NEW GALENA LEAD ISOTOPIC DATA FROM CARBONATE ROCKS IN NORTHEASTERN B.C. - IMPLICATIONS FOR REGIONAL MVT FLUID MIGRATION

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INTRODUCTION

Outcropping Siluro-Devonian carbonate strata in the northeastern Rocky Mountains host a series of Mississippi Valley-type Zn-Pb deposits (Figure 1). The largest and most extensively explored of these is the Robb Lake deposit (Nelson *et al*., this volume). Carbonate strata continue eastward into the subsurface as the Middle Devonian Presqu'ile barrier complex, which divides the Muskeg evaporite basin to the south from the McKenzie shale basin to the north. The world class Pine Point zinc-lead mine lies near the eastern end of the Presqu'ile barrier, where it overlies the McDonald-Hay River fault, a major Precambrian crustal break (Figure 1).

Mississippi Valley deposits are considered to form as the result of regional flow of basinal brines (Jackson and Beales, 1967). Recent models have emphasised the importance of tectonically-driven fluid flow in their formation (Leach and Rowan, 1986, Oliver, 1986). Sverjensky (1984) and Oliver (1986) proposed that the processes of hydrocarbon migration and metal transport were inseparable, both being the results of brine flow on a basin-wide scale.

Garven (1985) first applied regional hydrologic modelling to the Western Canada Sedimentary Basin, relating both petroleum migration and the formation of the Pine Point deposit to regional eastward fluid flow along the Presqu'ile Barrier, driven by post Early Cretaceous (Laramide) uplift of the Rocky Mountains. This model, although appealing, has been controversial ever since its publication, primarily because of the lack of absolute age constraints on major fluid transport events in the basin. There are two "end-member" hypotheses. It is possible that Pine Point formed through a Devonian-Mississippian, "Antler orogenic" fluid event. This hypothesis is supported by the data of Nesbitt and Muehlenbachs (1994), who contrasted the characteristics of fluid inclusions in secondary saddle dolomites with those in later, cross-cutting, syn-Laramide veins. They considered the former to be certainly pre-Laramide and probably Devonian-Mississippian. Alternatively, Qing and Mountjoy (1992), in studies of fluid inclusions and saddle dolomites, observed systematic easterly-decreasing temperatures and west-to-east evolution in the isotopic character of brines, which they considered consistent with Garven's (1985) Laramide model.

The Pine Point deposit has recently been dated at 361±16 Ma (Devonian-Mississippian) by Rb-Sr methods on sphalerite (Nakai *et al*., 1993). Although this method and the interpretation of results from it are themselves still controversial (see discussion by Pettke and Diamond, 1996), it at least offers the possibility of an absolute age, which can be evaluated in terms of other indirect evidence. An Rb-Sr age for Robb Lake is currently being attempted (Nelson *et al*., this volume).

LEAD ISOTOPIC MODELLING OF CARBONATE-HOSTED DEPOSITS

The isotopic composition of lead in deposits depends on the source reservoir (e.g., mantle, crust), the age of the deposit, and on the selectivity of the mineralisation process (Godwin *et al*., 1988). Galena lead isotopic signatures of carbonate-hosted sulphide deposits tend to fall into one of two categories: either as a well-defined cluster, or as a linear trend to extreme enrichment in radiogenic lead (Gulson, 1986). Most deposits of the Mississippi Valley type fall into the second category (Heyl *et al*., 1974, Vaasjoki and Gulson, 1986). Lead isotope analy-

