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Lead isotope signature of the Proterozoic sediment-hosted base metal deposits at the margin of the Indian plate in Besham area, northern Pakistan

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ABSTRACT: *Proterozoic base metal deposits in the rocks of the Indian plate occur along its northern margin at the Pazang and Lahor properties near Besham. These are stratiform exhalative type deposits which are highly deformed and regionally metamorphosed. Lead isotope studies were carried out on these deposits. Lead isotope ratios yield model ages of 2120-2199 Ma (Proterozoic) for both the Pazang and Lahor deposits. The assumed minimum age of mineralization is 2077 Ma, as suggested by the secondary isochron. These deposits are more primitive in terms of age and have lower μ values relative to the well known sediment-hosted deposits elsewhere in the world. The non-radiogenic isotopic composition and the homogeneity of the ore lead in both Pazang and Lahor ores suggest a well-mixed common source and similar processes for the formation of these ores.*

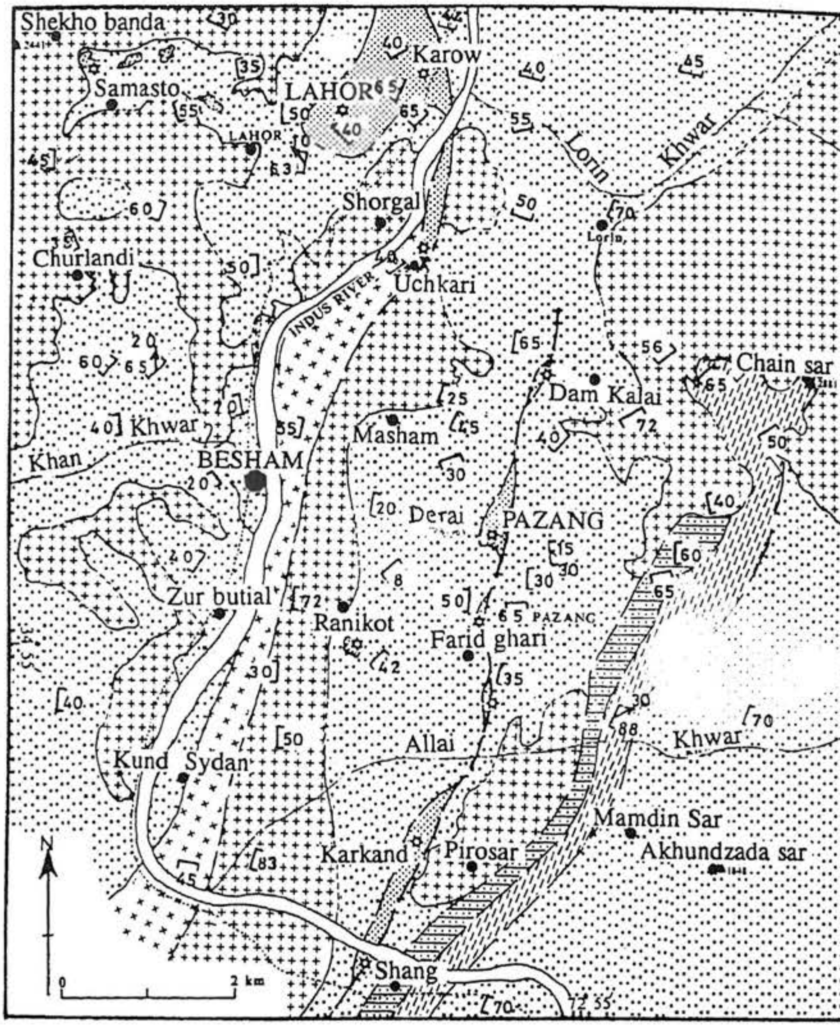
INTRODUCTION

Sediment-hosted base metal (Zn, Pb, and Cu) mineralization in the rocks of the Indian plate occurs along its northern margin in the footwall of the Main Mantle thrust (MMT) around Besham. The rocks of the Indian plate, south of MMT, have a complex tectonometamorphic history with polyphase deformation and metamorphism. These rocks have been divided into the Besham, Pazang and Karora groups. The first two groups are part of the basement complex and the third is composed of a cover of metasediments that unconformably overlie the basement gneisses (Fletcher et al., 1986; Treloar et al., 1989). The base metal mineralization is confined to the Pazang group (Fig.1), a supracrustal sequence of metasediments, which has been thrust over the basement gneisses of the Besham group (Fletcher et al., 1986).

