Lead Isotope Data From Epigenetic Sulphide Occurrences in the Purcell Supergroup, Southeastern British Columbia, and Implications for Exploration for Sediment-hosted Base Metal Deposits

By L.J. Marshall, J.K. Mortensen and J.E. Gabites
The University of British Columbia

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INTRODUCTION

This paper investigates Pb isotope and other data from epigenetic base-metal vein occurrences in the Shrink Lake study area, within the Mesoproterozoic Purcell Supergroup in southeastern B.C. The Purcell Supergroup is host to the world renowned Sullivan Pb-Zn deposit, as well as the St. Eugene and other epigenetic vein deposits thought to be of Proterozoic age. The study aims to determine whether Pb isotope data from a number of uneconomic base metal vein occurrences in the area result from remobilization of Pb from large tonnage, sediment hosted Proterozoic base metal deposits that have not yet been discovered.

Field work for this project formed the basis of the principal author's Bachelor's thesis at the University of British Columbia (Marshall, 1999). All field work was supported by Kennecott Canada Exploration Inc..

REGIONAL GEOLOGY

The main supracrustal rocks in the study area consist of Aldridge and Creston formation argillites, siltstones and sandstones that form part of the Mesoproterozoic Purcell Supergroup. The Purcell Supergroup comprises a sequence over 12km thick of siliciclastic and lesser carbonate rocks (Hoy, 1993) that is exposed in a large region in southeastern British Columbia and southwestern Alberta.. The Supergroup is inferred to unconformably overlie Proterozoic and Archean gneissic basement rocks, and is unconformably overlain by Late Proterozoic Windermere Group rocks and Cambrian clastic and carbonate rocks (Hoy, 1993).

The dominantly gabbro and diorite Moyie Sills intrude the lower Aldridge and the lower part of the middle Aldridge formations. The cumulative thickness of the Moyie sills exceeds 2000 meters. Hoy (1993) cites soft sediment deformation, large scale dewatering structures and coarse grained hornblende hornfels as evidence for intrusion of at least some of the sills into wet, unconsolidated sediments. Anderson and Davis (1995) report U-Pb zircon ages of 1468 ±2 Ma for Moyie sills. Gabbro and diorite sills are also present higher in the Purcell stratigraphy, and are believed to be the result of a later magmatic event than that responsible for the Moyie sills (Hoy, 1993).

The White Creek batholith (Reesor, 1958) is one of several middle Cretaceous intrusions that cut the Purcell Supergroup. The most extensive phase of the batholith is a K-feldspar porphyritic biotite quartz monzonite, and Brandon and Lambert (1992) report Rb-Sr whole rock-apatite isochron ages of ~105-115 Ma for the body. The batholith crops out within several kilometers southeast of the study area.

Small biotite lamprophyre dikes (minettes) locally intrude lower Purcell sediments (e.g., McClay, 1983; LeCouteur, 1979; Hoy, 1993). An Early Cretaceous age (~130 Ma) has been assigned to lamprophyres that cut the Sullivan orebody (LeCouteur, op.cit.).

Tectonism

The earliest evidence for tectonism in the Purcell Supergroup is recorded by syndepositional normal block faulting associated with rifting of the Belt/Purcell basin (Hoy, 1993). Evidence for renewed block faulting during deposition of the Sheppard Formation, higher in Purcell stratigraphy, is cited by Hoy (1993).

A Mesoproterozoic tectonic event termed the East Kootenay orogeny has been interpreted by several authors (White, 1959; Leech, 1962; Hoy, 1993) as a compressive event, marked by folding and associated cleavage development. Anderson and Davis (1995), however, suggest that the deformational features observed could have been generated during an extensional event, if deformation had a strike-slip component to generate localized folding. The younger Goat River extensional tectonic event was marked by renewed block faulting, and is thought to mark the initiation of Windermere Group deposition (Hoy, 1993). The Goat River event is placed at approximately 762 Ma (Devlin *et al.*, 1988).

