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GALENA LEAD ISOTOPE MODEL FOR VANCOUVER ISLAND*

By Anne Andrew and Colin I. Godwin
The University of British Columbia

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INTRODUCTION

This paper demonstrates how a galena lead isotope model can be used to make decisions about the age and origin of ore deposits on Vancouver Island. To build this model we draw on the galena data of Table 1-9-1 (*compare* Andrew and Godwin, in press a, b, c and Godwin *et al.*, 1988).

Galena lead isotope data from Vancouver Island do not show a systematic evolution with time. Therefore they cannot be interpreted using existing lead isotope models [for example, Stacey and Kramers (1975), Doe and Zartman (1979), Godwin and Sinclair (1982), and Andrew *et al.* (1984)]. Godwin *et al.* (1988) have drawn attention to the need for terrane-specific models for lead isotope interpretation. The model presented here is applicable to Wrangellia, of which Vancouver Island is a part.

GENERAL GEOLOGY OF VANCOUVER ISLAND

The magmatic history of Vancouver Island can be simplified into four major episodes: (1) formation of the Paleozoic volcanic arc of the Sicker Group, (2) extrusion of the Triassic tholeiitic flood basalts of the Karmutsen Formation, (3) development of the Jurassic volcanic arc of the Bonanza Group and related Island intrusions, and (4) Tertiary volcanic and plutonic activity including emplacement of the Tertiary Catface intrusions.

Sicker Group anticlinoria consist of volcanic and volcaniclastic rocks and greywackes that constitute a Paleozoic volcanic arc. The lowermost part of the Sicker Group consists of the gabbroic and basaltic Nitinat Formation (Muller, 1980; Sutherland Brown *et al.*, 1986); this might be host to gold deposits in the Port Alberni area (for example, Debbie; R. Walker, personal communication, 1986). The middle part, the Myra Formation, consists mainly of more felsic volcanic and volcaniclastic rocks that host volcanogenic massive sulphide ore deposits at the south end of Buttle Lake (Buttle Lake camp; Walker, 1980; Juras, 1987) and at Mount Sicker (Lenora and Tyee; Massey and Friday, 1988). The top of the Sicker Group is delimited by limestone of the Buttle Lake Formation, which contains Middle Pennsylvanian fusilinids (Sada and Danner, 1974), and Early Permian conodont assemblages (Brandon *et al.*, 1986).

Massive outpourings of tholeiitic basalt of the Karmutsen Formation occurred in the Late Triassic. These basalts unconformably overlie the Sicker Group, forming a thick (up to 6 kilometres) sequence of massive, pillowed and brecciated flows and sills (Carlisle and Suzuki, 1974; Muller, 1980). The Karmutsen Formation is overlain conformably by the Late Triassic Quatsino and Parsons Bay formations, dominantly of limestone and shale respectively (Muller, 1980).

An Early to Middle Jurassic island arc assemblage is made up of volcanic and volcaniclastic rocks known as the Bonanza Group. Coeval with Bonanza volcanism was the emplacement of major quartz diorite to granodiorite batholiths, known as the Island intrusions. The Island Copper porphyry copper-molybdenum deposit is related to this magmatic episode.

Cretaceous sedimentary rocks of the Nanaimo Group overlie all preceding units with marked angular unconformity.

Tertiary tectonic events involved truncation of Vancouver Island to the west and south, and accretion of several small terranes. The Pacific Rim complex, a Mesozoic subduction complex analogous to the Franciscan of California, was accreted along the western margin of Vancouver Island during the Paleocene (65 to 55 Ma; Brandon and Massey, 1985). The Leech River complex was accreted to the south of the San Juan fault in the Late Eocene or Early Oligocene (40 to 30 Ma; Rusmore and Cowan, 1985). The paleogeography of southern Vancouver Island was further modified by accretion of the Eocene Metchosin volcanic rocks south of the Leech River fault (post 40 Ma; Rusmore and Cowan, 1985).

Relationships between the above Tertiary (about 40 Ma) tectonic events, and the small Eocene Catface quartz diorite intrusions throughout Vancouver Island (Carson, 1973) are not known unequivocally. Ewing (1981), Isachsen (1984), Sutherland Brown and Yorath (1985), and R.L. Armstrong *et al.* (*in preparation*), relate them to magmatism in the arc-trench gap between a Cenozoic subducting plate and the coeval Kamloops Group volcanism. They are also coeval with amphibolite-grade metamorphism in the Leech River complex (Rusmore and Cowan, 1985), and with a major reorganization of plate motions in the Pacific (Ewing, 1981; Brandon and Massey, 1985). Gold-quartz veins in the Zeballos district are related to this plutonic episode (Hansen and Sinclair, 1984; Andrew and Godwin, *in press* c).

