600 Ma of crustal evolution in the Central Andes: A site of crustal growth or destruction at an active continental margin?

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Introduction

The continental crust in the Central Andes records at least 600 Ma of history at the leading edge of South America and might be considered as a representative area to answer the question, if a continental arc is a site of crustal growth. Palaeogeographic reconstructions (e.g. Piper, 2000) suggest that the Central Andes (Fig. 1) formed the western edge of the South American craton since late Proterozoic and prolonged periods of subduction dominated the early Paleozoic and Late Paleozoic to Cenozoic history. This is documented by the chemical and isotopic composition of the diverse crustal rocks and by their ages of magmatism and metamorphism and deposition. We summarize the key compositional features of the crust for this transect of the Central Andes, from the earliest recorded period to the present Andean cycle. They allow to speculate that the history of the Andean active margin, although it has certainly been a major site of geological activity, did not result in significant net crustal growth by addition of juvenile material. The evolution of the upper mantle at that margin – although less well constrained due to the discontinuous record of mantle-derived magmatic rocks – produced a rather homogeneous reservoir in the mantle wedge with a depleted signature, quite different from the mantle lithosphere of the old craton, but also different from the present Pacific MORB-type mantle.

Geological evolution

The Central Andes formed part of a Mesoproterozoic cratonic area, as shown by its oldest metamorphic and magmatic rocks from the Sunsás orogeny at 0.9 – 1.2 Ga in the Arequipa massif of southern Peru and in a few small isolated outcrops in Bolivia (Fig. 1a); there is no record of Archean and early Proterozoic crust. There is also little known about the crustal evolution between the Mesoproterozoic and the early Paleozoic. During the Early Paleozoic, this basement was strongly reworked by erosion and sedimentation, and so the oldest widely distributed rocks are Neoproterozoic to early Cambrian sedimentary rocks (e.g. Puncoviscana Formation). It was also reworked in a mobile belt; ages of metamorphic rocks from a large area from southern Bolivia down to western Argentina and into northern Chile (where they are mostly covered by younger volcanic and sedimentary rocks) (Fig. 1) cluster between 530 - 500 Ma (Pampean) and 470 - 400 Ma (Famatinian). The dominant rock types are felsic gneisses and migmatites of upper amphibolite facies. Granitoid magmatism (560 – 400 Ma) is widespread and voluminous, especially in the early Ordovician. Detritus from the evolving early Paleozoic orogen is preserved in extensive Ordovician siliciclastic sediments of southern Bolivia and northern Argentina. Uplift and erosion of the orogen, as the result of the long-time subduction processes was largely completed in the Devonian to Carboniferous. It was followed by an episode of passive margin-type siliciclastic sedimentation and only minor magmatism. Magmatism started again along the margin at ca. 300 Ma, and continued into the Permian and Triassic. Isolated late Paleozoic intrusions (Fig. 1b) in the uppermost levels of the crust are mainly granite with minor diorite. The Triassic magmatism is mainly granitic in composition but of minor volume.