Following these events, the Purcell Supergroup was subject to intermittent periods of extensional tectonism through the Late Proterozoic and Early Paleozoic (Hoy, 1993).

From Late Jurassic to Paleocene time, accretion of tectonostratigraphic terranes to the west produced large scale thrust faulting which led to compression, thickening and eastward displacement of miogeoclinal sedimentary packages along the western margin of North America. The geology of the region is further complicated by syn- to post-thrusting back thrusts and normal faults (Hoy, 1993).

Economic Deposits

The Sullivan deposit (Figure 1) is hosted in the lower Aldridge Formation, at the contact with the middle Aldridge (LMC) (Hoy, 1993; Leitch *et al.*, in prep.). It is a stratiform, sedimentary exhalative (SEDEX) Pb-Zn deposit which contained original reserves of approximately 160 million tonnes of ore, grading 6% lead, 6% zinc, 28% iron and 67 grams per tonne silver (Ransom *et al.*, 1985). Over 125 million tonnes of ore have been extracted from the deposit.

The St. Eugene deposit (Figure 1) consists of epigenetic Ag-Pb-Zn veins that cut middle Aldridge, upper Aldridge and Creston Formation metasediments. Production between 1899 and 1929 produced some 1,475,266 tonnes of ore, with average grades of 7.7% Pb, 1.0% Zn and 124g/tonne Ag and 0.05g/tonne Au (Hoy, 1993). Galena grains found within garnet porphyroblasts in the deposit are interpreted by Beaudoin (1997) to constrain the age of mineralization to prior to East Kootenay metamorphism. The St. Eugene is classified with similar epigenetic deposits of the Coeur d'Alene District, Idaho (Beaudoin, 1997).

LOCAL GEOLOGY

Sedimentary rocks of the middle Aldridge, upper Aldridge and Creston formations crop out in the study area. Contacts between these formations are all conformable, and dip at shallow to moderate angles to the northwest.

The middle Aldridge Formation consists of medium to thickly bedded , siltstones and sandstones, with intermittent thinly bedded argillite layers. Upper Aldridge