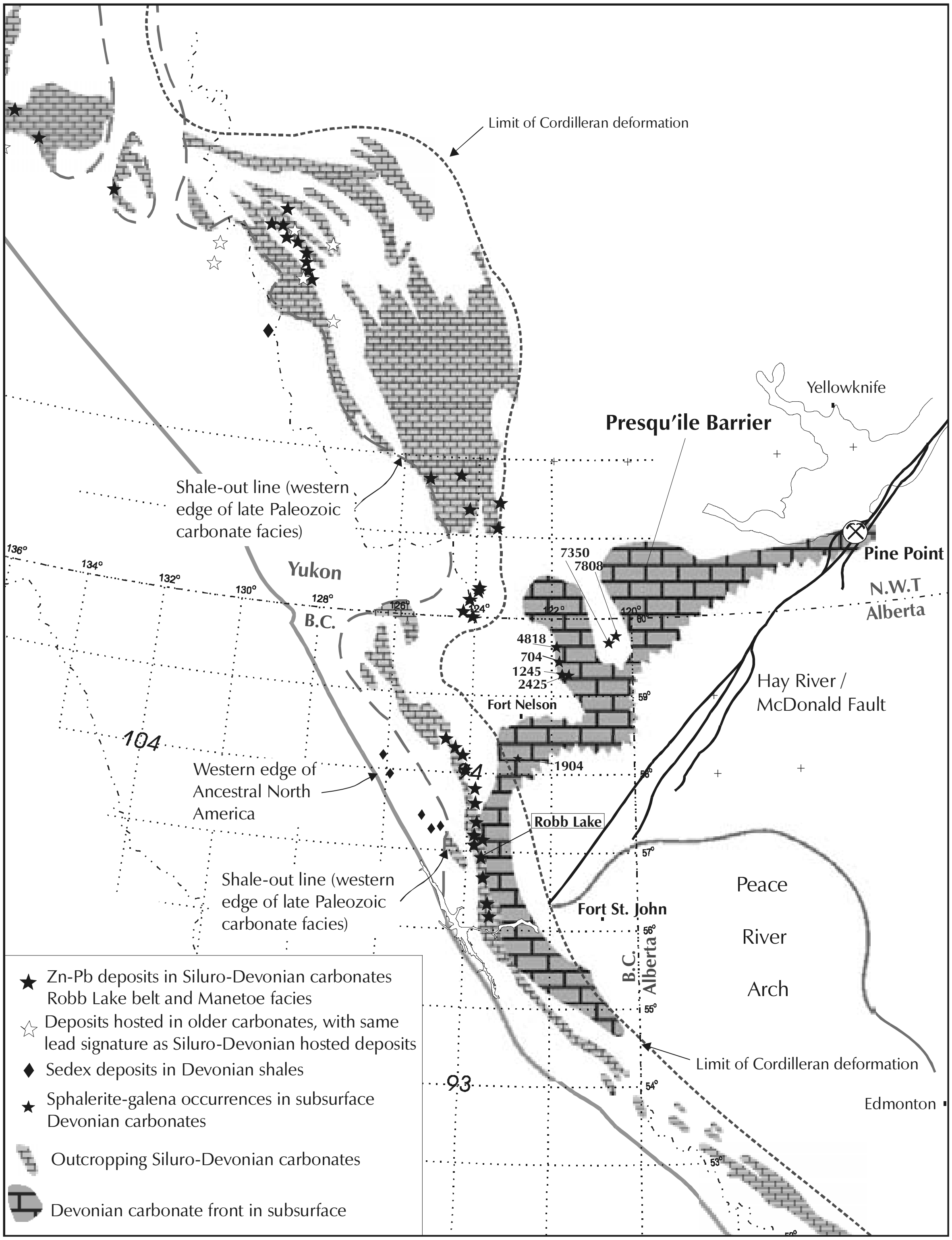


Figure 1. Location of outcropping and subsurface sulphide occurrences in Silurian-Devonian carbonates of northeastern British Columbia, N.W.T. and Yukon.

ses from the Pine Point district (Cumming *et al*., 1990) form a very tight cluster, despite the deposits sampled being spread through an area of 15 by 60 km. The brines carrying lead to Pine Point had a very homogeneous isotopic composition (Cumming *et al*., 1990), which implies that either the source was homogeneous or that the fluids homogenised during transport through large distances. By contrast, leads from Cordilleran carbonate-hosted deposits, including the Robb Lake belt and deposits in the Yukon (Morrow and Cumming, 1982, Godwin *et al*., 1982, Morrow *et al*., 1986), form a trend (or closely spaced trends) to very radiogenic values (Figure 2a). The least-radiogenic end of the trend intersects the "shale curve" of Godwin and Sinclair (1982). This model curve is a reference for the growth of lead in upper crustal environments in the Canadian Cordillera, defined using data from stratiform shale-hosted deposits in British Columbia and Yukon Territory. In terms of lead sources, Pine Point and the Cordilleran deposits therefore appear to represent two highly disparate fluid systems.

