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Tertiary to Quaternary chemical trends of basalts from the Cordillera Baguales (50°S): Constraints on the geotectonic evolution of the southernmost Andes

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Introduction

The geotectonic and magmatic evolution of the southernmost Andes was strongly effected by the collision and subduction of the Chile ridge[1] (15-10 Ma B.P., Fig. 1). The subduction of the Chile ridge probably was followed by the formation of a slab window causing melting of the asthenospheric and/or lithospheric mantle below the Southern Andes[1,2,3]. In addition, during the subduction of the Chile ridge and the following slow subduction of the Antarctic plate, adakitic slab melts were produced which subsequently contaminated and enriched the lithospheric mantle[4-6].

In this context we have investigated a suite of presumable Tertiary to Quaternary volcanic rocks from the Cordillera Baguales in the southernmost Andes (50°S, Fig. 1).

Samples were taken in a stratigraphic order (Fig. 2) which probably includes the period of the Chile ridge collision and subduction below the Southern Andes. The 1500 m thick basaltic to andesitic suite is exposed about 25 km to the east of the Quaternary volcanic front, i.e. at the transition to the alkali basalt plateaus of the back arc[7]. Geochemical data of this volcanic suite enables constraints on the complex Tertiary to Quaternary geotectonic evolution of the southernmost Andes. Previous geochemical data of similar 'transitional' basalts from other localities in the Southern Andes show intermediate chemical characteristics between arc basalts and alkaline intraplate basalts[7], but give no informations on time related geochemical trends.

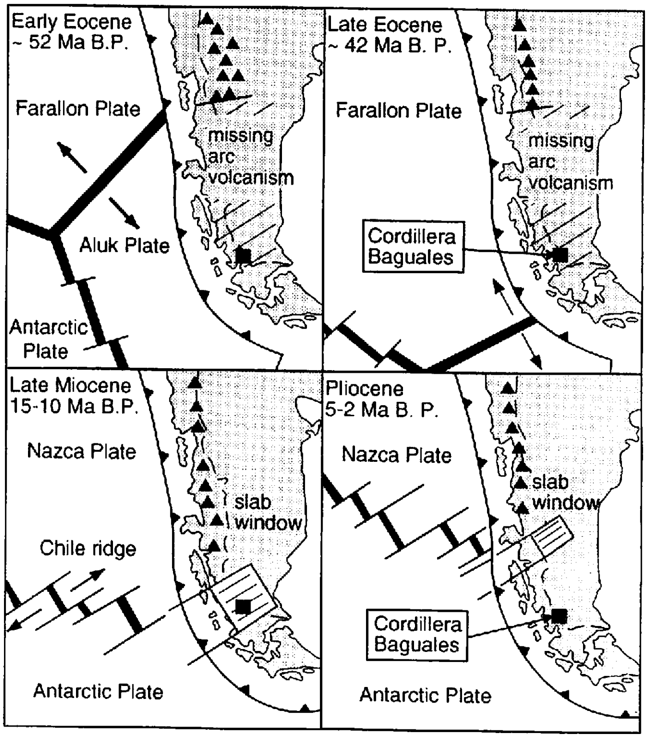

Fig. 1: Plate tectonic evolution of the Southern Andes between the early Eocene and Pliocene and the location of the Cordillera Baguales. The collision of the Chile ridge[1] and the possible formation of a slab window are also illustrated.

