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Lead Isotope Data for Gold-Bearing Veins and Their Host Metasedimentary Rocks of the Goldenville Formation, Eastern Nova Scotia

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Lead isotope analyses have been determined for galenas which occur in small quantities in quartz veins in the Goldenville Formation of the Meguma Terrane, and also for five whole rock samples from this formation. The ten least radiogenic galenas are homogeneous in isotopic composition, and they plot close to the average terrestrial growth curve of Stacey and Kramers and the "orogene" curve of Doe and Zartman. The mean model ages are 550 Ma (Stacey and Kramers) and 600 Ma (Doe and Zartman), which are in approximate agreement with the Cambro-Ordovician age of deposition of the sediments. The close position of the galena compositions to these average growth curves suggests that these compositions were established by mixing processes as envisaged in the Doe and Zartman "plumbotectonics" model. The isotopic analyses of the whole rocks indicate that small amounts of radiogenic lead are present in non-mineralized sections of the sedimentary sequence. Three galenas from veins in rocks metamorphosed to biotite and staurolite-andalusite grades, and from late veins (post-dating deformation, metamorphism and plutonism) are significantly more radiogenic than the majority of the samples. We interpret the isotopic characteristics of these galenas to be the result of extraction of lead from Meguma metasediments or of additions of radiogenic lead to less radiogenic lead during remobilization. Other interpretations consistent with the isotopic data are possible.

Des analyses aux isotopes de plomb ont été déterminé pour les galènes qui se trouvent en petite quantités dans les veines de quartz de la formation Goldenville du terraen Meguma, et aussi pour cinq échantillons de roches entières de cette formation. Les dix galènes les moins radiogeniques sont homogènes en composition isotopique, et elles ont une tracé proche de la courbe de croissance terreste moyenne de Stacey et Kramers, et de la courbe "orogène" de Doe et Zartman. Le âges moyens des modèles sont de 550 Ma (Stacey et Kramers) et de 600 Ma (Doe et Zartman), ce qui s'accorde approximativement avec l'âge Cambro-Ordovicien du dépot des sédiments. La position proche des compositions de la galène avec ces courbes moyennes de croissance, indique que ces compositions ont été établies par un processus de mélanges, comme le propose le modèle "Plumbotectonique" de Doe et Zartman. Les analyses isotopiques de roche entière indiquent que de petites quantités de plomb radiogénique sont présentes dans les sections non-minéralisées de la sequence sèdimentaire. Trois galènes, provenant de veines de roches métamorphosée au degrés de biotite et de staurolite-andalusite, et de veines avancées (post-datant la déformation, le métamorphisme et le plutonisme) sont d'une manière significative plus radiogéniques que la majorité des échantillons. Nous interprétons les caractéristiques isotopiques de ces galènes comme le résultat de l'extraction de plomb des méta-sédiments Meguma, ou a l'addition de plomb radiogénique au plomb moins radiogénique durant la remobilisation. D'autres interpretations en accord avec les donnés isotopiques sont possible.

INTRODUCTION

The Meguma Group is a metamorphosed sequence of alternating sandstones and shales of Cambro-Ordovician age which underlie much of southern Nova Scotia. The sequence contains gold and sulphide deposits and occurrences of stratabound, stratiform and vein types, the occurrence and relative ages of

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which are being studied in detail as part of a joint Nova Scotia Department of Mines and Energy - Geological Survey of Canada mineral resources project.

The mineral assemblages in a number of the deposits include small quantities of galena. In many other areas the lead isotopic composition of galena has been used to estimate mineralization age and to define, in a broad way, the source region (or regions) from which the lead has been derived. To date, the majority of the data on lead isotope abundances in galena have been obtained for massive sulphide deposits and vein occurrences. Many of the massive sulphides have been clearly volcanogenic. The host rocks of the sulphides in the Meguma Terrane appear to have been originally continentally-derived sediments, thus we have the opportunity of determining whether lead isotope ratios can be used to define a mineralization age and metal sources in a depositional environment very different from that for the host rocks of the massive sulphide deposits. Specifically, we have determined lead isotope abundances in the eastern Meguma Terrane for (1) galenas in gold-bearing quartz veins hosted by the Goldenville Formation, and, (2) a limited number of whole-rock samples of Goldenville metasedimentary rocks both adjacent to and distant from auriferous quartz veins.

