LEAD ISOTOPE EVIDENCE FOR LATITUDINAL MANTLE HETEROGENEITY BENEATH THE ANDES

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INTRODUCTION

Geochemical data suggest that Andean arc melts are generated in the mantle wedge whence they migrate into and become variably contaminated by continental crust. This model is supported also by lead isotopes, which, among the radiogenic systems, represent the most extensive database of the Andes, including analyses on both magmatic rocks and associated ore minerals.

Many studies have shown that the Pb isotope variability of arc magmas in segments of the Central Andes is mainly due to crustal contamination. In this paper we discuss 234 new lead isotope data on Late Cretaceous-Tertiary magmatic arc rocks and associated ores of the Northern Andes of Ecuador (N=165) and mining districts of Peru (N=69) together with literature data on magmatic arc rocks and associated ore deposits of the Central Andes. The new data allow us to compare lead isotope reservoirs for arc magmatism of the Northern and Central Andes (10°N-40°S). We present, for the first time, evidence that the sub-Andean mantle is characterised by a systematic decrease in the $^{206}Pb/^{204}Pb$ ratio from north to south, and propose a possible explanation for this heterogeneity.

THE DATABASE

This study is based on about 500 lead isotope data, 234 of which are from analyses performed at our laboratories while the remainder is from previous investigations. They include magmatic arc rocks and related mineralization (VHMS, porphyry, epithermal, skarn) with Late Cretaceous to Late Tertiary ages. The time span chosen is determined by the homogeneous distribution of magmatism and associated mineralization along the whole Andean chain in the Late Cretaceous-Tertiary, and by the availability of a much larger database than for older periods, thus permitting a reasonable comparison of different segments of the Cordillera. Ores of province III of Macfarlane et al. (1990) have been excluded because they do not have magmatic signatures, deriving most of the lead from hydrothermal leaching of crustal basements. The Tertiary-Quaternary volcanics of the Arequipa massif and Belén segment in Chile, which have low radiogenic lead isotope signatures due to contamination by lower crust-type basements, have also been excluded.

The Pb isotope data have been subdivided into four latitudinal areas: 8°N-5°S (Ecuador and Colombia); 5°S-15°S (Northern Peru); 15°S-20°S (Southern Peru); 20°S-40°S (Chile). These subdivisions coincide with major geomorphologic features (Huancabamba deflection at 5°S; Arica elbow at 20°S) and/or with lead isotope provinces of Macfarlane et al. (1990) (e.g. the 15°S limit between subprovinces Ib, II to the north and subprovince Ic to the south).

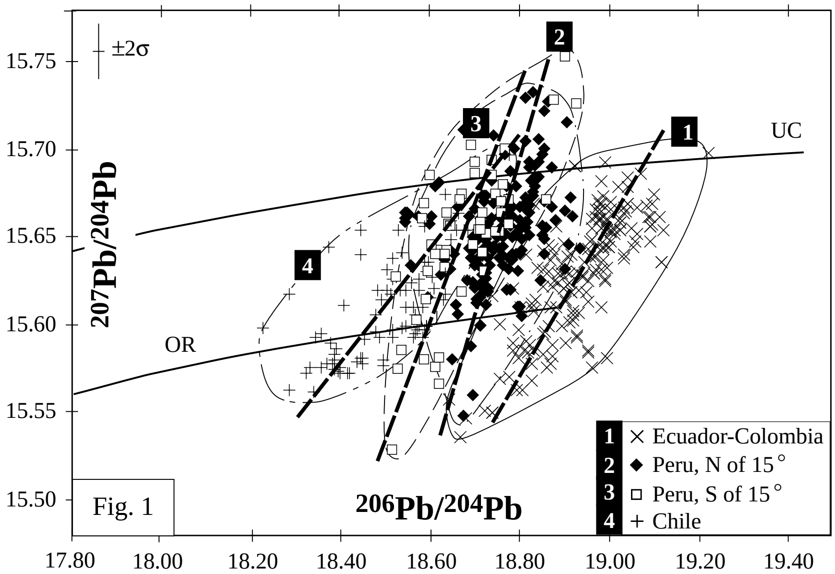

Fig. 1: $^{208}Pb/^{204}Pb$ and $^{207}Pb/^{204}Pb$ vs. $^{206}Pb/^{204}Pb$ plots of Late Cretaceous-Tertiary magmatic rocks and associated ores of the Andean Cordillera, subdivided according to the geographic provinces of this work.

