PRELIMINARY INTERPRETATIONS OF LEAD ISOTOPES IN GALENA–LEAD FROM SHALE–HOSTED DEPOSITS IN BRITISH COLUMBIA AND YUKON TERRITORY

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INTRODUCTION

Large stratiform, syngenetic deposits commonly yield galena-lead isotope 'model' ages that agree closely with the stratigraphic ages of their host rocks. However, analyses in Table 1 from stratiform, shale-hosted deposits (located on Fig. 70) of Cambrian to Devono-Mississippian age in or adjacent to the Selwyn Basin in British Columbia and Yukon Territory do not give reasonable ages if the models of Stacey and Kramers (1975) or Cumming and Richards (1975) are used. In fact, ages calculated with these models are unrealistically young, although isotopic analyses from the British Columbia and Yukon Territory deposits, plotted on a $^{207}Pb/^{204}Pb$ versus $^{206}Pb/^{204}Pb$ graph form distinct clusters (Fig. 71). Each cluster can be characterized by a specific deposit age and the locations of the clusters are in an appropriate order and position to define a growth curve (Fig. 70). The four clusters identified on Figure 71 are:

(1) Devono-Mississippian (*circa* 370 Ma), for example, MacKenzie area, British Columbia and Tom-Jason, Yukon Territory.
(2) Silurian (*circa* 425 Ma), for example, Howards Pass, Yukon Territory—Northwest Territories.
(3) Ordovician (*circa* 475 Ma), for example, MacKenzie Fold Belt, Northwest Territories.
(4) Cambrian (*circa* 550 Ma), for example, Anvil district, Yukon Territory.

Growth curves on the $^{207}Pb/^{204}Pb$ versus $^{206}Pb/^{204}Pb$ plot can be calculated in several ways. Here, we postulate that the growth curve for the shale-hosted deposits started from some point on the 'average crustal' growth curve of Stacey and Kramers. An appropriate point in time to begin the curve is about 2.0 Ma ago, which is near the expected time of homogenization of continental basement by the Hudsonian orogeny, and slightly older than the basement source age indicated by the galena-lead isotope isochron for pre-Ordovician ('old') carbonate-hosted deposits that we have defined elsewhere at 1.887 Ma (Godwin, *et al.*, in press). Using the 'old' deposit age and measured lead-isotope ratios as constraints, an average uranium to lead ratio of 11.8 was calculated for an 'average shale' growth curve that passes through each average and closely predicts the mean ages of the four clusters. We conclude from the relatively high uranium to lead ratio that the Precambrian basement source is 'upper crustal' (Doe and Zartman, 1979), therefore probably sialic and an appropriate source for the abundant lead commonly found in these deposits.

Figure 72 illustrates our model for an 'average shale' growth curve which is applicable to the northern Canadian Cordillera. The 'average shale' curve is in reality the last part of a three-stage model for lead evolution. A meteoric growth curve generated in an environment with a relatively low uranium-lead ratio of 7.19 is applicable for the period between 4.57 and 3.7 Ma. Much evidence indicates that near 3.7 Ma an accretional stage of continental growth began. At this time a uranium-enriched differentiated crust formed with a slightly higher uranium-lead ratio of 9.74. Evolution of lead in average crust followed this growth curve until about 2.0 Ma ago. From this point onward the lead evolved in an even more uranium-rich environment with ratio 11.82.