GEOLOGICAL SETTING

The locations of gold deposits in the Meguma Terrane, and of the sample areas are given in Figure 1. The Meguma Terrane (Schenk, 1978) comprises a thick metasedimentary sequence (Meguma Group consisting of the Goldenville Formation overlain by the Halifax Formation). The Goldenville Formation is a thick flyschoid sequence of wackes with thin silt and slate interbeds. The Halifax is a thick slate succession with minor sand and silt units. The Meguma Group is considered to be turbiditic in origin but details of deposition are controversial (Phinney, 1961; Schenk, 1970, 1971; Harris and Schenk, 1975; Smith, 1981; Stow, 1982; Waldron, 1983). The gold deposits are located mainly in the upper part of the Goldenville Formation (Faribault, in Malcolm, 1929).

In the Eastern Meguma domain, (Figure 2) low pressure-high temperature pyreneean metamorphism (Keppie and Muecke, 1979) ranges from chlorite grade in the southwest (Wine Harbour) through biotite (Isaacs Harbour, Goldenville) and garnet to staurolite-cordierite-andalusite isograds (Forest Hill). The chlorite grade metamorphism is associated with the deformations accompanying Acadian folding (O'Brien, 1983). However, at higher grades the characteristic mineral isograds are associated with a later period of static metamorphism (Smith, 1981). This metamorphism may be related to the same tectono-thermal event that resulted in post-folding intrusion of Devonian granitoid plutons. In the north (amphibolite facies), these plutons and the Meguma Group metasedimentary rocks were subsequently strongly deformed by east-west zones of ductile shear (Keppie, 1983; Haynes, 1984).

The last major tectonic event was brittle deformation related to left-lateral movement on the Country Harbour fault. At Widow Point (Figure 1) this is associated with stockwork chlorite-carbonate veining and retrograde alteration of amphibolite facies assemblages (Haynes, 1984).

QUARTZ VEINS

In the area of greenschist facies metamorphism, eleven different quartz-vein polytypes are present (Haynes, 1983). The earliest vein polytypes predate the cleavages associated with Acadian folding, and include the most auriferous polytypes (stratiform, stratabound and side). Other vein polytypes were emplaced syn- or post-folding and are essentially devoid of gold.

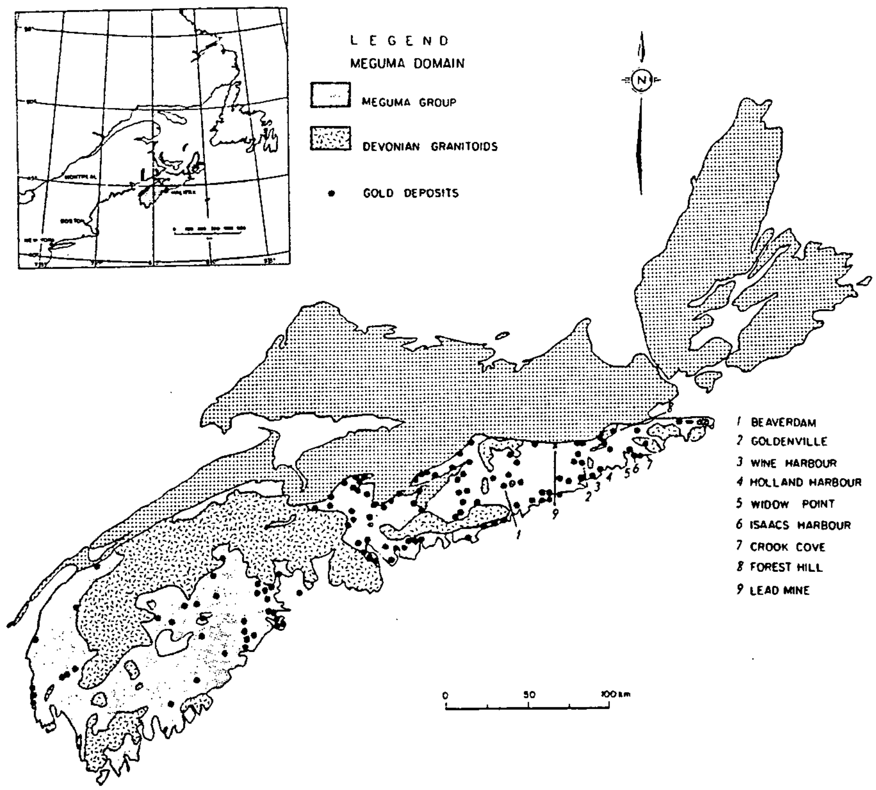

Figure 1. Gold deposits in the Meguma domain, and sample locations from which galena and rock specimens were obtained.