THE MODEL

Galena lead isotope data (Table 1-9-1) from Paleozoic, Triassic, Jurassic and Tertiary episodes of mineralization are plotted on Figure 1-9-1. Also shown are whole-rock initial ratios for the Jurassic Island intrusions and Tertiary Catface intrusions. Where these plutons directly contribute lead to deposits, there should be similarities in lead isotopes. Three fields are defined in both the $^{207}Pb/^{204}Pb$ versus $^{206}Pb/^{204}Pb$, and $^{208}Pb/^{204}Pb$ versus $^{206}Pb/^{204}Pb$ plots in Figure 1-9-1. A lower field in both of these plots is defined by

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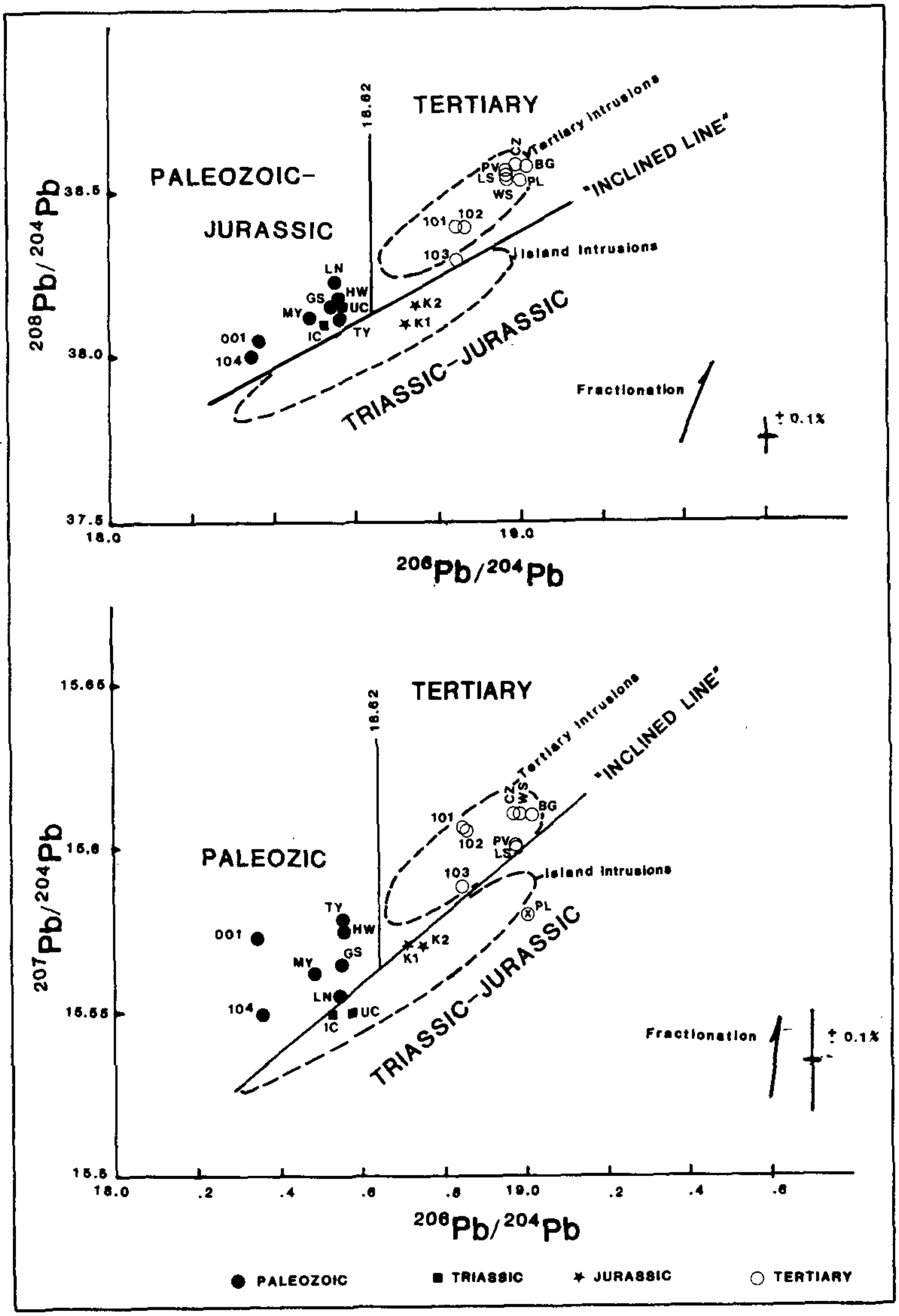

Figure 1-9-1. Lead-lead plots of galena lead isotopes from mineral deposits on Vancouver Island. Data and codes identifying deposits plotted are in Table 1-9-1. Also shown are whole-rock initial ratios for the Jurassic Island intrusions and the Tertiary Catface intrusions (data from Andrew, 1987). Three fields define and distinguish the age of most deposits on the Island.

