Mineral. Deposita 19, 132–137 (1984)

IPEN
FOLHETO
Nº 803
BIBLIOTECA

MINERALIUM
DEPOSITA
© Springer-Verlag 1984

A Discussion on the Lead Isotope Geochemistry of Galenas from the Bambui Group, Minas Gerais – Brazil

S. S. Iyer

Departamento de Processos Especiais, Instituto de Pesquisas Energéticas e Nucleares, Caixa Postal 11049, Pinheiros, São Paulo, Brazil

Abstract. Lead isotope data on galenas from the Bambui group, Minas Gerais have been assembled and discussed. The isotope data, when plotted on the Single Stage Model III lead isotope development curve of Cumming and Richards (1975), yield 207/206 ages of 650±50 m.y and a linear array of data points with negative model ages, which intercept the growth curve at 650±60 m.y and 1850±150 m.y. The radiometric dates coincide with the two major orogenic episodes, the Brazilian and the Trans-amazonian. The data are interpreted in terms of a two stage model, where the source of lead for galenas, formed during Brazilian orogeny, is the basement rocks of Trans-amazonian age. The calculated Th/U value for the source rock is 2.9±0.3. The geographical distribution of lead isotope ratios shows a zonation in Vazante Paracatu region, an area containing large deposits of zinc. The implication of the distribution on the ore formation is discussed.

Introduction

The Bambui group, a sedimentary cover of hundreds of meters thick, extends over an area of more than 400,000 Sq. Km. in central Brazil (Almeida et al., 1976). This group contains major lead-zinc deposits, which are thought to be of the "Mississippi Valley Type" (Robertson, 1963; Amaral, 1968a). Based on radiometric dates (Amaral and Kawashita, 1967; Bonhomme, 1976; Cordani et al., 1978; Couto et al., 1981) and fossil content (Cloud and Dardenne, 1973; Marchese, 1974) the sediments were probably deposited during the Upper Proterozoic.

Lead isotope analyses of galenas from Bambui group have been reported by Amaral (1968a) and Cassedanne and Lasserre (1969). Recently eighteen galenas have been analysed for their lead isotope composition by the author in his laboratory and the preliminary data have been published in Couto et al. (1981). In that publication lead isotope data on galenas together with the Rb-Sr isotope data for whole rock samples from the Bambui group have been discussed. In the present paper the lead isotope data in general are discussed emphasising the aspects of the age of mineralisation and the age of the source rocks that provided lead to the deposits. A comparison of the lead isotope data of Bambui with those of "Mississippi Valley Type" deposits is attempted.

Regional Geology

The name "Bambui group" is applied to an extensive sequence of clastic and carbonaceous sediments that occur mainly in the São Francisco Valley, which includes part of the State of Minas Gerais, Bahia and Goias (Fig. 1 of Cassedanne, 1973). The group is represented essentially by unmetamorphosed or poorly metamorphosed limestones, dolomites and pelitic rocks with minor amounts of quartzites, arkoses and greywackes. Misi (1979) has reviewed the geology, stratigraphy and the mineralization of the Bambui group in the State of Bahia. In the State of Minas Gerais the Bambui group occupies nearly one third of the area of the State and is the major source of zinc, lead and phosphate minerals. The analysed galenas are from different localities in the State of Minas Gerais (Fig. 1) extending from Vazante in the west to Itacarambi in the east. The paleogeography and the mineralization of the region has been studied by Robertson (1963), Amaral (1968b), Cassedanne (1973) and Dardenne (1979). Cassedanne (1973) observed rapid and frequent variation in the lithological profile in the zone between Itacarambi and Vazante and attributed it due to different sedimentation conditions. According to Cassedanne (1973) the mineral deposits in the region are of three types, veins, stratabound occurrences and secondary (altered), all of which are practically without iron. The sedimentary cover rocks in which the deposits occur are poorly metamorphosed or unmetamorphosed.

Recently Alecrin (1982) summarised the geology of the zinc-lead deposits from Vazante area, Paracatu area and Januaria-Itacarambi-Montalvania-region. The Vazante-Paracatu-region contains almost the whole of lead-zinc reserve of the State of Minas Gerais and a major part of the Brazilian national reserve of zinc. Mineralogically the deposits in Vazante are composed mainly of calamine and willemite formed from the decomposition of sulphides present in the Vazante sequence. Two types of deposits can be found in somewhat parallel strips;

a) Western Strip: hematite-willemite with sulphides two to five meters thick.
b) Eastern Strip: blocks between carbonate rocks with calamine mineralization.

