GALENA LEAD ISOTOPE CHARACTERISTICS OF MINERALIZATION IN KOKANEE GLACIER PROVINCIAL PARK, SOUTHEASTERN BRITISH COLUMBIA (82F/11, 14)

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KEYWORDS: Lead isotopes, Kokanee Glacier Park, Nelson batholith, shale curve, pericratonic curve, Bluebell curve, epigenetic veins.

INTRODUCTION

This paper presents new galena lead isotope data from 22 mineral deposits located in and around Kokanee Glacier Provincial Park and is part of a 2-year mineral evaluation being conducted by the Geological Survey Branch (Brown and Logan, this volume). The study was undertaken to determine lead isotope characteristics of a variety of mineral occurrences. Deposits were selected on the basis of past production, mineralogy and vein orientation, to insure all types were represented. Lead isotope ratios cluster in three groups. The groupings suggest three separate lead sources; two show mixing with Nelson batholith leads. The majority of deposits have lead signatures close to Nelson batholith potassium-feldspar leads and a few have old nonradiogeneic leads. Lead isotope ratios, when interpreted with a geological database, provide a framework within which to evaluate the park's mineral potential, in particular its potential for gold-bearing deposits.

GEOLOGY

Much of Kokanee Glacier Provincial Park is underlain by rocks of the Nelson batholith. The batholith can be divided into six phases (Brown and Logan, this volume). The main phase is potassium-feldspar porphyritic granite and was intruded during the Middle Jurassic. Zircon uranium-lead dates range from 165 to 170 Ma (Carr *et al.*, 1987; Ghosh, 1986; Parrish, personnal communication, 1987). A rubidium-strontium isochron of 162 $\pm$ 6 Ma is reported by Duncan and Parrish (1979). Potassium-argon dates range from 171 to 49 Ma (Duncan and Parrish, 1979) and indicate a prolonged and complex thermal history. Tertiary potassium-argon dates from biotite indicate a thermal event, but no intrusions, except narrow dykes, were mapped within the park. It is speculated that Tertiary intrusives are present, in the southwest corner of the map area.

The northern end of the batholith intrudes Late Triassic Slocan Group argillite, siltstone and minor limestone. The eastern edge is a moderate west-dipping sequence of Lower Cambrian to Late Triassic rocks (Brown and Logan, this volume; Fyles, 1967). The western boundary is the Slocan Lake fault zone and Cretaceous to Tertiary gneissic intrusions of the Valhalla complex (Carr *et al.*, 1987).

Lithoprobe seismic reflection profiles are interpreted to illustrate that the Nelson batholith is about 8 to 10 kilometres thick (Cook *et al.*, 1987). Stratigraphy east of the map area, near Ainsworth, projects down dip beneath it. The Tertiary age Slocan Lake fault extends eastward from Slocan Lake under the batholith and continues eastward below Kootenay Lake. The fault is shown to be about 12 kilometres below the central part of the park on Lithoprobe profiles (Cook *et al.*, 1987).

ANALYTICAL METHODS

Analysis of galena lead isotopes at The University of British Columbia was carried out by J.E. Gabites. Two milligrams of pure galena were hand-picked from each sample. Pure lead chloride solution was obtained by dissolution of the galena in pure 2-normal hydrochloric acid and evaporation to dryness. Lead chloride crystals so formed were cleaned by washing several times in 4-normal hydrochloric acid. The cleaned lead chloride crystals were dissolved in ultrapure water. One microgram of lead in the lead chloride solution was loaded with phosphoric acid and silica gel onto a cleaned, single rhenium filament. Lead isotope ratios were measured on a Vacuum Generators Isomass 54R solid source mass spectrometer linked to a Hewlett-Packard HP-85 computer.

Within-run precision is better than 0.01 per cent standard deviation. The variation observed in duplicate analyses is less than 0.05 per cent. Isotope ratios are normalized to the values of Broken Hill Standard lead (BHS-UBC1) given in Richards *et al.* (1981). Analytical precision is monitored by repeated measurement of BHS-UBC1 and systematic duplicate analyses of samples.

Two errors in mass spectrometric measurement of lead isotopes are ^{204}Pb-error and fractionation error (Godwin *et al.*, in preparation). The trends of these errors are shown on data plots so that trends in data can be assessed as being real or due to analytical problems.

FRAMEWORK FOR INTERPRETATION

Different sources of lead within the earth (mantle, lower crust, upper crust, orogene) have different characteristic lead isotopic signatures (Doe and Zartman, 1979). These signatures are dependant on the relative amounts of uranium and thorium in the source, and the length of time of isolation from other sources. Thus galena lead isotopic analyses cannot be used to date mineralization absolutely. Lead growth model

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curves, however, provide a reference framework within which lead isotope data can be interpreted. The three growth curves used in this paper have been derived empirically from lead data from mineral deposits in the Canadian Cordillera.