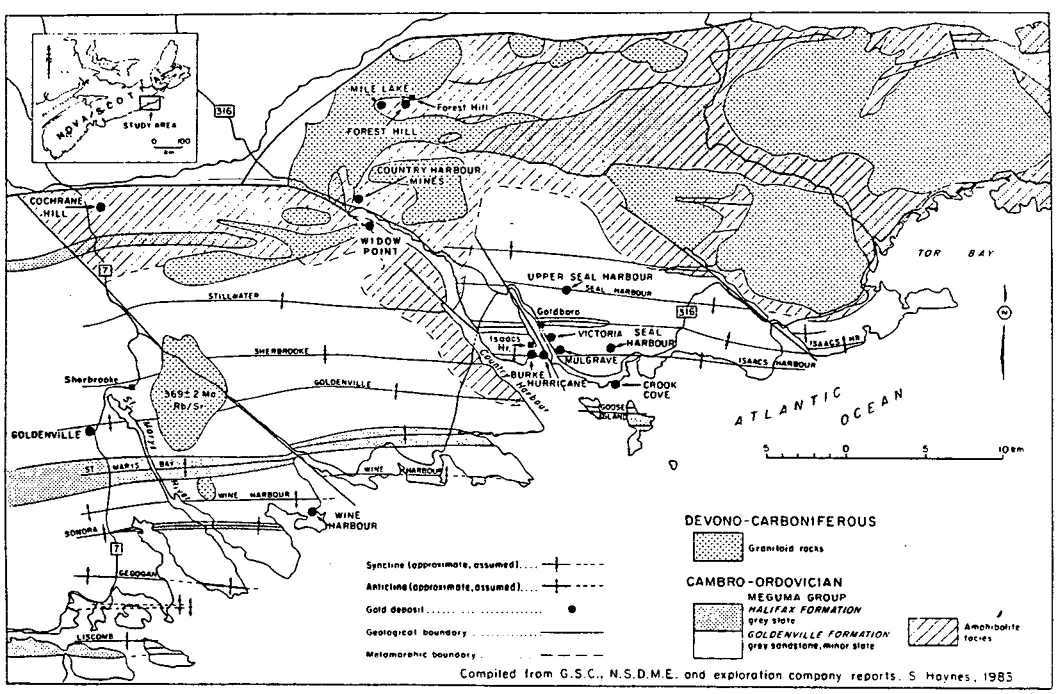

Figure 2. Gold deposits and sample locations in the Eastern Meguma region showing locations in more detail.

In the northern part of the eastern Meguma Terrane (amphibolite facies) a further period of quartz veining and gold mineralization is associated with intrusion of the granitoid plutons (Smith, 1983; Haynes, 1984). In this region the quartz veins are strongly deformed (bedding-parallel transposition) by the post-granitoid ductile shear, although remnants of the original relationships of quartz veins to Acadian fold structures are preserved at Forest Hill in thick wacke units which acted as semi-rigid blocks during ductile shear deformation (Haynes, 1984).

The final period of quartz vein formation is evident as several sets of post-folding/metamorphism veins in the greenschist facies (late and ac veins of Haynes, 1983), veins that postdate ductile shear in the amphibolite facies (ac veins of Smith, 1983), quartz stringers associated with the chlorite-carbonate veins and alteration adjacent to the Country Harbour fault (Haynes, 1984), and a cross-cutting lead vein on the East St. Mary's River (Lead Mine, Figure 1). Although there is no direct evidence, all these late veins may be equivalent in age, possibly related to the tectonic event that resulted in the extensive northwest-southeast strike-slip faulting (Hercynian ?) prevalent throughout the Meguma Terrane.