According to Dardenne (1979) the primary mineralization was remobilised in the form of sphalerite, galena and hematite in normal longitudinal faults with later supergene alteration producing hydrated zinc silicates.

COMISSÃO NACIONAL DE ENERGIA NUCLEAR/SP - IPEN

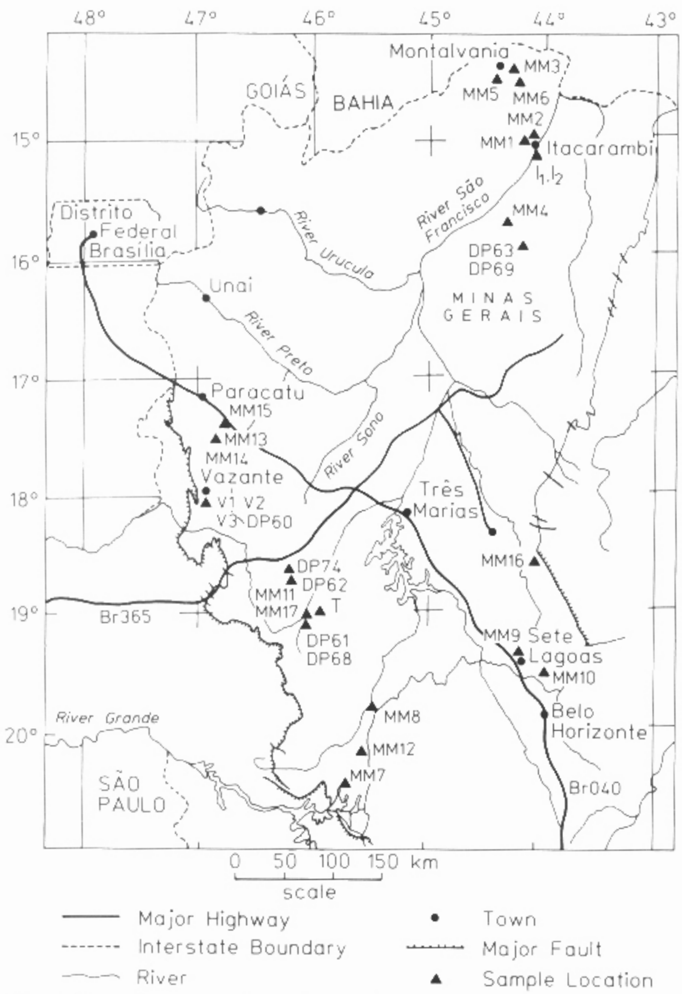

Fig. 1. Location map for galenas from Bambui group, Minas Gerais state, Brazil

Table 1. Lead Isotope Analyses of Galenas from Bambui

Sample No	$^{206}Pb/^{204}Pb$	$^{207}Pb/^{204}Pb$	$^{208}Pb/^{204}Pb$	Ref.
V_3	17.85	15.81	37.39	1
V_1	17.68	15.62	37.06	1
V_2	17.64	15.56	37.06	1
I_1	20.30	16.10	40.90	1
I_2	20.54	16.36	41.56	1
T	19.60	15.85	38.87	1
F	19.06	15.90	38.99	1
DP60	17.61	15.59	36.90	2
DP61	19.02	15.52	37.63	2
DP68	19.34	15.78	38.34	2
DP63	19.95	16.00	39.53	2
DP69	19.96	16.10	39.45	2
DP62	19.86	15.86	38.98	2
DP74	19.92	15.96	39.21	2
MM1	19.72	15.79	38.55	3
MM2	20.24	15.94	40.09	3
MM3	20.02	15.93	39.85	3
MM4	19.83	15.85	39.05	3
MM5	18.92	15.83	38.64	3
MM6	18.94	15.80	38.48	3
MM7	24.87	16.29	46.05	3
MM8	36.43	18.21	45.63	3
MM9	20.52	15.48	43.93	3
MM10	19.95	15.29	37.21	3
MM11	18.92	15.75	37.95	3
MM12	32.12	17.69	44.93	3
MM13	17.69	15.57	36.89	3
MM14	17.79	15.60	36.98	3
MM15	17.91	15.81	37.60	3
MM16	18.91	15.62	37.89	3
MM17	19.13	15.82	38.54	3

1) Amaral (1968a).
2) Cassedanne and Lassere (1969).
3) Present work.

In Paracatu the major deposit is that of Morro Agudo, stratiform lenticular bodies of different thickness found within the dolarenitic layers and consist essentially of lead and zinc sulphides (Pb to Zn ratio 2 : 3) with some cadmium and large amounts of pyrite.