The regional extent of "Robb Lake" as opposed to "Pine Point" lead in the subsurface Presqu'ile Barrier may outline the extent of these two fluid systems. Although an extensive lead isotopic database exists for surface sulphide occurrences in Paleozoic carbonate rocks of the northern Rockies and the Yukon (Morrow and Cumming, 1982, Godwin *et al*., 1982, Morrow *et al*.,1986), so far very few samples from the subsurface have been analysed. In 1998, we began a program of systematic sampling of galena-sphalerite occurrences from cored intervals of Devonian carbonates in the subsurface of B.C. and Alberta. As part of the Central Foreland NATMAP project, our study aims at a deeper understanding of MVT mineralization in the northeastern Rockies, and of the possible relationship between sulphide deposition and hydrocarbon formation in the Western Canada Sedimentary Basin.

PRESENT STUDY

This paper reports lead isotopic compositions of six samples collected in 1998 at the B.C. Ministry of Energy and Mines Core Storage Warehouse in Charley Lake, B.C. The locations of these samples are shown on Figure 1. Three of them, and also sample 704, a previously unpublished analysis, are from dolostones of the Slave Point and Pine Point formations along the buried Devonian carbonate front in NTS sheets 94P/5 and 94P/12. Sample 1-98-1904-2 is from within the carbonate barrier in 94J/2; of the sample suite, it lies closest to the mountain front. Samples 1-98-7350-1 and 1-98-7808-1 are from the Jean Marie Formation in the Helmet North Field.

In all of them except sample 1-98-1904-2, galena and sphalerite occur in veins and patches with coarse secondary dolomite, and in open spaces with saddle dolomite and, in some instances, drusy quartz. Sample 1-98-1904-2 is unique in that it contains a 0.5 metre thick, bedding-parallel replacement body of massive pyrite, sphalerite and galena that grades out into heavily disseminated sulphides.

Analytical Techniques

Small clean cubes of galena were handpicked, washed, and dissolved in dilute hydrochloric acid. Approximately 10 to 25 nanograms of the lead in chloride form was loaded on a rhenium filament, and isotopic compositions were determined using a modified VG54R thermal ionization mass spectrometer. The measured ratios were corrected for instrumental mass fractionation of 0.13% per mass unit based on replicate measurements of the N.B.S. 981 Standard Isotopic Reference Material. Errors reported in Table 1 were obtained by propagating all mass fractionation and analytical errors through the calculation.

Results

The results of lead isotopic analyses of galena are shown in Table 1, and plotted in Figures 2a, 2b and 2c. Figure 2a and 2b are standard $^{206}Pb/^{204}Pb$ versus $^{207}Pb/^{204}Pb$ and $^{206}Pb/^{204}Pb$ versus $^{208}Pb/^{204}Pb$ plots. Figure 2c is a plot of uranogenic and thorogenic lead, $^{207}Pb/^{206}Pb$ versus $^{208}Pb/^{206}Pb$. The small peak of 204Pb is not used in the isotopic ratios in this plot, thus removing a major source of analytical error. The analyses have been plotted against the shale curve of Godwin and Sinclair (1982). The $^{206}Pb/^{204}Pb$ versus $^{207}Pb/^{204}Pb$ isotopic ratios of

