MAGMATIC EVOLUTION OF THE BERENGUELA-CHARAÑA REGION NORTHWESTERN ALTIPLANO, BOLIVIA

Néstor JIMENEZ CH.[1], Luis BARRERA I.[1], Oscar FLORES B.[1], José Luis LIZECA B.[1], Fernando MURILLO S.[1], Orlando SANJINES [1], Richard F. HARDYMAN[2], Richard M.TOSDAL[3], Alan R. WALLACE[4]

(1) Servicio Geológico de Bolivia, casilla 2729, La Paz
(2) U.S. Geological Survey, Mackay School Mines, Reno, Nevada 89557
(3) U.S. Geological Survey, 345 Middlefield Road, Menlo Park, California
(4) U.S. Geological Survey, Box 25046 M.S. 905, Denver, Colorado

RESUMEN: El magmatismo cenozoico de la región Berenguela-Charaña se inició en el Oligoceno superior y se prolongó, casi en forma continua, hasta el Cuaternario. Un cambio composicional de los magmas de afinidad alcalina y shoshonítica a calcoalcalina rica en potasio ocurrió en el límite Mioceno inferior y medio.

KEY WORDS: Cenozoic, Altiplano, magmatism, alcaline, calc-alkaline

INTRODUCTION

The Berenguela-Charaña region, located East from tripartite point border of Bolivia, Peru and Chile, was the site for long although intermittent Cenozoic magmatic activity alternating with periods of sedimentation. Conspicuous changes in the magma composition suggest variations in the tectonic regime and thickness of the continental crust throughout Late Cenozoic time. New field investigations, supported by K-Ar data and chemical analyses, carried out as part of an international cooperation program (Jiménez et al., 1993; Wallace et al., 1993), give some insight for the discussion of the magmatic evolution of the Bolivian Altiplano.

GEOLOGICAL SETTING

The oldest rocks outcropping in the area are the Eocene-Oligocene sandstones of the Berenguela Fm (Sirvas, 1964)

deposited over a basement formed by unexposed precambrian rocks and cretaceous sediments (Lehmann, 1978). These sandstones were gently folded by an orogenic phase about 28 Ma (Lavenu et al., 1989). Unconformably to disconformably over them, a thick sequence of sedimentary and volcanic rocks was deposited. This sequence is constituted by basaltic to andesitic lava flows intercalated with violaceous and well stratified arcosic sandstones in the base, and brownish, massive, and unconsolidated siltitic sandstones and conglomerates in the top. Sirvas (1964) and Ferrey (1970) named this sequence either Abaroa Fm or members 1, 2, 3 and 4 of the Mauri Fm. In this work, all these rocks are called Abaroa Fm. Avalaible K-Ar data for this formation range from 25 to 13 Ma (Evernden et al., 1977; Lavenu et al., 1989), but recent field observations and correlations with another areas of the Altiplano (Soler and Jiménez, this volume) constrain the bulk magmatic activity between 25 and 20 Ma. The younger ages seem to be obtained in some of the younger dikes and sills emplaced in the Abaroa Fm.

The name of Mauri Fm is reserved, in this work, for a volcanic and volcaniclastic sequence overlaying both the Berenguela Fm and the Abaroa Fm. It includes tuffaceous sandstones, reworked tuffs, nonwelded ash flow tuffs, debris flows and conglomerates. A tuff from the base of this Formation, disconformably emplaced over the underlaying units, gave an age of 18.3$\pm$0.7 Ma (Jiménez et al., 1993). The tuffs of its upper part were dated at 10.5 and 13.6 Ma (Evernden et al., 1977; Jiménez et al., 1993), On the other hand, many dacitic and rhyolitic intrusive bodies, dated at 10 and 11 Ma (Soria and Terrazas, 1992; Jiménez et al., 1993), were emplaced in all the area. Since the composition of the ash flow tuffs of the Mauri Fm is rhyolitic, a remarkable change of the magma composition occurs during the early Miocene (at 20-18 Ma).

In the Late Miocene and Early Pliocene a chain of volcanoes and a field of domes were built in the area. The Antajavi, Huaricunca and Serkhe volcanic complexes are made of rhyolitic nonwelded tuffs, dacitic to andesitic lava flows and intrusives, and other volcaniclastic deposits. The Antajavi volcano has been dated at 7$\pm$0.3 Ma (Jiménez et al., 1993), and two ages of 5.7$\pm$0.7 Ma were obtained for the Huaricunca and Serkhe volcanoes (Lavenu et al., 1989; Jiménez et al., 1993). The Thola Kkollu dome field is not dated but the chemical composition of its rocks is closely similar to the composition of the rocks of the volcanoes.

A huge volume of pyroclastic volcanism has been emitted during the Late Pliocene in the Berenguela-Charaña region giving rise to extended plateaus in the southern part of the area. First, a rhyolitic, crystal rich, weakly welded ash flow tuff (Pérez Fm of Sirvas, 1964), poured out from an unknown vent. Evernden et al. (1977) dated it in 2 and 3 Ma. Later, lacustrine sediments and a nonwelded, rhyolitic pumice flow of the Quaternary Charaña Fm (Sirvas, 1964) deposited over the nearly horizontal topography formed by the Pérez tuff.