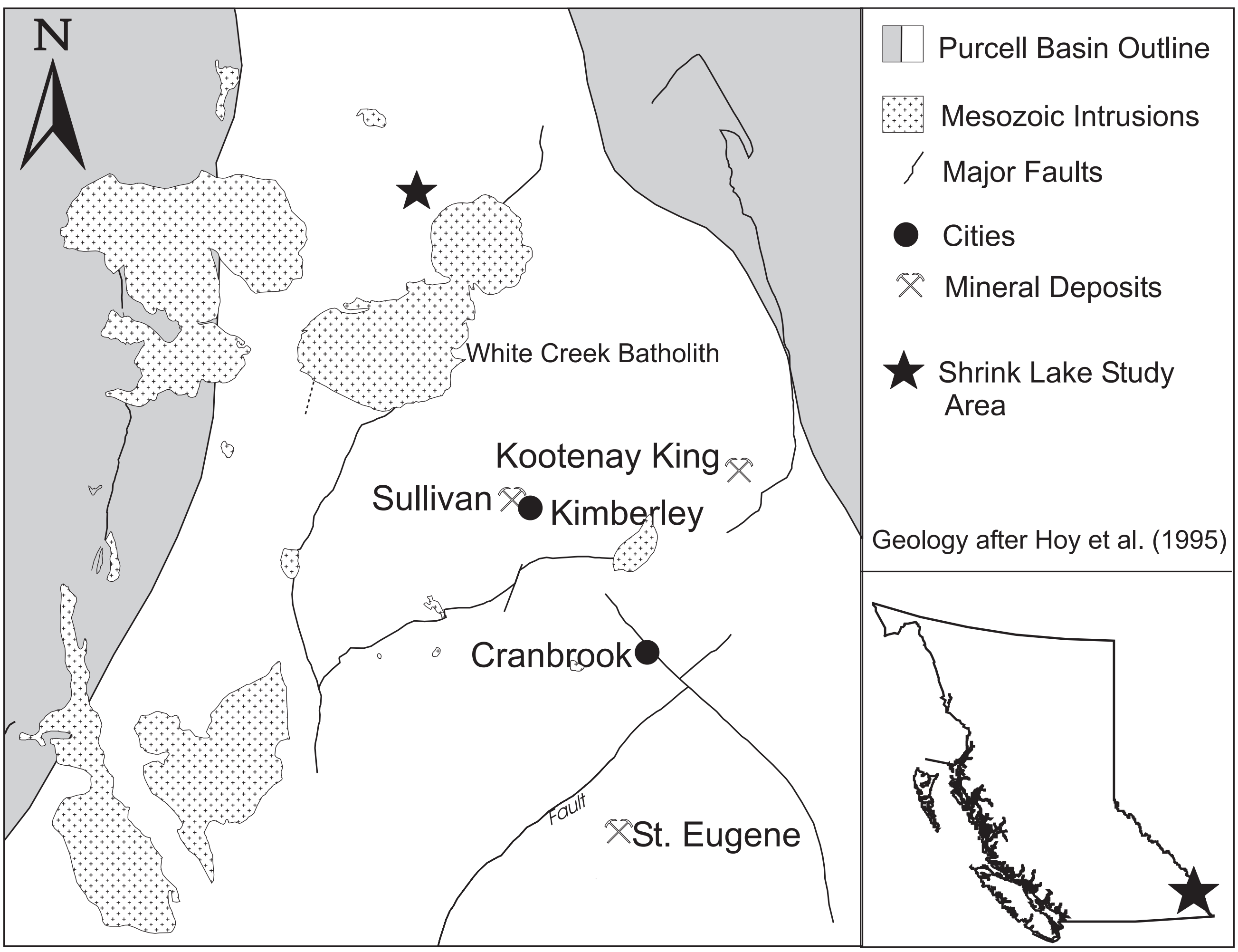

Figure 1. Regional geology, mineral deposits and location of the Shrink Lake study area.

stratigraphy consists dominantly of thinly bedded siltstones and argillites. Strong tourmaline alteration is found locally within the Shrink Lake study area, and is pervasive in the upper Aldridge in the vicinity of the Doc mineral showing, northeast of the study area. The Creston Formation is characterized by green, mauve and grey siltstones and argillites.

Gabbro to diorite sills are present throughout the study area. Within the upper middle Aldridge, upper Aldridge and Creston formations, the intrusions are generally less than 10 meters in thickness, and relatively rare. In the lower middle Aldridge Formation, intrusions are commonly in excess of 100m in thickness, and are relatively abundant.

Small discontinuous lamprophyre dikes were noted at two locations in the study area. One dike was observed to crosscut a gabbroic sill. The mineralogy of these *dike*s is characterized by abundant biotite, lesser quartz and plagioclase and minor calcite.

Numerous small fault zones were noted in the study area. Most faults are moderately to steeply dipping to the west-northwest.

Mineralization

Numerous discontinuous, sulphide-bearing quartz veins are present in the study area. These veins commonly occur along joint sets associated with faults. Veins exhibit a wide variety of textures, degrees of deformation and mineralogy, suggesting multiple veining events. Locations of vein samples for this study are shown in Figure 2. Detailed descriptions of the veins are given by Marshall (1999).

Two mineral occurrences, the Alpine showing (MINFILE 82KSE081) and the Doc showing (MINFILE 82KSE060) are located several kilometres northeast of the study area, within Creston Formation and upper Aldridge Formation stratigraphy, respectively (Figure 2).

