LEAD RESERVOIR INTERACTIONS AT A MULTIACCRETED CONVERGENT MARGIN: THE CASE OF ECUADOR

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Introduction

The Ecuadorian Andes consist of a mosaic of NNE-SSW-trending terranes representing different geotectonic domains formed during the Triassic separation of the North and South American continents (Figure 1). These domains, of attenuated, oceanic and continental crust, were accreted to the Amazon craton, during subduction of the Farallon and Nazca plates, from the Early Cretaceous to the Early Tertiary (Litherland et al., 1994). In the southern part of Ecuador, E-W-striking crustal-scale faults related to the Huancabamba deflection were continuously activated due to the stress induced by the oblique subdution of the Farallon and Nazca plates.

The interest of applying a large-scale lead isotope survey to the Northern Andes stems from such a geotectonic evolution characterized by multiaccretionary episodes involving also oceanic crust. In this contribution more than 200 lead isotope compositions of ores and magmatic as well metamorphic rocks of Ecuador are discussed.

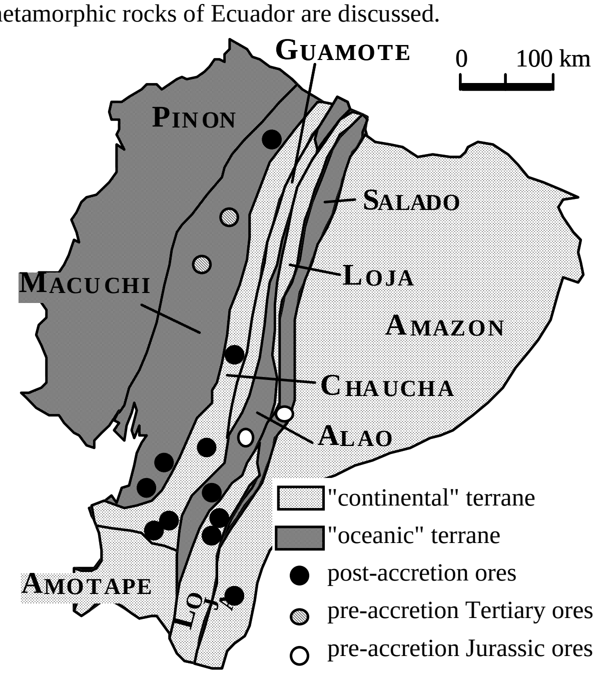

Figure 1: Geotectonic map of Ecuador (from Litherland et al., 1994).

The review begins with uneconomic mineralization of Jurassic age (VHMS deposits of Las Pilas and Guarumales) associated with island arc and marginal basin settings. The Tertiary is the most productive metallogenic period in Ecuador with Au-rich VHMS deposits, Au-Ag epithermal deposits and Cu-Mo-Au porphyries. Two different geotectonic settings, with both of which ore deposits are associated, were developed in the Ecuadorian Andes during the Tertiary: the Paleocene-Eocene Macuchi island arc, and the post-Eocene continental arc over the accreted terranes and the western margin of the Amazon craton. The Macuchi island arc hosts the Au-rich VHMS deposits of La Plata and Macuchi. During the Early Miocene, the splitting of the Farallon plate into Nazca and Cocos causes a shallowing of the subduction. This produces a widening of magmatism and associated Au-Ag epithermal (e.g., Portovelo, Zaruma, S. Bartolomé, Pilzhum) and Cu-Au-Mo porphyry deposits (e.g., Chaucha, Junin) which encompass a broad section of the newly accreted Ecuadorian Andes in the Late Tertiary, reaching the western margin of the Amazon craton (e.g., Zn-Pb-Ag epithermal deposit of Chinapintza).

Results and discussion

For the discussion of Ecuadorian ore deposits from a lead isotope point of view it is convenient to subdivide them into those formed within discrete geotectonic domains (i.e. island arcs, marginal basins) before complete assemblage of the Ecuadorian crust (herein referred to as pre-accretionary deposits), and those formed in relation with continental magmatism encompassing the whole section of the Ecuadorian Andes, after accretion of the different geotectonic domains onto the continental margin (herein referred to as post-accretionary deposits). Temporally, this subdivision corresponds to pre- and post-Eocene ore deposits.

Pre-accretionary ore deposits

The pre-accretionary ore deposits of Ecuador considered here are Jurassic and early Tertiary VHMS deposits formed in island arc and marginal basin settings. The isotopic signatures of these deposits cluster into discrete and distinct fields in conventional isotope plots and do not show any apparent correlation with age (Figure

2). Therefore, lead in these ores results from mixing among different reservoirs rather than from extraction from a common, time-evolving reservoir.

The Jurassic VHMS deposit of Las Pilas is hosted by tholeiitic island arc basalts of the Alao terrane. Lead isotope signatures of the VHMS ores and of the island arc basalts are identical and homogeneous (Figure 2). They are characterized by very radiogenic $^{207}Pb/^{204}Pb$ ratios implying contamination of mantle-derived basalts by upper crustal lead, either through pelagic sediments assimilated at the magma source or through upper crustal rocks assimilated at shallow crustal levels. Isotopic signatures of the Jurassic Guarumales VHMS deposit are less radiogenic than those of Las Pilas, reflecting the geotectonic emplacement of this deposit in the Salado marginal basin, where volcanism occurs through the attenuated crust of the Amazon craton (Litherland et al., 1994). Therefore, the lower radiogenic compositions of the Guarumales VHMS deposit likely reflect a contribution of relatively low radiogenic lead from lower crustal rocks of the Amazon craton.

