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Lead Isotope Patterns in Galenas from some Selected Ore Deposits in Croatia and NW Bosnia

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Samples of galenas from different ore deposits and occurrences situated in the Upper Paleozoic rocks in Croatia and NW Bosnia have been analyzed. The sampling sites were at: (Zagrebačka gora), Rude (Samoborska gora), Brdo and Adamuša (Ljubija), Srebrenjak (Trgovska gora), and the Triassic Pb—Zn occurrence Lisina near Srb in the Lika region.

The deposits have syngenetic (stratiform, conformable) and veinlike characteristics, whose composition varies from simple monomineralic barite and siderite ones to complex polysulfide paragenesis, more or less resembling to Rammelsberg or Meggen type deposits. The ore bodies are in the Upper Paleozoic sediments (predominantly clastics with some carbonates), with exception of the Lisina occurrence, which is in Triassic carbonate host rocks.

The genesis of the deposits is interpreted in different ways by hydrothermal-metasomatic or volcano-sedimentary mechanism, but in Ljubija siderite deposits even terrigenous origin of iron was proposed. The age of mineralization is also in question, either Variscan or younger Triassic metallogenesis starting in the Permian time were considered. (The opinions on Cainozoik or even recent time origin may not be accepted as an argumentative statement.)

Isotope analyses, using Doe and Stacey (1974) and Stacey and Kramers (1975) models of lead growth curve, have given reasonable ages. The former one suggests age between 234 and 293 million of years, what is in good agreement with age of the host rocks, corresponding to volcano-sedimentary origin.

The latter one gives values more appropriate to the Triassic magmatic activity, preferring epigenetic mechanism of ore deposit formation. On the basis of secondary isochron y = 0.3531 + 9.1066, passing through 3.7 b. y. and cutting Stacey and Kramers growth curve at 220 m. y., it could be interpreted as a mixing line (for age 220 m. y.) in »plumbotectonic« model.

Lead isotope pattern in the Lisina occurrence near Srb corresponds to Pb—Zn Alpine deposits in Triassic carbonate host rocks (B type), although the age is fairly higher.

INTRODUCTION

Appearance of a great number of papers of our and foreign investigators, which are intended to give a synthetic model of Dinaridic and surrounding realms in concordance with the latest achievements of the global tectonics, is based upon intensive accumulation of material facts in the field of regional geology and petrology. Application of geochemical methods is less present, while isotopic investigations are neglected.

Reason for that is probably in lack of appropriate analytical technique in our geological institutes.

Lead isotope geochemistry, popularly named »plumbology« as a new branch of geosciences, found its way to multifold use in petrogenesis and metallogenesis. It is due to a simple fact, that it helps in direct or indirect way to solve important geological problems concerning origin and time of magma generation and metal concentration. Isotope composition in particular rock or mineral sample is not only a geological chronometer but also a witness of geochemical lithosphere evolution, greatly effected by its change.

In principle, there are two methods for tracing up development of lead isotope ratios, which may serve for age determination or explanation of their origin. The first one is based upon desintegration of radioactive parents since time t up to the present time (U-Th-Pb method). The second one, known as »common lead method« operates on principle of lead ratio conservation developed since elapsing of time T, when the Earth became closed system for U, Th and Pb to the time t, when Pb isotopes were deprived of their radioactive parents and fixed in some minerals like galenas, feldspars, etc., with negligible small quotient of U/Pb and Th/Pb.

Application of lead isotope studies to ore deposits (using relationship $^{207}Pb/^{204}Pb$, $^{206}Pb/^{204}Pb$, and $^{208}Pb/^{204}Pb$, $^{206}Pb/^{204}Pb$) led to recognition of two distinctively different groups of deposits. The first group embraces syngenetic, stratiform or conformable deposits of massive sulfides with homogeneous isotope composition, which can be used for direct calculation of mineralization age. Stanton and Russell (1959), observing that phenomenon, constructed a growth curve for conformable deposits, which is applicable in a simple manner for »model age« determination. This is so called »ordinary lead«. Its feature to follow up a single-stage growth curve was then explained by its upper mantle origin, which had been supposed to have a uniform composition of U, Th and Pb.

Epigenetic deposits belong to the other group, whose isotopic composition varies greatly and »model age« is often too young, too old or even negative (future time). In many cases a group of deposits form a linear array of data in $^{207}Pb/^{204}Pb$ vs, $^{206}Pb/^{204}Pb$ diagram, which is usually interpreted by a multistage growth history in a system with different U/Pb and Th/Pb ratios. Linear array (or a secondary isochron), if the time of mineralization is known, may give rise to the age determination of source material. Such lead is known as »anomalous lead«.