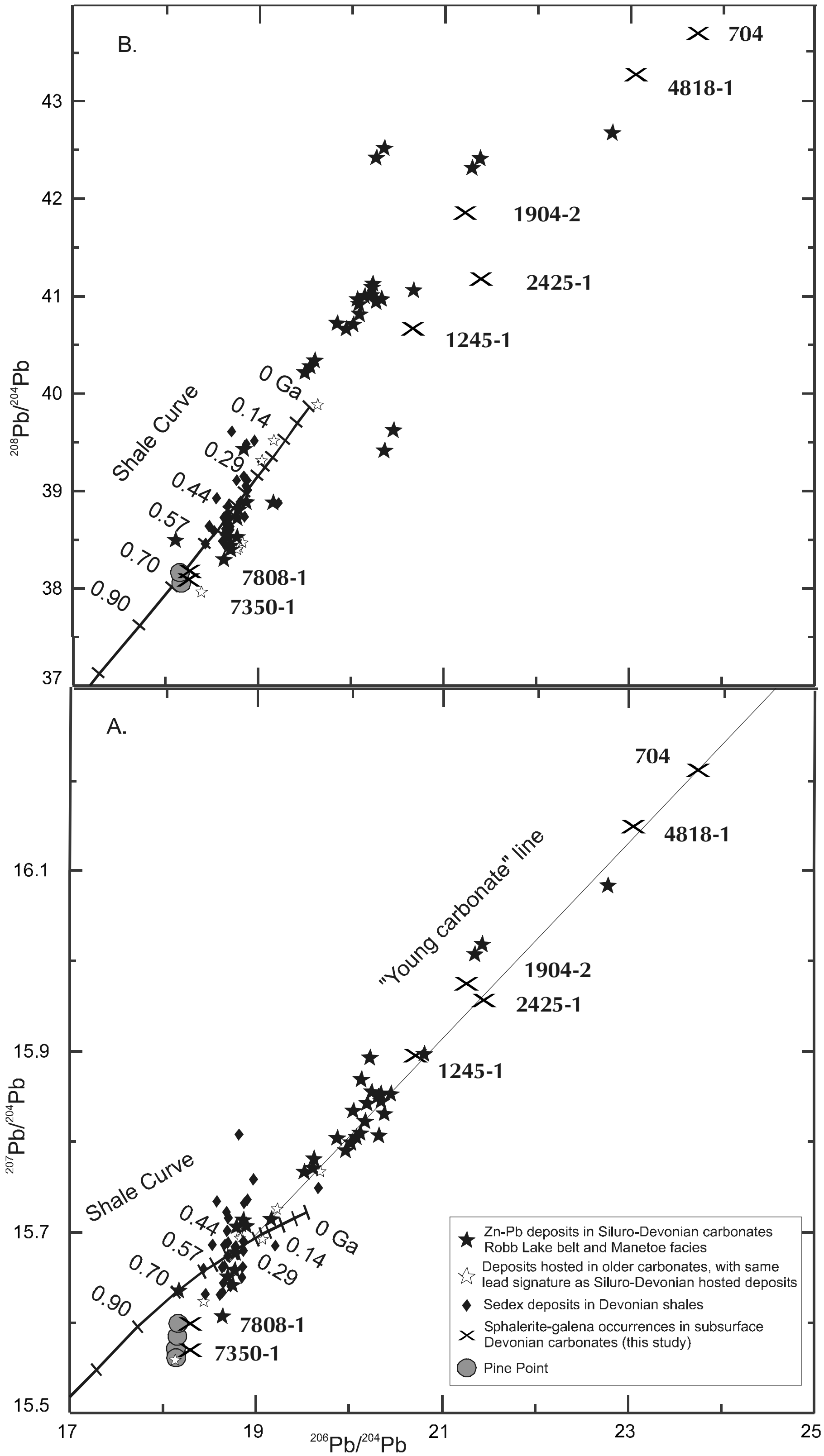
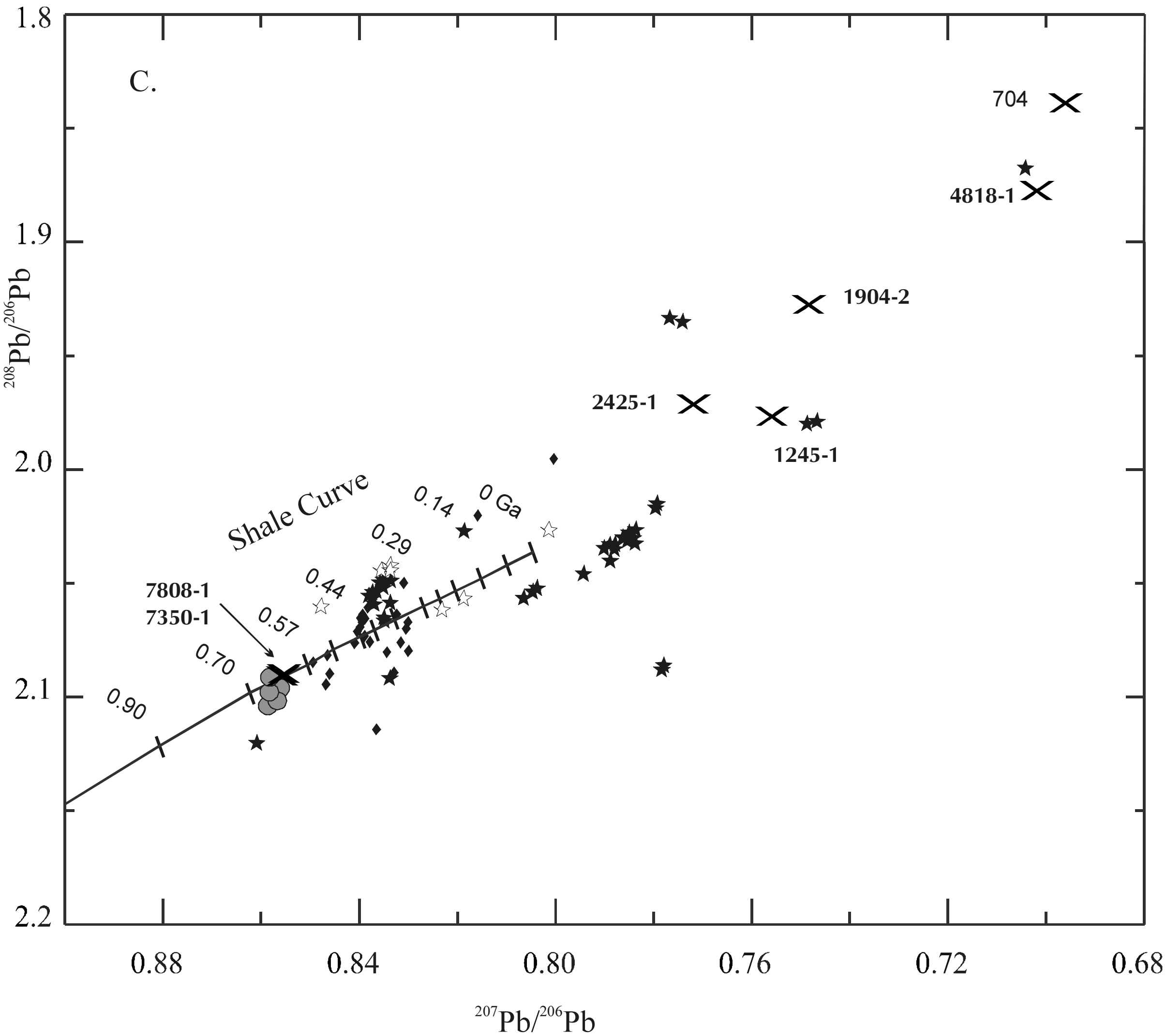