The Early Tertiary VHMS deposits of La Plata, Macuchi and El Patiño occur in the Macuchi island arc sequence, consisting of basaltic to andesitic volcanics. Also in this case ore and magmatic rock signatures overlap indicating derivation of the ore lead from the magmatic rocks (Figure 2). Nevertheless, rock and ore signatures are different from those of Jurassic VHMS deposits, reflecting formation in a different geotectonic context.

In conventional isotope diagrams the Macuchi arc volcanic rocks and associated ore minerals define linear trends which indicate mixing between one ore more MORB-type reservoirs, and a l.s. upper crustal source (Figure 2). Positive correlations of lead isotope ratio with fractionation indexes (i.e. ratios of compatible to less compatible or incompatible elements like Cr/Sr, Cr/Zr, Cr/Nd) argue against assimilation of upper crustal lead from crystalline rocks in the Macuchi basalts and are compatible with shallow level fractional crystallization accompanied by assimilation of a MORB-type lead, either of oceanic crust or oceanic plateau (San Juan Complex, a possible basement to the arc sequence: Reynaud et al., 1999), by a primary magma enriched in radiogenic lead (Chiaradia and Fontboté, submitted). This leaves pelagic sediments, assimilated in the source region of the primary magmas, as the only possible source of the radiogenic lead present in the volcanic rocks of the Macuchi arc and in the associated VHMS ore deposits.

Ore minerals of the Macuchi island arc have very consistent isotopic signatures within each of the three VHMS deposits although the latter differ significantly in isotopic ratios one from the other (Figure 2). Such a feature is related to the small dimensions of the convective cells and to the different stratigraphic positions of the three deposits, at variable distance from the contact with underlying volcanics of the basal part of the Macuchi arc sequence characterized by less radiogenic lead than the volcanics directly hosting the VHMS deposits.

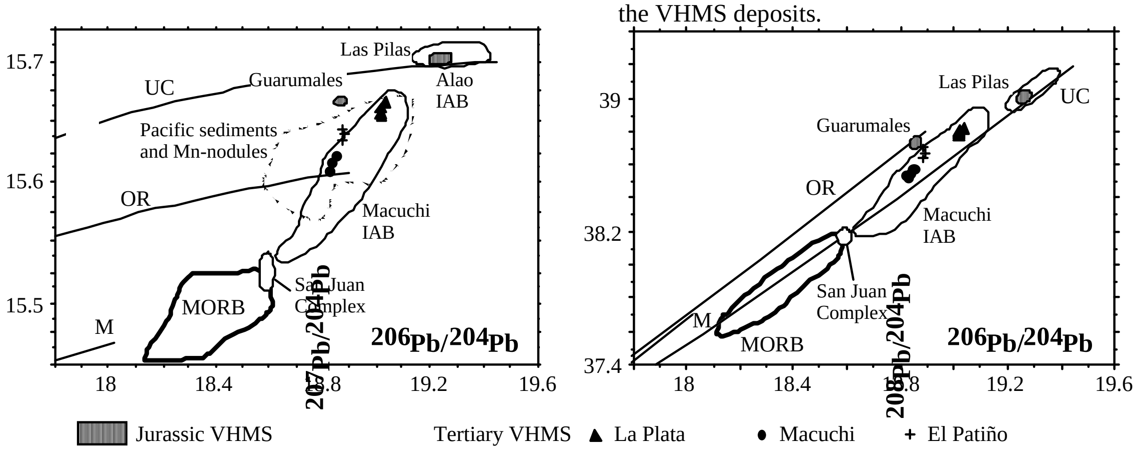

Figure 2: Isotope diagrams for the pre-accretionary VHMS deposits and volcanic rocks of the Alao and Macuchi island arcs. The field of the San Juan Complex is from unpublished data of M. Mamberti (University of Lausanne, Switzerland).

In summary, isotopic compositions of pre-accretionary Ecuadorian ore deposits are internally consistent, but vary according to their emplacement within distinct geotectonic domains (island arcs, microcontinental terranes, marginal basins). It can be concluded that leads of various origins were mixed in variable proportions and homogenized within each of these domains according to different geotectonic processes.

Post-accretionary epithermal and porphyry deposits associated with continental magmatism

Isotopic compositions of Middle-Late Tertiary epithermal and porphyry ore deposits associated with continental magmatism, spread over the different microterranes of Ecuador and the western margin of the Amazon craton, are reported in Figure 3 together with the isotopic compositions of associated magmatic rocks and of basement rocks of each terrane. In contrast with the pre-accretionary deposits, isotopic compositions of post-accretionary ore deposits overlap only partially the relatively homogeneous isotopic field of associated magmatic rocks (Figure 3). With respect to the latter they scatter towards the isotopic compositions of the different basement rocks of the terrane by which the deposits are hosted.