TABLE 1-9-1
GALENA LEAD ISOTOPE ANALYSES[1] FROM ORE DEPOSITS, VANCOUVER ISLAND

Sample No.[1]	Analyst[2]	Deposit Name	Fig. Code	Lat. North (decimal deg.)	Long. West (decimal deg.)	Lead Isotope Ratios $^{206}Pb/^{204}Pb$	$^{207}Pb/^{204}Pb$	$^{208}Pb/^{204}Pb$
PALEOZOIC: Buttle Lake – Sicker-hosted sulphides								
30443-GS-AVG	1	G and S zones (n = 5)	GS	49.58	125.61	18.55	15.57	38.15
30443-HW-AVG	1	HW main orebody (n = 4)	HW	49.57	125.57	18.56	15.58	38.19
30443-MY-AVG	1,2	Myra high grade (n = 4)	MY	49.58	125.60	18.49	15.56	38.12
PALEOZOIC: Mount Sicker – Sicker-hosted sulphides								
30702-LN-AVG	2	Lenora (n = 2)	LN	48.87	123.78	18.55	15.56	38.22
30702-002	2	Tyee	TY	48.87	123.78	18.56	15.58	38.12
PALEOZOIC: Debbie – Sicker-hosted massive sulphides								
30457-001	1	Debbie	001	49.24	124.69	18.35	15.57	38.00
30457-101	1	Debbie	101	49.24	124.69	18.85	15.61	38.39
30457-102	1	Debbie	102	49.24	124.69	18.86	15.61	38.39
30457-103	1	Debbie	103	49.24	124.69	18.85	15.59	38.28
30457-104	1	Debbie	104	49.24	124.69	18.36	15.55	38.05
TRIASSIC: Karmutsen-hosted cogenetic(?) sulphides								
30314	1	Starlight	K1	49.06	124.71	18.66	15.57	38.23
30335	1	Nutcracker (Texada Island)	K2	49.75	124.59	18.71	15.57	38.27
JURASSIC: Island intrusion and Bonanza volcanic related mineralization								
30432	1	Utlah Creek	UC	50.30	127.45	18.58	15.55	38.19
30699	1	Island Copper	IC	50.61	127.48	18.53	15.55	38.09
TERTIARY: gold-quartz veins related to Zeballos intrusions								
30317	1	Lone Star/Rey Oro	LS	50.02	126.79	18.98	15.60	38.55
30318	1	White Star	WS	50.03	126.81	18.99	15.61	38.58
30320	1	Peerless	PL	50.04	126.84	19.00	15.58	38.53
30349	1	Privateer	PV	50.03	126.81	18.98	15.60	38.56
30484	1	Central Zeballos	CZ	50.04	126.78	18.98	15.61	38.57
30487	1	Bragg	BG	50.04	126.78	19.01	15.61	38.59

[1] Sample numbers with the suffix -AVG are average values; all others are single analyses. (*See also* listings in Godwin *et al.*, 1988, Tables 5.5I and 5.6I).
[2] 1 = analyses by A. Andrew, done in the Geochronology Laboratory, The University of British Columbia.
2 = analyses by B. Ryan, reported in Andrew (1982); these were done in the Geology-Geophysics Laboratory, The University of British Columbia.

the "inclined line" that forms the upper envelope to initial whole-rock lead for the Jurassic Island intrusions. Above this inclined line two fields are defined that are either less than or greater than $^{206}Pb/^{204}Pb = 18.62$. Deposits with galena lead values that plot on this line are not known. If such lead was found on or very close to this line, its classification would be indeterminate.

Paleozoic mineralization can be identified firstly by "fingerprinting" the lead against the Buttle Lake and Mount Sicker galena lead (Table 1-9-1; Figure 1-9-1). Paleozoic galena lead plots in Figure 1-9-1 above the inclined line and has $^{206}Pb/^{204}Pb$ less than 18.62. On the $^{208}Pb/^{204}Pb$ versus $^{206}Pb/^{204}Pb$ plot, Jurassic galena lead and Paleozoic lead overlap in the upper-left field, but are distinguishable on the $^{207}Pb/^{204}Pb$ versus $^{206}Pb/^{204}Pb$ plot.