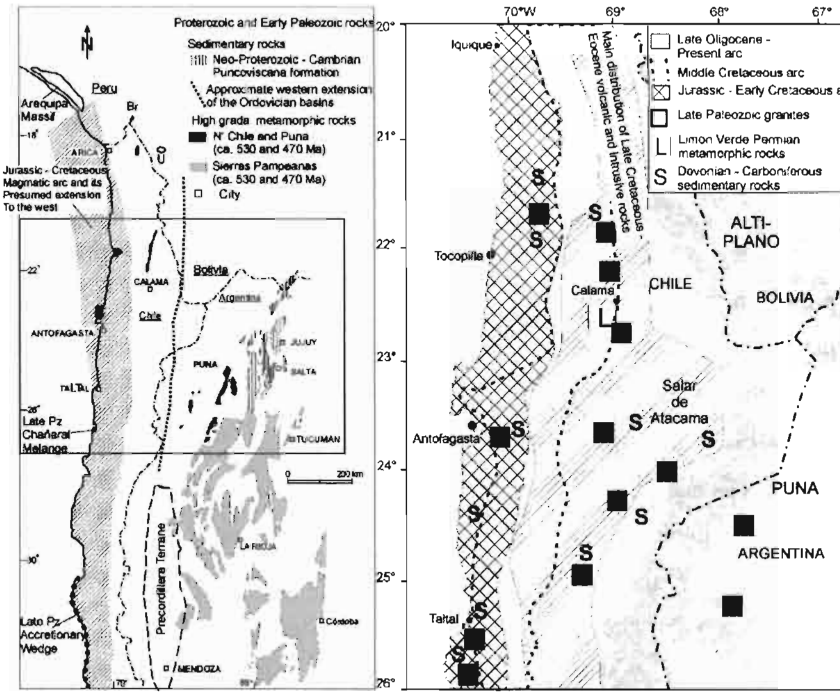

Figure 1a: Distribution of Proterozoic (Arequipa Massif, Br = Berenguela, U = Uyarani;) and early Paleozoic rocks between ca ≈ 16 and 33°S and the position of the Precordillera Terrane; extension of the early Jurassic – Cretaceous magmatic arc. The box shows the approximate area covered by Figure 1b.
Figure 1b: Late Paleozoic – Cenozoic magmatic rocks from the various magmatic arcs intruded or overlay early Palaeozoic crust. Devonian – Carboniferous sedimentary rocks frequently form the host rocks of the late Paleozoic intrusions.

A dramatic change in the nature of magmatism took place in late Triassic - early Jurassic. Large volumes of mantle-derived magmas extruded and intruded during the Jurassic to lower Cretaceous, mainly in the Coastal Cordillera (Fig. 1b). The volcanic and intrusive rocks are dominantly of basaltic andesite to andesite composition, with subordinate amounts of both more basic and more evolved compositions. The tectonic regime of late Paleozoic, Mesozoic and early Tertiary was dominated by extension and transpression and even during compressional phases, large-scale crustal thickening is ruled out by the sedimentary record for the late Paleozoic and Mesozoic with low average-sedimentation rates in continental or shallow marine environments and the absence of deep erosion. The late Cretaceous and Tertiary magmatic arc migrated east with time and from the Oligocene onward the present orogen formed (Fig. 1b). The compositions changed to dominantly andesite during Tertiary and during the Neogene, the large-scale ignimbrites are largely crustal melts. Juvenile (basaltic) magmas in these belts are rare, although it is reasonable to assume that the andesites are associated with more mafic intrusive and/or cumulate material in the lower crust.

Growth or recycling of the crust?

In this discussion we place strong emphasis on the Rb-Sr and Sm-Nd isotope systems (Fig. 2) because they give the most direct information on mantle versus crustal provenance of the rocks concerned. The Th-U-Pb systems, which are not shown here, yield similar results. The data show that the material reworked in the Mesoproterozoic and Phanerozoic orogenies formed during a major period of crustal growth between 1.6 and 2.0 Ga, which is evident in many areas of the South American craton (e.g. Cordani et al., 2000; Rino et al., 2004). Proterozoic ages are abundant in Nd model ages of these rocks (well-defined peak at 1.8 – 2.0 Ga), and in U-Pb ages from relict zircons of Phanerozoic rocks. This thorough reworking produced a homogeneous felsic crust with a composition close to average upper-crustal values. These model ages are also seen in the Neogene ignimbrites, which represent the recycled basement. Initial Nd-Sr isotope compositions (Fig. 2a) of the early Paleozoic rocks show overlapping compositional ranges for the different lithological or age groups. Some Ordovician granitoids show hybrid compositions between depleted mantle and the bulk of the crust (Fig. 2a), which has a typical composition of old continental crust. The isotopic signatures of the late Paleozoic granites indicate high proportions of recycled early Paleozoic continental crust (Figs. 2b). The Sr-Nd isotope compositions of the Jurassic – lower Cretaceous igneous rock are different from both the older (Paleozoic) and younger (Cenozoic) magmatic suites in the region and indicate a depleted mantle source with MORB affinities (Fig. 2b). Magmatic rocks of the late Cretaceous – lower Tertiary eastward shifting arc show an increasing contribution of Paleozoic crustal material in their isotope signatures (Fig. 2b). Isotope compositions of Cenozoic andesite and ignimbrite are hybrid between depleted mantle and crust (Fig. 2b). The andesites contain at least 20% and most ignimbrite > 70% of crustal Sr, Nd, and Pb. The average Sr (initial)-Nd (measured) composition of the metamorphic crust is considered as the principal crustal endmember of the late Paleozoic – recent deeper crust (with loss of Rb during early Paleozoic high grade metamorphism and melting), which is reflected by the isotope composition of most Mesozoic- Recent hybrid magmatic rocks (Fig. 2b).