Kanasewich (1968) observed tendency of the Phanerozoic conformable deposits to have younger ages, determined by single-stage model than evidenced by geological relations. Russell (1972), studying oceanic volcanic rocks, noticed that upper mantle is far of being homogeneous as was expected by isotopic patterns of conformable massive sulfides.

Thereafter, the proceeded models were prepared by taking into account mixing of different material and multistage growth, in order to produce a rectified curve, able to fit ages of conformable ore deposits.

D o e and S t a c e y (1974) introduced a new curve by accepting a smaller value for the Earth age (T = 4.43 b.y.), instead of an old value T = 4.57 b.y., what is again, in effect, a pseudosingle-stage model.

S t a c e y and K r a m e r s (1975) elaborated two-stage model with two growth phases. The earlier one started coeval with the earth formation (T = 4.57 b.y.) and ended up 3.7 b.y. ago, with the first crust formation ($^{238}U/^{204}Pb = \mu = 7.19$). After 3.7 b.y. a single episodic increase of μ to 9.75 was encountered. The Stacey and Kramers model is controled by modern ocean sediments.

C u m m i n g s and R i c h a r d s (1975) model is controled by the stratiform deposit Captain's Flat, Australia, and is based upon continuous increase of μ value, due to more expressed ensialic environment.

D o e and Z a r t m a n (1979) systematized a great number of isotopic analyses in accordance to plate tectonic concept, introducing »plumbotectonic model«, which recognises three main environments, regarding U, Th and Pb concentrations, i.e. upper and lower continental crust and mantle. The orogen is a product of mixing of their material by erosional, sedimentary, subduction and volcanic processes, typical for volcanic arc activity. The newly obtained curve is compatible with conformable deposits, while $^{207}Pb/^{204}Pb$ ratio is indicative for maturity of arc.

GEOLOGICAL SETTING

Common characteristics of the selected deposits and mineral occurrences is their spatial affilliation to the Upper Paleozoic clastic series in the Lika region, Zagrebačka gora, Trgovska gora, and Samoborska gora mountains and in the Bosanska Krajina region. Their syngenetic (stratiform, conformable) and epigenetic appearance and obscure link with magmatic activity made investigators facing dilemma, whether genetical processes to attribute to Variscan or some younger, likely Triassic metallogenesis, which brougth many heavy metal and iron deposits in Dinaridic geosyncline. Geographical positon of the sampling sites is shown in Fig. 1. Short description of geological setting is presented in the proceeding text.

B i s t r a, Z a g r e b a č k a g o r a

The galena sample No. 1 was taken from meso-thermal quartz-siderite veins with sulfides placed in the Upper Paleozoic sediments, mostly clastics, of the northeastern Zagrebačka gora (Medvednict) near Bistra vilage (J u r k o v i ć, 1962, according to personal communication by Š i n k o v e c B.). Ore minerals are pyrite, galena with minor chalcopyrite and sporadic tetrahedrite. The ore occurrences, according to their paragenetical and morphological features belong to hydrothermal genetic cycle of the Variscan metallogenic epoch, owing to their similarity to mineralization in the Petrova gora and Trgovska gora mountains.

R u d e, S a m o b o r s k a g o r a

The Samoborska gora Paleozoic terrain is built of the Upper Carboniferous and partly Permian clastic sediments (H e r a k, 1956). Stefanian