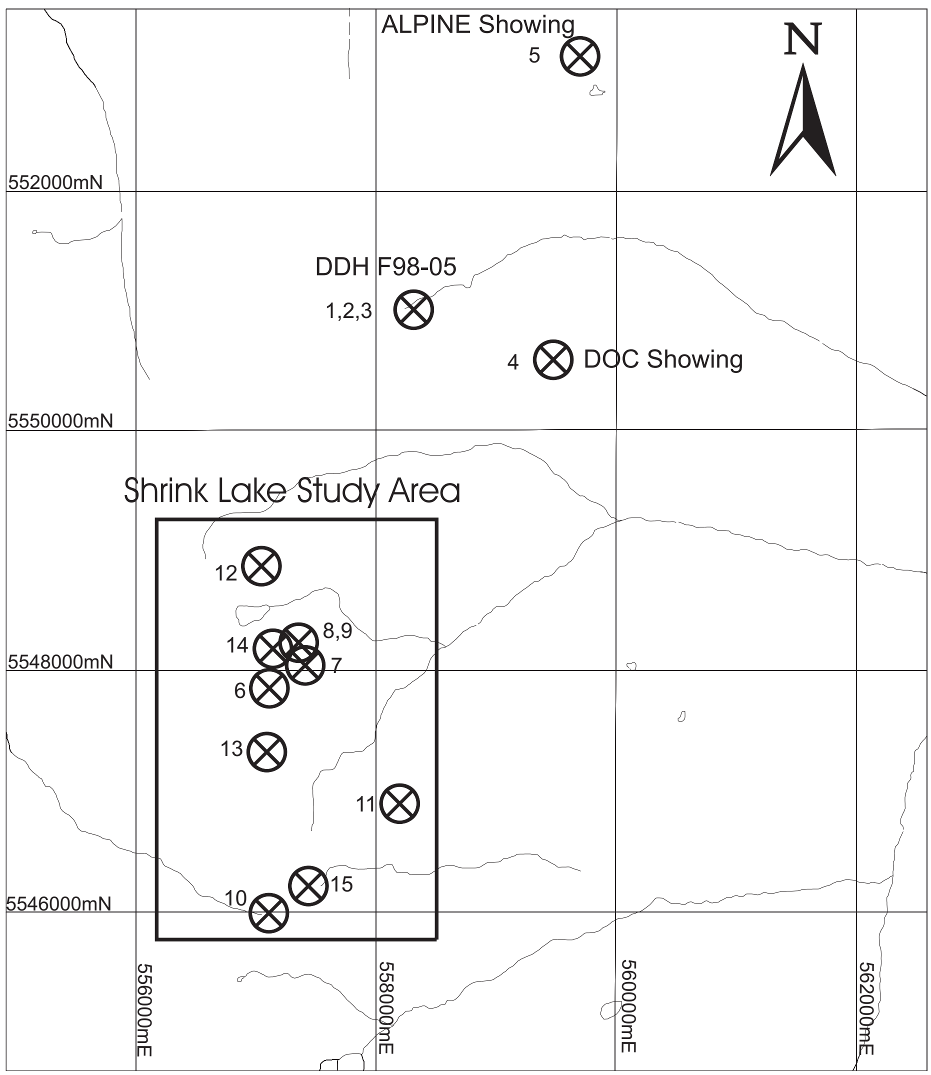

Figure 2. Sample location map.

Stratabound galena mineralization was intersected in 1998 by Kennecott Canada Exploration in DDH F98-05 northeast of the study area (Figure 2). Two samples were obtained from drill core for this study.

The Alpine showing, also referred to as the Rocky Top or Four Tops showing, has been investigated by several companies, including Cominco Ltd. (Mawer, 1986). Disseminated sulphides and high grade bands of pyrite, sphalerite and galena occur within a silicified, albitized and sericitized, shear-controlled alteration zone at the showing. Uneconomic grades of 0.5% Pb and 0.6% Zn across an average width of 3.5m and length of 80m have been previously determined, based on the results of geochemical sampling, geological mapping, bulldozer trenching and diamond drilling (Mawer, op. cit.).