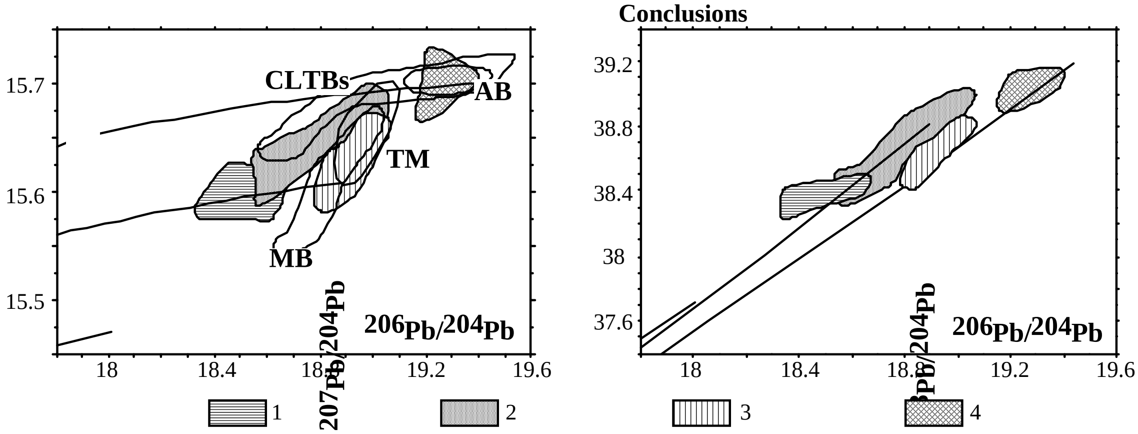

Figure 3: Lead isotope diagrams for the post-accretionary Tertiary ore deposits associated with continental arc magmatism. Abbreviations: CLTBs=Chaucha-Loja-Tahuin Basement rocks; AB=Alao Jurassic metabasalts; MB=Macuchi island arc basalts; TM=Tertiary magmas (all terranes). Legend: 1=Amazon craton ore deposits; 2=Chaucha-Loja terranes ore deposits; 3=Macuchi terrane ore deposits; 4=Alao terrane ore deposits.

This suggests that lead was not entirely delivered to the hydrothermal system by magmatic fluids or magmatic rocks, as in pre-accretionary ores, but was also leached from the basement rocks. Additionally, a significant correlation exists between increasing size and increasing $^{207}Pb/^{204}Pb$ ratios of ore deposits hosted by the continental microterranes of Chaucha and Loja indicating a lithological control on the formation of productive deposits within these terranes, probably due to hydrothermal leaching and/or magmatic assimilation of a metal-rich reservoir characterized by radiogenic lead. Graphitic schists of the Paleozoic Chiguinda Unit and correlative Units, which represent the basement of the Chaucha, Loja and Amotape terranes, are characterized by radiogenic lead isotope signatures and are a potential metal source lithology.

Epithermal ore deposits of the western margin of the Amazon craton display the least radiogenic signatures with a significant contribution of lead from the continental lower crust (Figure 3), which is compatible with the emplacement of these ore deposits through the thick crust of the craton. Similar relatively low radiogenic signatures are also found in few other deposits hosted by the continental microterranes of Chaucha and Loja derived from the fragmentation of the craton margin (Figure 3).

Conclusions

Ore deposits of Ecuador can be subdivided into pre- and post-accretion of the Ecuadorian crust according to Pb isotope systematics. The lead isotope signatures of the pre-accretionary ore deposits (which are pre-Eocene in age) vary according to the setting and reflect a strong geotectonic control on the ore lead. Isotopic signatures are internally consistent within but differ among geotectonic domains. This may be a result of variable magmatic homogenization of leads of various origins, dictated by distinct processes in each context. Since the geotectonic domains (terranes) and associated ore deposits were formed in geographically separate areas, there was no interactions among them, as shown by lead isotope systematics.

Post-accretionary ore deposits of Ecuador (which are post-Eocene in age) are emplaced within a crust resulting from the juxtaposition of the different domains previously formed. These deposits are spatially associated with magmas characterized by relatively homogeneous isotopic signatures because resulting from the same subduction process of the Nazca plate under the multiaccreted margin of Ecuador in post-Eocene times (Barreiro, 1984 and this study). Different from pre-accretionary ore deposits, post-accretionary mineralization displays isotopic signatures which scatter outside the compositional field of associated magmas, indicating a mixed lead contribution from magmatic fluids and local basement rocks. It is suggested that the multiaccreted nature of the Ecuadorian crust caused a fragmentation of mantle-derived melts into a small stocks which reached shallow crustal levels through terrane sutures (Litherland and Aspden, 1992) and crustal scale fractures related to the Huancabamba deflection. At these levels local hydrothermal systems were established in which the isotopically homogeneous magmatic lead was variably mixed with lead leached from basement rocks of the different terranes resulting in the observed isotopic scatter of the Middle-Late Tertiary ore deposits.

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