The data for the curve of Godwin and Sinclair (1982) was mainly from shale-hosted sedimentary exhalative deposits in the Canadian Cordillera (Carne and Cathro, 1984). The shale curve reflects an upper crustal environment of lead evolution (Zartman and Doe, 1981). Goutier's (1986) curve was modified from the shale curve to more accurately fit data from deposits in the Eagle Bay assemblage, Adams Plateau. The deposits that Goutier analysed are volcanogenic but have an upper crustal signature. The Adams Plateau area is in the pericratonic terrane (Wheeler *et al.*, in preparation), as is the Nelson batholith. Thus the model of Goutier is used here because it is more appropriate. In the rest of this paper, Goutier's curve is referred to as the pericratonic curve. The Bluebell curve of Andrew *et al.* (1984) approximates the evolution of nonradiogenic, probably mantle and/or lower crust-derived lead, for deposits in the Canadian Cordillera. This curve was modelled by assigning the Bluebell deposit an assumed age at the base of the Cambrian.

Previous lead isotope studies of the Nelson batholith (Sinclair 1964, 1966; Reynolds and Sinclair, 1971), Slocan Group (Logan, 1986; Ghosh, 1986) and vein deposits (LeCouteur, 1973; Andrew *et al.*, 1984) led to interpretation of the anomalous nature of Slocan leads by various models which involve mixing of components from two separate lead reservoirs. In these models the batholith, which is of uranium-depleted upper mantle/lower crustal derivation, supplied the nonradiogenic component, which mixed during emplacement with upper crustal leads to produced the observed Slocan data array (Reynolds and Sinclair, 1971; Andrew *et al.*, 1984). By approximating a lower crustal growth curve, Andrew *et al.* show Slocan lead isotope data to lie along a mixing isochron that corresponds to the age of mineralization and presumbaly to the time mixing occurred.

RESULTS

The lead isotope database for the map area is extensive. However, comparison with previous studies is complicated by inaccurately located samples and old data of poorer quality. Therefore, only new analyses from the Kokanee Park mineral evaluation are discussed (Table 5-12-1).

Table 5-12-1.
Galena lead isotope data[1, 2] for mesothermal veins, Kokanee Park, southeastern British Columbia