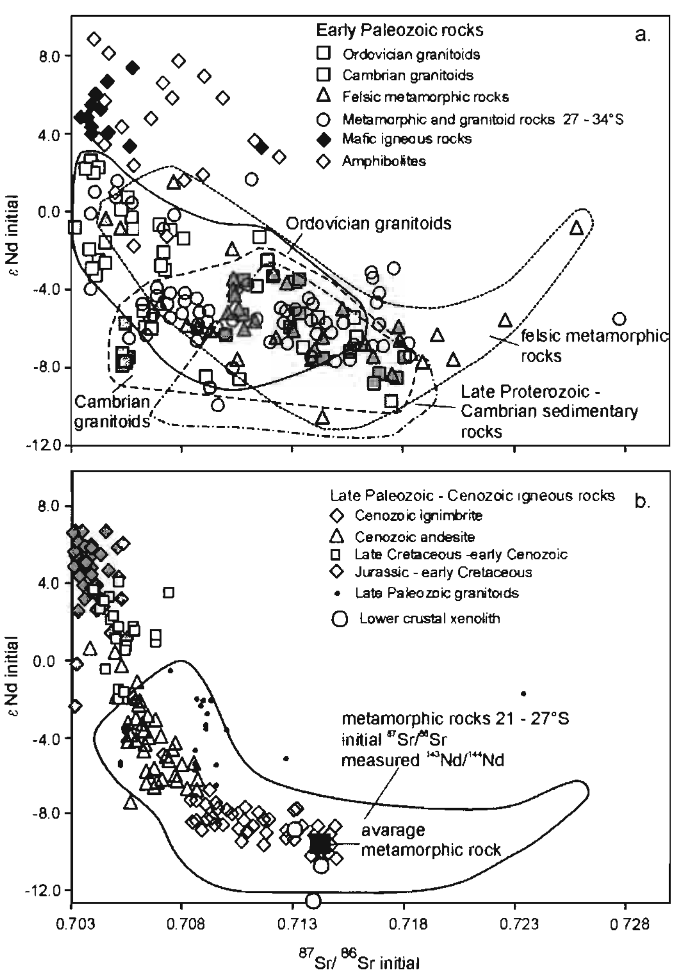

Figure 2: Initial Nd-Sr isotope ratios of rock groups of different age from Bolivia, Chile and Argentina of the early Palaeozoic basement.

(a) **Early Paleozoic** felsic rocks show typical crustal signatures, indicating that only few (such as the Ordovician granitoids) represent juvenile crust. Amphibolites and mafic igneous rocks (volumetrically unimportant) scatter between εNd +3 and +8; their Sr isotope ratios have partially been influenced by Rb and Sr mobility during metamorphism.

(b) **Late Paleozoic – Recent** rocks show similar compositional trends between a depleted sub-arc mantle (represented by the Jurassic – early Cretaceous igneous rocks) and the early Palaeozoic felsic crust. The isotopic composition of felsic lower-crustal xenoliths, indicative for the **lower crust,** a likely source of contamination for the magmas, is the same as the average metamorphic rocks. Data sources: Kleine et al. (2004), Lucassen et al. (2001, 2002) and references therein.