TABLE 1. LEAD ISOTOPES ANALYSES^1 ON GALENA^2 FROM ZINC–LEAD DEPOSITS OF KNOWN AGE

Sample Number	Deposit Name	Map Name	Lat.° North	Long.° West	Lead Isotope Data (Relative 1S Error as %) $^{206}Pb/^{204}Pb$	$^{207}Pb/^{204}Pb$	$^{208}Pb/^{204}Pb$	Remarks
<u>Skarn Deposits (negative model age)</u>								
10084-001	A+B	YT084	60.12	130.43	19.516 (.08)	15.714 (.07)	39.657 (.11)	L.Cam PHYL
10093-001	Pike	YT093	62.18	130.65	19.324 (.06)	15.731 (.11)	39.428 (.10)	Had-M.Cam PHYL (skarn)
10095-001	Mar	YT095	62.03	129.84	19.324 (.12)	15.722 (.09)	39.460 (.09)	Had-M.Cam PHYL-QZIT(sk)
<u>Epigenetic: Cretaceous (ca. .12 Ga model age)</u>								
10093-001	McMillan (Qz Lk)	YT089	60.50	127.93	20.098 (.06)	15.820 (.09)	39.889 (.16)	Had ARGL-QZIT-LIMS
<u>Devonian-Mississippian (ca. .37 Ga)</u>								
G78AK-001	Alcock	BCOAK	57.67	125.42	18.984 (.09)	15.764 (.08)	39.561 (.09)	Dev-Miss SHAL
G78CQ-001	Cirque	BCOCQ	57.52	125.12	18.795 (.08)	15.689 (.08)	39.166 (.08)	Dev-Mis SHAL
G78DC-AVG	Driftpile (n=3)	BCODC	58.07	125.95	18.859 (.08)	15.669 (.06)	39.113 (.09)	Dev-Mis SHAL
G78EF-001	Elf	BCOEF	57.42	124.72	18.834 (.09)	15.661 (.09)	39.310 (.04)	Dev-Mis SHAL
G78FK-001	Fluke	BCOFK	57.42	124.87	18.846 (.08)	15.714 (.04)	39.477 (.06)	Dev-Mis SHAL
G79PI-001	Pie (float)	BCOPI	57.45	124.78	18.888 (.03)	15.739 (.10)	39.526 (.09)	M.Dev LIMS-SHAL
G79RG-001	Rough (shear)	BCORG	58.27	126.17	18.709 (.03)	15.617 (.07)	38.548 (.11)	Cam-Ord LIMS
10077-AVG	Jason (n=5)	YT077	63.15	130.25	18.695 (.07)	15.666 (.09)	38.863 (.10)	Dev-Mis SHAL
10078-AVG	Tom (n=5)	YT078	63.17	130.15	18.662 (.08)	15.672 (.06)	38.712 (.07)	Dev-Mis SHAL
20017-007	Keg (float)	NW017	64.00	129.23	18.907 (.10)	15.741 (.09)	39.086 (.11)	Ord? SHAL
20076-AVG	Vulcan (n=11)	NW076	62.31	128.21	18.839 (.08)	15.702 (.08)	39.094 (.10)	L-M.Dev SHAL-DOLM-CHER
Average for Dev-Mis SHAL: n=11, <u>arith. average</u> = $\overline{X}$ <u>std. error of mean</u> = $S \cdot n^{-1/2}$					[18.820 (.07)] 0.029	[15.694 (.07)] 0.013	[39.132 (.09)] 0.099	
<u>Young Carbonate Cluster (ca. .37 Ga)</u>								
10034-AVG	Birkeland (n=2)	YT034	64.15	131.92	18.808 (.04)	15.707 (.06)	38.488 (.08)	Had DOLM
10050-001	Odd	YT050	63.91	132.00	18.813 (.09)	15.696 (.07)	38.476 (.03)	Had DOLM
20003-002	Palm	NW003	64.40	129.80	18.879 (.08)	15.695 (.08)	38.771 (.04)	L. Cam DOLM
20004-002	Jude	NW004	64.37	129.87	18.892 (.05)	15.710 (.07)	38.925 (.12)	Ord-Sil DOLM
20008-009	Backbone	NW008	63.85	129.17	18.739 (.07)	15.647 (.05)	38.460 (.09)	Dev LIMS
20009-002	Weather	NW009	63.97	129.28	18.761 (.06)	15.700 (.08)	38.574 (.13)	Dev DOLM
20011-001	Lau	NW011	63.85	129.35	18.800 (.05)	15.692 (.06)	38.807 (.07)	L. Cam DOLM
20012-006	Twitya	NW012	64.03	129.27	18.691 (.05)	15.652 (.09)	38.564 (.09)	M. Dev DOLM
20022-001	Guild	NW022	64.63	130.10	18.798 (.08)	15.680 (.12)	38.761 (.05)	Ord-Dev? DOLM
20023-014	Rev:Main	NW023	64.13	129.33	18.762 (.22)	15.675 (.08)	38.537 (.29)	Ord-Sil DOLM
20023-098	Rev:Waterfall	NW023	64.13	129.33	18.747 (.09)	15.662 (.02)	38.498 (.09)	Ord-Sil DOLM
20023-137	Rev:Cirque	NW023	64.13	129.33	18.767 (.06)	15.653 (.08)	38.509 (.05)	Ord-Sil DOLM
20025-008	Tegart	NW025	64.53	130.17	18.770 (.10)	15.680 (.09)	38.823 (.08)	Ord-Sil DOLM
20034-007	Kind	NW034	64.37	129.73	18.779 (.10)	15.684 (.08)	38.846 (.06)	Ord-Sil DOLM
Average for Carb Cluster: n=14, <u>arith. average</u> = $\overline{X}$ <u>std. error of mean</u> = $S \cdot n^{-1/2}$					[18.786 (.08)] 0.014	[15.681 (.07)] 0.006	[38.646 (.01)] 0.044	