Leadfile[3] No.	Minfile No.	Deposit Name	Run No.	Run Quality	$^{206}Pb/^{204}Pb$	% error	$^{207}Pb/^{204}Pb$	% error	$^{208}Pb/^{204}Pb$	% error	$^{207}Pb/^{206}Pb$	$^{208}Pb/^{206}Pb$
GROUP A												
30033-001	082/F/NW-120	Smuggler	1	good	17.590	0.00	15.492	0.01	38.187	0.00	0.88074	2.17102
30037-001	082/F/NW-119	Slocan Chief	1	fair	17.783	0.00	15.522	0.02	38.354	0.00	0.87289	2.15673
30040-001	082/F/NW-118	Blackburn	1	good	17.719	0.00	15.520	0.01	38.317	0.00	0.87590	2.16252
30053-001	082/F/NW-121	Molly Gibson	1	good	17.587	0.00	15.489	0.01	38.177	0.00	0.88072	2.17078
30053-002	082/F/NW-121	Molly Gibson	1	good	17.599	0.00	15.494	0.00	38.191	0.00	0.88035	2.17002
30053-AVG	082/F/NW-121	Molly Gibson	1	good	17.593	0.00	15.492	0.01	38.184	0.02	0.88053	2.17045
GROUP B												
30029-001	082/F/NW-106	Revenue	1	good	18.968	0.00	15.657	0.00	39.158	0.00	0.82545	2.06444
30030-001	082/F/NW-099	BNA	1	good	18.873	0.00	15.647	0.00	39.033	0.00	0.82904	2.06812
30031-001	082/F/NW-109	Baltimore	2	good	18.981	0.00	15.655	0.01	39.177	0.00	0.82481	2.06406
30032-001	082/F/NW-141	Marmion/Maryland	1	good	18.859	0.00	15.631	0.01	39.026	0.00	0.82884	2.06934
30036-001	082/F/NW-114	Silver Cup	1	fair	19.031	0.00	15.668	0.02	39.111	0.00	0.82334	2.05515
30046-001	082/F/NW-077	Comstock	1	fair	18.693	0.00	15.618	0.01	38.961	0.00	0.83552	2.08426
30046-001R	082/F/NW-077	Comstock	2	good	18.704	0.00	15.628	0.01	38.998	0.00	0.83556	2.08499
30046-001A	082/F/NW-077	Comstock		good	18.698	0.01	15.623	0.02	38.980	0.01	0.83554	2.08463
30625-001	082/F/NW-152	Arlington	1	good	18.853	0.00	15.629	0.00	39.091	0.00	0.82901	2.07346
GROUP C												
30025-001	082/F/NW-127	Alpine	1	good	19.171	0.00	15.666	0.00	38.937	0.00	0.81718	2.03102
30026-001	082/F/NW-111	Pontiac	1	good	18.974	0.00	15.655	0.01	38.770	0.00	0.82507	2.04329
30027-001	082/F/NW-113	Sunrise	1	good	18.881	0.00	15.653	0.02	38.702	0.00	0.82905	2.04981
30038-001!	082/F/NW-122	Oro Fino	1	fair	19.130	0.00	15.654	0.02	38.446	0.01	0.81834	2.00971
30038-001R	082/F/NW-122	Oro Fino	2	good	19.144	0.00	15.667	0.02	39.047	0.00	0.81837	2.03961
30039-001	082/F/NW-105	Para	1	good	19.007	0.00	15.653	0.00	38.789	0.00	0.82353	2.04074
30039-002	082/F/NW-105	Para	1	good	19.011	0.00	15.647	0.00	38.768	0.00	0.82306	2.03928
30039-AVG	082/F/NW-105	Para	1	good	19.009	0.00	15.650	0.00	38.779	0.00	0.82330	2.04001
30042-001	082/F/NW-215	Silver Ranch	1	good	19.044	0.00	15.654	0.02	38.822	0.00	0.82201	2.03856
30043-001	082/F/NW-253	Al	1	good	18.980	0.00	15.644	0.01	38.762	0.00	0.82422	2.04219
30044-001	082/F/NW-256	King Solomon	1	good	19.185	0.00	15.674	0.02	38.995	0.00	0.81697	2.03256
30045-001	082/F/NW-208	Jumbo/Mary	1	good	19.069	0.00	15.650	0.01	38.810	0.00	0.82071	2.03520
30048-001	082/F/NW-212	East of LH	1	good	19.041	0.00	15.666	0.01	38.809	0.00	0.82275	2.03816
30059-001	082/F/NW-113	Granite/Sunrise	1	good	18.959	0.01	15.644	0.03	38.739	0.01	0.82513	2.04331

[1] Analyses by J.E. Gabites.
[2] Analyses normalized to Broken Hill lead standard values of Richards et al. (1981); $^{206}Pb/^{204}Pb$ = 16.004, $^{207}Pb/^{204}Pb$ = 15.390, $^{208}Pb/^{204}Pb$ = 35.651.
[3] Suffixes on Leadfile numbers are: 00x = sample number, ! = poor analysis, not used in average.
R = rerun analysis. A = arithmetic average of rerun analyses, plotted on figures. AVG = arithmetic average of analysis from the same deposit, plotted on figures.

Galena lead isotope ratios from new analyses are plotted on $^{207}Pb/^{204}Pb$ versus $^{206}Pb/^{204}Pb$ (Figure 5-12-1A), $^{208}Pb/^{204}Pb$ versus $^{206}Pb/^{204}Pb$ (Figure 5-12-1B) and $^{206}Pb/^{208}Pb$ versus $^{206}Pb/^{207}Pb$ (Figure 5-12-2) diagrams, and compared to the shale curve of Godwin and Sinclair, the pericratonic, curve of Goutier and the Bluebell curve of Andrew *et al.* The deposit name, location, host lithology, MINFILE number and deposit type are documented in Table 5-12-2. Property descriptions and bibliography for each sample location are available in MINFILE records.

INTERPRETATION

The lead isotope ratios from epigenetic vein deposits in Kokanee Park fall into three groups labelled A, B, and C. The grouping is most apparent on the $^{208}Pb/^{204}Pb$ versus $^{206}Pb/^{204}Pb$ plot (Figure 5-12-1B). The groups are assigned distinct symbols, that have been used in Figure 5-12-3 to show the distribution of deposits. Group A deposits lie along a northwest linear whereas Groups B and C are distributed randomly throughout the map area.

