegie Ridge collision. *Earth Planet. Sci. Lett...*

Kay M.S., Ramos V.A. and Marquez M (1993) Evidence in Cerro Pampa volcanic rocks for slab-melting prior to ridge-trench collision in South America. *J. Geol.*, 101, 703-714.

Samaniego P., Monzier M., Robin C. and Hall M.L. (1998) Late Holocene eruptive activity at Nevado Cayambe volcano, Ecuador. *Bull. Volcanol.* 59:451-459.

Robin C., Hall M.L., Jimenez M., Monzier M. and Escobar P. (1998) Mojanda Volcanic Complex (Ecuador): development of two adjacent contemporaneous volcanoes with contrasting eruptive styles and magmatic suites. *J. South Am. Earth. Sci.* Vol. 10; No. 5-6, 345-359.

Yogodzinsky G.M., Kay R.W., Volynets O.N., Koloskov A.V. and Kay S.M. (1995) magnesian andesite in the western Aleutian Komandorsky region: Implications for slab melting and processes in the mantle wedge. *Geol. Soc. Am. Bull.*; vol. 107; No. 5; 505-519.

Yogodzinsky G.M. and Kelemen P.B. (1998) Salb melting in the aleutians / implications of an ion probe study of clinopyroxene in primitive adakite and basalt. *Earth Planet. Sci. Lett.* 158, 53-65.