Silurian (ca. .44 Ga)								
10064-001	Kate	YT064	62.25	130.68	18.712 (.17)	15.720 (.10)	38.874 (.08)	Ord-Sil QZIT-SHAL
10069-001	Maxi	YT069	61.63	129.17	18.749 (.10)	15.726 (.06)	38.843 (.07)	L.Pal PHYL
10094-001	Pay	YT094	61.98	130.50	18.672 (.05)	15.704 (.12)	38.788 (.05)	Sil-L.Dev QZIT-CARB
10091-001	Howards Pass-XY	YT091	62.47	129.18	18.590 (.10)	15.621 (.10)	38.592 (.09)	L.Sil SHAL
10091-002	Howards Pass-AN	YT091	62.47	129.18	18.602 (.10)	15.657 (.08)	38.583 (.11)	L.Sil SHAL
10091-003	Howards Pass-OP	YT091	62.47	129.18	18.553 (.08)	15.630 (.04)	38.561 (.08)	L.Sil SHAL
10073-001	Matt Berry	YT073	61.47	129.40	18.689 (.07)	15.698 (.06)	38.576 (.08)	L.Pal PHYL
Average for Sil SHAL: n=7, arith. average = $\bar{X}$					[18.652 (.09)]	[15.679 (.08)]	[38.688 (.08)]	
std. error of mean = $S \cdot n^{-1/2}$					0.027	0.016	0.053	
Ordovician (ca. .48 Ga)								
20016-001	Tap	NW016	63.95	129.13	18.440 (.08)	15.665 (.10)	38.511 (.07)	Ord SHAL
20029-002	Sonnendrucker	NW029	64.83	131.50	18.477 (.08)	15.637 (.10)	38.683 (.07)	Ord-Sil SHAL
20065-003	Show: 106/B/14W	NW065	64.8A[3]	131.2A[3]	18.586 (.06)	15.739 (.06)	38.983 (.05)	Ord-Sil SHAL-LIMS
20068-007	Show: 106/B/10W	NW066	64.6A[3]	130.8A[3]	18.543 (.07)	15.692 (.05)	38.655 (.06)	Ord-Sil SHAL-LIMS
Average for Ord SHAL: n=4, arith. average = $\bar{X}$					[18.512 (.07)]	[15.683 (.08)]	[38.708 (.06)]	
std. error of mean = $S \cdot n^{-1/2}$					0.032	0.022	0.099	
Cambrian (ca. .55 Ga): Anvil District*								
10092-AVG	Grum (n=8)	YT092	62.27	133.23	18.470 (.09)	15.678 (.09)	38.427 (.08)	Cam SCHS-PHYL
10109-AVG	DY (n=22)	YT102	62.23	133.20	18.411 (.09)	15.649 (.09)	38.360 (.09)	Cam SCHS
10110-AVG	Faro (n=3)	YT110	62.37	133.37	18.357 (.08)	15.648 (.10)	38.286 (.10)	Cam SCHS
10125-AVG	Swim (n=2)	YT125	62.22	133.03	18.332 (.08)	15.637 (.06)	38.217 (.08)	Cam PHYL
10126-AVG	Vangorda (n=5)	YT126	62.23	133.22	18.349	15.659	38.282	Cam PHYL*
10127-AVG	SB (n=4)	YT127	62.18	133.90	18.481 (.07)	15.669 (.09)	38.500 (.12)	Cam SCHS-PHYL
10128-AVG	Sea (n=2)	YT128	62.18	133.90	18.350	15.644	38.280	Cam SCHS*
Average for Anvil District: n=4, arith. average = $\bar{X}$					[18.393 (.08)]	[15.655 (.09)]	[38.336 (.09)]	
std. error of mean = $S \cdot n^{-1/2}$					0.023	0.005	0.037	
Epigenetic: Cambrian (ca. .51 Ga model age)								
100001-004	Carne/Eg	YT001	64.85	133.13	17.933 (.07)	15.587 (.10)	37.841 (.09)	Had SHAL
Syngenetic: Helikian (ca. 1.43 Ga model age)								
10082-AVG	Hart River (n=2)	YT082	64.63	136.87	16.519 (.10)	15.455 (.08)	36.374 (.12)	Hel ARGL