The Doc showing on Tourmalinite Ridge (Figure 2) was first recognized by Kerr Adison Mines in the late 1970's. The showing consists of quartz-galena veins with minor sphalerite, arsenopyrite and chalcopyrite. Veins are exposed in blocky felsenmeer, and are traceable for up to 100m along strike (Brown and Termuende, 1998).

Lead Isotopic Study

A detailed Pb isotopic investigation of mineral occurrences in the study area was undertaken in order to assess the possible sources for Pb, place constraints on the possible timing of mineralization and in particular, determine whether any of the occurrences could represent remobilized, syngenetic mineralization of Sullivan (Mesoproterozoic) age.

Several potential reservoirs from which metals may have been extracted are present in or near the study area, including:

- Lead extracted at different times from Proterozoic metasedimentary rocks of the Purcell Supergroup
- Lead remobilized from Sullivan-type SEDEX deposits contained within the Purcell Supergroup
- Lead remobilized from Proterozoic epigenetic occurrences such as the St. Eugene deposit
- Magmatic Pb from Moyie-type intrusions, Mesozoic granitoids or young lamprophyres.
- Lead introduced from lower crustal and/or mantle reservoirs

Lead remobilized from Pb-rich deposits such as the Sullivan or St. Eugene would be expected to retain the original isotopic composition of those deposits. The isotopic signature of the Sullivan deposit can be approximated by data compiled by Beaudoin (1997) (Figure 3). Beaudoin interprets the distribution of the Sullivan data as a mixing of leads derived from the Lower Aldridge Formation and Precambrian basement gneiss. The St. Eugene Ag-Pb-Zn vein deposit has been classified with deposits of the Coeur d'Alene District, Idaho. Despite being epigenetic, most of these deposits are characterised by Pb isotopic ratios that are less radiogenic than those of the syngenetic Sullivan deposit (Figure 3). Beaudoin (1997) addresses this paradox by attributing the Coeur d'Alene data array to a mixing of upper crustal and mantle Pb. He suggests that mantle Pb was introduced into the Purcell basin environment during intrusion of the Moyie sills.

The expected isotopic composition of Pb extracted from Purcell Supergroup metasedimentary rocks at any particular time can be estimated with some confidence using the "shale curve" (Godwin and Sinclair, 1982), which models the evolution of Pb isotopic compositions in sedimentary strata of the western Canadian miogeocline (Figure 3). The composition of lead derived from Moyie intrusions has been inferred by Andrew *et al.* (1984) from data for epigenetic mineralization thought to be genetically associated with these intrusions (Figure 3). Magmatic Pb from Mesozoic granitoids is expected to have the same isotopic composition as Pb in feldspars contained within the intrusions. Brandon and Lambert (1992) determined Pb isotopic compositions for K-feldspar phenocrysts in each of five major intrusive phases within the mid-Cretaceous White Creek batholith. No constraints are available for the Pb isotopic composition of the young lamprophyres in the study area, although Bevier (1987) reports Pb isotopic compositions for Eocene lamprophyres in the Valhalla complex approximately 100 km west of the study area. Lead introduced from lower crustal and/or mantle reservoirs during or since deposition of Purcell strata can be approximated by the lower crust and mantle curves presented by Zartman and Doe (1981). These curves are estimates made on a global scale and do not account for regional heterogeneity. The possibility of other unrecognized Pb sources for mineralization in the Shrink Lake study area also cannot be ruled out.

Lead isotopic compositions were determined for galena and other sulphide minerals from ten sulphide-bearing samples within the Shrink Lake study area. Additionally, isotopic data was obtained from the Alpine and Doc mineral occurrences in the vicinity of the study area. Two galena samples from a galena rich stratabound horizon intersected in drill core obtained northeast of the study area were also analysed. A K-feldspar phenocryst from the K-feldspar megacrystic quartz monzonite phase of the White Creek batholith was analysed to complement the data from Brandon and Lambert (1992).