Figure 2A). Lead isotopic analyses of samples plotted on $^{207}Pb/^{204}Pb$ versus $^{206}Pb/^{204}Pb$ diagram, with shale curve (Godwin and Sinclair, 1982) for reference, the "young carbonate" line (Godwin *et al*., 1982); additional data from Godwin *et al*. (1989), Morrow and Cumming (1982), Morrow *et al*. (1986) and Cumming *et al*. (1990).B). Lead isotopic analyses of samples plotted on $^{208}Pb/^{204}Pb$ versus $^{206}Pb/^{204}Pb$ diagram. Sources as for Figure 2a.



2C). Lead isotopic analyses of samples plotted on $^{208}Pb/^{206}Pb$ versus $^{207}Pb/^{206}Pb$ diagram. Sources as for Figure 2a.

samples 1-98-7350-1 and 1-98-7808-1, the Jean Marie samples, plot below the shale curve, but very near to the Pine Point cluster (Figure 2a). The other four samples are highly radiogenic, plotting above and to the right of the shale curve, along the same trend as the Robb Lake belt (Morrow and Cumming, 1982), the "young carbonate" deposits of Godwin *et al*. (1982, 1988), and sulphides within the Devonian Manetoe Facies of southern Yukon (Morrow *et al*.,1986).