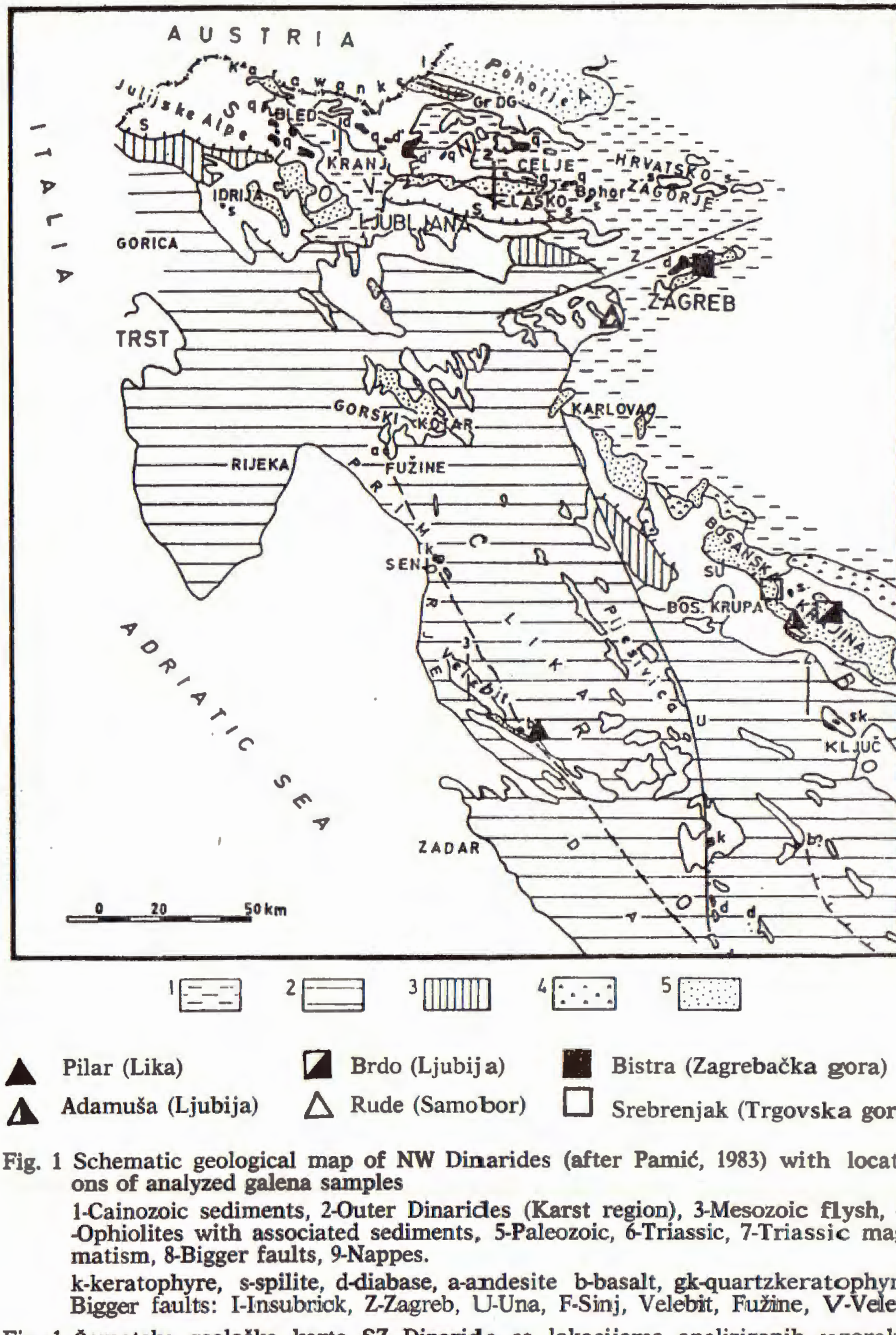

Fig. 1 Schematic geological map of NW Dinarides (after Pamić, 1983) with locations of analyzed galena samples

1-Cainozoic sediments, 2-Outer Dinarides (Karst region), 3-Mesozoic flysh, 4-Ophiolites with associated sediments, 5-Paleozoic, 6-Triassic, 7-Triassic magmatism, 8-Bigger faults, 9-Nappes.

k-keratophyre, s-spilite, d-diabase, a-andesite b-basalt, gk-quartzkeratophyre Bigger faults: I-Insubrick, Z-Zagreb, U-Una, F-Sinj, Velebit, Fužine, V-Velež.

Fig. 1 Šematska geološka karta SZ Dinarida sa lokacijama analiziranih uzoraka galenita

1-Kenozojski sedimenti, 2-Vanjski Dinaridi (Kraško područje), 3-Mezozojski fliš, 4-Ofioliti sa pridruženim sedimentima, 5-Paleozojik, 6-Trijas, 7-Trijaski magmatizam, 8-Veći rasjedi, 9-Navlake.

b-bazalt, s-spilit, d-dijabaz, a-andezit, k-keratofir, gk-kvarc keratofir. Veći razlomi: I-Insubrick, Z-Zagreb, U-Una, F-Sinj, Velebit, Fužine, V-Velež.

is presented by black argillaceous shales, dark gray sandy shales with micas, and finegrained sandstones. Locally, there are interlayers of dolomites, siderites and hematites, and thick beds of gypsum and anhydrite. Conglomerates are rare. The sediments are overlain by the Permian light gray, fine to coarsegrained sandstones and quartz conglomerates with fragments of older rocks. Red sandstones crop out locally. There are two morphological types of ore bodies in Paleozoic sediments. The first type are beds and lenses of siderite, hematite, anhydrite and gypsum with dolomite, and the second one are epigenetic, quartz-siderite (barite) veins with sulfides (sphalerite, galena, tetrahedrite, lineite, marcasite, barite), (Šinkovec, 1971, Jurković, 1962). The sample No. 2 was taken from the barite-galena vein pertinant to the latter one. Šinkovec considers it as an exhalative-sedimentary, and Jurković (1962) as a submarine-juvenile deposit not excluding possibility of terrigenous origin of iron. The deposit is of Permian age, related to a late phase of Herzinian orogenesis. Presence of barite and composition of paragenesis point out to acid character of ore parent magma, whose existance has not been proved yet.