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1. All analyses done in the Geology - *Geophysics Laboratory, The University of British Columbia.*
2. Host rock ages recorded as: Cam=Cambrian, Dev=Devonian, Had=Hadrynian, Hel=Helikian L=Lower, M=Middle, Mis=Mississippian, Ord=Ordovician, Pal=Paleozoic, Unk=unknown, ?=uncertain.
3. Host rock types redorded as: ARGL=argillite, CARB=carbonate, CHER=chert, DOLM=dolomite, LIMS=limestone, PHYL=phyllite, QZIT=quartzite, SCHS=schist, SHAL=shale.
4. *Values, from LeCouteur (1973), are adjusted to conform to the same standard base used in our analyses.*

In the northern Canadian Cordillera, at least, our 'average shale' growth curve is more suitable for calculating model ages of stratiform shale-hosted deposits than any published models. Because we can either calculate model ages from the growth curve or assign ages to deposits if their measured isotopic ratios coincide with established clusters, we can make some interesting and significant interpretations.

(1) 'Young' (post-Cambrian) carbonate-hosted zinc-lead deposits have galena-lead isotope ratios (Table 1) that plot within the Devono-Mississippian shale cluster but are distinct from shale clusters of other ages (Figs. 71 and 73). This strengthens arguments made elsewhere (*ibid.*) that these two types of deposit, although formed in different environments, are related to the same metallogenic event – namely, dewatering of the Selwyn shale basin during Devono-Mississippian time.

(2) Vulcan deposit, Northwest Territories, has galena-lead isotope ratios that plot near the centre of the Devono-Mississippian shale cluster on Figure 71. A year ago host rocks for this deposit were thought to be of Ordovician to Silurian age. Recent field mapping, however, has shown the host rocks to be Early to Middle Devonian in age (R. Hewton, 1980, personal communication). It is significant to geological exploration that our galena-lead isotope data indicate that the deposit is syngenetic; by the earlier stratigraphic interpretation it was epigenetic. It apparently formed during a Devono-Mississippian metallogeny related to dewatering of the Selwyn shale basin and consanguineous deposition of stratiform, syngenetic shale-hosted deposits like the Tom-Jason deposit in Yukon Territory and those north of MacKenzie.