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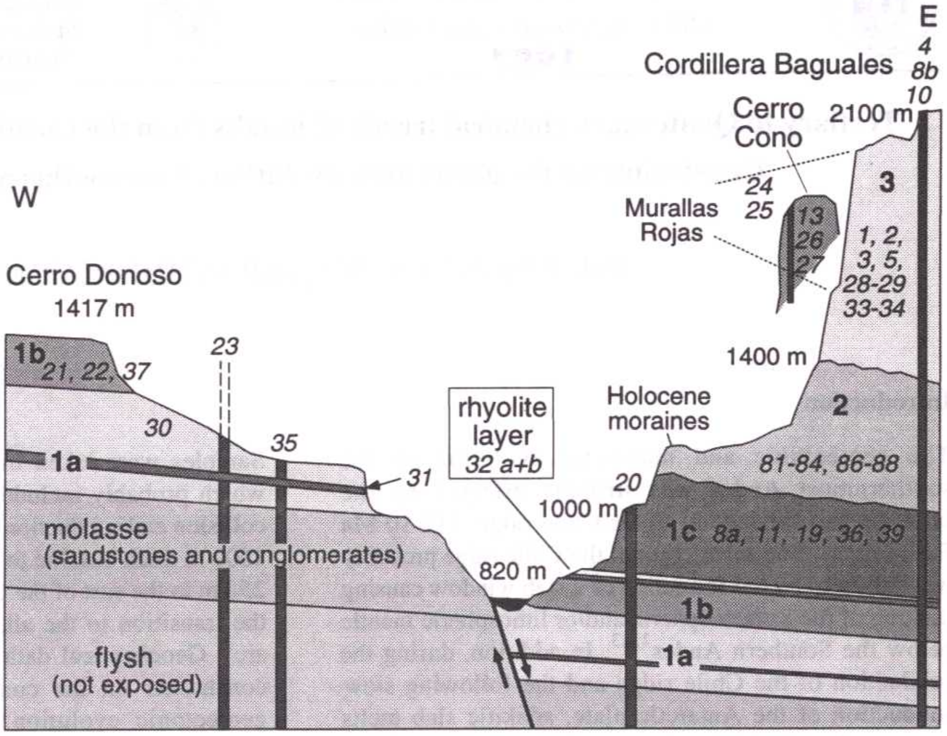
Fig. 2: Schematic W-E profile across the Cerro Donoso and Cordillera Baguales, illustrating a stratigraphic order (1-3) and sample numbers partly shown in figures 3-5.



Sampling and analytical procedures

Samples were taken from the Cerro Donoso and the Cordillera Baguales in stratigraphic order (Fig. 2), possibly ranging from syn-collisional lower Miocene (Group 1, Fig. 1) to Pliocene (Group 2) and a Quaternary (Group 3). The W-E profile of Fig. 2 shows the investigated volcanic units deposited at the eastern Andean slopes. Our preliminary stratigraphy is solely based on field mapping.

The mineral structures and the phenocrysts of most of these samples were investigated by optical microscopy of thin sections. Chemical compositions of typical phenocrysts were investigated by electron microprobe to constrain the effects of fractional crystallization and to detect mantle or crustal xenocrysts. For chemical investigations only volcanics with fresh mineral and glass content were selected. Only rhyolitic ash layers of the oldest group 1 are slightly altered, i.e. biotite. XRF data were produced from 42 samples using a Siemens SR 303 (Mineralogisches Institut, Heidelberg). 12 of these samples covering the compositional range of the XRF data were investigated by ICP-MS analysis at Memorial Institute of St. John´s, Canada. Calibrations were done by using various international geostandards.

Chemical characteristics and their implications

The investigated volcanic rocks are subdivided into three stratigraphic groups (Fig. 2), each of these exhibit distinct chemical characteristics. This is illustrated in Figures 3 to 5 and summarized thereafter. The oldest volcanic rocks of group 1 consist of low-K to med-K basalts and low-K andesites and interbedded layers of low-K rhyolites. The basalts have relatively high Nb/U (33-42) and Ce/Pb (14-23), and low K/Nb (<300) and K/Ta (<50). These values are similar to MORB or OIB suggesting a mantle source which was not significantly modified by subduction related metasomatism[8-11]. However, basaltic samples of group 1 (22, 35, 37) show variable alkalinity and variations of the Ce/Pb and Nb/U ratios between two end members: Sample 37 has the highest Ce/Pb and Nb/U and the highest alkalinity which suggests relatively low degrees of partial melting. In mantle normalized trace element pattern this basalt (and of sample 22, Fig. 5) shows a strong depletion of Cs and slight depletion of Rb, Ba, U and K when compared to Nb and Ta[8,9]. These basalts also show a negative Pb anomaly (Fig. 5) suggesting a slightly depleted mantle source (asthenosphere?). Basalt sample 35 represents the other end member of group 1 by having lower alkalinity and lower Ce/Pb and Nb/U and no depletion of the very incompatible elements Cs, Rb, U. This reflects higher degrees of partial melting and a mantle source which was less depleted than that of the basalt samples 37 and 22, i.e. similar in composition to primitive mantle or to an OIB mantle source[8,12,13].