Srebrenjak, Trgovska gora

The Trgovska gora mountain terrain is built of the Upper Paleozoic clastic sediments, black-gray argillaceous shales, sandstones with subordinate quantity of conglomerates, breccias, quartz sandstones, limestones and dolomites. It is possible to distinguish an older and younger series. The older one is represented by argillaceous shales, while sandstones, limestones and dolomites are rarer like interlayers in the shales. The younger series is more sandy with thin shale intercalations.

The Trgovska gora mountain sediments are surrounded by younger Triassic, Tertiary and Quarternary sediments. According to new comprehensions the Paleozoic terrain is not a horst but rather eugeosynclinal formations thrusted over younger Mesozoic sediments of the miogeosyncline carbonate platform and its northeastern margin (Šparica, 1981).

The mineralization is connected exclusively to the shale sequence. Jurković (1959, 1962) differs two ore types: meso-epithermal ankerites in stratiform bodies and vein-like occurrences. The vein mineralization may be subdivided into mesothermal siderite, mesothermal quartz-siderite veins with galena and Ni-Co sulfides and epithermal barite veins.

The sample No. 3 is from an abandoned Srebrenjak mine, and belongs to a vein-like type with Ni-Co sulfides. This is an epithermal deposit in the cryptobatholitic level connected with an occult granite pluton (Jurković, 1960).

Ljubija, (Adamuša, Brdo localities), the Sana-Una river Paleozoic

The Sana-Una river Paleozoic is situated in the northwestern Bosnia covering an area of 12000 km². The oldest observed rocks are the Upper Devonian marine, clastic sediments, mostly subgraywackes, graywackes, clayey shales and at end of the Middle Carboniferous carbonates were deposited in some places. Coeval volcanic activity is manifested by spilites and tuffites and significant quantity of stratiform siderite bodies with sulfides (galena, sphalerite, sample No. 4), metasomatic ankerites and epigenetic siderite veins with sulfides (sphalerite, galena, chalcopyrite, etc.). It could be attributed to the Asturian orogenic phase (Jurković, 1961, Marić and Crnković, 1961, Jurić, 1971). In the surrounding of Ljubija, there are many barite occurrences (with fluorite and siderite) of Early Permian age in the Variscan tectonic elements (Jeremić, 1960).

Pilar, the Southwestern Lika

The Paleozoic terrain on an area of 15 km², in vicinity of St. Rok village, consists of the Upper Carboniferous, Auernian deposits of different facies: clayey shales, quartz conglomerates and fusulinidic limestones. The Permian Val Gardena sandstones may be found only at the southwestern part near Poljana. The contact between The Paleozoic rocks and younger stratigraphic members is tectonic.

The barite deposits are exclusively in the Auernian sediments, while in the Val Gardena (Permian) sediments have not been found. The ore is in layered bodies implaced in argillaceous shales or is between shales and bituminous-clayey limestones. The biggest body is in Pilar village. Beside barite in the paragenesis participate also pyrite, sphalerite, and galena (sample No. 5), Jurković, 1959). The deposit became by hydrothermal activity in the course of the Mesozoic geosynclinal magmatic cycle, which enabled leaching out of metal content situated more deeply in the Variscan metallogenic zone (Jurković, 1962).

Lead and zinc occurrences at Lisina near Srb in the Lika region

Mineralization is placed at a tectonic contact between the Scythian shale and Anisian massive, less often brecciated dolomites. The host rocks are carbonates, which are hydrothermaly altered (Šinkovec, 1957). Paragenesis is simple sphalerite, wurtzite, galena (sample No. 6), and sporadic chalcopyrite, pyrite and marcasite. Composition of paragenesis and gel textures point out to low temperature crystallization. This is telethermal, apomagmatic mineralization, younger than the fault, cutting the Scythian and Anisian sediments (Šinkovec, 1957). According to Jurković (1962), genesis of the occurrence should be explained in the same way as the ore deposit Pilar.

ANALYTICAL PROCEDURE

Galena samples were dissolved in HNO_3 and $HClO_4$, then lead was electroplated as the oxide on a platinum anode (2V). Lead isotope ratios were measured on National Bureau of Standards Nier-type 12-in., 60° mass spectrometer in the laboratory of the Florida State University, Tallahassee. The analyses were made by using surface emission (silica gel) technique. All analyses have been normalized to the National Bureau of Standards SRM 981 common lead standard.

LEAD ISOTOPE INVESTIGATION

Long lasting mining activity and extensive geological explorations in connection with this (mapping of surface and underground mining works, drillings, etc.) have given fairly clear picture about geological relations in the deposits, kind of host rocks and mineral composition of ores and gangüe. Obscure traces of magmatic activity in the country rocks, however, still puzzle origin of metal and time of mineralization. This preliminary study, that is how it should be called, since small number of analyzed samples and difficulties in analytical procedure (expressed fractionation), had a task to open a new approach to problems unsolved by classical geological methods. If continuation of this kind of investigation shed some more light upon mentioned unknowns, it will be a contribution not only to economic geology, but also to regional geology and petrology as well.

