Early Mesozoic rift-related magmatism in the Bolivian Andes and Subandes: The southernmost record of the Central Atlantic Magmatic Province

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The Central Atlantic Magmatic Province (CAMP) represents one of the largest igneous events on Earth and was associated with the onset of fragmentation of the supercontinent Pangea at the Triassic-Jurassic boundary. Its extent in South America has been documented in Guyana (Deckart et al., 1997) and Brazil (Marzoli et al., 1999), but whether its original extension reached present-day Andean regions was unknown to date. Recognition of possible CAMP remnants in the Andes and Subandes is hindered by the subsequent orogenic history, yet it is of prime importance to define the contours of this huge province. In addition, because pre-Andean extensional structures and related magmatism may have controlled the subsequent crustal thickening (Sempere et al., 2002), they may shed light onto the orogenic evolution of the Andes.

The area of interest is here the Bolivian Eastern Cordillera and adjacent Subandes, where a Permian-Triassic rift system developed (Sempere et al. 2002), now forming an arcuate structure in the Bolivian Orocline. The sedimentary sequence consists of 1) Permian fluvio-aeolian sandstones (Cangapi Formation), 2) restricted-marine deposits (Vitiacua Formation) of Late Permian - Early Triassic age, 3) continental red strata (Ipaguazú Formation) of Triassic age, believed to have been deposited in a rift setting, and 4) dominantly aeolian coarser-grained sandstones (beginning with the Tapecua Formation) presumed to have a Lower Jurassic age.

In the southern part of the Bolivian rift system (southern Eastern Cordillera and adjacent Subandes), elongated outcrops of basaltic lava-flows occur in the areas of Tarabuco and Entre Ríos (Fig. 1). They are generally intercalated between the sandstones of the Ipaguazú and Tapecua Formations, and may have covered an initial surface of about $3x10^4$ km^2. The maximum thickness of the lava unit is ~150m. Alternating massive and vesiculated zones, as well as pillow lava structures, were observed in places near Tarabuco. South of Tarabuco, a gabbroic sill, 100-150 m thick, intrudes into red sandstones ascribed to the Ipaguazù Formation, and a thinner sill, ~30 m-thick, intrudes into the Cangapi Formation near Camiri (Sempere et al. 2002).

The rocks sampled from these lava-flows and sills are basalts, dolerites and gabbros, displaying an homogeneous mineralogical composition dominated by plagioclase (An 40-83), augite (Fs 9-26), pigeonite (Fs 27-39), Ti-magnetite and interstitial glassy to granophyric mesostasis. Alteration products are weakly to moderately developed after interstitial glass (clay minerals) and plagioclase (sericite). The rocks are low-TiO_2 (1.2-1.5 wt%) tholeiitic basalts (SiO_2 = 50-52.4 wt%), displaying a very limited range of differentiation (Mg# = 0.55-0.59) except some gabbros in the Tarabuco sill (Mg# = 0.4). The very homogeneous trace elements patterns are slightly LILE and LREE enriched (La/Yb_n = 2.7-2.9; Fig. 2a) and display negative Nb-Ta anomalies. They have a near-chondritic Nd isotopic composition (εNd_i = - 0.7 / - 0.2) and a slightly more variable $^{87}Sr/^{86}Sr_i$ ratio (0.7052-0.7061) (Fig. 3). The geochemical and isotopic homogeneity argues for a common mantle source and similar magmatic processes throughout the three investigated areas (confirming Soler and Sempere's [1993] preliminary results), and is in agreement with CAMP compositions. Bolivian basalts match the mean composition of low-Ti CAMP for isotopes (Fig. 3), and have trace element compositions similar to CAMP lava-flows from SW Brazil, USA (lower part of formation), Morocco (upper part of formation), and Portugal (Fig. 2b).

Age determinations were mostly performed on small fractions of carefully selected plagioclase, by using either CO2 laser (lab number heading letter G or H) and high frequency furnace (M1669) heating systems. Nevertheless, all data reflect a more or less slight alteration by sericite, as observed in thin sections.