In Figs. 3 and 4 samples of group 1 define trend A from a low alkali basalt end member (i.e. sample 35) to a low-K andesite (sample 11). This trend is characterized by a decrease of Nb/U and Ce/Pb, and a slight

Fig. 3: K_2O (a) and K/Nb (b) plotted versus SiO_2 in volcanic rocks of the Cordillera Baguales (Fig. 1). Samples of groups 1 to 3 represent different old samples. Their stratigraphic relations are illustrated in fig. 2. Samples for which ICP-MS data exist are numbered (see figs. 2, 4, 5). Three different possible calcalkaline trends (A, B, C) are distinguished.

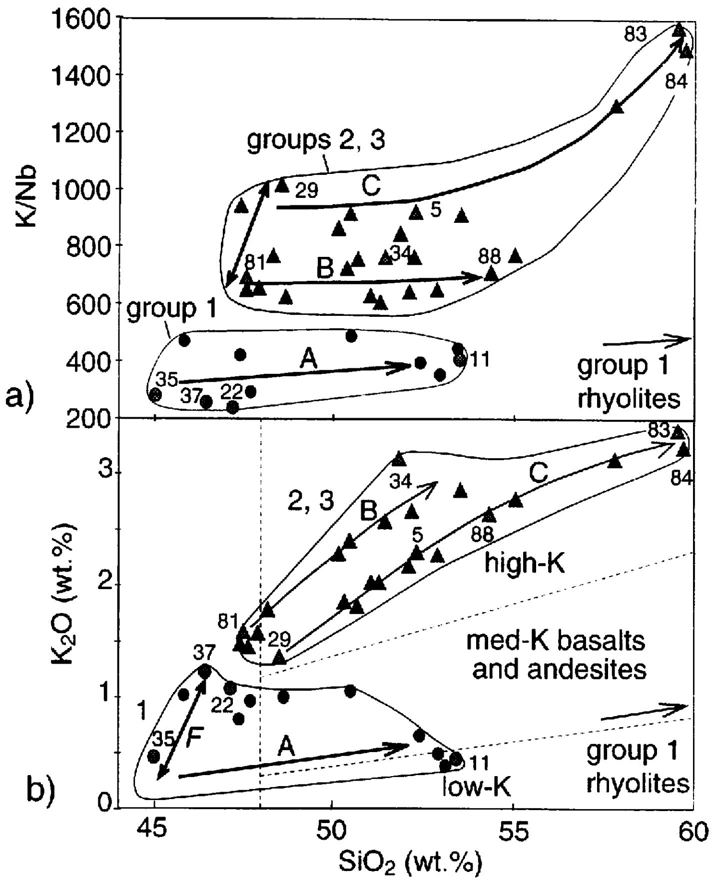
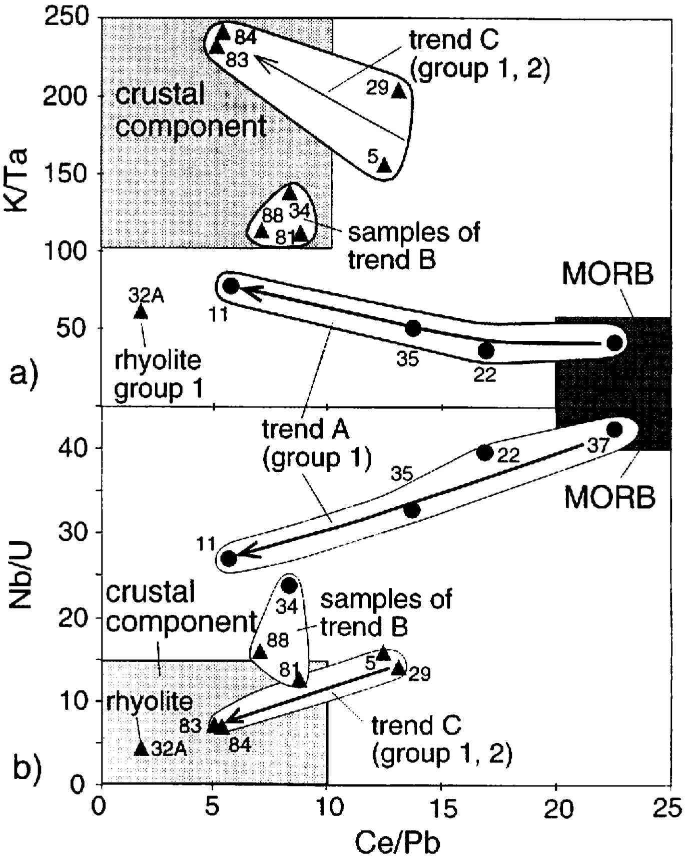