In the Januaria-Itacarambi-Montalvania-region there are many small deposits, where the primary sulphide minerals are essentially sphalerite and galena with local alteration to willemite, cerussite and anglesite (Robertson, 1963; Alecrin 1982). This mineralization is accompanied by fluorite, barite, vanadinite etc. The deposits occur in the form of karstic lenses and pockets interstratified in the dolomitic rocks which are rose in color and saccoroid in nature.

Lead Isotope Data

The lead isotope data discussed in this paper are based on the work of Amaral (1968a), Cassedanne and Lasserre (1969) and fresh measurements carried out in the laboratory on the samples reported in Couto et al. (1981). The isotope analyses were carried out using a Varian TH-5 Mass Spectrometer coupled to an on line computer system for data collection and processing. The data reported in Cassedanne and Lasserre (1969) are isotope analyses using triple filament ionization source. The precision of the analysis varied from 0.2 to 0.4%. The isotope ratios measured in author's laboratory were carried out using single filament silica gel method and some of the samples were reanalysed using a double filament. The data reported were normalised using the values obtained for Broken Hill Standard Ore (Cooper et al., 1969) which was run repeatedly. The uncertainties of the isotope ratios, which include estimates of reproducibility and internal precision of the analysis, varied from 0.08% to a 0.21% at 95% confidence limit.

Results and Discussion

The lead isotope data are plotted on the Single Stage Model III isotope development curves of Cumming and Richards (1975) (Fig. 2a, 2b). It can be seen from the Fig. 2a that the lead isotope ratios of most of the galenas are anomalous indicating future ages (J type lead). However lead isotope data for galenas from Vazante and Paracatu region (MM 13, MM 14, V1, V2, V3 and DP 60) plot close to 650 m.y. on the evolution curve. The isotopic linear Model III ages for these galenas are calculated and shown in Table 2. A model age of 650±50 m.y. can be assigned to the galenas of the Vazante-Paracatu-region on the basis of