The rocks of the Pazang group are seperated into Pelitic Formation, Sulfide Formation, and Metaquartzite/Meta-arkose Formation from bottom to top (see Fletcher et al., 1986; Shah, 1991). The two areas, Lahor and Pazang, which are of prime importance for their base metal mineralization, are situated about 1370 meters and 1680 meters above sea level on western and eastern side of the Indus River, respectively (Fig.1). The Sulfide Formation contains the Zn-Pb mineralization and constitutes the most distinct portion of the Pazang group in both of these localities. The base metal mineralization in the Besham area has been considered to be of different genetic types: (a) skarn type (Ashraf et al., 1980), (b) derived from metamorphitic rocks and remobilized during the process of anatexis (Butt, 1983), and (c) stratiform exhalative type (Fletcher et al., 1986; Shah, 1991).

The lead isotope compositions of ores provide a powerful tool in solving the problems of petrogenesis and metallogenesis. The isotopic composition of lead in galena remains unchanged after its initial crystallization because of its extremely low U/Pb and Th/Pb ratios. The lead isotope ratios of galena are, therefore, used to calculate the model ages of the deposits in which galena crystallized.

Various lead evolution models have been proposed in the past (see Holmes, 1942; Houtermans, 1946; Stacey and Kramers, 1975; Afifi et al., 1984; Deb et al., 1989). The Plumbotectonics model is another important contribution by Doe and Zartman



EXPLANATION

Besham Group

- Pelitic, Psammitic calcareous, Graphitic schist and Gneisses
- Banded Gneiss
- Mica schist with quartz nodules
- Graphite augen gneiss and pegmatite gneiss

Pazang Group

- Sulfide-rich Quartzite, Carbonate, Calc-silicate Clinopyroxenite and Quartzo-feldspathic rocks
- Pb, Zn & Fe sulfide mineralization
- Foliation
- Compositional layering
- Lineation crenulation
- Village, Peak in meters

Lahor Granitic Complex

- Metagranites and Pegmatites
- Fault
- Contacts
- Inferred contacts
- Karakoram highway
- Streams

Fig. 1. Geological map of the area around Besham, northern Pakistan.

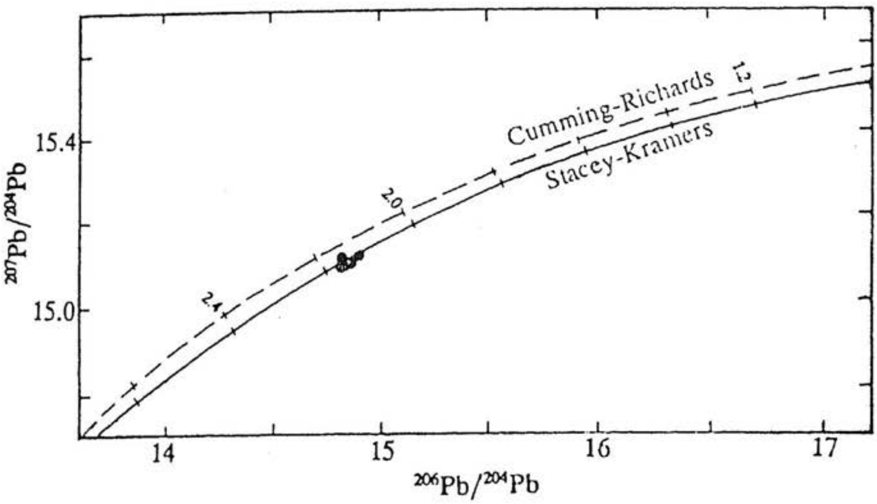


Fig. 2. $^{207}Pb/^{204}Pb$ diagram for the massive sulfide ore leads from the Lahor and Pazang prospects. The primary growth curves are after Stacey and Kramers (1975) and Cumming and Richard (1975).

(1979) and Zartman and Doe (1981) in the systematics of Pb isotopes. In this model they presented parameters for three geologic environments or reservoirs (1) mantle, (2) upper crust, and (3) lower continental crust, which have appreciable amount of U, Th, and Pb. They interpreted another geologic environment (orogene) which is responsible for the gross terrestrial isotopic patterns. The plumbotectonics model, therefore, dealt with restricting the fields for average modern mantle, upper crust, lower crust and orogene lead.

The Stacey and Kramers (1975) model yields reasonable age estimates and is particularly applicable for galena lead from Precambrian massive sulfide deposits that are syngenetic with the host rocks (see Stacey et al., 1977). The Proterozoic model has yielded reasonable estimates of model ages for the sediment-hosted base metal deposits elsewhere in the world (Deb et al., 1989). Both these models are, therefore, used to get reliable estimates of the ages of the Besham base metal deposits and to correlate these deposits with the host metasediments.