Group A data are relatively nonradiogenic and lie on the Bluebell curve on the $^{207}Pb/^{204}Pb$ versus $^{206}Pb/^{204}Pb$ plot. The model age implied by this curve is Cambrian to Ordovician. Two points are just above the Bluebell curve. These data come from four batholith-hosted deposits, the Blackburn, Molly Gibson, Slocan Chief and Smuggler. The Molly Gibson was the largest past producer (Table 5-12-2). They lie along a northwesterly striking joint set west of Kokanee

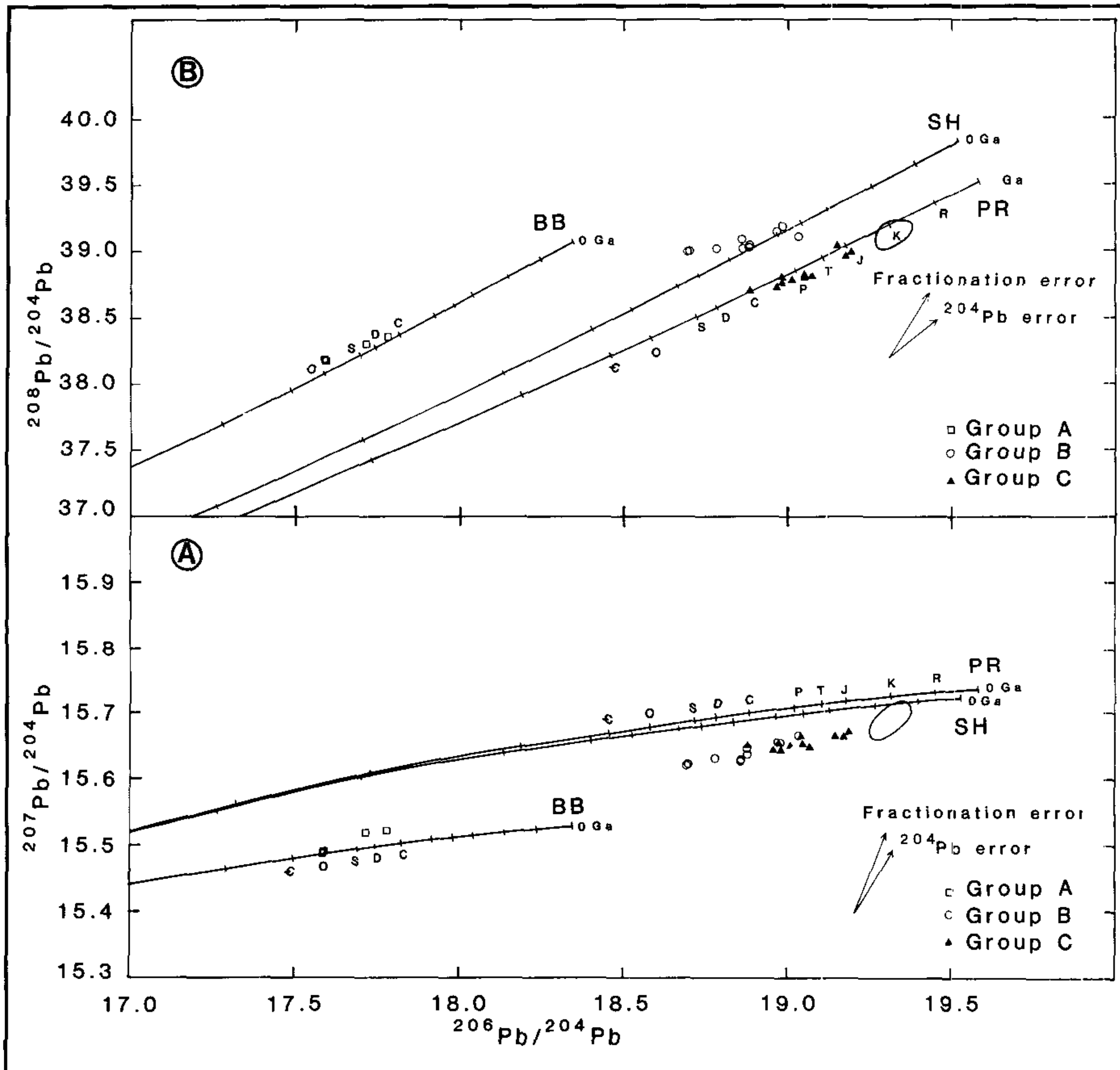

Figure 5-12-1. Galena lead isotope ratio diagram for mesothermal quartz veins in Kokanee Glacier Provincial Park, southeastern British Columbia. Model growth curves are: PR = pericratonic (Goutier, 1986), SH = shale (Godwin *et al.*, 1982), and BB = Bluebell (Andrew *et al.*, 1984). Time intervals are marked with standard abbreviations.