(3) The Rough showing is situated close to the newly discovered shale-hosted deposits in northeastern British Columbia but lies in a possible shear zone in Ordovician carbonates. Lead isotope data from this deposit fall in the field of Devono-Mississippian deposits on Figure 71, so the deposit is probably epigenetic.

(4) Matt Berry and Maxi deposit, Yukon Territory, have galena-lead isotope ratios that plot in the Silurian shale cluster (Fig. 71). Both deposits occur in phyllite with a poorly defined Early Paleozoic age. Thus, the deposits formed during a Silurian metallogenic event and it is plausible that they are syngenetic.

(5) Anvil district, Yukon Territory (point 4, Figs. 70 and 73) is, according to isotopic evidence, Cambrian in age (Fig. 71), as suspected by others.

(6) The Carne/Eg deposit, Yukon Territory (point 5, Figs. 70 and 73), is in Hadrynian shale. Galena-lead isotope ratios from this deposit give a model age, based on our average shale growth curve, of about 520 Ma. Consequently, the deposit is probably epigenetic. Coincidentally, perhaps, this is the age of mineralization in most pre-Ordovician ('old') carbonate rocks determined previously by us from galena-lead isotopes (*ibid.*), minor elements in sphalerite, and stratigraphic distribution of the deposits (McLaren and Godwin, 1979a and 1979b).

(7) The Hart River deposit, Yukon Territory (point 6, Figs. 70 and 73), is in Helikian argillite. Galena-lead isotope ratios from this deposit give a model age of about 1.43 Ma. This is slightly older than ages reported in Morin (1979) calculated from models of Stacey and Kramers (about 1.3 Ma) or Cumming and Richards (about 1.2 Ma). Since the host rock age is apparently the same as the deposit model age, the deposit is likely to be syngenetic.

(8) The McMillan (Quartz Lake) deposit, Yukon Territory (point 7, Figs. 70 and 73), hosted by Helikian sedimentary rocks, is unlikely to be syngenetic as is widely believed. Galena-lead isotopes from this deposit are highly radiogenic suggesting a complex history of formation. It is perhaps significant that our average shale growth curve defines a model age for this deposit of about 120 Ma (Cretaceous). Granitic intrusions in the vicinity of

this deposit are also Cretaceous. We conclude that the deposit is epigenetic and speculate that the granitic intrusions might be responsible for its formation.

(9) Galena-lead isotopes from several deposits plot in a field on Figure 73 that we previously defined (*ibid.*) for vein and skarn deposits of Cretaceous age. From our average shale growth curve, negative ages were obtained for these deposits. Although the field relationships of these deposits could not conclusively distinguish whether they are metamorphosed syngenetic deposits or epigenetic skarn deposits, the isotopic evidence shows them to be the latter.

We believe that definition of our average shale growth curve for the northern Canadian Cordillera on Figures 71 and 72 has both theoretical and obvious exploration applications. From galena-lead isotope data we are able to define:

(1) basement source ages and geochemistries,
(2) a series of major metallogenic events and relationships between different classes of deposits,
(3) the age of a deposit in many instances, and
(4) *whether a deposit is syngenetic or epigenetic.*

This information, particularly the last two items, can be of critical importance in defining exploration models for the evaluation of properties.