The analyzed isotopic ratios are shown in the Table 1. and on diagrams $^{208}Pb/^{204}Pb$, $^{206}Pb/^{204}Pb$ and $^{207}Pb/^{204}Pb$, $^{206}Pb/^{204}Pb$ (Fig. 2a and 2b). The model ages have been calculated by Doe and Stacey (1974) and Stacey and Kramers (1975) models and presented in the Table 2. The former one was elaborated to solve problem of »too young« stratiform deposits, what is a consequence of ensialic environment influence where lead had resided, giving higher values for $^{206}Pb/^{204}Pb$ ratio than is possible mathematically by single-stage growth. Stacey and Kramers curve uses two stage model, by what, the time $t = 3.7$ b.y. is the first differentiation of the crust and mantle. Comparing model age values obtained by calculation, to the age of ore bearing rocks, it seems, that the first model fits into conception of volcano-sedimentary deposits.

Few other characteristics may be observed in the diagrams. The sample from Ljubija, i.e. Adamuša and Brdo are essentially different in all ratios, but particularly in $^{207}Pb/^{204}Pb$, what is caused by rather expressive fractionation of the latter. (Coefficient of fractionation of Brdo is 0.8538, and of Adamuša 0.8534, that is, practically the same. That is why, Adamuša has not been included in consideration).

Furthermore, the sample from Pilar, Brdo (Ljubija), Srebrenjak and Rude form a good regression line $y = 0.3541x + 9.1066$, passing through the point $t = 3.7$ b.y. (Fig. 3), and cutting Stacey and Kramers curve at 220 m.y. (Fig. 2b). The interpretation of this manifestation should not be a simple »second-stage« isochron, but rather mixing line of lead isotopes from different environments in the geosynslinal sedimentary package with different U, Th and U concentrations. The age of mineralization, in that way, corresponds to an early phase of the Triassic magmatic activity, which could cause formation of circulating hydrothermal cell, necessary for metal secretion from the sedimentary series.

The samples otherwise show fairly different values. Pilar has very low value, the group Ljubija, Rude and Srebrenjak have pretty similar values, and Bistra sample rather high one.

Table 1. Locations, lead isotope composition of galenas and geologic relationship in selected NW Dinaridic ore deposits

Tablica 1. Lokacije, izotopski sastav olova u galenitu i geološki odnosi u nekim odabranim rudnim ležištima u SZ Dinaridima

No. smpl.	Ore deposits District mine or occurence	$^{206}Pb/^{204}Pb$	$^{207}Pb/^{204}Pb$	$^{208}Pb/^{204}Pb$	
1	Bistra (Zagrebačka gora)	18.3315	15.6592	38.5216	Epigenetic quartz-siderite veins with sulfides (py, gn, cpy) in black Upper Carboniferous shales, Variscan orogenesis. Igneous activity obscure.
2	Rude (Samoborska gora)	18.2547	15.5661	37.9736	Epigenetic quartz-siderite veins with sulfides (gn, sp, cpy) and barite, and lenses of conformable siderite and hematite ore bodies in Permian sediments. Late stage of Herzinian orogenesis. No igneous activity.
3	Srebrenjak	18.1943	15.5546	38.1310	Epigenetic veins of siderites and sulfides (Ag-rich galena, sp, cpy, etc.) and stratiform siderite ore bodies in Upper Carboniferous clastic. Igneous activity unknown. Variscan metallogenesis.
4	Ljubija-Brdo (Sana-Una pal.)	18.2244	15.5609	38.0431	Stratiform siderite beds, metasomatic ankerites, epig. siderite veins with sulfides (gn, sp, cpy) in Middle Carboniferous black shales and carbonates. Spilites and tuffites inbedded in sediments. Variscan metallogenesis.
	Ljubija-Adamuša	18.1397	15.4800	38.1457	
5	Pilar (Lika)	18.1047	15.5148	37.8959	Stratabound barite accumulation in Upper Carboniferous dolomite and shales (gn, py), Triassic metallogenesis.
6	Lisina (Srb)	18.0873	15.7359		Low temperature vein-like Pb-Zn (gn, sp) deposit in Triassic carbonate rocks.