Table 5-12-2.
Location and host lithology for mesothermal veins, Kokanee Park, southeastern British Columbia

Minfile No.	Deposit Name	UTM Location Easting	UTM Location Northing	Host Lithology[1]	Deposit Type	Production (tonnes)
GROUP A						
82F/NW-118	Blackburn	485563	5513364	K-spar	vein	0
82F/NW-119	Slocan Chief	486953	5512505	K-spar	vein	4
82F/NW-120	Smuggler	487559	5511750	K-spar	vein	13
82F/NW-121	Molly Gibson	489035	5508600	K-spar	vein	55 860
GROUP B						
82F/NW-077	Comstock	483296	5526295	Qtz monz/lamp	vein	456
82F/NW-099	BNA	492000	5523600	Pel/psa/lst	vein	173
82F/NW-106	Revenue	491131	5519134	Hb por gn	vein	244
82F/NW-109	Baltimore	495950	5517754	Hb por gn	vein	60
82F/NW-114	Silver Cup	487625	5511666	Hb por gn	vein	4
82F/NW-141	Marmion/Maryland	476241	5514056	Hb por gn	vein	50
82F/NW-152	Arlington	473981	5515135	K-spar	vein	19 217
GROUP C						
82F/NW-105	Para	482390	5520617	K-spar	vein	15
82F/NW-111	Pontiac	496325	5515133	Hb por gn	vein	1160
82F/NW-113	Granite/Sunrise	495114	5523532	Hb por gn	vein	145
82F/NW-113	Sunrise	494714	5514283	Hb por gn	vein	145
82F/NW-122	Oro Fino	485356	5507733	K-spar	vein	4
82F/NW-127	Alpine	481934	5503399	Qtz monzonite	vein	15 551
82F/NW-208	Jumbo/Mary	479651	5516615	K-spar	vein	25
82F/NW-212	East of LH	477354	5526027	Metavol/skarn	vein	0
82F/NW-215	Silver Ranch	483690	5514368	K-spar	vein	0
82F/NW-253	Al	498281	5511798	K-spar	vein	0
82F/NW-256	King Solomon	481420	5501622	Qtz monzonite	vein	0

[1] Abbreviations are: K-spar = potassium-feldspar porphyritic granite, Qtz monz/lamp = quartz monzonite and lamprophyre, Pel/psa/lst = pelite, psammite and limestone, Hb por gn = hornblende-porphyritic granite, Qtz monz = quartz monzonite, Metavol/skarn = metavolcanic rocks and skarn.