Composition of the mantle

Mantle derived rocks occur locally in the early Paleozoic and Mesozoic magmatic arcs, probably bound to phases of tectonic extension, and in a mainly Cretaceous extensional system ('Cretaceous rift') located in what is now the back-arc and eastern foreland. We restrict the discussion to the Sr-Nd isotope system for simplicity. Sr and Nd isotope compositions of most mafic rocks from the Paleozoic arcs and mafic – intermediate rocks from the Mesozoic arcs (18°-27°S), most Cretaceous rift related alkaline rocks (16 – 27° S) and upper mantle xenoliths (26°S) indicate a depleted asthenospheric or lithospheric source (Fig. 3). The depleted mantle in the arc system is different from the mantle described by the composition of the Pacific MORB. It is also significantly different from the cratonic mantle lithosphere (Fig. 3) inferred from the composition of some Cretaceous, rift related alkaline rocks of mantle origin (south of 27°S and north of 21°S), which resembles the composition of old enriched mantle lithosphere beneath the cratonic parts of South America. The Cenozoic magmatic rocks from the Central Andes south of 34°S are also from a depleted mantle source (Fig. 3), but less radiogenic than those from the arc at 21-27°S. The difference in Nd-ratios could be attributed to the evolving mantle, and the difference in Sr-ratios to ca. 160 Ma of input of crustal material into the wedge with slowly growing unradiogenic Nd and radiogenic Sr in the ambient crust. The slightly different mantle type represented by the late SCVZ samples could equally serve as an endmember in the formation of hybrid magmas.

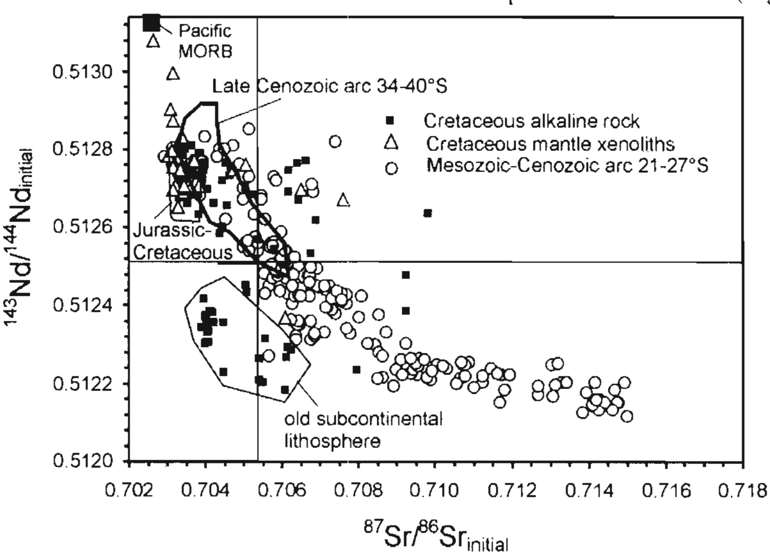

Figure 9 Nd-Sr isotopic compositions of mantle-derived rocks from the Central Andes' Cretaceous rift and mantle-derived and hybrid rocks from the Mesozoic – Cenozoic magmatic arcs. The Cenozoic volcanic rocks south of 34-40°S show slightly more radiogenic Nd and Sr compared with the respective ratios of rocks from 21-27°S. Data sources: see Fig.2; volcanic rocks 36 – 42°S from http://georoc. mpch-mainz. gwdg. de/ georoc/

Conclusions

On a large regional and time scale, the crust and mantle in the Andean continental arc are described by two endmembers, continental crust and a depleted mantle. The continental crust reflects the Proterozoic evolution of the western part of the South American continent and was largely homogenized by the early Paleozoic orogeny. Juvenile additions to the crust are rare, except in the Jurassic arc, and these additions to the crust are likely balanced out by destruction of the crust by lithospheric delamination or tectonic fore-arc erosion. There is no evidence in the Central Andes (21-27°S) for significant net crustal growth. There is also no evidence for a significant contribution of old lithospheric mantle of the craton, because the dominant mantle type in the Paleozoic - Recent arcs was 'depleted mantle'; the Sr – Nd isotope array of the early Paleozoic magmatic rocks is the same as that for the Andean Mesozoic – Cenozoic arc magmatism (Figs. 2, 3). The first order process seems undisturbed by 'exotic' compositions as accreted terrains of continental crust or of Proterozoic shield lithosphere, and this indicates that also accretion did not produce significant crustal growth in the Central Andes.

References

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