Three plateau ages (concordant ages corresponding to at least 70% of ^{39}Ar released) were obtained, ranging from 192.9 ± 0.8 (2 sigma) to 200.0 ± 2.7 Ma. (Bo18, Bo12 and Bo991105-1 samples), but other age spectra are disturbed (Fig. 4, Table 1). Nevertheless, all $^{37}Ar_{Ca}/^{39}Ar_{K}$ ratio spectra (this ratio is proportionnal to Ca/K ratio), including samples displaying plateau ages, show either slightly (Bo18) or strongly (Bol12, Bo991105-1) variable ratios resulting from a mixture of plagioclase (Ca-rich) and sericite (K-rich). The highest apparent ages generally correspond to the highest $^{37}Ar_{Ca}/^{39}Ar_{K}$ ratios, and therefore to the less altered plagioclase fractions. Therefore, it is likely that even in the case of plateau ages, the best estimate of the age of these samples is given by the highest apparent ages of the plateau fraction.

For Bo18, a weighted mean age (w.m.a.) of 196.1 ± 1.5 Ma (steps 4-5), and for Bo991105-1 a mini-plateau age at 203.7 ± 4.1 Ma (steps 3-9), are preferred. In the case of Bol12, for which no plateau appears, the w.m.a. of 197.2 ± 2.2 Ma calculated on steps corresponding to highest Ca/K ratios (steps 5 to 7, 12-13) represents the best age estimate. At last, the S14-2 sample gave too imprecise data (low Ar signals) to be useful and sample Bol19-1 is altered and yielded a staircase-shaped spectrum with meaningless ages from 120 to 168 Ma. In conclusion, the best estimates of the ages of the investigated samples are ranging between 194.6 ± 0.7 and 203.7 ± 4.1 Ma.

Although they are located ~1000-km away from the nearest Brazilian records (Fig. 1), combined geological, geochemical and geochronological data support that these Bolivian basalts belong to the huge CAMP province. The CAMP thus extends through South America down to an Andean-Subandean area in southern Bolivia, and is therefore much larger than previously recognized. This finding opens the possibility that other CAMP remnants occur somewhere in the Andes, and puts additional constraints on the genesis of this vast province as well as on its bearing on Andean-age deformation.

References

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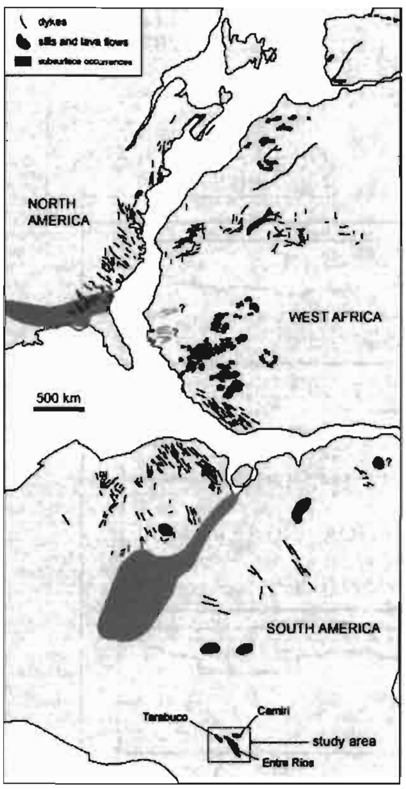
Fig. 1 Sketch map of the CAMP with location of the studied Bolivian basalts