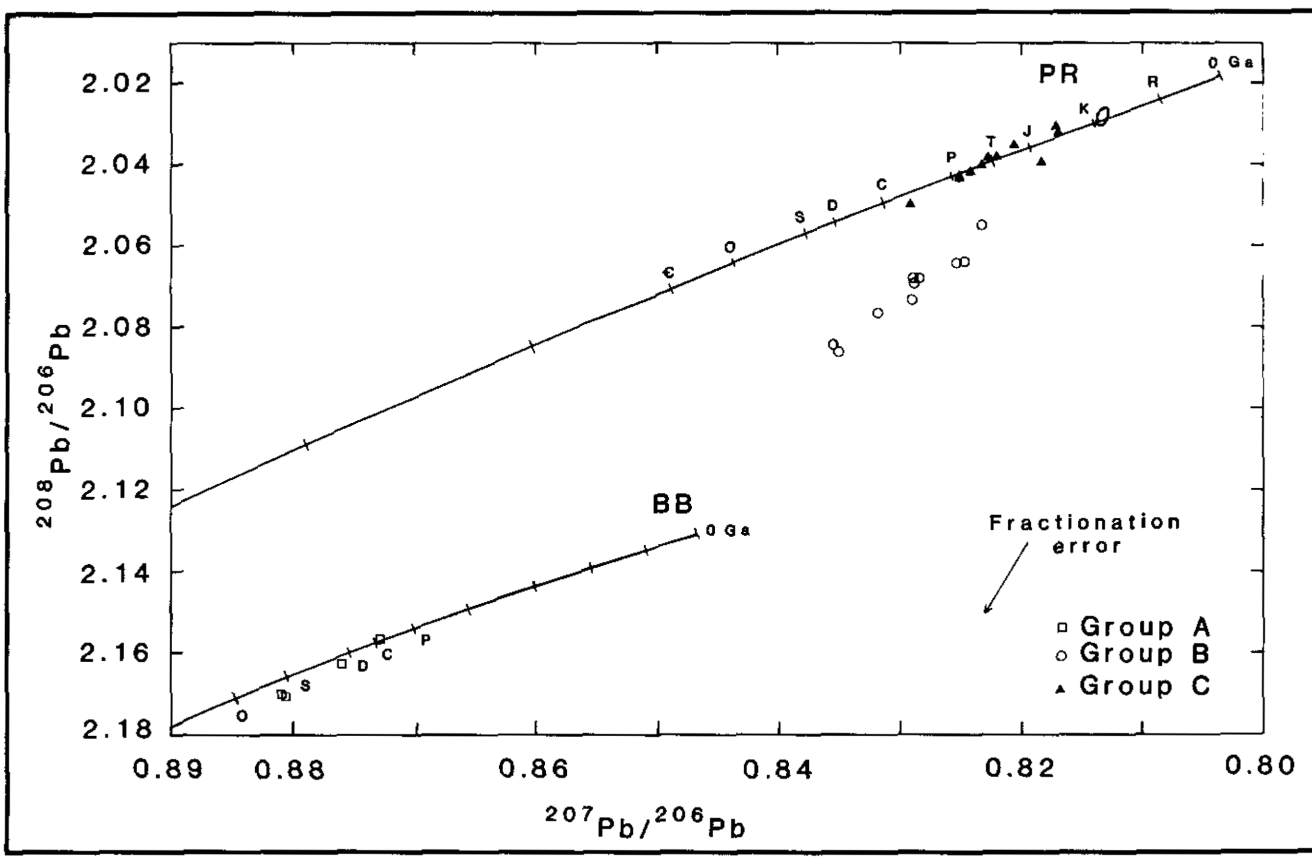

Figure 5-12-2. Galena lead isotope ratio diagram for mesothermal quartz veins in Kokanee Glacier Provincial Park, southeastern British Columbia. Model growth curves are: PR = pericratonic (Goutier, 1986), SH = shale (Godwin *et al.*, 1982), and BB = Bluebell (Andrew *et al.*, 1984). Time intervals are marked with standard abbreviations.

Glacier (Plate 5-12-1). Vein mineralogy of the four deposits comprises galena, sphalerite, arsenopyrite, pyrite and minor chalcopyrite in a gangue of brecciated buff to pink siderite. Manganese-rich siderite gangue, coated with black manganese oxide, is unique to the batholith-hosted deposits which are typically quartz-rich. Arsenopyrite is only reported from one other deposit in the Slocan camp, the LH. These characteristics emphasize the unusual nature of these four deposits. The presence of this anomalous lead, with a Cambro-Ordivician Bluebell curve model age, from veins that crosscut the Middle Jurassic batholith is enigmatic.

A possible interpretation for Group A lead is that it represents a hydrothermal event during the Jurassic to Tertiary, involving fluids derived from either the lower crust/upper mantle, or from Precambrian basement. However, this requires that the Bluebell deposit be of the same age and epigenetic (Sinclair, 1964; LeCouteur, 1973). Deposits near Ainsworth, 15 kilometres to the east, have been interpreted to be either epigenetic or syngenetic stratiform veins (Hoy *et al.*, 1981). These deposits have similar lead isotope ratios (LeCouteur, 1973) to Group A.

An alternative explanation is that Group A is directly derived from a Bluebell-type Cambrian or older deposit. Incorporation by the batholith of a large mineralized inclusion of miogeocline, Lardeau Group or older rocks is implied. Mineralization in the Lardeau Group near Ainsworth contains lead with similar isotope ratios. The siderite gangue of Group A is typical of sediment-hosted deposits in the Slocan camp, 15 kilometres to the north, and suggests a sediment-derived component to the mineralizing fluids. However, there is no surface expression of sedimentary inclusions near Group A deposits. Remobilization of lead from the supposed "inclusion" by fluids during the Jurassic-Tertiary could produce the observed shift from Cambrian age, assigned to the Bluebell deposit. However, mixing of lead with the younger mineralizing fluids would be expected to pro-

