THE HIGH-K NEOGENE BACK-ARC VOLCANISM OF THE BOLIVIAN ALTIPLANO : A COMPLEX PETROGENETIC STORY.

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INTRODUCTION

The high-K back-arc volcanism which was emplaced on the Bolivian Altiplano during the Neogene differs from the Andean Cordillera Central Volcanic Zone (CVZ) arc activity in the small volumes of lavas emitted by minor monogenetic centers instead of stratovolcanoes, and its close relations with the tectonic regime on the Altiplano. But its genesis seems to be linked to complex processes as in the arc. Try to decipher the story of these small magma batches, using mineralogical and isotopic evidences, is the purpose of this study.

GEOLOGICAL SETTING

Since the Upper Oligocene period, a peculiar volcanism was emplaced on the Bolivian Altiplano, in a back-arc situation, East of the CVZ subduction-related volcanic arc (400 km from the trench), above a very thick continental crust of about 70 km. This volcanism is characterized by a temporal alternation of mainly two types of minor events, distributed along major fractures, essentially in the northern and central parts of the Altiplano (Fig.1) : acidic phenocryst-rich domes (andesitic to dacitic in composition) on the one hand, mafic aphyric flows on the other hand. According to available radiochronological data (K/Ar method), this alternation seems to be related to tectonic episodes (Soler & Jimenez, 1993) : during periods of compressive deformation, domes were emplaced whereas, during extensive or transtensive short-lived episodes, the lavas were erupted as reduced flows. These volcanic events represent small volumes of magma (between 10^{-3} and 10^{-1} km^3) compared to the large volumes emitted by active stratovolcanoes of the volcanic arc. This observation leads to suppose that these monogenic centers erupted from small crustal reservoirs (or conduits?) rather than large magma chambers. The edifices concerned by this study are Early to Late Miocene domes and Middle Miocene and Quaternary flows. The whole-rock geochemistry of the two types of events is quite similar, excepted for K_2O contents which are higher in the lava flows, classified for this reason as "shoshonitic" flows instead of "high-K calc-alkaline" for the domes.