COMISSÃO NACIONAL DE ENERGIA NUCLEAR/SP - IPEN

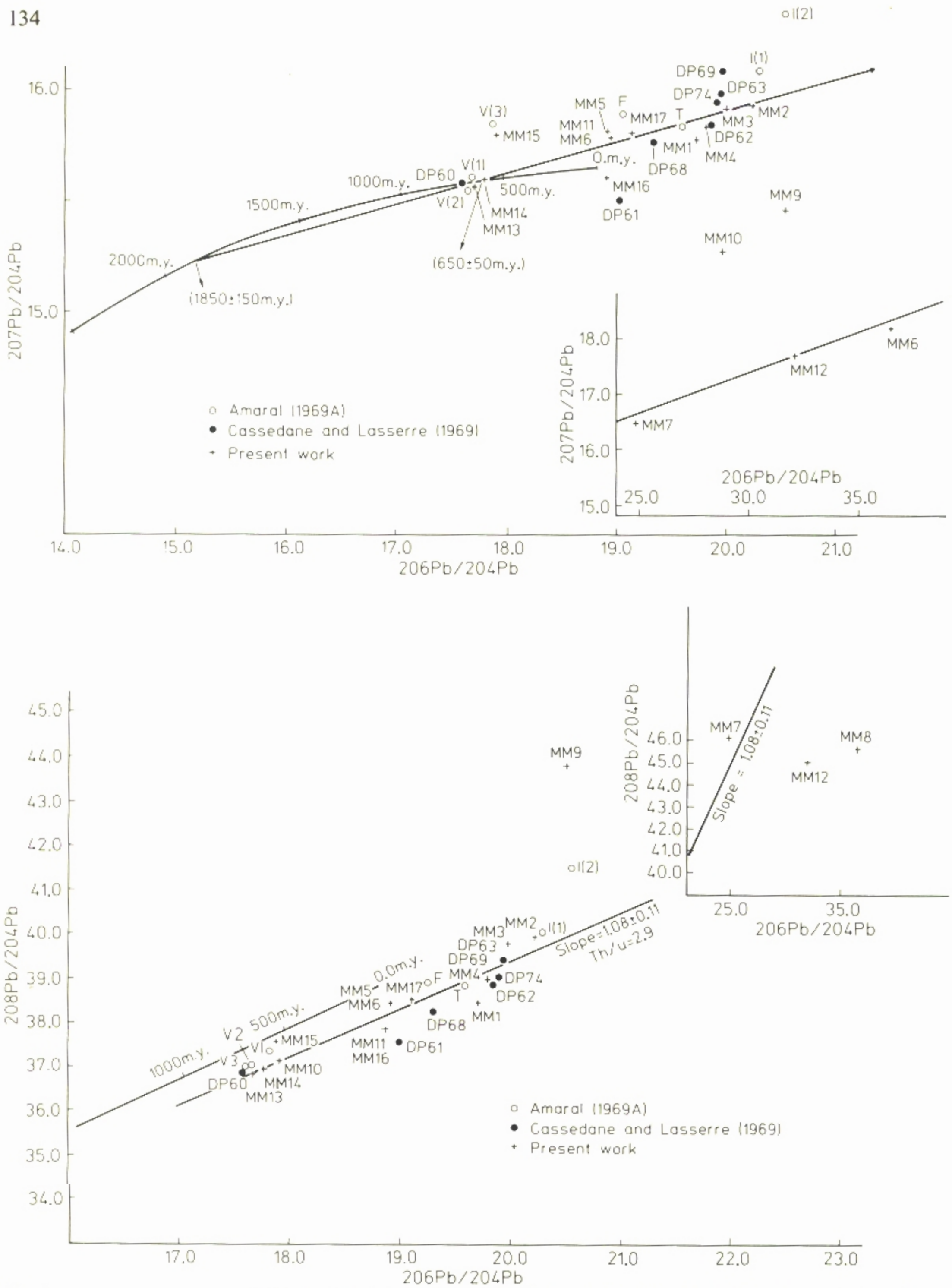

Fig. 2. **a** Data points for galenas from Bambui group on the Single State Model III lead isotope evolution diagram (Cumming and Richards, 1975) ^{207}Pb/^{204}Pb against ^{206}Pb/^{204}Pb. **b** Data points for galenas from Bambui group on the Single State Model III lead isotope evolution diagram (Cumming and Richards, 1975) ^{208}Pb/^{204}Pb against ^{206}Pb/^{204}Pb

calculated ^{207}Pb/^{206}Pb ages. A detailed Rb-Sr isotope dating study carried out on whole rock samples by Couto et al. (1981) yields isochron ages in the range of 590 to 680 m.y. for the Paraopeba formation in Paracatu, Itacarambi and Formiga, Pirapora formation in Pirapora and Três Maria formation in Felixlandia. All the samples analysed for the Rb-Sr dating programme are from the same area where the lead isotope study has been carried out. The Rb-Sr isochron dates confirm the isochron age of 600±20 m.y. obtained by Amaral and Kawashita (1967) for rock samples from this area.

In the Paracatu region Couto et al. (1981) obtained a Rb-Sr isochron age of 680±10 m.y. with an initial ^{87}Sr/^{86}Sr ratio of 0.7255. This isochron age as well as the initial ratio are higher than those obtained for rock samples for Paraopeba formation in Itacarambi, Formiga [640±15 m.y.; (^{87}Sr/^{86}Sr) initial = 0.7109]; Três Maria Formation in Felixlandia [620±40 m.y.; (^{87}Sr/^{86}Sr) initial = 0.7125];

Table 2. Calculated Linear Model III Ages of Galenas from Vazante

Sample number	$^{207}Pb/^{206}Pb$ age M. Y.	^{208}Pb age M. Y.
V_1	750	750
V_2	650	850
V_3	650	850
DP60	650	950
MM13	630	980
MM14	600	970
MM15	730	630

and Pirapora formation in Pirapora [590±40 m.y. ($^{87}Sr/^{86}Sr$) initial=0.7115]. Couto et al. (1981) interpreted the age data as being related to the sedimentation process (590–640 m.y.) in Pirapora, Três Maria and Paraopeba formations, whereas in Vazante-Paracatu- region the 680 m.y. age may be related to isotope homogenization event associated with tectonic/metamorphic regional event. The linear model ages of galenas from Vazante and Paracatu region (Table 2) are in agreement with the 680 m.y. Rb-Sr isochron age obtained for the whole rock samples from the area. Though the lead isotope data are different, the deposits of Vazante-Paracatu do not seem to show any clearly distinguishing features in relation to deposits of other areas. The data points, when plotted on Fig. 2 (a) show a linear trend and using the method of York (1966) a straight line with a slope of 0.142±0.005 can be fitted on the $^{207}Pb/^{204}Pb$ – $^{204}Pb/^{204}Pb$ diagram. The straight line intercepts the growth curve at two points, namely 650±60 m.y. and 1850±150 m.y. The isotope data for galenas from Vazante and Paracatu region that plot close to 650 m.y. have been excluded from the calculation. The inclusion of these data points will make the isochron line compulsorily intercept the growth curve at 650 m.y. The radiometric ages 650 m.y. and 1850 m.y. correspond to two of the most important orogenic cycles recorded in Brazil, namely, Brazilian (450–750 m.y.) and Transamazonian orogenic cycles (1800–2200 m.y. Cordani et al., 1973). The Brazilian orogeny is widespread and more than four million square kilometers area have been affected by it. In São Francisco craton, where the Bambui group is deposited the granitic-migmatitic rocks that generally underlie them are related mainly to the Transamazonian cycle (Hasui and Almeida, 1970, Brito Neves et al., 1980).