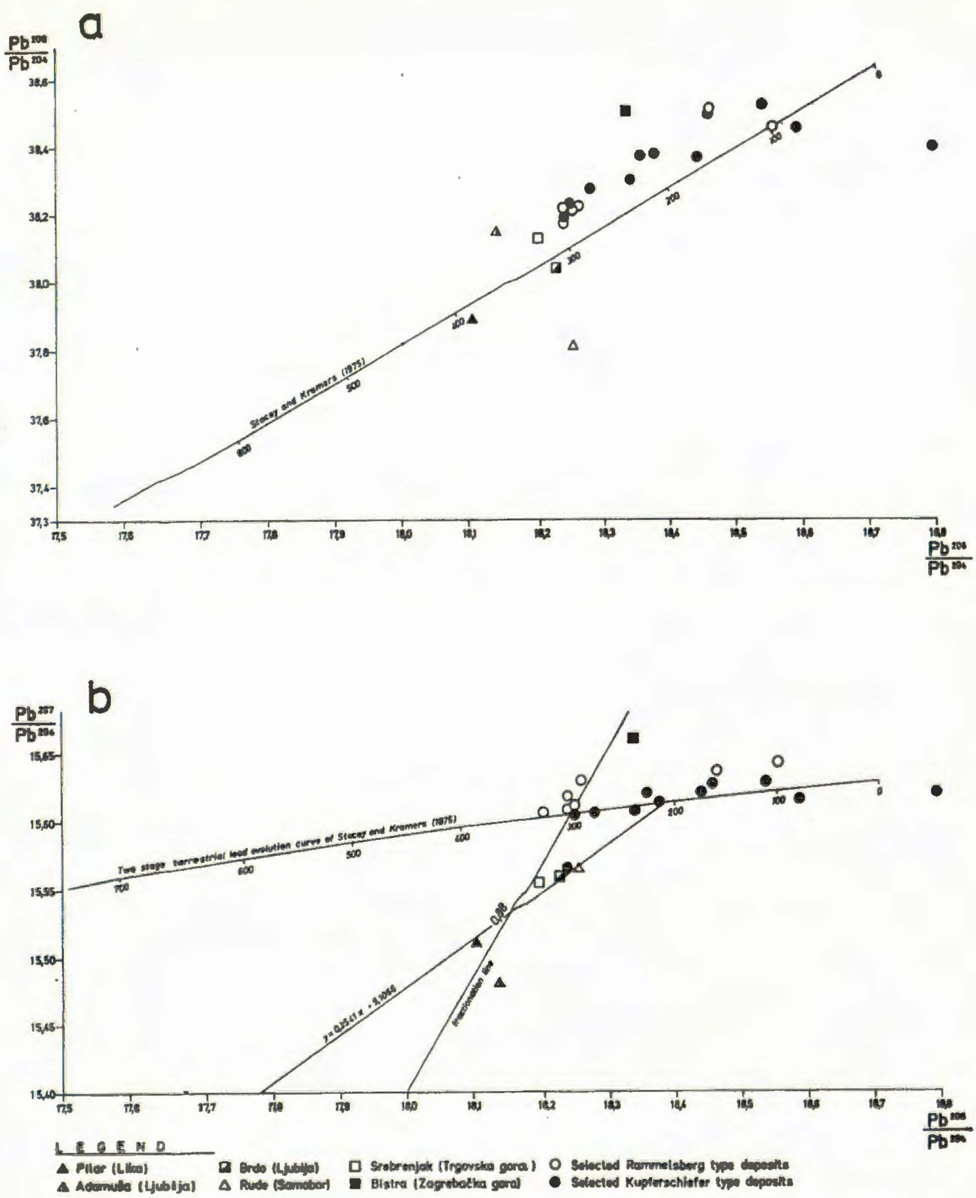

Fig. 2a and 2b

Isotope composition of lead in galenas from some selected ore deposits and occurrences in Croatia and NW Bosnia shown as ratios

$^{208}Pb/^{204}Pb$, $^{206}Pb/^{204}Pb$ and $^{207}Pb/^{204}Pb$, $^{206}Pb/^{204}Pb$.

Izotopski sastav olova u galenitu iz nekih odabranih rudnih Ležišta i pojava u Hrvatskoj i SZ Bosni prikazani u vidu odnosa

$^{208}Pb/^{204}Pb$, $^{206}Pb/^{204}Pb$ i $^{207}Pb/^{204}Pb$, $^{206}Pb/^{204}Pb$.