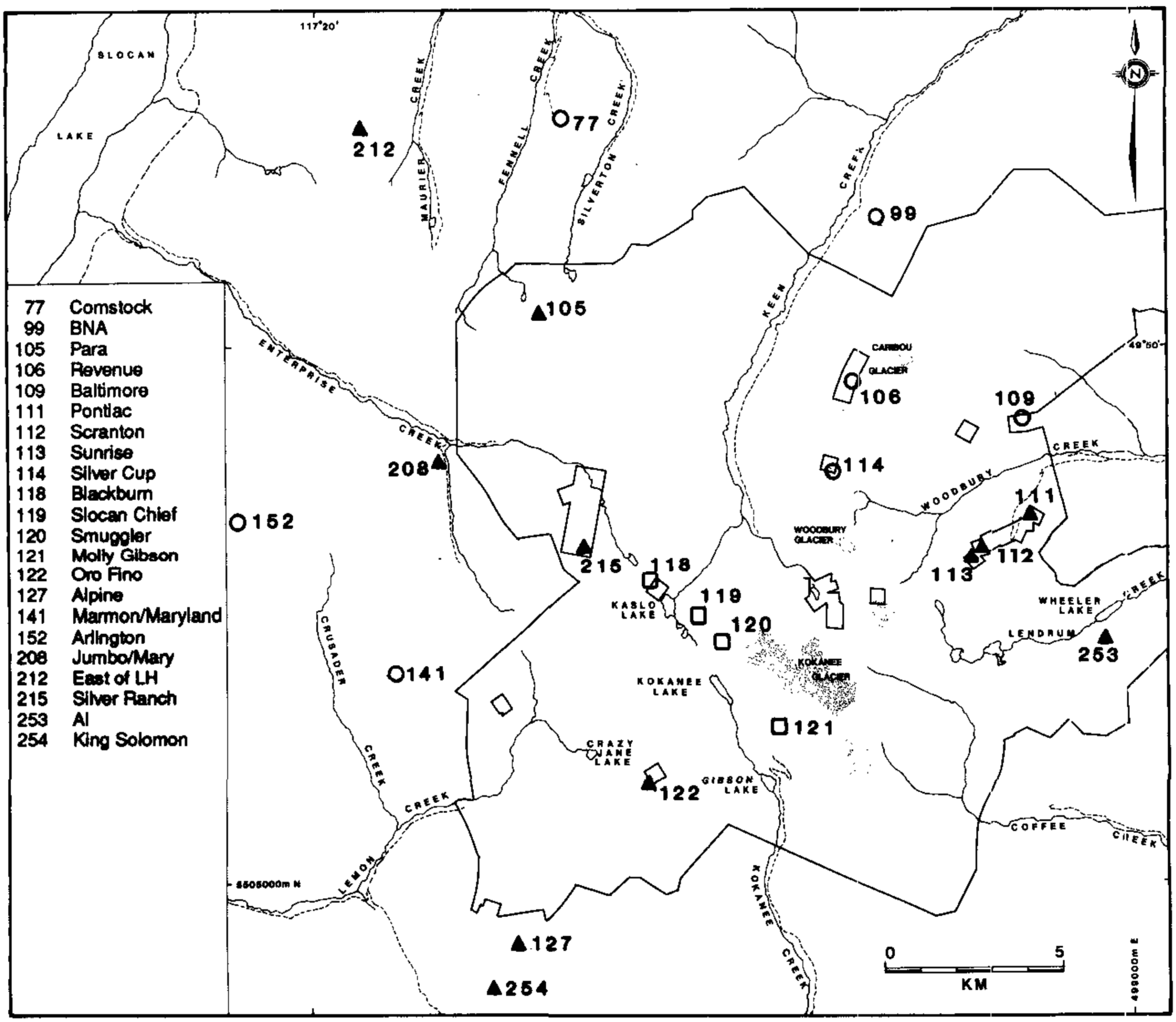

Figure 5-12-3. Vein deposit locations and MINFILE numbers for those galena lead isotope samples analysed. Symbols distinguish 3 groups: □ = Group A, ○ = Group B, ▲ = Group C.

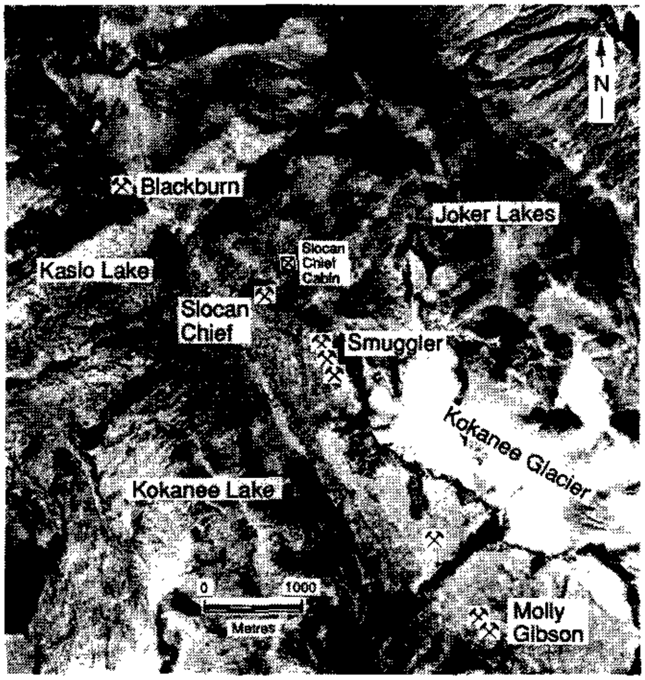

Plate 5-12-1. Group A deposits parallel a prominent northwest-trending linear located west of Kokanee Glacier. The Molly Gibson, Smuggler, Slocan Chief and Blackburn are steep southwest-dipping veins that are coplanar with the northwest-striking joint set.

duce a more significant shift in lead ratios, generating ratios transtitional between Groups A and B.