From Fig. 2 (b) it is seen that a thorium lead line can be fitted for majority of the galenas suggesting an anomalous lead mixing pattern. The slope of the line is calculated to be 1.08±0.11, which yields Th/U value of 2.9±0.3 for the integrated source. The linear pattern indicates that the lead in the region evolved in a crustal environment with a restricted or narrow range of Th/U values. However, when the U/Pb and Th/Pb values in the individual samples are calculated for the time interval of 1850 and 650 m.y., they are found to have the following range.

$^{238}U/^{204}Pb$ – 9.7 to 80.12
$^{235}U/^{204}Pb$ – 0.06 to 0.54
$^{232}Th/^{204}Pb$ – 29 to 152

The lead isotope system of Bambui group in Minas Gerais can be interpreted to have evolved in two stages. In the first stage, during Transamazonian orogeny, the lead isotope system homogenised to a certain degree and then probable U/Pb and Th/Pb fractionation occurred. The second stage evolution started with the growth of the lead isotope ratios and terminated 650 m.y. ago when the lead was incorporated into galenas. In some cases, as in Vazante-Paracatu, lead isotope system may have evolved under single stage condition during Brazilian cycle. This alternative can not be ruled out.

The origin of the lead zinc deposit in the Bambui group has been discussed by Robertson (1963), Amaral (1968a) and Cassedane (1973). Robertson (1963) classified the deposit as hydrothermal in origin, probably mesothermal to epithermal. The source of the ore and the gangue minerals was considered unknown by him. Amaral (1968a) considered that the lead of the deposits of the Bambui group was remobilised from rocks of this group and from basement in varying amounts during the Upper Cretaceous or Lower Tertiary. Cassedanne (1973), on the other hand, considered the deposits to be of sedimentary origin, where in heavy metals deposited in the carbonate formations were remobilised and precipitated during the Assyntric orogeny (700 to 500 m.y.) either in fractures or in some preferential beds. The lead isotope investigation demonstrates a two stage evolution for the lead system. The 1850 m.y. intercept of the isochron line on the growth curve and the calculated Th/U value of 2.9±0.3 for the integrated source indicate that the source of lead in galenas is the Transamazonian basement rocks.

Lead-zinc deposits of Bambui group are considered to be "Mississippi Valley Type" (Robertson, 1963; Amaral, 1968a, b; Bez, 1978). Brown (1970) listed eleven common characteristics for Mississippi Valley deposits and noted that the distinguishing characteristic feature of a truely Mississippi Valley lead-zinc deposit is the presence of J-type anamolous lead. Heyl et al. (1974) concur with such a view on their discussion of the isotopic evidence for the origin of Mississippi Valley Type deposits. According to these authors all deposits contain markedly radiogenic J-type lead with $^{206}Pb/^{204}Pb$ ratios greater than 20 and the enrichment in the radiogenic isotopes can be interpreted as signifying a shallow crustal source for the lead from the underlying Precambrian basement rocks and/or Paleozóic sandstone and carbonate rocks. Doe and Delevaux (1972) argued that the Lamotte Sandstone was the probable source of lead, based on whole rock lead isotope investigation of basement rocks as well as overlying sediments. Bjorlykke and Thorpe (1982) argue that the lead, rather than having been derived from the Lomotte Sandstone, could have been derived more directly from the same basement area that served as a source for the Lamotte Sandstone.