Descriptions of the veins sampled and their locations are given in Table 1. Galena was only observed in stratiform, stratabound and side veins. Stratiform veins are bedding-parallel quartz-carbonate veins displaying fine laminar textures and, often, columnar cstructures. Typically, they contain silicate mineralogies identical to the regional metamorphism isograd (e.g. chlorite at Wine Harbour; andalusite at Forest Hill). Stratabound veins are restricted to specific horizons, but may locally crosscut bedding. Typically, they are massive and their wallrocks and inclusions exhibit marked arsenopyritization, sericitization and silicification. Side veins are veins tapering away from T-junctions with stratiform or stratabound polytypes. Normally, they are present on the stratigraphically lower wall of stratiform veins and on both walls of stratabound veins. They display mineralogies and wall rock alteration effects which are similar to their "parent" vein.

GOLDENVILLE METASEDIMENTS

Samples F4WH23 and 25 (Table 1) represent arsenopyrite-sericite-silica flooding alteration of Goldenville Formation wallrocks about an auriferous stratabound vein at Wine Harbour. Samples F4HR3DH5, 7 and 14 (Table 1) are different types of Goldenville Formation metasedimentary rocks collected at Holland Harbour, distant from known gold mineralization.

These samples were analyzed to compare lead isotope values resulting from the addition of radiogenic lead from in situ decay of uranium and thorium in unmineralization Goldenville sedimentary rocks, with those for vein galenas and possible "overprint" effects in the alteration zones of stratabound veins.

ISOTOPIC ANALYSES

In most of the specimens visible galena occurred as discrete blebs, which were hand picked to provide sufficient material for analysis. Galenas were dissolved in ultra-pure HCl and HNO_3, and the lead separated from other metals in ion exchange columns. Approximately 800 nanograms of lead were deposited with phosphoric acid on a silica gel substrate mounted on a single rhenium filament. The mass spectrometer used for the isotopic measurements was an instrument using 90° deflection, and a radius of curvature of 30 cm. Each analysis consisted of 50-70 scans over the Pb mass spectrum, and all data have been adjusted by applying a mass fractionation correction of 0.098% per

TABLE 1

DESCRIPTION AND LOCATION OF ANALYZED SAMPLES

Sample #	Deposit	Description and Sample Type
Chlorite Grade metamorphic zone		
F4BI8	Wine Harbour	Au Stratiform vein in slate, galena
F4WH26	"	Au stratabound vein in altered
F4WH23	"	Hanging wall alteration zones to
F4WH25	"	Footwall alteration zone to F4WH26, rock lead
F4HR3DH5	Holland Harbour	Laminated meta-siltstone with pyrite, rock lead
F4HR3DH7	"	Fe/Mn concretions, in meta-wacke, rock lead
F4HR3DH14	"	Coarse meta-wacke, rock lead
Biotite Grade metamorphic zone		
HGV1	Goldenville	Au stratiform, galena
F4BH10	Isaacs Harbour (Bakers House)	Au stratiform, galena
F4BL21	Isaacs Harbour (Burke Lead)	Side vein to Au stratiform vein, galena
F4GF5	" (Goldfinch, dump sample)	Stratabound?, galena
F4GF14	" " "	Qtz-carbonate vein (stratiform?), galena
Staurolite-Andalusite Grade metamorphic zone		
FHL3N8/8	Forest Hill (School House Lead)	Au stratiform in metawacke, galena
FH9N15	" (Kennedy Lead)	Au stratiform in slate, galena
(Granite Contact Aureole)		
HBVD23	Beaverdam	Au Stratiform, galena
Chlorite Retrograding of Staurolite-Andalusite metamorphic zone		
WP2	Widow Point	Au stratiform, galena
Post-Folding/Metamorphism		
F4SB2	Isaacs Harbour (Ragged Point)	late quartz vein, galena
HLM1	Lead Mine	Pb-quartz, galena

mass unit, determined by replicate analyses of standard lead SRM-981. Details of the procedure are given by Fletcher (1979).