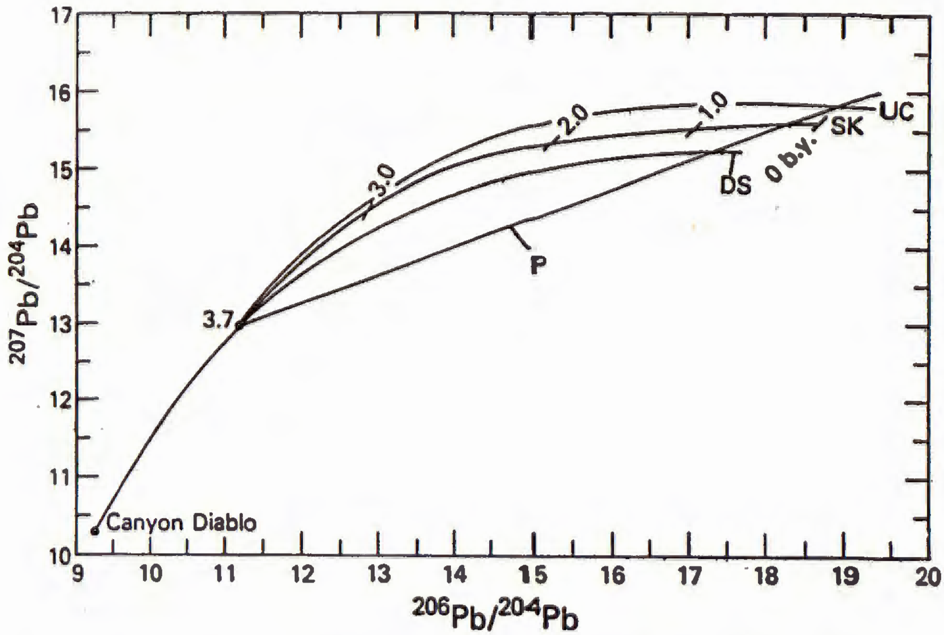

Fig. 3 $^{207}Pb/^{204}Pb$, vs. $^{206}Pb/^{204}Pb$ diagram illustrates evolution of lead isotope ratios in depleted source (DS) (regarding uranium), with continous increase of U/Pb value from the primary differentiation (3.7 b.y.). The average growth evolution in the crust is shown by SK, Stacey and Kramers (1975) curve. UC is a curve of average growth in the upper crust. The line P ($y=0.3541x+9.1066$) is a regression line for deposits: Rude, Pilar, Brdo and Srebrenjak, representing a mixing line of lead isotopes in orogene.

Fig. 3 $^{207}Pb/^{204}Pb$ vs. $^{206}Pb/^{204}Pb$ diagram ilustrira evoluciju olova u osiromašenom izvoru (DS) (s obzirom na uran) sa kontinuiranim povećanjem U/Pb vrijednosti od primarne diferencijacije (3,7 milijardi godina). Prosječni rast u kori je prikazan sa SK "Stacey - Kramers (1975) krivuljom.UC je krivulja prosječnog rasta u vanjskom omotaču. Pravac predstavlja liniju miješanja olova iz različitih izvora u orogenu (P).

Table 2. Model ages of deposits and approximate age of the host rocks
Tablica 2. Modelne starosti rudnih ležišta i približna starost okolnih stijena

No. smpl.	Model lead age (assuming single-stage evolution by Doe and Stacey (1974) model) Isochron	Model lead age (assuming two-stage evolution by Stacey and Kramers (1975) model) Isochron	Approx. geol. age of host rocks
1	293 m. y.	341 m. y.	290 m. y.
2	234	207	230
3	264	219	270
4	239	227	290
5	264	213	270
6	538	650	200

The central group, from geochemical point of view (Rude, Srebrenjak and Ljubija) are significant bearer of copper in comparison to the peripheral deposits (Pilar and Bistra).

The both phenomena might have regional significance. Increase of μ from the inner margin of the carbonate platform, where Pilar undoubtedly belongs, toward Bistra which is the nearest to the ensialic Pannonian mass, is logical explanation. It means, that material from the Adriatic promontory had much lower U/Pb ratio, i.e. originates from the lower crust (Doe and Zartman, 1979). Further consideration could be directed toward origin of clastic material, or contribution of African Precambrium and younger structures in the northern Europe.

Geological position of the separated group, rich in copper, as well as mineralization age, determined by Stacey and Kramers model and by mixing line in orogene (plumbotectonic model) corresponds to beginning of the Triassic rift magmatism (Pamić, 1983), or at least to initiation of thermal flux, which caused rifting and intensive Triassic, basic, intermediate and acid magmatism of calc-alkaline series at plutonic, hypabissal and volcanic level.

Isotopic composition of lead in Lisina (Srb) appropriates to characteristics of Alpine Pb-Zn deposits in Triassic carbonate rocks (B type), but the age in comparison to Bleiberg (420 m.y.) and to Mežica (440 m.y.) (Schroll, 1962), is much higher. Unusually old lead of the Alpine Pb-Zn deposits was explained by secondary remobilization of an old lead from the fundament, what corresponds to conception expressed by Jurković (1962).