PETROGRAPHIC AND CHEMICAL COMPOSITION

Basalts and andesites of the Abaroa Fm exhibit pilotaxic matrix with microlites of labradorite and small rounded crystals of augite. Occasionally, small crystals of nepheline can be found in the groundmass. The common phenocrysts of these rocks are zoned augite and labradorite +/- olivine. In the more differentiated terms lamprobolite and phlogopite are usual.

Dacitic to andesitic lavas and intrusives of the Medium to Late Miocene are characterized by hornblende, biotite and plagioclase (oligoclase-andesine) phenocrysts. In some of these rocks augite is the principal mafic mineral, but usually it is present in minor proportions. Quartz and sanidine are found in the rhyolites. The matrix can be either glassy or microcristaline.

The weakly welded ash flow tuff of the Pérez Fm, and the nonwelded ash flow tuffs of the Mauri Fm and of the Huaricunca and Serkhe volcanoes exhibit the same mineralogy. All these tuffs are rhyolites with laths of biotite and fragmented phenocrysts of quartz, plagioclase and sanidine scattered in a glassy groundmass with shards and spherolites. Xenoliths of basalts and Precambrian rocks are not uncommon.

The chemical analyses confirm the existence of two groups of magmatic rocks. Basalts and andesites of the Abaroa Formation have contents of SiO_2 ranging between 46 and 56%. Many of these rocks are nepheline-normative and usually they are silica undersaturated. Although some terms can be classified in the shoshonitic series, most of these rocks show alkaline affinities with TiO_2 varying between 0.71 and 1.35%, MgO from 1.90 to 9.90%, and often with $K_2O/Na_2O>1$. Contents of Cu vary between 56 and 285 ppm, Sr between 542 and 2500, Ni from 9 to 71, and Co between 15 and 100 ppm. On the contrary, the felsic rocks of the mid-Miocene to Quaternary exhibit contents of SiO_2 between 58 and 75%. Cu vary between 5 and 67 ppm, Sr between 46 and 1620, Ni from 2 to 31, and Co between 1 and 41 ppm. All these rocks are subalkaline but an increase in the alkalis content is evident in the rocks of the Late Miocene compared with the Medium Miocene ones. Some terms prove to be corindon-normative.

CONCLUSIONS

The magmatism of the Berenguela-Charaña region started in the Late Oligocene with the eruption and intrusion of rocks of alkaline affinities (Abaroa Fm). These rocks can be correlated with another ones known in the central and southern Altiplano (Tambillo lavas, Julaca and Rondal Formations, etc.) which are part of a more or less continuous belt (discussion and references in Soler and Jiménez, this volume). The origin of these rocks is poorly understood yet, but they seem to be generated in the upper mantle without noticeable crustal

contamination, probably during an transtensional period (Soler et al., 1992; Soler and Jiménez, this volume). The magma composition changes to a "normal" high-K calc-alkaline composition of the arc magmas of the Central Volcanic Zone in the Medium Miocene. This compositional change can be interpreted as a result of changes in the tectonic regime and the thickness of the continental crust.

REFERENCES

Evernden, J., Kriz, S., Cherroni, C., 1977, Potassium-Argon ages of some bolivian rocks. Economic Geology, v. 72, 1042-1061.

Ferrey, C.J., 1970, Estudio geológico de la región de la Estación ferroviaria Eduardo Abaroa. Unpublished thesis, Universidad Mayor de San Andrés, La Paz, 70 p.

Jiménez, N., Barrera, L., Flores, O., Lizeca, J.L., Murillo, F., Hardyman, R.F., Tosdal, R.M., Wallace, A.R., 1993, Marco geológico de la región de Berenguela. In Investigación de metales preciosos en los Andes Centrales, final report of Proyecto BID-USGS-GEOBOL, p. 63-74.

Lavenu, A., Bonhomme, M.G., Vatin-Perignon, N., De Pachtere, P., 1989, Neogene magmatism in the bolivian Andes between 16° and 18°S: Stratigraphy and K/Ar geochronology. Journal of South American Earth Sciences, v. 2, n° 1, p. 35-47.

Sirvas, J.F., 1964, Estudio geológico de la región Tambo Mauri-Berenguela, Provincia Pacajes del Departamento de La Paz, República de Bolivia. Unpublished thesis, Universidad Mayor de San Andrés, La Paz, 84 p.

Soler, P. and Jiménez, N., this volume, Magmatic constraints upon the evolution of the Bolivian Andes since Late Oligocene times.

Soler, P., Carlier, G., Fornari, M., Hérail, G., 1992, An alternative model for the origin and the tectonic significance of the Neogene and Quaternary shoshonitic volcanism of the Andes. AGU, Spring Meeting Suppl., 73, 14, p. 341.

Soria, E., Terrazas, R., 1992, La Española prospect. In Geology and Mineral Resources of the Altiplano and Cordillera Occidental, Bolivia, U.S. Geological Survey bulletin 1975, p. 184-187.

Wallace, A.R., Hardyman, R.F., Tosdal, R.M., Jiménez, N., Lizeca, J.L., Murillo, F., 1993, Cenozoic geology and mineral deposits of the Berenguela district, northwestern Bolivia. In Advances related to United States and international mineral resources-developing frameworks and exploration technologies, B.R. Berger and P.S. Detra eds., U.S. Geological Survey Bull. 2039, p.79-86.