Fig. 4: K/Ta (a) and Nb/U (b) plotted versus Ce/Pb for volcanic rocks from the Cordillera Baguales (Fig. 1). The trends, volcanic groups and sample numbers are the same as in Figs 2, 3 and 5.



increase of K/Nb, Ba/Nb and K/Ta. Sample 11 also shows a positive Pb anomaly in the normalized trace element pattern[9] of Fig. 5. This suggests contamination by a crustal component during an AFC process[9,14]. Low-K rhyolites of group 1 have very low Ce/Pb (~3) and Nb/U (~4) and high Ba /Nb (45). These values are similar to the continental crust[15] suggesting that the rhyolites represent either an end member of such an AFC process or fused continental crust. The relatively low K/Ta and K/Nb ratios of these rhyolites may be due to the alteration of biotite and therefore not representative for their petrogenesis.

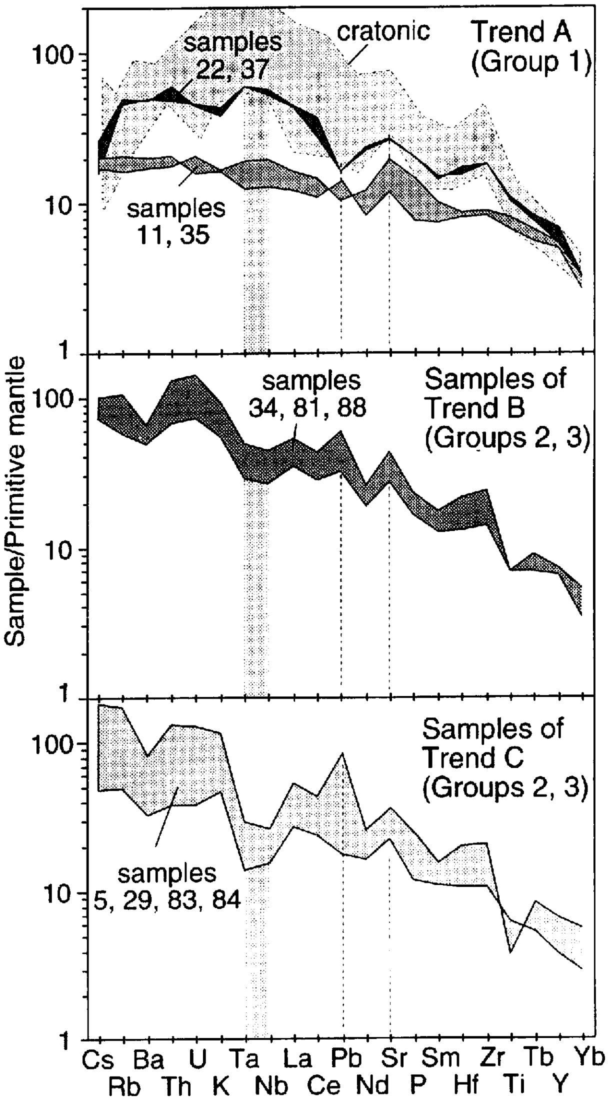


Fig. 5: Trace element pattern for volcanic rocks of trends A, B and C from the Cordillera Baguales, normalized to primitive mantle[9]. Samples of trend A (Group 1) are compared to a cluster defined by cratonic alkali basalts of the southern South America[7].