Heyl et al. (1974) observed that each major district of Mississippi Valley has a distinct regional isotope pattern in lead and sulphur that reflect the direction of solution flow, buried heat source, the area of localization of ore fluids. The lead isotope data from Bambui show a large spread in the value of $^{206}Pb/^{204}Pb$ (17.61 to 36.43). The geographical distribution pattern of the isotope ratios in galenas is interpreted here with a view to gain some insight into the mechanism of ore formation, direction of fluid flow and clues for future prospecting. The distribution pattern is presented following the method of Kuo and Folinsbee (1974). Figure 3 shows the pattern using $^{(206+207)}Pb/^{204}Pb$ and $^{208}Pb/$

COMISSÃO NACIONAL DE ENERGIA NUCLEAR/SP - IPEN

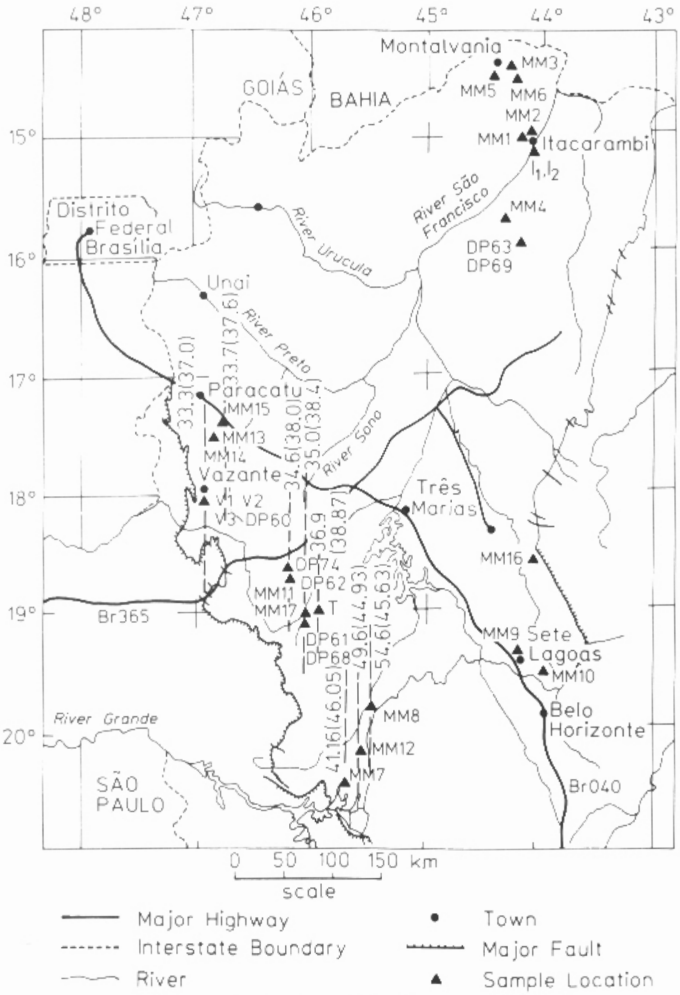

Fig. 3. Geographical distribution of lead isotope $^{(206+207)}Pb/^{204}Pb$ and $^{208}Pb/^{204}Pb$ values

^{204}Pb ratios. Even though the data are few, the Figure demonstrates that the lead isotope system close to the fault zone along the Vazante-Paracatu region is least radiogenic and an isotopic zonation can be observed away from the region as the lead isotope ratios became more radiogenic. In the region near Itacarambi the lead isotope ratios measured are intermediate in values between those found in the zonation around Vazante.

In order to explain the zonation in the lead isotope ratios in the Vazante-Paracatu region a model of Heyl et al. (1974) can be invoked. This model involves incomplete mixing of a solution containing common lead with a solution containing varying proportions of radiogenic lead or a mixing of a solution containing radiogenic lead with varying proportions of common lead. The zoning in the region extends over a distance of over 200 km, which is probably large for a process of single flow. A plausible explanation may be that solutions of different "strength" and during different lengths of time attacked the basement rocks. A slight and short attack will preferentially remove radiogenic lead and a prolonged and strong attack will eventually liberate the feldspar lead, which normally is the least radiogenic lead of the rock. Thus the zoning is a result of the preferential removal of lead isotopes.

Recently Bjorlykke and Torpe (1982) investigated the source of lead in Osen Sandstone lead deposit in Baltic Shield, Norway and argued that the lead was derived from the basement granite and that mineralization took place soon after sedimentation. They interpreted the isotopic composition of lead within Osen to be probably due to changes in the proportions of groundwater supplied from different basement areas within the drainage basin or by changes in the weathering process. The lead isotope data of other Sandstone deposits hosted by Cambrian sedimentary rocks that lie on Proterozoic basement rocks of Baltic Shield showed a regional variation, which was interpreted by the authors as due to the complex isotope nature of basement rocks.