RESULTS AND INTERPRETATION

Three samples from Lahor and two samples from Pazang massive sulfide ores, several kilometers apart, were collected from underground workings for Pb-isotope studies. The lead isotopic compositions were measured in the mass spectrometry laboratory of the Department of Physics, University of Alberta, Edmonton, Canada. The ratios are normalized to the National Bureau of Standard 981 common lead standard. The accuracy of the analyses for Pb isotope composition of galena is in the range of 2σ.

The Pb-isotope analyses, along with computed model ages and their μ values, are listed in Table 1 and plotted in conventional Pb-isotope diagrams in Figures 2-6. The lead isotope ratios are non-radiogenic and very similar in both the Lahor and Pazang prospects. This isotopic uniformity and the $^{207}Pb/^{204}Pb$ ratios, which are close to 15.10, are characteristic of well mixed sediments. This isotopic homogeneity of the ore leads in both the Pazang and Lahor deposits suggests that (a) these ores were formed by similar processes, and (b) the lead was derived from a common source which was isotopically well mixed. The homogeneous and non-radiogenic nature of the studied galena is in accord with the pattern for sediment-hosted exhalative deposits (Large, 1981).

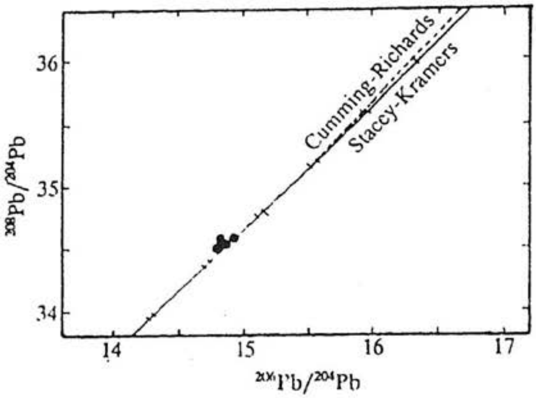


Fig. 3. $^{208}Pb/^{204}Pb$ diagram for the massive sulfide ore leads from the Lahor and Pazang prospects. The primary growth curves are after Stacey and Kramers (1975) and Cumming and Richard (1975).

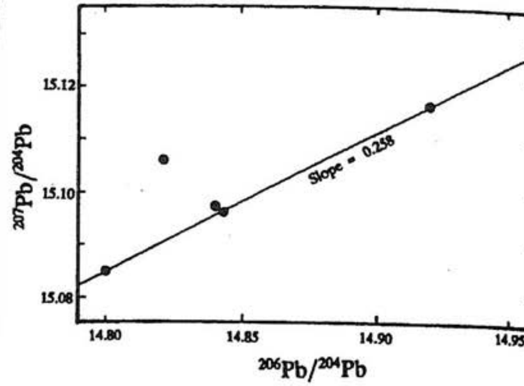


Fig. 4. An expanded plot of the isotopic compositions of the Lahor and Pazang massive sulfide ore leads.

The model ages of the Pazang and Lahor deposits have been calculated (Table 1) according to the Stacey and Kramers (1975) model and the Proterozoic model of Deb et al. (1989). The Proterozoic model yields ages about 70 million years higher than those of the Stacey and Kramers model. Average model ages of 2120 ± 34 Ma (according to the Stacey and Kramers model) and 2199 ± 35 Ma (according to the Proterozoic model) are obtained for these deposits. No isotopic ages have yet been determined for the host and underlying basement gneisses: however, a Proterozoic age is assigned to both the host rocks and the underlying basement gneisses on the basis of field observations (see Fletcher et al., 1986; Treloar et al., 1989). The ore bodies and the host rocks were subjected to thermal and regional metamorphism, but it is unlikely to say that the isotopic compositions of the deposits were affected by metamorphism in a way to completely reset the age.