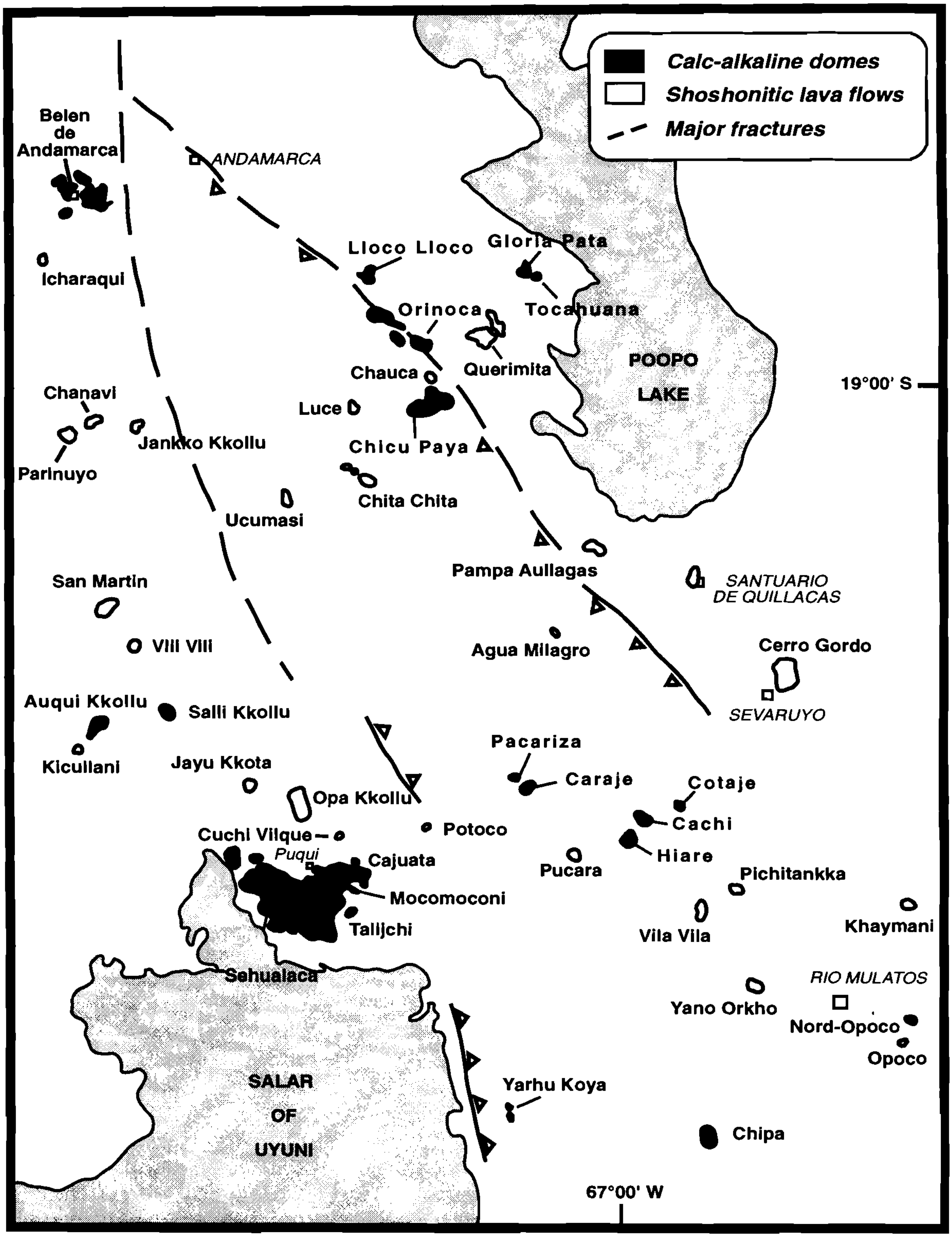

FIG.1 : Location map of miocene to quaternary back-arc volcanic minor centers of the central Bolivian Altiplano.

COMPLEX MINERALOGICAL ASSOCIATIONS

Domes and lava flows, though differing in their type and time of emplacement and their amount of phenocrysts, share complex mineralogical associations and show xenoliths of crustal and magmatic origin.

The two main petrogenetic processes highlighted by this unusual mineralogy are crustal assimilation and magma mixing. For both processes, we can observe two kinds of evidences : complete xenoliths and/or xenocrysts (with reaction rims) coming from disaggregated or digested xenoliths.

- Crustal assimilation. Some lava flows contain numerous metamorphic crustal xenoliths of granulite to amphibolite facies. These xenoliths, millimetric to centimetric in size, are partially digested but exhibit a well-preserved schistosity. The most frequent xenolith type corresponds to a sillimanite and biotite-bearing gneiss, probably extracted at lower crustal level since this part of the crust is supposed to be composed of high-grade crystalline metamorphic rocks, instead of sedimentary, volcanic and plutonic rocks as in the upper crust (Gill, 1981). Domes sometimes contain amphibolite xenoliths coming certainly from the same crustal depth as the gneiss xenoliths.

However, the majority of our samples (domes and flows) only present metamorphic xenocrysts with reaction rims. The most frequent xenocrysts are : garnet rimmed by plagioclase and orthopyroxene, sillimanite, kyanite replaced by green spinel, quartz with undulatory extinction and clinopyroxene rim... Biotite and feldspars (plagioclase and K-feldspar) of metamorphic origin are microscopically distinguishable from the host-rock magmatic phenocrysts by their degree of alteration or destabilisation (with or without rims).

The only possibility to explain the occurrence of such minerals in volcanic rocks is the involvement of crustal assimilation during magma ascent through the continental crust (Maury & Bizouard, 1974 ; Pognante, 1990). According to the nature of the xenoliths and preserved xenocrysts, this process probably occurred in the lower crust, at a depth between 20 and 70 km.

Major elements contents show that these rocks are not peraluminous and then cannot be interpreted as crustal melts, such as Macusanites (Pichavant et al. 1988).

Isotopic data (Soler et al., 1993) confirm the importance of crustal contamination and, more precisely, the role of the lower crust Precambrian gneiss. We can indeed see, on a $^{143}Nd/^{144}Nd$ versus $^{87}Sr/^{86}Sr$ diagram, that isotopic values of our rocks tend towards the deep crustal end-member represented by a quartz-sillimanite gneiss xenolith found in one of the lava flows (Pampa Aullagas) from the central Altiplano (Davidson & de Silva, 1995). Even the most mafic flows (with Mg# between 61 and 64) are contaminated and cannot provide informations on the nature of the mantelic source.

- Magma mixing. In the same way, we can find in both domes and flows rounded dark basaltic xenoliths with vacuolar hyalodoleritic texture, composed of large acicular hornblende crystals, around olivine and pyroxenes cores. Plagioclase (sometimes with skeletal shapes) and Fe-Ti oxides occur as microcrystals in a glassy groundmass. All these characteristics are typical of quenched basaltic liquids (Coulon et al., 1984) and imply that these xenoliths formed by mixing of a hot basaltic magma with a more acidic and cooler one.