Groups B and C data overlap on the $^{207}Pb/^{204}Pb$ versus $^{206}Pb/^{204}Pb$ plot (Figure 5-12-1A), between the pericratonic and Bluebell curves. However, plots of $^{208}Pb/^{204}Pb$ versus $^{206}Pb/^{204}Pb$, and $^{208}Pb/^{206}Pb$ versus $^{207}Pb/^{206}Pb$ clearly distinguish Groups B and C (Figures 5-12-1B, 5-12-2). Group B is more thorogenic (^{208}Pb) and less radiogenic (^{207}Pb and ^{206}Pb) than Group C and forms a linear array between the Bluebell and pericratonic curves. Mineralogically, these deposits are mesothermal silver-lead-zinc-bearing quartz veins. The exception, Marmion/Maryland, recorded appreciable gold recovery, more typical of Group C. On the $^{208}Pb/^{204}Pb$ versus $^{206}Pb/^{204}Pb$ and $^{208}Pb/^{206}Pb$ versus $^{207}Pb/^{206}Pb$ plots, the spread of data may reflect mixing in the batholith between pericratonic and Bluebell-type leads in the Jurassic. Thus, the spread of data is representative of the mixed source for the plutonic rocks and associated mineralizing fluids that has been described from other isotope systematics (LeCouteur, 1973; Andrew *et al.*, 1984; Ghosh, 1986).

Group C data are more uranogenic and less thorogenic than Group B data. They form a linear array along the pericratonic curve in Figures 5-12-1B and 5-12-2. These data suggest a source distinct from Group B. On the $^{206}Pb/^{204}Pb$ diagram, Group C data plot with younger model ages than Group B. Mineralogically Group C deposits cannot be distinguished from Group B, gold has been recovered from the majority and is the only economic mineralization in some deposits. Lead isotope analysis of feldspar concentrates from the Nelson batholith (Ghosh, 1986) cluster at the radiogenic end of Groups B and C on Figure 5-12-1A. On Figures 5-12-1B and 5-12-2 the batholith leads plot on the pericratonic curve coincident with the projected intersection of the Group B and C linear clusters. Mixing in the batholith is inferred from both linear arrays and suggests an equivalent age for Groups A and B. Three deposits in Group C plot at the more radiogenic end of the linear arrays in Figures 5-12-1A and 5-12-2. They are characterized by high-grade gold mineralization. They are located in the southwest corner of the map area, where Tertiary potassium-argon dates from biotite have been obtained (Parrish, personnal communication, 1987). It is not known whether these dates reflect either a Tertiary thermal resetting of a Jurassic monzonite, or Tertiary intrusion. The low thorium content suggests that the bulk of the lead source is not the batholith.

CONCLUSIONS

Lead isotope ratios in the mineral occurrences in Kokanee Park fall into three groups. All deposits analysed are epigenetic veins in and near the Middle Jurassic Nelson batholith. Three separate lead sources are necessary to produce the data arrays. These are a lower crustal/upper mantle Bluebell-type, pericratonic type and an unknown source. Mixing of these three reservoirs occurred in the batholith during the Middle Jurassic. Group A deposits are surrounded by deposits of Groups B and C near the centre of the batholith. A subset of Group C represents occurrences in the southwest corner of the map area with more radiogenic lead and a gold-enriched mineralogy and may correlate with a Tertiary intrusive event.

FUTURE WORK

A regional synthesis of all previous lead isotope data is in progress. Establishing the characteristics of the three source regions is necessary to understand the metallogenic processes operative throughout the Kootenay arc. Fluid inclusion and stable isotope studies of deposits from each group are planned. Two unknowns inherent in the common lead isotope age-modelling equations are the source age of lead (t_1) and the age of mineralization (t_2). Potassium-argon isotopic age determinations of sericite wallrock alteration from two deposits are underway to date the age of mineralization. A sample for zircon uranium-lead dating should be collected from the biotite quartz monzonite in the southwest corner of the map area, where gold mineralization occurs and where Tertiary potassium-argon dates have been obtained.

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