The implication of the distribution pattern combined with the present knowledge of the occurrences of different types of mineral deposits and their geographical distribution can be used as clues for prospection and evaluation of ore deposits (Doe and Stacey, 1974; Kuo and Folinsbee, 1974). Doe and Stacey (1974) suggest that the difference in lead isotope composition may be used as a tool for evaluating a prospect. According to these authors most base metal deposits of the world have characteristic lead isotope ratios and many appear to have a lead isotope composition that evolved under conditions approximating single stage growth. This characteristic has been recommended as a tool for evaluating ore prospects. It is interesting to note that the galenas of the Vazante-Paracatu region have lead isotope compositions that appear to have evolved under single stage conditions and thereby yield model III ages (Cumming and Richards, 1975) of 600–700 m.y. (Table 2). Kuo and Folinsbee (1974) observed that anomalous ore leads are frequently encountered peripheral to region in which conformable ore leads occur, and this seems to be the case in Vazante rgion.

Bez (1978) reviewed the lead isotope data of galenas from different parts of Brazil based on the data available at that time. It was observed that galenas from Vazante and Morro Agudo have lead isotope compositions that evolved under single stage conditions, whereas galenas from Boquira, Bahia (Cassedanne and Lasserre, 1969) a lead-zinc mine, have lead isotope composition that plot above the single stage lead growth curve. However these leads are much less radiogenic in comparison with galenas of Bambui from Minas Gerais.

Further lead isotope study of lead ore minerals is to be undertaken. It will be interesting to see if zoning of isotope distribution can be observed in other areas. Additional work may reveal reverse zoning of isotope distributions, which may yield clues for economic deposits. A study of the sulfur isotope systematics in the area is warranted for a better understanding of the transport mechanism of ore fluids and to identify reactions that cause base metal sulfides to precipitate from solution.

Conclusions

The lead isotope data of galenas from Bambui group from Minas Gerais State, Brazil are discussed. The data can be interpreted in terms of two stages of isotope development where the source for the lead in galenas has to be sought in the basement rocks of Transamazonian age and the lead was separated and concentrated in deposits during the Brazilian orogeny. However, near Vazante-Paracatu region, the lead isotope system seem to have developed under single stage condition yielding Model III ages in the range of 600–700 m.y. In the Vazante-Paracatu region a zonation in the lead-isotope ratios is observed, which may be used as a clue for future prospecting.

Acknowledgment. The author is indebted to the authorities of the Instituto de Pesquisas Energéticas e Nucleares, especially to Dr. Cláudio Rodrigues for all the facilities and encouragement.

Discussions with Prof. U. G. Cordani, as well as the comments by one of the anonymous referee on an earlier draft, helped to shape the ideas expressed here. Dr. J. R. Richards of Australian National University sent a detailed description of the analytical method and the Broken Hill galena Standard. Financial assistanc was provided by Fundação de Amparo à Pesquisa do Estado de São Paulo (FAPESP) and Conselho Nacional de Desenvolvimento Científico e Tecnológico (CNPq).

References

Alecrin, J.D.: Recursos Minerais do Estado de Minas Gerais. Governo do Estado de Minas Gerais, Belo Horizonte 1982

Almeido, F.F.M. de, Hasui, Y., Brito Neves, B.B.: The Upper Pre-cambrian of South America. Bol. Inst. Geoc. Uni. São Paulo. 7, 45–80 (1976)

Amaral, G.: Aplicação do Estudo da Composição Isotópica do Chumbo a Problemas Metalogenéticas: Resultados Preliminares para Galenas de Depósitos de Grupo Bambui. Anais do XXIL Congresso. Sociedade Brasileira de Geologia, Belo Horizonte, 131–138 (1968 a)

Amaral, G.: Geologia e Depósitos de Minério da região de Vazante, Estado de Minas Gerais. Thesis (Ph. D.) Univ. São Paulo, São Paulo (1968 b)

Amaral, G., Kawashita, K.: Determinação da Idade do Grupo Bambui pelo Método Rb-Sr. Anais do XXI Congresso. Sociedade Brasileira de Geologia, Curitiba. 214–217 (1967)

Bez, L.: Isótopos de Chumbo e sua Aplicação na Prospecção Mineral; Uma reavaliação dos dados existentes. Anais de XXXI Congresso. Sociedade Brasileira de Geologia. Balneário de Camboriu. 1417–1430 (1978)

Bjorykke, A., Thorpe, R.I.: The Source of Lead in Osen Sandstone Deposits on the Baltic Shield, Norway. Econ. Geol. 77, 430–440 (1982)