Table 1. Lead isotopic analytical data

Lab Number	Sample Number	$^{206}Pb/^{204}Pb$	$^{206}Pb/^{204}Pb$ % 1* err	$^{207}Pb/^{204}Pb$	$^{207}Pb/^{204}Pb$ % 1* err	$^{208}Pb/^{204}Pb$	$^{208}Pb/^{204}Pb$ % 1* err	$^{207}Pb/^{206}Pb$	$^{207}Pb/^{206}Pb$ % 1* err	$^{208}Pb/^{206}Pb$	$^{208}Pb/^{206}Pb$ % 1* err
31198-001	1-98-1245-1	20.6715	0.01	15.8991	0.01	40.7209	0.013	0.7691	0.004	1.9699	0.009
31199-001	1-98-2425-2	21.4054	0.015	15.9603	0.014	41.2292	0.016	0.7456	0.006	1.9261	0.003
31200-001	1-98-7350-1	18.2667	0.004	15.5742	0.002	38.1483	0.005	0.8526	0.003	2.0884	0.003
31201-001	1-98-7808-1	18.2958	0.006	15.6044	0.005	38.2296	0.007	0.8529	0.004	2.0895	0.004
31202-001	1-98-4818-1	23.0992	0.006	16.1475	0.005	43.3369	0.006	0.6991	0.003	1.8761	0.003
31203-001	1-98-1904-2	21.2185	0.01	15.9786	0.006	41.9101	0.011	0.7531	0.007	1.9752	0.005
31205-001	95-704-1	23.707	0.005	16.212	0.005	43.73	0.005	0.68385	0.007	1.8446	0.005

Discussion

In this preliminary study, five galena lead samples from the subsurface Presqu'ile Barrier in northeastern B.C. show lead signatures similar to those of outcropping deposits in the northeastern Rockies and along the margins of the Selwyn Basin. These five highly radiogenic samples plot along the "young carbonate line" of Godwin *et al*. (1982), and are more radiogenic than most of the Robb Lake belt analyses (Figure 2a, b, and c). This suggests that the metal-bearing fluids scavenged radiogenic lead during transport, possibly from a zircon-rich source such as old basement or a sandstone aquifer (Godwin *et al*., 1988). The lead sampled is heterogeneous, indicating either that the source was heterogeneous, fluid flow was relatively localised, and /or transport distances were not great enough to allow homogenisation. The location of these five deposits along the westernmost margin of the Presqu'ile Barrier supports the theory that metal-bearing fluids flowed eastwards from a western source until they intersected the carbonates, where sulphide-precipitating reactions occurred. The fact that there was no apparent mixing of Pine Point lead in the formation of these deposits suggests that the fluids forming the two systems were entirely separate.

On the plots of $^{206}Pb/^{204}Pb$ versus $^{208}Pb/^{204}Pb$ and $^{207}Pb/^{206}Pb$ versus $^{208}Pb/^{206}Pb$ (Figures 2b and 2c), which involve both thorogenic and urogenic lead, samples from the Jean Marie Formation lie in a tight cluster, apparently on the shale curve. The lead source for Pine Point and the two occurrences reported here was slightly enriched in thorium over lead compared to the shale curve, shown by the different relationships of the uranogenic and thorogenic isotopes to the growth curve. However, the model age at which the Pine Point - Jean Marie array projects onto the shale growth curve in $^{206}Pb/^{206}Pb$ versus $^{206}Pb/^{206}Pb$ space is close to 700 Ma (Figure 2a), significantly older than either the Middle Devonian age of the host rocks or the 361 Ma Rb/Sr age of the deposit itself. This shows that the shale curve is not an appropriate model for all northern Canadian carbonate-hosted deposits, only for those associated with the Cordilleran shale basins from which the shale curve data base was derived.

The similarity in lead signatures between Pine Point and the two Jean Marie samples offers a surprise and a puzzle. These samples are located within an embayment in the Presqu'ile barrier, remote from Pine Point and also from the Hay River/McDonald Fault. Was there a physical barrier to fluid flow between the Helmet Field and the deposits along what is now the western margin of the Presqu'ile Barrier? Does their lead signature reflect the growth curve of the McKenzie shale basin, or fluids sourced directly from Precambrian basement? We intend to undertake further studies to expand the scope of the data set, in order to build a regional lead isotopic distribution for the Western Canada Sedimentary Basin.

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