Doe and Zartman (1979) found that lead derived from most upper crustal sedimentary rocks (that have not been involved in or derived from granulite or high grade metamorphic rocks) by lateral secretion processes plot close to or above the Stacey and Karamers (1975) evolution curve in the $^{207}Pb/^{204}Pb$ vs $^{206}Pb/^{204}Pb$ diagram and close to or below the evolution curve in their $^{208}Pb/^{204}Pb$ vs $^{206}Pb/^{204}Pb$ diagram. The lead isotope analyses for the Pazang and Lahor ore bodies plot very close to the evolution curve in $^{207}Pb/^{204}Pb$ vs $^{206}Pb/^{204}Pb$ diagram (Fig.2) and above the evolution curve in $^{208}Pb/^{204}Pb$ vs $^{206}Pb/^{204}Pb$ diagram (Fig.3) of Stacey and Kramers

TABLE 1. LEAD ISOTOPE COMPOSITIONS AND MODEL AGES OF STRATIFORM ZINC-LEAD DEPOSITS FROM LAHOR AND PAZANG PROSPECTS, BESHAM, NORTHERN PAKISTAN

				1		2	
	$^{206}Pb/^{204}Pb$	$^{207}Pb/^{204}Pb$	$^{208}Pb/^{204}Pb$	Model age	μ	Model age	μ
Lahore deposit	14.821	15.106	34.581	2154	9.69	2234	10.16
"	14.841	15.097	34.546	2129	9.61	2205	10.03
"	14.800	15.085	34.511	2148	9.60	2223	10.01
Pazang deposit	14.844	15.096	34.517	2124	9.58	2201	10.02
"	14.920	15.116	34.561	2087	9.39	2164	10.01

Model ages and μ values (present day $^{238}U/^{204}Pb$ of the lead source) according to (1) the Stacey & Kramers (1975) model and (2) the adjusted Proterozoic model of Deb et al. (1989).

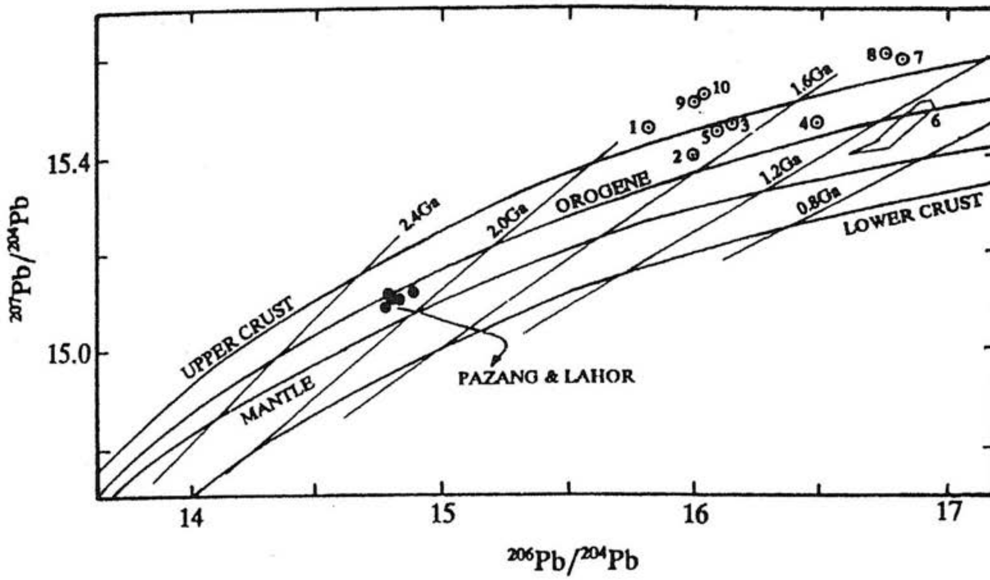


Fig .5. Isotopic composition of Lahor and Pazang massive sulfide ore lead in relation to growth curves of plumbotectonic model (version ii, Zartman and Doe, 1981). Approximate primary isochrons are after Johansson and Rickard, 1985. Other sediment-hosted deposits also shown for comparison are taken from Deb et al. (1989). These are: (1) Koongie Park, (2) Broken hill, (3) Mt. Isa, and (4) McArthur River in Australia (Gulson et al., 1983; Gulson, 1984, 1985); (5) Sullivan in Canada (LeCouteur, 1973); (6) Balmat district in United States (Fletcher, 1979; Fletcher and Farquhar, 1982); (7) Gamsberg and (8) Aggeneys in South Africa (Koeppel, 1980); (9) Rampura Agucha and (10) Rajpura-Dariba in India (Deb et al., 1989).

(1975). One explanation for the slightly higher $^{208}Pb/^{204}Pb$ values could be that they reflect derivation of the lead, in part, from a source terrane that contained rocks subjected to granulite facies or high grade metamorphism at asignificantly earlier time in the Precambrian (see Wedepohl et al., 1978). Such a metamorphism causes a preferential loss of U relative to Th and, therefore, yields high Th/U ratios (Doe and Zartman, 1979). The high $^{208}Pb/^{204}Pb$ ratios, therefore, imply lead evolution in a source material with a higher average Th/Pb ratio than assumed in Stacey and Kramers model or an episodic increase of the Th/Pb ratio as a result of high grade metamorphism.