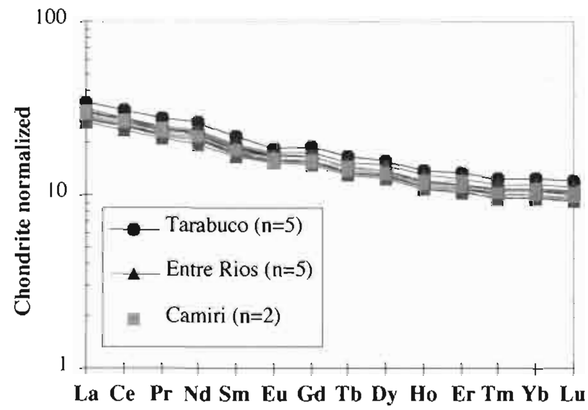


Fig.2a REE contents of bolivian basalts

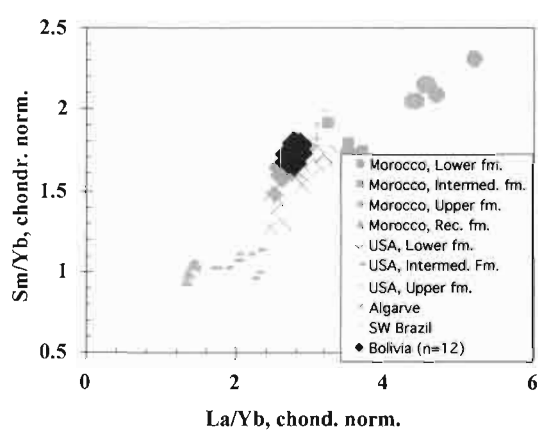


Fig.2b REE contents of bolivian basalts compared to other low-Ti CAMP basalts

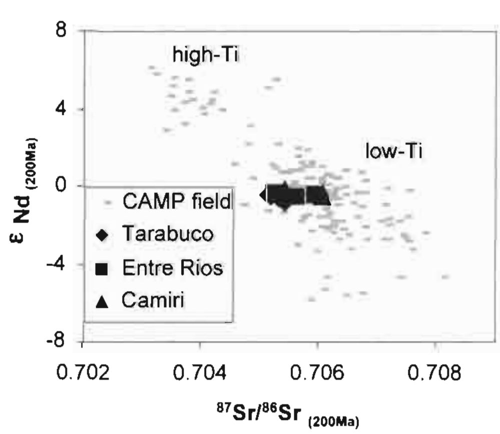


Fig.3 Isotopic compositions of bolivian basalts compared to other CAMP basalts

Sample Number	Location	Lab N#	Plateau age Ma ± 2σ	^{39}Ar %	Steps in the plateau /number of steps	Total gas age Ma ± 2σ	Preferred age Ma ± 2σ
Bol8 Pl	Tarabuco	H319	192.9 ± 0.8	75%	6-14 / 14	192.3 ± 0.8	**196.1 ± 1.5**
Bol2 Pl	Tarabuco	H369	194.6 ± 0.7	70%	5-15 / 19	193.9 ± 0.8	**194.6 ± 0.7**
Bol12 Pl	Camiri	H368	**193.0 ± 1.7*	64%	*7-13 / 13*	189.5 ± 1.3	**197.2 ± 2.2**
Bo991105-1	Camiri	H30	200.0 ± 2.7	83%	6-14 / 14	198.4 ± 2.6	**203.7 ± 4.1**
Bo991105-1	Camiri	M1664	**189.5 ± 1.4*	54%	*8-14 / 14*	184.4 ± 1.2	-
S14-2 Pl	Tarabuco	G194	**201.2 ± 10.6*	26%	*7-9 / 9*	177.1± 6.6	-
S14-2 Pl	Tarabuco	G168	**194.9 ± 6.6*	18%	*11-13 / 13*	168.0 ± 3.0	-
S14-2 Pl	Tarabuco	G07	**185.5 ± 6.3*	37%	*5-7 / 7*	174.4 ± 4.6	-
Bol19-1	EntreRios	H320	*(120 to 168 Ma)*			150.7 ± 0.8	-