The younger volcanic rocks of the groups 2 and 3 belong to a high-K calcalkaline basaltic to andesitic rock suite. Volcanics of both groups show similar chemical characteristics and variations, but differ significantly from volcanics of group 1. In contrast to group 1 rocks, their trace element pattern show typical signatures of arc rocks[10-13], i.e. low U/Nb, low Ce/Pb and high K/Nb. However, this signature is variably developed in volcanics of the groups 2 and 3. Figs. 3 and 4 distinguish between two possible AFC trends (B and C). Their parental magmas are characterized by different K/Nb, Ba/Nb, K/Ta and Nb/U ratios. Samples 34, 88 and 81 which are representative for trend B have the highest alkalinity and show only slightly negative Nb and Ta anomalies (Fig. 5). Samples of trend C have slightly lower alkalinity compared to trend B and show the strongest Nb and Ta anomalies, high K/Nb, Ba/Nb and low U/Nb and Ce/Pb ratios, and a significant positive Pb peak (Fig. 5). This suggests a mantle source which was variably contaminated by subduction related metasomatic fluids or slab melts[4-6, 10-13].

Samples of trend B range between 48 and 55 wt. % SiO_2 contents and do not show significant variations of Ce/Pb, Nb/U, K/Ta, K/Nb ratios. They may be best explained by closed fractional crystallization[16]. Samples of trend C range from 48 to 60 wt. % SiO_2 and, in contrast to trend B, show a significant increase of K/Nb, K/Ta, Ba/Nb ratios, and a decrease of Ce/Pb and Nb/U ratios. Such trends cannot be originated by closed fractional crystallization and suggest an AFC process involving an additional crustal component.

Conclusions

Previous data of basalts from the transition between the Holocene arc and the Quaternary alkali plateau basalts in the Southern Andes do not give clear implications for time related geochemical trends[1,7,12,13]. Our data of volcanic rocks from the Cordillera Baguales show that during the Tertiary to Quaternary period magmas originated from two different mantle sources. The oldest volcanics of group 1 are derived from a mantle which was not significantly modified by subduction related magmatic processes. However, their mantle source was chemically only little depleted compared to Primitive Mantle[9]. This precludes a N-MORB forming asthenosphere as source which, however, is a possible source for many of the alkali plateau basalts of the back arc[1,7,8] (Fig. 5). Principally trace element pattern of group 1 volcanics could be inherited from melting of an old lithospheric mantle[17]. However, because of the predominant harzburgitic nature of the mantle below the

Cordillera Baguales this possibility is unlikely. Xenoliths from Cerro del Fraile, located 30 km to the North of the Cordillera Baguales, document this harzburgitic composition of the lithospheric mantle. Upwelling of asthenosphere into a slab window[2] appears to be a more likely scenario for the formation of basalts from the oldest group 1 assuming that the asthenosphere contained mantle plume components. If we propose that the Chile ridge collision and formation of a slab window were responsible for the formation of group 1 volcanics, there was only a short magmatic cycle (15-10 Ma, Fig. 1). In this context we try to explain the chemical variations of group 1: At first, low alkali basalts were produced from a less depleted mantle source. Subsequently low melt fractions may be produced from a mantle which was previously depleted by basalt extractions (Fig. 5). In this period, underplating of basalts could have triggered lower crustal melting and the formation of the rhyolites of group 1.

In contrast to the older group 1, volcanic rocks of the Pliocene and Pleistocene groups 2 and 3 were derived from a mantle source which was contaminated to variable degrees by fluids or melts derived from the subducted Antarctic Plate. The relative depletion of Ba and K compared to Th and U is typical for melts derived from the subducted Antarctic plate, but is untypical for arc basalts[6,10-13]. This suggests that the mantle source was contaminated mainly by slab derived melts[5]. The high alkalinity of group 2 and 3 basalts suggests significantly lower degrees of partial melting in the mantle source compared to common circum pacific arcs[10,11]. During this period, parental magmas with variable degrees of chemical arc signatures were generated and fractionated to andesites. The intracrustal magma evolution was also very variable, ranging from nearly closed fractional crystallization to AFC processes involving a highly fractionated arc crust[16].

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