The isotopic ratios for the galenas and sulphides are listed in Table 2. Several of the samples (F4GF5, HBDV23 and HLMI) are significantly different in isotopic composition from the remainder. Because the Meguma Group has been deformed and metamorphosed, it seemed possible that these differences in isotopic composition could have been produced by the addition of radiogenic lead to primary galena. To estimate the amounts of radiogenic lead in the sedimentary rocks, five whole rock samples were analysed for lead (by isotope dilution), and their isotopic ratios determined. Lead was extracted by dissolving, in HF and HNO_3, approximately 300 mg splits of slices cut from drill cores. Although the

TABLE 2

LEAD ISOTOPE RATIOS FOR ANALYZED SAMPLES

	Sample	Pb(p.p.m)	$^{206}Pb/^{204}Pb$	$^{207}Pb/^{204}Pb$	$^{208}Pb/^{204}Pb$
Chlorite Metamorphic Zone	F4B18	galena	$17.74_5 \pm .02_5$	$15.56_3 \pm .02_4$	$37.81 \pm .08$
	F4Wh26	"	$17.77_5 \pm .02_5$	$15.56_2 \pm .02_4$	$37.83 \pm .08$
	F4WH23	17.0	$18.11 \pm .07$	$15.61 \pm .06$	$38.21 \pm .14$
	F4WH25	9.5	$18.56 \pm .17$	$15.64 \pm .13$	$18.6 \pm .4$
	F4HR3DH5	7.3	$18.94 \pm .03$	$15.64 \pm .02$	$39.60 \pm .08$
	F4HR3DH7	38.7	$17.91 \pm .02$	$15.56 \pm .02$	$38.02 \pm .07$
	F4HR3DH14	ND	$19.01 \pm .07$	$15.65 \pm .05$	$39.22 \pm .16$
Biotite Metamorphic Zone	HGV1	galena	$17.78_9 \pm .02_0$	$15.56_8 \pm .02_1$	$37.82 \pm .08$
	F4BH10	"	$17.77_0 \pm .01_7$	$15.54_8 \pm .01_6$	$37.80 \pm .05$
	F4BL21	"	$17.77_0 \pm .01_8$	$15.55_0 \pm .01_9$	$37.82 \pm .07$
	F4GF5	"	$17.92_8 \pm .02_3$	$15.56_2 \pm .02_2$	$37.97 \pm .07$
	F4GF14	"	$17.78_4 \pm .02_2$	$15.56_4 \pm .02_3$	$37.86 \pm .07$
Staurolite-andalusite Metamorphic Zone	FHL3N8/8	galena	$17.81_7 \pm .01_8$	$15.56_7 \pm .02_0$	$37.88 \pm .07$
	FH9N15	"	$17.78_2 \pm .01_8$	$15.56_7 \pm .01_9$	$37.87 \pm .07$
	HBVD23	"	$18.23_9 \pm .02_0$	$15.60_3 \pm .02_0$	$38.06 \pm .07$
Chlorite retrograde Staurolite-andalusite Metamorphic Zone	WP2	"	$17.77_6 \pm .03_5$	$15.55_1 \pm .02_3$	$37.78 \pm .08$
Post folding veins	F4SB2	"	$17.83_9 \pm .01_9$	$15.56_8 \pm .02_0$	$37.94 \pm .07$
	HLM1	"	$18.22_2 \pm .02_0$	$15.60_6 \pm .02_1$	$38.35 \pm .07$

precision of the isotopic data is not as high for the whole rocks as for the galenas, the results indicate that significant amounts of radiogenic lead have been generated in the sedimentary rocks. The lead concentrations and isotopic ratios are included in Table 2.

LEAD ISOTOPIC DATA

The isotopic data for the Meguma galenas and sulphides are plotted on Figures 3a and 3b as ratios of $^{207}Pb/^{204}Pb$ and $^{208}Pb/^{204}Pb$ against $^{206}Pb/^{204}Pb$. On both figures most of the points lie in compact groups, but several analyses have substantially higher $^{206}Pb/^{204}Pb$, and $^{207}Pb/^{204}Pb$ ratios. Shown for reference on Figures 3a and 3b are growth curves from Doe and Zartman (1979). These curves define the average lead isotopic evolution of three reservoirs, the upper crust, the mantle and the orogene. In Doe and Zartman's "plumbotectonics" model, the orogene is composed of materials input from the mantle, upper crust and lower crust, and is considered to represent