From the distribution of Pb isotopic data in Figure 3, the following general observations can be made:

All analyses lie on or near the "shale curve," suggesting that upper crustal rocks represent a major Pb source for the samples analysed.

Some analyses fall significantly below the shale curve suggesting the introduction of at least a minor component of lead from a lower-μ reservoir.

Much of the data forms a roughly linear array, that could represent a single mixing event between a non-radiogenic upper crustal source, and a much more radiogenic upper crustal source. Alternatively, the array may represent complex mixing of Pb from several different sources.

The sample suite likely includes mineralization formed by more than one process, and of more than one age.

TABLE 1
PB ISOTOPIC DATA FROM THE SHRINK LAKE STUDY AREA (SL), STRATABOUND GALENA MINERALIZATION IN THE UPPER ALDRIGE FORMATION (STRAT), THE DOC SHOWING (DOC), THE ALPINE SHOWING (ALPINE) AND THE WHITE CREEK BATHOLITH (WCB)

Sample	Original Sample No.*	Mineral	Location	Pb isotopic data 206/204	207/204	208/204	207/206	208/206
1	zone 2	Galena	STRAT	16.48817	15.42701	36.16196	0.935645	2.193222
2	zone 30	Galena	STRAT	16.51753	15.44671	36.24876	0.935174	2.194578
3	zone 30	Galena	STRAT	16.51894	15.44125	36.21776	0.934764	2.192515
5	LM-058	Galena	ALP	17.72479	15.59184	38.09016	0.879666	2.148992
6	LM-120	Galena	SL	18.52290	15.63239	38.71285	0.843952	2.090014
7	LM-158B	Galena	SL	17.35287	15.52122	37.44653	0.894450	2.157960
8	LM-160	Galena	SL	16.97564	15.49678	36.82133	0.912887	2.169084
9	LM-160	Galena	SL	16.97702	15.50324	36.84027	0.913193	2.170023
10	NT-184a	Galena	SL	17.62106	15.52770	37.74589	0.881204	2.142105
11	VR30307a	Galena	SL	16.52549	15.43508	36.25739	0.934020	2.194044
12	VR30311a	Galena	SL	18.27621	15.60639	38.53895	0.853921	2.108710
13	LM-126	Pyrite	SL	18.44807	15.61731	38.66923	0.846558	2.096128
14	LM-129	Pyrite	SL	18.54023	15.63409	38.73587	0.843255	2.089302
15	LM-139	Pyrite	SL	18.09201	15.59063	38.28208	0.861745	2.115982
16	VR30264	Arsenopyrite	DOC	16.73622	15.45765	36.52043	0.923608	2.182134
17	LM-171	K-Feldspar	WCB	18.50368	15.67265	39.18572	0.847005	2.117741

* (Marshall, 1999)