Domes and flows more often exhibit xenocrysts in disequilibrium originated from the mafic magma : olivine rimmed by orthopyroxene, clino- and orthopyroxene aggregates rimmed by amphibole microcrystals, or scattered hornblende phenocrysts with pyroxene cores. Host-rock felsic phenocrysts can also develop reaction textures such as sieve-textures for plagioclase (systematically with an inverse zoning) or clinopyroxene rim around quartz...These features were already recognized as the result of a magma mixing phenomenon by several authors (Paz,1992 ; Stimac & Pearce, 1992 ; Matthews et al., 1994). Exceptionally, in some lava flows, there are evidences of two mixing episodes, one with a more basic magma, and the other with a more felsic (i.e. rhyolitic) magma.

The problem is to determine at what crustal level this process happened. Since the mixing occurred between a basaltic and a more felsic, i.e. cristallized magma, it probably took place in small shallow reservoirs, where the acidic magma was trapped. After the basaltic intrusion in the reservoir, mixing occurred between the two different magmas and probably triggered the eruption of the hybrid mixing product (Sparks et al, 1977).

Fractional crystallization is supposed to have occurred during the last part of the ascent, in small chambers.

CONCLUSIONS

We can conclude from the petrographical, mineralogical and isotopic data available on the domes and lava flows that mantle-derived parental magmas have undergone at least one episode of crustal assimilation and magma mixing during their ascent through the thick continental crust under the Bolivian Altiplano. The petrogenetic story can be as follows : primary magmas, generated by partial melting of a mantelic source that is still not well defined, first arised in the lower continental crust where they sampled and partly digested ancient granulitic crustal rocks, such as sillimanite and biotite gneiss found as xenoliths in some lava flows. Then, parental magmas continue their ascent and mix with more acid magmas stocked in shallow reservoirs, triggering the eruption of small volumes hybrid magmas, emplaced as high-K calc-alkaline domes under compressive tectonic conditions or as shoshonitic flows under transtensive or extensive conditions.

REFERENCES

Coulon C., Clocchiatti R., Maury R.C. & Westercamp D. 1984. Petrology of Basaltic Xenoliths in Andesitic to Dacitic Host Lavas from Martinique (Lesser Antilles) : Evidence for Magma Mixing. *Bull. Volcanol.*, 47-4 (1), 705-734.

Davidson J.P. & de Silva S.L. 1995. Late Cenozoic magmatism of the Bolivian Altiplano. *Contrib.Mineral.Petrol.*, 119, 387-408.

Gill J.B. 1981. Orogenic andesites and plate tectonics. *Berlin-Heidelberg ; Springer-Verlag*, 390 pp.

Matthews S.J., Jones A.P. & Gardeweg M.C. 1994. Lascar Volcano, Northern Chile; Evidence for steady-state disequilibrium. *J. Petrol.*, 35, part 2, 401-432.

Maury R.C. & Bizouard H. 1974. Melting of Acid Xenoliths into a Basanite : an Approach to the Possible Mechanisms of Crustal Contamination. *Contrib.Mineral.Petrol.*, 48, 275-286.

Paz Moreno F. 1992. Le volcanisme mio-plio-quaternaire de l'état du Sonora (nord-ouest du Mexique) : évolution spatiale et chronologique ; implications pétrogénétiques. *Thèse d'Université*, Université Aix-Marseille III, 196p.

Pichavant M., Kontak D.J., Briqueu L., Valencia Herrera J. & Clark A.H. 1988. The Miocene-Pliocene Macusani Volcanics, SE Peru. II. Geochemistry and origin of a felsic peraluminous magma. *Contrib. Mineral. Petrol.*, 100, 325-338.

Pognante U. 1990. Shoshonitic and ultrapotassic post-collisional dykes from northern Karakorum (Sinkiang, China). *Lithos*, 26, 305-316.

Soler P. & Jimenez N. 1993. Magmatic constraints upon the Evolution of the Bolivian Andes since Late Oligocene times. *Second ISAG*, Oxford (UK), 21-23/9/1993, 447-451.

Soler P., Carlier G., Aitcheson S.J. & Fornari M. 1993. Sr, Nd and Pb isotopic constraints upon the origin of the Quaternary shoshonitic lavas and the deep structure of the Central Altiplano of Bolivia. *EUG VII, Strasbourg (France), Terra Abstracts, Abstract suppl. N°1 to Terra Nova*, 5, 584-585.

Sparks S.R.J., Sigurdsson H. & Wilson L. 1977. Magma Mixing : a Mechanism for Triggering Acid Explosive Eruptions. *Nature*, 267, 315-318.

Stimac J.A. & Pearce T.H. 1992. Textural evidence of mafic-felsic magma interaction in dacite lavas, Clear Lake, California. *Amer.Mineral.*, 77, 795-809.