Bonhomme, M.G.: Mineralogie des fractions fins et datations Rb-Sr dans le Grupo Bambui. Revista Brasileira de Geociências, 6, 211–222 (1976)

Brito Neves, B.B., Cordani, U.G., Torquato, J.R.F.: Evolução Geocronologia do Precambriano do Estado da Bahia. In: Geologia e Recursos Minerais do Estado da Bahia, Inda, H.A.V., Duarte, F.B. (Eds.), Vol. 3, pp. 1–101. Salvador: Secretaria das Minas e Energia, Govt. of Bahia (1980)

Brown, J.S.: Mississippi Valley type lead-zinc ores, A review and sequel to the "Behre Symposium". Mineral. Deposita. 5, 103–119 (1970)

Cassedanne, J.P.: Paleogeographic et Mineralisation de la Zone Itacarambi-Vazante dans le Nord-Ouest de l'étal de Minas Gerais. Mineral. Deposita. 8, 101–114 (1973)

Cassedanne, J.P., Lasserre, M.: Etude Geologique et analyse isotopique par la méthode au plombe de quelques galénas du Brésil. Bull. B.R.G.M. Ser. 2, Sec. 4 (1), 71–87 (1969)

Cloud, P., Dardenne, M.: Proterozoic age of the Bambui Group in Brazil. Geol. Soc. Am. Bull.: 84, 1673–1676 (1973)

Cooper, J.A., Reynolds, P.H., Richards, J.R.: Double Spike Calibration of the Broken Hill Standard lead. Earth Planet. Sci. Lett. 6, 467–478 (1969)

Couto, J.P., Cordani, U.G., Kawashita, K., Iyer, S.S., Moraes, N.M.P.: Considerações sobre a Idade do Grupo Bambui com Base em Análises Isotópicas de Sr e Pb. Revista Brasileira de Geociências. 11, 5–16 (1981)

Cordani, U.G., Amaral, G., Kawashita, K.: The Precambrian Evolution of South America. Geol. Rond. Sc. 62, 309–317 (1973)

Cordani, U.G., Kawashita, K., Thomaz Filho, A.: Applicability of Rubidium-Strontium Method to Shales and related rocks. In: Contributions to the geologic time scale. American Association of Petroleum Geologists Studies in Geology 6, 93–117 (1978)

Cumming, G.L., Richards, J.R.: Ore lead isotope relations in a continuously changing earth. Earth Planet. Sci. Lett. 28, 155–171 (1975)

Dardenne, M.A.: Les Mineralisation de Plomb, Zinc, Fluor, du Protérozoique Supérieur dans le Brésil Central; Avec Une Mise au Point Sur la Chronologie du Precambrien Brésilein. These (Doctoral d'etat). Univ. Pierre & Marie Curie, Paris (1979)

Doe, B.R., Delevaux, M.H.: Source of lead in Southeast Missouri Galena ores. Econ. Geol. 67, 409–425 (1972)

Doe, B.R., Stacey, J.S.: The application of lead isotopes to the problems of ore genesis and ore prospect evaluation: A review. Econ. Geol. 69, 757–776 (1974)

Hasui, Y., Almeida, F.F.M. de: Geocronologia do Centro Oeste Brasileiro. Sociedade Brasileira de Geologia Bull. 19 (1), 5–26 (1970)

Heyl, A.V., Landis, G.P., Zartman, R.E.: Isotopic evidence for the origin of Mississippi Valley Type Mineral deposits: A review. Econ. Geol. 69, 992–1006 (1974)

Kuo, S.L., Folinsbee, R.E.: Lead isotope geology of mineral deposits spatially related to the Trintina Trench, Yukon Territory. Econ. Geol. 69, 806–813 (1974)

Marchese, H.C.: Estromatolites "gymnosolenoidos" en el lado Oriental de Minas Gerais. Revista Brasileira de Geociências 4, 257–271 (1974)

Misi, A.: O Grupo Bambui no Estado da Bahia. In: Geologia e Recursos Minerais do Estado da Bahia, Inda, H.A.V. (Eds.) 120–155, Salvador, Secretaria de Minas e Energia, Govt of Bahia (1979)

Robertson, J.F.: Geology of the lead-zinc deposits in the Municipio de Januária, State of Minas Gerais, Brazil. Geol. Surv. Bull. U.S. 1110-B (1963)

York, D.: Least Square fitting of a straight line with correlated errors. Earth Planet. Sci. Lett. 5, 320–324 (1966)

Received: October 6, 1982
Accepted: September 21, 1983

COMISSÃO NACIONAL DE ENERGIA NUCLEAR/SP - IPEN