CONCLUSION

Isotopic analyses, using Doe and Stacey (1974) and Stacey and Kramers (1975) models of lead growth curve, have given reasonable ages. The former one suggests age between 234 and 293 million of years, what is in good agreement with age of the host rocks, responding to volcano-sedimentary origin. The latter one gives values more appropriate to the Triassic magmatic activity, which started in the Permian time. On the basis of the secondary isochron y = 0.3541 x + 9.1066, passing through 3.7 b.y. directly, and cutting Stacey and Cramers growth curve at 220 m.y., the Triassic activity was likely encountered. The datum 3.7 b.y. should not be taken like age of source material with different independent systems (regarding μ), but rather a part of a mixing line for age 220 m.y. in »plumbotectonic« model. The mixing is due to lateral secretion in circulating cell in a geosynclinal sedimentary sequence. The circulation was effected either by igneous activity or increased thermal flux due to initial rifting processes. Discordance between age of the host rocks and time of mineralization preferes epigenetic mechanism of ore deposits formation.

Extraordinarily high age of lead in Pb-Zn occurrence Lisina near Srb in the Lika region (the only analyzed deposit in the Anisian dolomite) corresponds to Pb-Zn Alpine deposits in Triassic carbonate host rocks (Bleiberg type), which are usually interpreted by lead remobilization from on old galena accumulation.

It should be emphasized, that interpretation is based upon relatively small number of analyses and that Adamuša sample encountered high fractionation. In spite of that, the data show certain regularity, which is in good agreement with geological evidences, like age, μ values and logical Pb mixing line in orogene. The preliminary study of this type points out to wide possibility of isotope geochemistry to shed more light upon problems investigated only by classical methods.

This study is a part of my doctoral thesis in preparation.

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Karakteristike izotopskih odnosa olova u galenitu iz nekih odabranih rudnih ležišta u Hrvatskoj i SZ Bosni

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U radu su prikazani rezultati izotopskih analiza uzoraka galenita iz nekih rudnih pojava i ležišta smještenih u gornjopaleozojskim stijenama Hrvatske i SZ Bosne, i to Bistra (Zagrebačka gora), Rude (Samoborska gora), Pilar (Jugozapadna Lika), Srebrenjak (Trgovska gora), Brdo i Adamuša (Ljubija, sansko-unski paleozoik). To su ležišta sa singenetskim (stratiformnim) i epigenetskim (žičnim) karakteristikama, čiji sastav varira od monomineralnih baritnih i sideritnih pojava do složenih polisulfidnih žica. Rudna tijela su isključivo u gornjopaleozojskim sedimentima, pretežno klastitima s nešto karbonata.

Geneza ležišta se različito interpretira, sa tipično hidrotermalnim, hidrotermalno-metasomatskim ili vulkanogeno-sedimentnim procesima. Željezo u sideritskim ležištima Ljubije prema nekim autorima moglo bi biti i terigenog porijekla. O starosti mineralizacija postoje također različita mišljenja, koja genezu vežu za variscijsku metalogenetsku epohu, do nekih novijih ideja u vezi s trijaskim magmatizmom, koji započinje vjerojatno već sredinom perma. (Mišljenja, da su ležišta kenozojske starosti ili čak recentna, ne bi se mogla prihvatiti kao argumentirani stav.)

Izotopske analize, koristeći Doe-Stacey (1974) i Stacey-Kramers (1975) modele razvoja odnosa olovnih izotopa, daju približno slične vrijednosti. Po prvom modelu starosti su u dobroj suglasnosti sa starošću okolnih stijena, što sugerira vulkanogeno-sedimentni način postanka. Prema Stacey-Kramers modelu, rana faza trijaskog magmatizma, koja bi započela u permu, bolje bi odgovarala općoj situaciji. Na bazi sekundarne izokrone $y = 0.3541\,x + 9.1066$, koja prolazi direktno kroz točku na krivulji označavajući 3,7 milijardi godina, i siječe Stacey-Kramersovu kri-

vulju kod 220 miliona godina, epigenetski način orudnjenja bolje bi odgovarao. Vrijednost 3.7 milijardi godine, dobivenu na opisani način, ne bi trebalo shvatiti kao starost fundamenta iz kojeg se razvijaju nezavisni sistemi sa različitim vrijednostima za μ, već kao točku na liniji miješanja olovnih izotopa, koje je uzrokovano lateralnom sekrecijom u geosinklinalnom paketu sedimenata, tj. cirkulirajućom hidrotermalnom ćelijom (Doe i Zartman, 1979). Njezino formiranje koincidira s predpostavljenom ranom fazom riftovanja, koje dovodi do masovnog magmatizma u trijasu.

Velika starost olova u ležištu Lisina kod Srba u Lici (pojava u anizičkim dolomitima) odgovara izotopskim karakteristikama olova u Pb-Zn ležištima u trijaskim karbonatnim kompleksima istočnih Alpa (B tip), (iako je znatno starije).