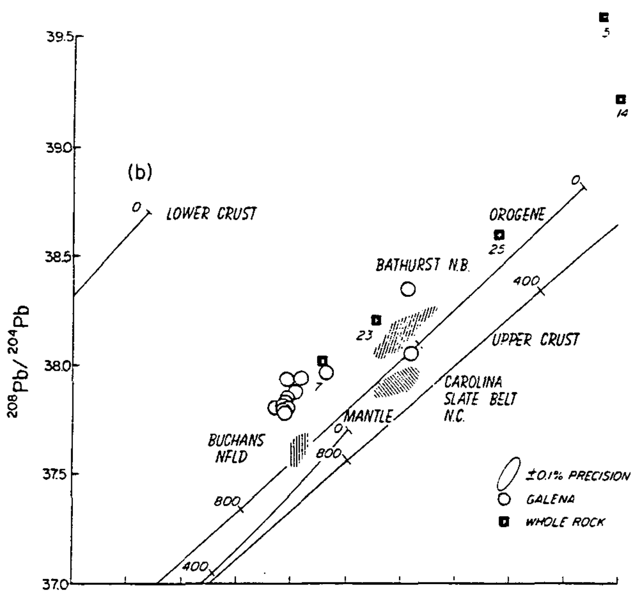

Figure 3a. $^{207}Pb/^{204}Pb$ - $^{206}Pb/^{204}Pb$ plot for Meguma galena and whole rocks. The ±0.1% error ellipse denotes the typical uncertainty in accuracy (2σ) of the isotopic ratios. The uncertainties for samples 23 and 25 are substantially larger (see Table 2). Growth curves are plotted from the data of Doe and Zartman (1979). Isotopic data fields for Bathurst, Buchans and the Carolina Slate Belt are included for comparison. See text for data sources.

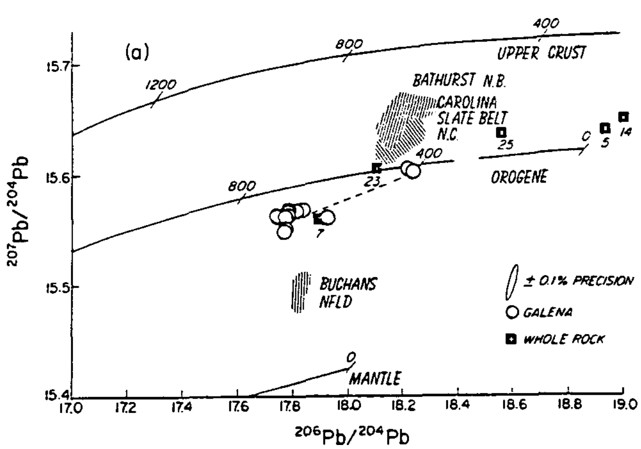

Figure 3b. $^{208}Pb/^{204}Pb$ - $^{206}Pb/^{204}Pb$ plot for Meguma galenas and whole rocks. The ±0.1% error ellipse denotes the typical uncertainty in accuracy (2σ) of the isotopic ratios. The uncertainties for samples 23 and 25 are substabtially larger (see Table 2). Growth curves are plotted from the data of Doe and Zartman (1979). Isotopic data fields for Bathurst, Buchans and the Carolina Slate Belt are included for comparison. See text for data sources.

the reservoir from which many ore deposits have been derived. To put the Meguma isotopic data in the context of similar data from relatively nearby deposits, Figures 3a and 3b also include the fields (but not individual analyses) defined for the volcanic and volcano-sedimentary-hosted sulphides at Buchans Mine, Newfoundland (Doe and Rohrbough, 1977; Farquhar and Fletcher, 1980), at Bathurst, New Brunswick (Ostic et al., 1967; Farquhar, unpublished data, Swinden and Thorpe, in press), and in the Carolina Slate Belt (Kisn and Feiss, 1982).

The rock lead isotopic data are shown on 207-206-204 and 208-206-204 plots in Figures 3a and 3b. Although the radiogenic enrichments of the lead in these rocks are not large, a linear fit to the 207-206-204 data can be made and the slope of the line determined. The value of the slope (0.078 ± .017 (1σ) York, 1969) is based on the data for the samples F4HR3DH5, 7, and 14. Although this value is not well defined, it can serve to place limits on the age of some of the detrital minerals in the original sediments.