RESULTS AND DISCUSSION

Late Cretaceous-Tertiary ores and magmatic arc rocks of each of the four Andean provinces define distinct steep elliptical arrays in conventional plots (Fig. 1), indicating that the majority of lead within each province derives from mixing of two main end-members characterised respectively by low and high $^{207}Pb/^{204}Pb$ and $^{208}Pb/^{204}Pb$ ratios. The prolateness of the ellipses indicates that the 2-end-member mixing is disturbed by secondary sources, by short time-evolved reservoirs, and, probably, by $^{206}Pb/^{204}Pb$ variability of the main sources. Like previous studies (e.g. Macfarlane, 1995) we interpret these arrays as mixing lines between the mantle, possibly enriched by pelagic sediments, at the low $^{207}Pb/^{204}Pb$ (and $^{208}Pb/^{204}Pb$) end, and upper crustal rocks at the high $^{207}Pb/^{204}Pb$ (and $^{208}Pb/^{204}Pb$) end. Comparison of the arrays, especially in the uranogenic plot that allows the best discrimination between mantle and upper crust reservoirs, shows two remarkable features (Fig. 1): (1) Arrays are systematically shifted towards lower $^{206}Pb/^{204}Pb$ values from Ecuador-Colombia to Chile. (2) The low radiogenic (mantle) end-members of each array contain progressively ^{206}Pb-poorer lead from north to south.

Lead isotope systematics of the Late Cretaceous-Tertiary Andean mantle end-members

The compositional differences of the four mantle end-members cannot be attributed to a single time-evolved reservoir because of the similar Late Cretaceous-Tertiary ages of the investigated magmatic rocks and associated ores in all provinces. We also exclude the possibility that the different mantle end-members are an artefact of crustal contamination. Indeed, arrays of the four provinces being sub-parallel (Fig. 1), the low radiogenic end-members cannot derive from mixing between a homogeneous low $^{207}Pb/^{204}Pb$ and $^{208}Pb/^{204}Pb$ mantle and heterogeneous (variable $^{206}Pb/^{204}Pb$) high $^{207}Pb/^{204}Pb$ and $^{208}Pb/^{204}Pb$ reservoirs like upper crustal rocks and pelagic sediments. The $^{206}Pb/^{204}Pb$ spread of the mantle end-members cannot derive either from assimilation of low radiogenic lower crust by mantle-derived melts during melting-assimilation-storage-homogenisation (MASH) processes. This would imply enrichment in thorogenic lead concomitant with the southward decrease of $^{206}Pb/^{204}Pb$ values of the low radiogenic end-members, which is not observed (not shown). In contrast, the isotopic differences of the mantle end-members can be related to mixing between MORB components characterised by different $^{206}Pb/^{204}Pb$ and consistently low $^{207}Pb/^{204}Pb$ ($^{208}Pb/^{204}Pb$) ratios (Fig. 2). Mixing of DMM and enriched mantle components is considered responsible for MORB isotope variability (Zindler and Hart, 1986). Mixing between a low radiogenic MORB mantle, possibly carrying a DMM or EM I component, and a more radiogenic MORB mantle, possibly carrying an HIMU component, best explains the $^{206}Pb/^{204}Pb$ range of the Andean mantle end-members (Fig. 2). Note that the mantle end-member of the Ecuador-Colombia trend is ^{206}Pb-richer than E-Pacific MORB (Fig. 2).

