LEAD ISOTOPIC PROVINCES IN PERU, BOLIVIA, AND NORTHERN CHILE

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En el Perú, Bolivia y el norte de Argentina y Chile definimos cuatro provincias isotópicas principales: en dos de ellas las menas epigenéticas y singenéticas derivan su Pb de los intrusivos; en las otras dos el Pb proviene de los sedimentos.

Pb isotopes, isotopic provinces, metallogeny, magma and ore sources.

Previous studies of ores and their igneous, sedimentary and metamorphic host rocks in the Andes of Perú, Bolivia, Argentina and Chile have revealed a number of lead isotope provinces (Macfarlane et al., 1990; Tilton et al., 1981; Gunnesch and Baumann, 1984; Puig, 1988, 1990; Kontak et al., 1990). In two of the three main provinces the lead isotope signatures of the ores resemble mainly those of the intrusive igneous rocks with which they are associated. This appears to be true for both epigenetic and syngenetic (or stratabound) hydrothermal ore deposits. It also seems to apply to all the ore minerals, even if they belong to different mineralization stages, and to most of the few gangue minerals analyzed. This suggests very strongly that the ore forming fluids either emanated directly from a magma or that meteoric fluids (including seawater) percolated deeply into the crust, leaching the ore metals from hot intrusives. In the third main lead isotope province the ore lead was probably derived from regionally abundant carbonaceous shales, but it is not clear if directly or as a result of melting the shales. Although some ore deposit types predominate in certain provinces, each province has an assortment of different ore deposit types that formed at various times.

New unpublished data and further examination of the evidence requires some modifications, so that our current nomenclature comprises:

I. The coast of Perú and northern Chile;
II. The high Andes;
III. The eastern Andes;
IV. The eastern foothills of the Andes.

The lead isotope values of Province I lie close to the Stacey-Kramers growth curve for the Mesozoic and Tertiary, but there are insufficient independent age determinations to decide if the progression of lead isotope values correlates with age. The lead isotope values of ores and igneous rocks in the coast of southern Perú, which is in the middle of province I, deviate considerably from the aforementioned values and reflect the very low 206/204 lead isotope composition of the Precambrian Arequipa massif. Throughout province I the lead isotope values of the ores are similar to those of the uncontaminated intrusive rocks (in contrast to the volcanic rocks in the southern coast of Perú and to the felsic units of the batholith in the central coast of Perú).

Our lead isotope province II extends along the high Andes of Perú, Bolivia and Argentina. On a 207/204 vs 206/204 lead isotope diagram the few available values for intrusive igneous rocks in central and northern Perú have a surprisingly small range of 207/204 ratios, whereas the ores of this region define an elongate field with its long axis at a significant angle to the Stacey-Kramers growth curve. On 208/204 vs 206/204 lead isotope diagrams the values for the intrusive igneous rocks and ore deposits of this region define even more elongate fields with their long axes at an angle with the Stacey-Kramers curve. Only two analyses of small basalt flows or sills do not fit these generalizations. On 207/204 vs 206/204 diagrams the aforementioned elongated ore field appears unrelated to the composition of the Paleozoic, Mesozoic and Tertiary metamorphic and sedimentary rocks in the region, although on 208/204 vs 206/204 diagrams one could invoke a relation to the Olmos and Pataz metamorphic basement rocks. However, the elongated ore fields may be more convincingly related to the lead isotope composition of pelagic sediments (Chow and Patterson, 1962) and manganese nodules (Reynolds and Dasch, 1971) on the Nazca plate. Toward lower values their axes point to the lead isotope composition of mid-ocean ridge basalt (Unruh and Tatsumoto, 1976).

NW of Lake Titicaca the Cretaceous and Tertiary ore deposits (formerly assigned to province IIIb but now included in province II as "SE Andes A") define a trend for lead 208/204 vs 206/204 that is similar to the one for ores and igneous rocks in the high Andes of central and northern Perú, but pointing more toward the composition of metalliferous sediments (Dasch, 1981) on the Nazca plate. However, in contrast to the high Andes ore deposits in northern and central Perú, but similar to the igneous rocks in that region, the SE Andes A ores have a very narrow range of 207/204 values.

Some western Bolivian ore deposits formerly assigned to province IIIa are now recognized to belong to province II. The Capillitas deposit in northern Argentina is assigned to province II because it is an enargite deposit like those in Perú and Bolivia that belong to this province and because its 206/204 lead isotope values correspond to this province. Some of the ore deposits in the high Andes of Chile also appear to belong to province II, as suggested by our unpublished lead isotope analyses for El Indio and Tambo and by some results of Tosdal et al. (1992) for Esperanza and Cancan. Hence, province II can now be traced, with minor variations in lead isotope fields, from Hualgayoc in northern Perú ($6^{o}46'S$) to somewhat south of $27^{o}S$ in nothern Argentina and Chile.

There are no obvious endmembers for the extensions of the longitudinal axes of the high Andes lead isotope fields toward greater 206/204, 207/204 and 208/204 values, unless one chooses to invoke crustal contamination with a Precambrian basement terrane that is isotopically like the Imataca Series of Venezuela (Montgomery and Hurley, 1978). Alternatively, one may infer that the high Andes intrusives and ores reflect the lead isotopic composition of varying mixtures of MORB, metalliferous sediments, manganese nodules, pelagic sediments and, perhaps, metamorphic basement complexes.

The eastern Andes ore deposits of Perú, Bolivia and Argentina which constitute province III are often located in Paleozoic carbonaceous marine shales. Their lead isotope values lie in an elongated field parallel to the Stacey-Kramers growth curve and to the field for province I ores and intrusives uninfluenced by the Arequipa massif, but at generally higher 207/204 and 208/204 values (for given 206/204 values). The progression of their lead isotope values (mainly 206/204) correlates with their ages. Given the known Ordovician age and current lead isotope composition of their predominant host rocks, this suggests that these ore leads were mostly derived from these sediments (Macfarlane et al., 1990).

In the region NW of Lake Titicaca the Carboniferous and Permo-Triassic ore deposits have very high 206/204 values (Kontak et al., 1990), indicating an important contribution of lead from metamorphic, sedimentary or volcanic country rocks. They correspond to a separate Fe-Mn-W-Sn-Cu metallogenic province IIIb ("SE Andes B") that predated the Andean orogen.

The only lead isotope information available for the eastern foothills of the Andes pertains to the San Vicente ore deposit, which is generally considered to be of the Mississippi Valley type. Its 206/204 and 208/204 lead isotope ratios are generally higher than those for provinces I, II and III. Presumably San Vicente inherited its lead from weathering products derived from Precambrian rocks in the Brasilian craton.

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