DISCUSSION

Sediments of the Meguma Terrane were deposited in late Cambrian - early Ordovician times and consist of sequences of turbidites, slates, siltstones and sandstones. Following deposition these sequences were multiply deformed, metamorphosed and intruded by granitic plutons. Poole (1971) reports K-Ar ages of 475 - 500 Ma on two "detrital" muscovites from the Goldenville Formation (which hosts the galenas analysed in this study). An age of 400 - 415 Ma for the metamorphism associated with the Acadian orogeny was determined by Reynolds and Muecke (1978), through K-Ar stepwise outgassing measurements on slates. Intrusion of the granitic plutons followed at 369 ± 2 Ma, as defined by Rb-Sr whole rock isochron measurements (Keppie, 1983).

The rock samples for which we have isotopic data (Table 2) are from the chlorite grade metamorphic zone. If alteration of detrital minerals has taken place, the degree of this alteration will be minimal at this level of metamorphism. If we interpret the isotopic variations among these rock samples to result from radiogenic lead generated in small amounts of detrital minerals, then the slope of the 207-206-204 rock lead plot (Figure 3a) gives the primary age of these minerals. The value we compute for this age is approximately 1.2 ± 0.5 (1 σ) Ga. The very large uncertainty in this figure is mainly a result of the relatively small proportion (less than approximately 4%) of radiogenic lead in the rocks.

Detailed studies have been made of the formation of the gold-bearing veins in relation to the structural deformations and metamorphic alterations which have modified the rocks of the Goldenville Formation (Haynes, 1983). These indicate that the earliest, Au-bearing stratiform and stratabound veins predated or accompanied the earliest deformation events. The isotopic compositions of the galenas associated with these veins are uniform and define a cluster of least radiogenic values. Using the time-scales on the orogene growth curves in Figures 3a and 3b, the mean "model" age for this cluster is 600 ± 50 Ma. This value is, of course, model-dependent. The Stacey and Kramers (1974) average growth curve, which is based on a much less complex evolutionary development scheme than that proposed by Doe and Zartman, gives a mean "model" age of 550 ±50 Ma for the least radiogenic Meguma galenas. Considering that both models are based on world-wide data and only represent the average evolution of lead isotope ratios, the mean "model" age computed using either approach seems remarkably close to the known age of deposition of the sedimentary rocks which enclose the mineral deposits. For two of the three other lead isotope fields outlined on Figure 3a, the time scale of the plumbotectonics model appears to give ages for the mineral deposits which are not grossly different from the ages of the host rocks. Buchans, Newfoundland, associated with well-dated Silurian volcanic rocks (Bell and Blenkinsop, 1981) has a "model" age of 400 ± 50 Ma. The age for Bathurst, New Brunswick (middle Ordovician) is 550 ± 50 Ma. The model age for the least radiogenic Carolina Slate Belt ores is about 480 Ma, less than the accepted middle Cambrian age of the enclosing sedimentary rocks. Kish and Feiss (1982) presented an alternative model to explain this discrepancy.

By comparison with the other data sets on Figures 3a and 3b, the majority of the Meguma galenas have slightly lower $^{206}Pb/^{204}Pb$ and $^{207}Pb/^{204}Pb$ ratios, and higher $^{208}Pb/^{204}Pb$ values. No lead isotopic data are available for similar sediment-hosted mineral deposits with which to compare these characteristics, and hence it is not possible to determine whether the differences are significant clues to the type of source rocks from which the lead has been derived.