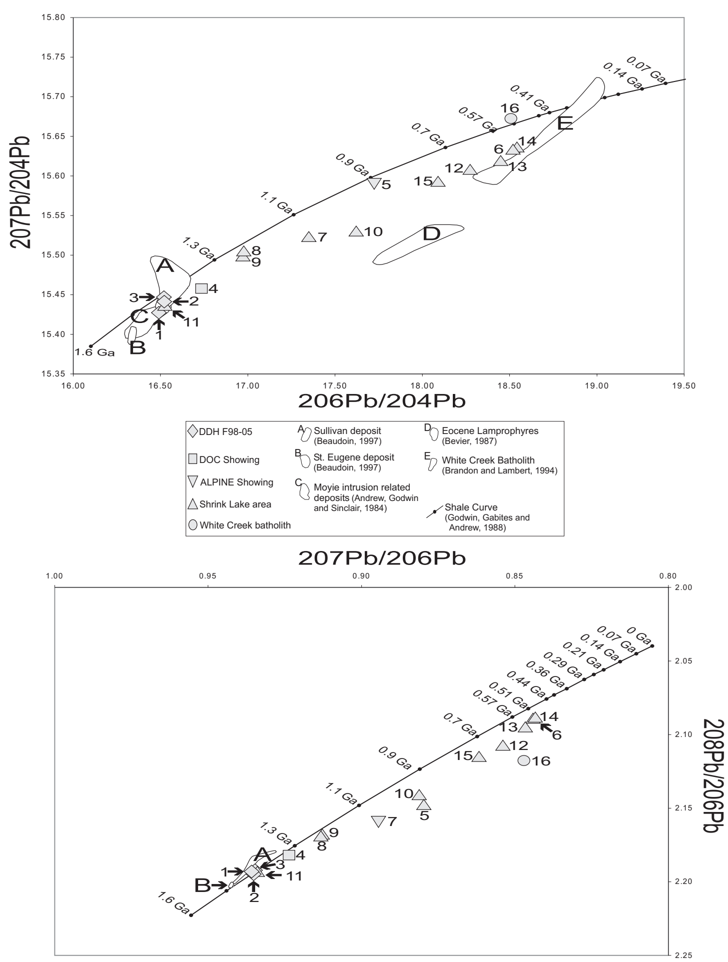

Figure 3. Pb isotopic diagrams for new data from the Shrink Lake study area, DDH F98-05, the Doc showing and the Alpine showing. Previous data for selected reservoirs are shown as fields and model curves.

Finally, some of the epigenetic samples have isotopic compositions that are consistent with remobilization from a Mesoproterozoic base metal deposit.

DISCUSSION

Stratabound Galena Mineralization in the Upper Aldridge Formation

Samples 1, 2 and 3 are galena from mineralized horizons within upper Aldridge sediments. Samples 2 and 3 contain fine grained galena associated with tourmaline rich laminations, in a horizon that has been described as being stratabound and possibly stratiform (Kennecott internal communication, 1998). Sample 1 contains coarse grained galena associated with a siliceous horizon, or a concordant quartz vein (Kennecott internal communication, 1998). Similar mineralization within the same system exhibits irregular vein-sediment contacts that have been interpreted to result from the injection of fluids into wet sediments (Kennecott internal communication, 1999). The isotopic compositions of these samples plots near the intersection of the Sullivan and Moyie arrays (Figure 3), and are therefore consistent with a Mesoproterozoic age of formation. Textural data suggests that this occurrence is epigenetic, but likely formed before consolidation of upper Aldridge sediments, possibly as a result of leaching of Pb from the sediments during basin dewatering (Kennecott internal communication, 1999). Alternatively, Pb in the occurrence may have been remobilized from a syngenetic Sullivan-type deposit, or another Mesoproterozoic base metal deposit. An plutonic-related Pb source is not considered likely, as gabbroic intrusions noted within the upper Aldridge appear to be volumetrically too minor to account for the extent of mineralization.

Doc Showing

Sample 4, from the Doc showing on Tourmalinite Ridge, is slightly more radiogenic than the strongly mineralized samples 1, 2 and 3. This sample was obtained from a quartz-galena-arsenopyrite-chalcopyrite vein within upper Aldridge sediments, at approximately the same stratigraphic level as samples 1, 2 and 3.

The upper Aldridge is a highly permeable formation and is marked by significant geochemical soil anomalies along its strike in the vicinity of Tourmalinite Ridge. These anomalies suggest that the argillites of the upper Aldridge may have acted as a conduit for mineralized fluids at some time. It is conceivable that fluids leached Pb from the nearby stratabound galena occurrence as well as from upper Aldridge sediments, resulting in a shift away from the isotopic ratios characteristic of samples 1, 2 and 3, towards a more radiogenic composition, as seen in sample 4. Alternatively, this shift may be explained by a mixing of Proterozoic Pb with Pb associated with the White Creek batholith, or other as yet unidentified radiogenic Pb sources. Other possibilities for Pb sources for sample 4 include a mixing between upper crustal lead, and Pb derived from either a mantle source, a lower crustal source, or both.