Four out of five data points form a very linear array with a slope of 0.258 on the plot of $^{207}Pb/^{204}Pb$ vs $^{206}Pb/^{204}Pb$ (Fig.4). This linear relationship implies that a small radiogenic component was added to those samples at a commen time. If this line is considered to be a true secondary isochron, then the calculated 2077 Ma (t_{min}) age is a minimum age for the source of the radiogenic lead component, most likely the host sedimentary rocks, and also for the mineralization if this is indeed syngenetic. This is also the maximum age for remobilization and addition of a radiogenic lead component. If an age of 2200 Ma is assumed for the mineralization and for the source of the small radiogenic lead component added to at least most of the ore specimens, two stage calculation yields an age of about 1950 Ma for the radiogenic addition and probable metamorphic remobilization of the ore. It can be concluded from the Pb-isotope data of the Besham ore bodies that: (a) the component of ordinary lead was separated from its source reservoir 2120 ± 33 Ma (according to the model of Stacey and Kramers, 1975) or 2199 ± 35 Ma (according to the Proterozoic model of Deb et al., 1989); (b) small components of radiogenic lead were then subsequently added to the common lead sometime after 2077 Ma. The data further suggest that there was probably little or negligible time difference between the age of the associated rocks and the time of mineralization.

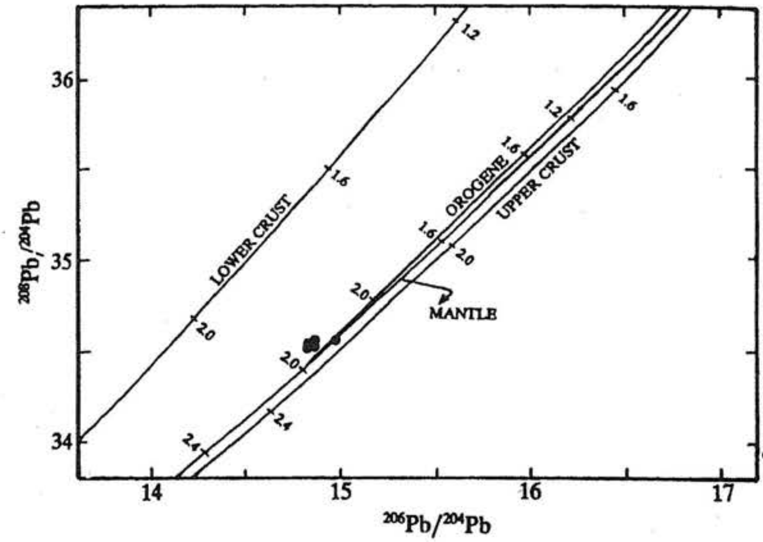


Fig .6. Isotopic composition of Lahor and Pazang massive sulfide ore lead in relation to growth curves of the plumbotectonic model (version ii, Zartman and Doe, 1981).

In terms of the general plumbotectonic model of Stacey et al. (1977), Doe and Zartman (1979), and Zartman and Doe (1981), the Pazang and Lahor lead isotope data plot between the evolution curves for average orogene and average mantle on the $^{207}Pb/^{204}Pb$ vs $^{206}Pb/^{204}Pb$ diagram (Fig.5) and between average orogene and average lower crust on the $^{208}Pb/^{204}Pb$ vs $^{206}Pb/^{204}Pb$ diagram (Fig.6). The model ages by the plumbotectonics model are greater than 2000 Ma, which is consistent with the calculated model ages given in Table 1 for these deposits.

The lead isotopic compositions of the Besham ore bodies are strikingly different from those of Mississippi Valley Type (MVT) deposits. The $^{206}Pb/^{204}Pb$ ratios are >19 for MVT deposits and <15 for Besham ore bodies, and similarly the $^{208}Pb/^{204}Pb$ ratios are >39 for MVT deposits and <35 for the Besham ore bodies. In order to compare the isotopic compositions of the studied deposits with other type of deposits elsewhere in the world, the Pb-isotope compositions of various well known sediment-hosted base metal deposits have been plotted in Figure 5. The Besham deposits are more primitive in term of ages, and also in terms of derivation from a source with a low μ value, than are the other sediment-hosted deposits elsewhere in the world.

CONCLUSIONS

The Lead isotopic compositions give Proterozoic model ages for the base metal deposits of the Besham area. The non-radiogenic nature and isotopic uniformity of the ore lead are suggestive of an isotopically well mixed source for these deposits.

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