Most of the galenas in the rocks of the Goldenville Formation have a single isotopic signature. However, three samples have significantly more radiogenic isotopic ratios, and all of these are located in metamorphic zones at biotite or higher grade or in late veins. There are three different models for interpreting these more radiogenic galenas. They could result from the mixing of lead of the less radiogenic type with lead from another source, at the time of intrusion of the late quartz veins. Two component mixtures will give rise to linear distributions on isotopic plots such as Figures 3a and 3b. Although the isotopic ratios are linearly distributed (within the limits of accuracy) on Figure 3a, the $^{208}Pb/^{204}Pb$ ratios do not lie on a straight line. A mixing process seems to be an unlikely hypothesis. A second possibility is that all of the leads (radiogenic and non-radiogenic) were deposited essentially simultaneously after being extracted from underlying rock units within the sedimentary pile. The $^{207}Pb/^{204}Pb$ - $^{206}Pb/^{204}Pb$ ratios for the whole rocks (Figure 3a) are linearly related and extend over approximately the same range of values as the radiogenic galenas. The data distribution for these galenas has a ^{207}Pb - ^{206}Pb slope of .14 $\pm$ .09 (1σ) (York, 1969), a value which could result from uranium decay between approximately 1.9 Ga and .5 Ga. If we consider only the isotopic data and the very large uncertainties in the age estimates it is conceivable that the radiogenic galenas could have been extracted approximately 500 Ma age from nearby Meguma sediments. The $^{208}Pb/^{204}Pb$ - $^{206}Pb/^{204}Pb$ ratios in the whole rocks are variable to roughly the same degree as observed in the radiogenic galenas. However, our whole rock isotopic data also suggests that the Meguma units have remained at least partially closed to uranium, thorium and lead losses under low grade metamorphic conditions. This suggests that a thermal energy source would be necessary to extract substantial amounts of lead from the sediments and there is no evidence that a source of this kind existed within or adjacent to the Meguma sedimentary rocks at the time the earliest stratiform and stratabound deposits were emplaced. This problem leads us to consider a variant of this hypothesis, that the more radiogenic galenas were generated later than those of less radiogenic composition. The whole rock data shown in Figures 3a and 3b suggest that lead of isotopic compositions similar to those in the more radiogenic galenas was available in Meguma sandstones. The isotopic data for these rocks are not sufficiently precise to define accurately the time at which the extraction of the lead could have taken place. We favour this "later-extraction" hypothesis because the more radiogenic galenas occur in the biotite and higher grade metamorphic rocks and post-folding veins. The metamorphism is an indication that energy sources must have existed in the areas or at the times when the more radiogenic galenas were being deposited. The lead in these galenas could be the product of complete extraction from the sedimentary rocks, or a mixture of radiogenic lead selectively removed from these rocks and mixed with lead dissolved from pre-existing galenas of less radiogenic composition.

CONCLUSIONS

Field studies of the mineralization in the quartz veins in the Goldenville Formation (Haynes, 1983) indicate that the stratiform, stratabound and side veins predate the main period of Acadian deformation. The lead in galenas which occur in the least metamorphosed of these vein types, have a Pb isotopic homogeneity which suggests that the metal source or sources were well-mixed prior to deposition in their primary sites. The position of the isotopic ratios of these galenas close to the orogene growth curve, implies that a significant fraction of the lead has been derived from crustal sources, and lends weight to the usefulness of the orogene concept as a basis for interpreting ore deposition in sedimentary environments. The time scale associated with the orogene growth curve appears to give the approximate age of sedimentation and primary ore deposition if the least radiogenic lead isotopic ratios are used.

We interpret the lead isotope data to suggest that in the Goldenville Formation more recent geological events have given rise to some alteration of lead isotope ratios. The more radiogenic galenas occur in metamorphic zones at biotite, and staurolite-andalusite grades, and in late veins, and the isotopic data for these galenas and for whole rocks are consistent with either local derivation and redeposition or extraction and mixing of radiogenic lead with primary galena. In theory it is possible to put limits on the time at which the extraction process took place. However, the amounts of radiogenic lead incorporated are small and the data is rather imprecise with the result that the time resolution of the method is too low to be useful. Remobilization during metamorphism could have resulted in the alteration of some but not necessarily all of the galenas, so there is not a one-to-one correspondence between isotopic alteration and those veins which are recognizably later than the primary polytypes.

It should be recognized that the isotopic data set is still rather small, and that several alternative interpretations of the isotopic results are possible. This is particularly true for the more radiogenic galenas, which might be contemporaneous with the less radiogenic sulphides or be derived later from the Meguma sedimentary rocks through complete extraction or mixing with earlier deposited galenas. Futher isotopic work would be necessary to determine which of these alternatives is correct.

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