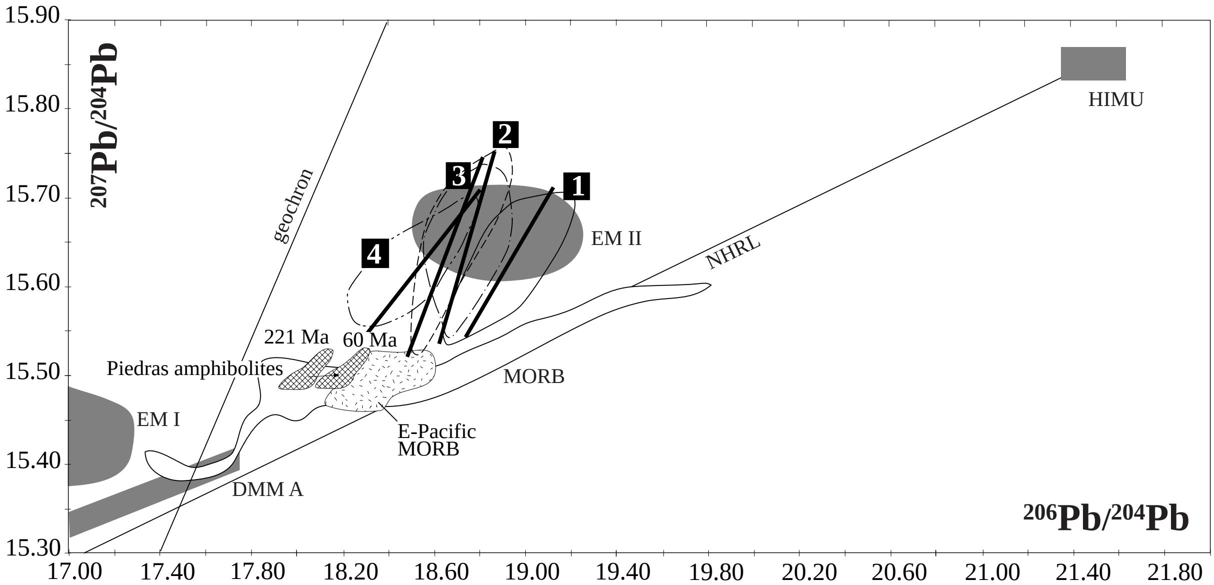

Fig. 2: $^{207}Pb/^{204}Pb$ vs. $^{206}Pb/^{204}Pb$ plot of the four trends of Fig. 1 together with the compositional fields of the main mantle reservoirs of Zindler and Hart (1986).

Although the presence of a true HIMU component in the northern sub-Andean mantle remains elusive, mixing of a low radiogenic and a high radiogenic mantle is further revealed in the Northern Andes by Triassic amphibolites (U-Pb zircon age of 221±17 Ma, Aspden et al., 1995) of the Piedras Group, which is part of a metamorphic complex cropping out in southwestern Ecuador. The Piedras amphibolites have MORB-type geochemical features with no signs of crustal contamination (Aspden et al., 1995) and Pb isotope compositions less radiogenic than the E-Pacific MORB field (Fig. 2). Lacking crustal contamination, they allow us to explore Pb isotope geochemistry of the Triassic mantle beneath northern South America. If this mantle had the isotopic composition of the Piedras amphibolites, with a μ ($^{238}U/^{204}Pb$)=9 and an ω ($^{232}Th/^{204}Pb$)=32, by Late Cretaceous-Tertiary times it would be far less radiogenic not only than the mantle end-member of the Ecuador-Colombia trend, but also of the Northern and Southern Peru trends (Fig. 2). Therefore, it could not be the source of the Late Cretaceous-Tertiary arc magmatism of the Northern Andes. In contrast, spiking of the time-evolved Triassic mantle by radiogenic MORB material (possibly carrying an HIMU component) between Triassic and Late Cretaceous times can explain the enriched mantle end-member in the Northern Andes (Fig. 2).

What could cause the lead isotope heterogeneity of the Andean mantle?

At the present stage it is very difficult to identify the cause of the sub-Andean mantle Pb isotope heterogeneity pointed out by our data. As working hypotheses, we propose two tentative scenarios of post-Triassic mixing between a radiogenic mantle, possibly carrying an HIMU-type component, and a low radiogenic mantle to explain the sub-Andean mantle heterogeneity. Oceanic plateaus generated by the mid-Cretaceous superplume event have been subducted during the Mesozoic beneath Central America and Northern South America but not beneath Central South America (Larson, 1991). These oceanic plateaus, characterised by ^{206}Pb-rich compositions, could have enriched the sub-Andean mantle of the Northern Andes or, if underplated under the continental crust, could have contaminated mantle-derived magmas on their way to the surface. Another speculative scenario is that Mesozoic plume events occurred at the northern edge of South America, e.g. the 90 Ma old Galapagos hotspot and the 106-82 Ma old hotspot in the Ecuadorian Oriente basin (Barragan and Baby, 1999), could have dispersed ^{206}Pb-rich material into the surrounding upper mantle creating the isotopic gradient observed along a distance of several hundreds of kilometres.

The main implication of our results is that, although crustal contamination is responsible for most of the Pb isotope variability in segments of the Central Andes (e.g. Davidson and de Silva, 1992; Wörner et al., 1992), mantle heterogeneity is an additional factor responsible for Pb isotope variability of the Andean provinces at the continental scale. Our data would also document the first example of a possible HIMU-type component in the source of continental arc magmas thus complementing similar conclusions drawn by Hickey-Vargas (1992) on the source of island arc magmatism.

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