Alpine Showing

Sample 5, from the Alpine Showing, plots immediately adjacent to the shale curve, indicating that all of the lead in this sample may have been leached from lower Purcell sedimentary strata. If this is in fact the case, a model age of approximately 0.9 Ga obtained from the shale curve can be inferred for mineralization at the Alpine showing. Analysis of additional samples from this occurrence would be required to test this hypothesis.

Shrink Lake Study Area Mineralization

Sample 11 is from a quartz-calcite-galena-chalcopyrite vein within a Moyie sill. Isotopic compositions of this sample plot at the intersection of the Sullivan and Moyie arrays. Fluid inclusion studies (Marshall, 1999) indicate that the vein contains very distinct carbonic fluids, inferred to be genetically related to intrusion of the Moyie sills. The isotopic data suggests that Pb in the sample may also be derived from the Moyie sills.

Sample 8 was obtained from within middle Aldridge rocks, near the base of the upper Aldridge, in a fracture filling vein within a well developed joint set. The analyses from this sample can be interpreted in the same way as sample 4. If a mixing of Mesoproterozoic Pb with a more radiogenic Pb source is responsible for the Pb composition of sample 8, a shift towards more radiogenic Pb can be explained by a greater component of Pb leached from Purcell sediments. This could be consistent with a greater distance from the upper Aldridge stratabound galena occurrence. As with Sample 4, this hypothesis is non-unique, and other geologically reasonable explanations are possible.

Interpretations of Pb sources for the remaining samples are more ambiguous. These occurrences likely represent several separate episodes, with Pb being derived from multiple sources. Samples 6, 13 and 14 all plot within the array from the White Creek batholith. As such these veins may represent Pb derived wholly from the intrusion, although this remains unproven. Furthermore, these samples are mineralogically and texturally different, and may not be genetically related to one another.

Samples 7 and 10 plot near the field defined by analyses of lamprophyre dikes from the Valhalla complex. Lamprophyre dikes are also present in the study area, although it is uncertain whether they are related to the dikes in the Valhalla area. The dikes are volumetrically minor, and are not exposed in the vicinity of the sample localities for samples 7 and 10. No veins of any kind were noted in close proximity to the exposed dikes. Omitting the lamprophyre dikes as a possible Pb source, mineralization in samples 7 and 10 likely represents mixing of upper crustal lead with Pb derived from one or more of the White Creek batholith, mantle, lower crustal, Moyie intrusion, and Proterozoic Pb reservoirs.

CONCLUSIONS

Results of this study suggest that mineralization in the study area and in adjacent mineral showings reflects several different mineralizing events. These events may be coincident with tectonic and/or intrusive events that have affected the area. The major interpreted Pb sources include Proterozoic syngenetic or epigenetic deposits, Moyie intrusions, lower Purcell Supergroup sedimentary rocks, and the White Creek batholith.Galena obtained from drill core intersections of galena-rich stratabound horizons within the upper Aldridge Formation contains non-radiogenic Pb. Mineralization is interpreted to be Mesoproterozoic in age, with Pb having been either leached from the Aldridge sediments, or remobilized from a proximal (syngenetic?) base metal deposit.

Lead compositions from an arsenopyrite-bearing quartz vein from the Doc showing are interpreted to represent mixing between a non-radiogenic Pb source and a more radiogenic Pb source. The non-radiogenic Pb source is possibly the stratabound mineralization described above.

If our interpretations of lead sources is correct, Pb isotopic ratios from vein hosted sulphide mineralization can be used as an indicator of remobilization of Pb from potential SEDEX or other Proterozoic base metal targets in the study area, and perhaps elsewhere in the Purcell Supergroup. It is recommended that the analysis of Pb isotopic compositions of vein hosted sulphide mineralization be applied in subsequent exploration for SEDEX mineralization in the region. Interpretation of future data would be greatly enhanced if independent age constraints on mineralizing events are available.

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