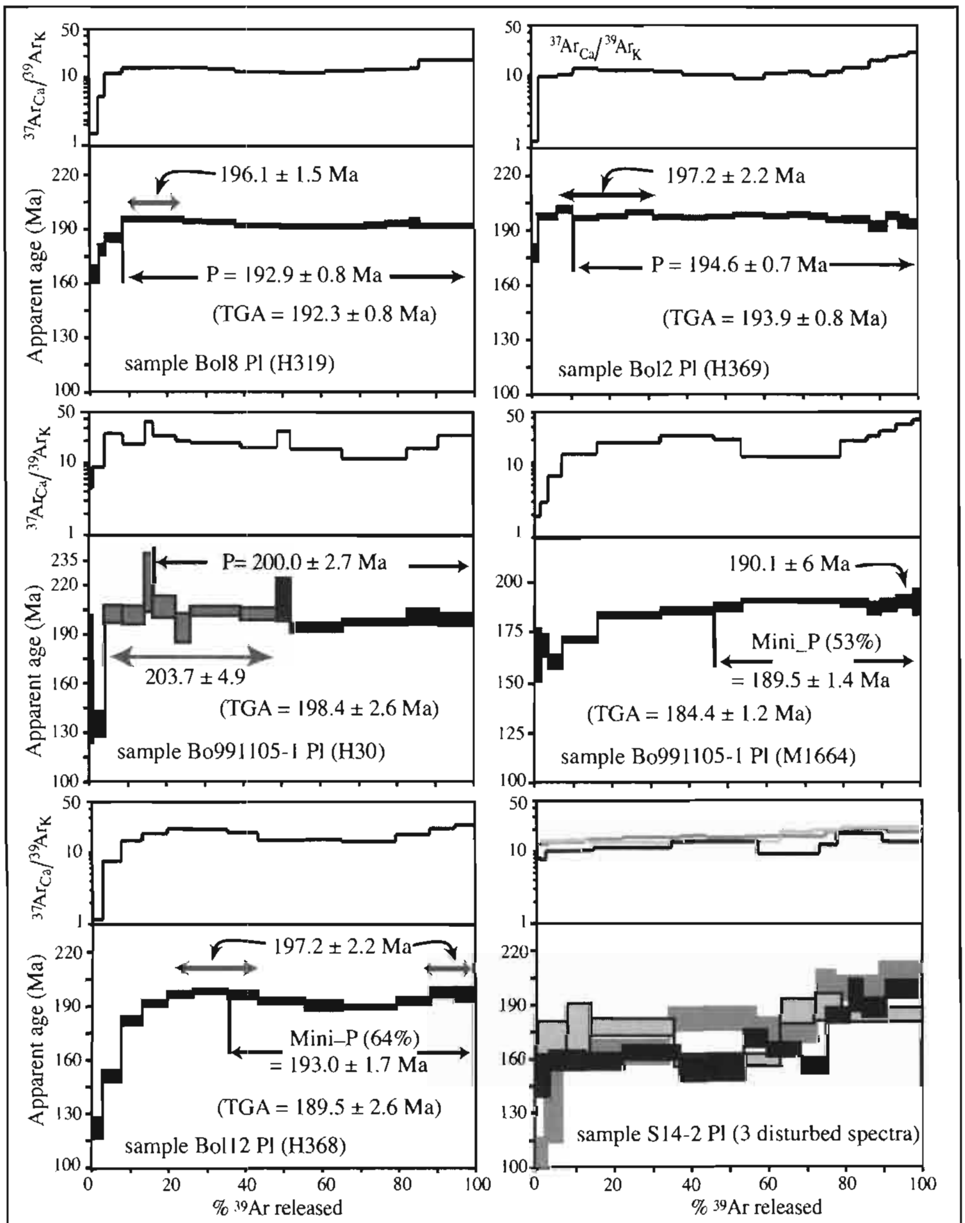


Fig 4. ^{40}Ar/^{39}Ar age and ^{37}Ar$_{Ca}$/^{39}Ar$_K$ ratio spectra obtained on plagioclases. Plateau, Total gas (TGA) and Preferred ages are given at the two sigma (2σ) confidence level but for apparent ages the thickness of each individual step represents one sigma.