Triassic Karmutsen Formation basalts have heterogeneous isotope ratios and the initial ratio field for the Karmutsen Formation is poorly defined (Andrew, 1987). Two galena analyses (Table 1-9-1), UC and IC, that we think are cogenetic with the Karmutsen Formation are shown on Figure 1-9-1. Their isotopic compositions are within the field of initial ratios for the Island intrusions. Thus, it appears to be difficult to positively identify Triassic mineralization using lead isotopes alone.

Tertiary galena lead plots above the inclined line on both the $^{207}Pb/^{204}Pb$ versus $^{206}Pb/^{204}Pb$ and $^{208}Pb/^{204}Pb$ versus $^{206}Pb/^{204}Pb$ plots, and has a $^{206}Pb/^{204}Pb$ greater than 18.62 (Figure 1-9-1). All the galena lead plots within the field of initial ratios from whole-rock lead, indicating a direct genetic relationship between plutons and gold mineralization. Leads from gold deposits associated with the Zeballos plutons are tightly clustered around $^{206}Pb/^{204}Pb = 19.0$, $^{207}Pb/^{204}Pb = 15.6$, and $^{208}Pb/^{204}Pb = 38.5$; Tertiary galena from the Debbie deposit group near $^{206}Pb/^{204}Pb = 18.85$, $^{207}Pb/^{204}Pb = 15.6$, and $^{208}Pb/^{204}Pb = 38.55$ (*see* following section).

EXAMPLE

Five samples from the Debbie gold property (Westmin Resources Limited) near Port Alberni are reported in Table 1-9-1. Two of these (Table 1-9-1 and Figure 1-9-1: 001 and 104), from the southern part of the property, plot above the inclined line and have low $^{206}Pb/^{204}Pb$ ratios (less than 18.6). This suggests that the mineralization is Paleozoic and therefore syngenetic with respect to its Sicker Group host rocks. Three others (101, 102 and 103) have $^{206}Pb/^{204}Pb$ greater than 18.8 and plot in the Tertiary fields in Figure 1-9-1. Thus it can be shown using lead isotopes that two different ages of mineralization exist at the Debbie property. This is consistent with other geological findings (R. Walker, personal communication, 1988).

DISCUSSION

The above model relies on simple comparison of lead isotope ratios of galena from a deposit of unknown age and origin, with ratios for galenas from known ore deposits. This "fingerprinting" technique relies on the recognition of isotopic differences between the rocks associated with the different mineralizing episodes. A detailed study of the lead and strontium characteristics of the major igneous rock units of Vancouver Island (Andrew, 1987; Andrew and Godwin, *in press* a, b, c) has shown that significant isotopic differences do exist among them. Galena lead isotope ratios of the ore deposits reflect these differences; it also can be demonstrated that the galena lead isotope ratios fall within the whole-rock initial ratio fields of the related plutonic rocks (Andrew, 1987; Andrew and Godwin, *in press* a, b, c). Volcanogenic massive sulphides contain lead which is similar to that in cogenetic volcanic rocks (Brevart *et al.*, 1981). Indeed, galena lead from the Sicker-hosted deposits occupies the same general trend as whole-rock lead isotope data from the Sicker Group (Andrew, 1987; Andrew and Godwin, *in press* a, b, c). Thus, for Vancouver Island the isotopic compositions of the ore deposits are more dependent on the origin of the lead than they are on the age of the deposit; no systematic increase in the ratios with time is observed. A growth-curve model for the evolution of lead on Vancouver Island is therefore inappropriate.

The fields on Figure 1-9-1 are defined by a limited number of analyses. Additional analyses from ore deposits and rocks of known age and origin could enlarge these fields. However, the general isotopic characteristics for each "episode" are robust. For example, although there is only one case of Jurassic galena (Island Copper), others are likely to have the same low $^{206}Pb/^{204}Pb$ and $^{207}Pb/^{204}Pb$ signature that characterizes the Jurassic arc-building episode.

CONCLUSIONS

Galena lead isotope composition can be used to determine the age and origin of lead in many mineral deposits on Vancouver Island. Dating, and determination of an epigenetic versus a cogenetic origin to mineralization, has important exploration applications, and can guide important exploration decisions. Potential applications of the lead isotope model presented here include:

- Paleozoic massive sulphide deposits and related feeder veins are isotopically distinct from epigenetic veins related to Mesozoic or Tertiary plutonic activity.
- Jurassic mineralization related to either Bonanza Group volcanic rocks or Island intrusions (such as the Island Copper porphyry deposit) can be distinguished isotopically from Paleozoic mineralization related to the Sicker Group.
- Gold-bearing veins related to Tertiary plutonic activity are isotopically different from mineralization related to Jurassic plutonic activity.

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NOTES