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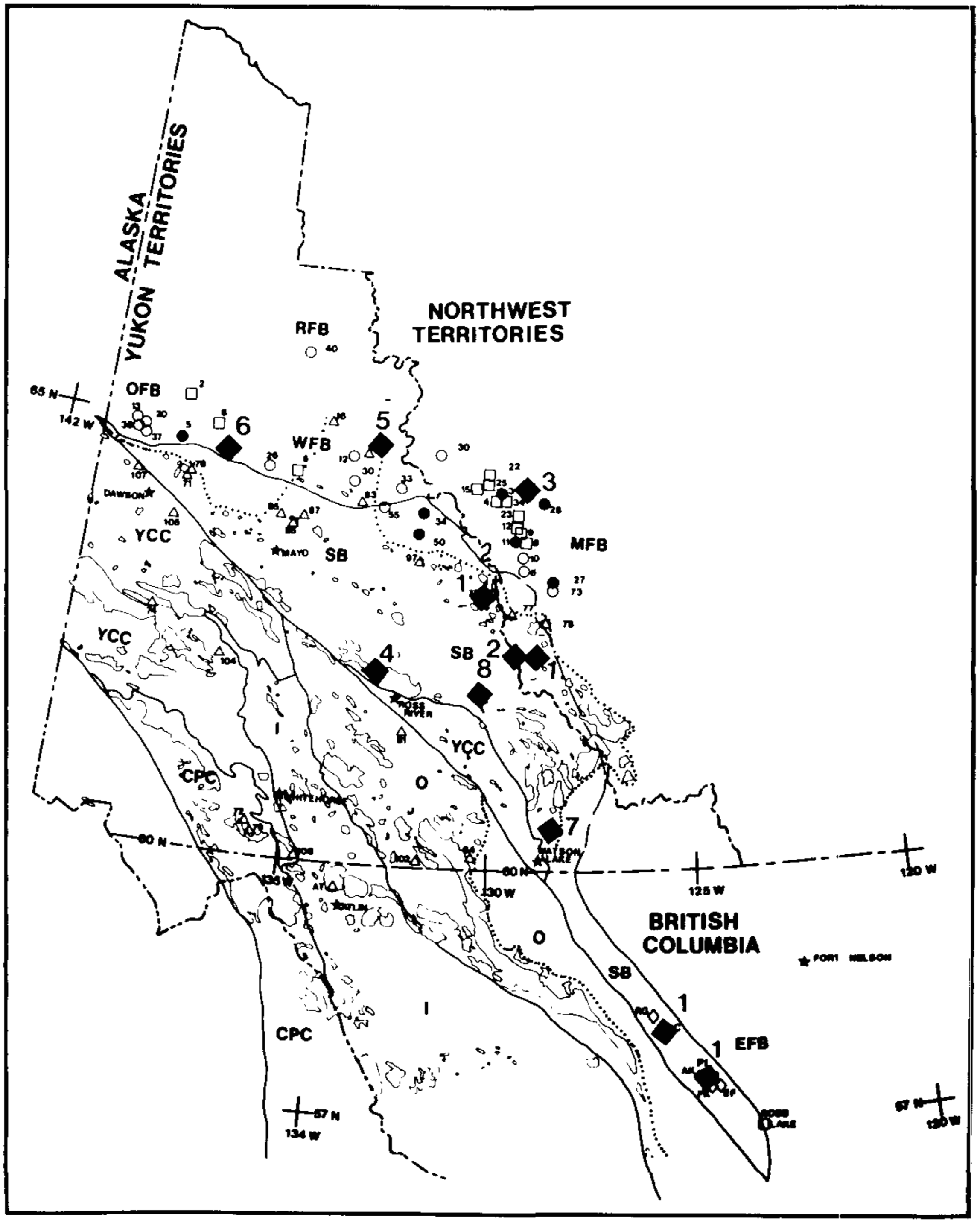

Figure 70. Location of galena-lead isotope analyses on Figure 71. Small circles are 'old carbonate' hosted, small squares are 'young carbonate' hosted, and small triangles are 'silver rich' vein and skarn deposits. Large numbered diamonds locate those sale-hosted deposits with analyses in Table 1. 1 = Devono-Mississippian; 2 = Lower Silurian; 3 = Ordovician; 4 = Cambrian; 5 = Cambrian model age; 8 = negative model age. I = Intermontane Belt; O = Omineca Crystalline Belt; SB = Selwyn Basin; OFB = Ogilvie Fold Belt; WFB = Wernecke Fold Belt; RFB = Richardson Fold Belt; MFB = Mackenzie Fold Belt; EFB = East Fold Belt.

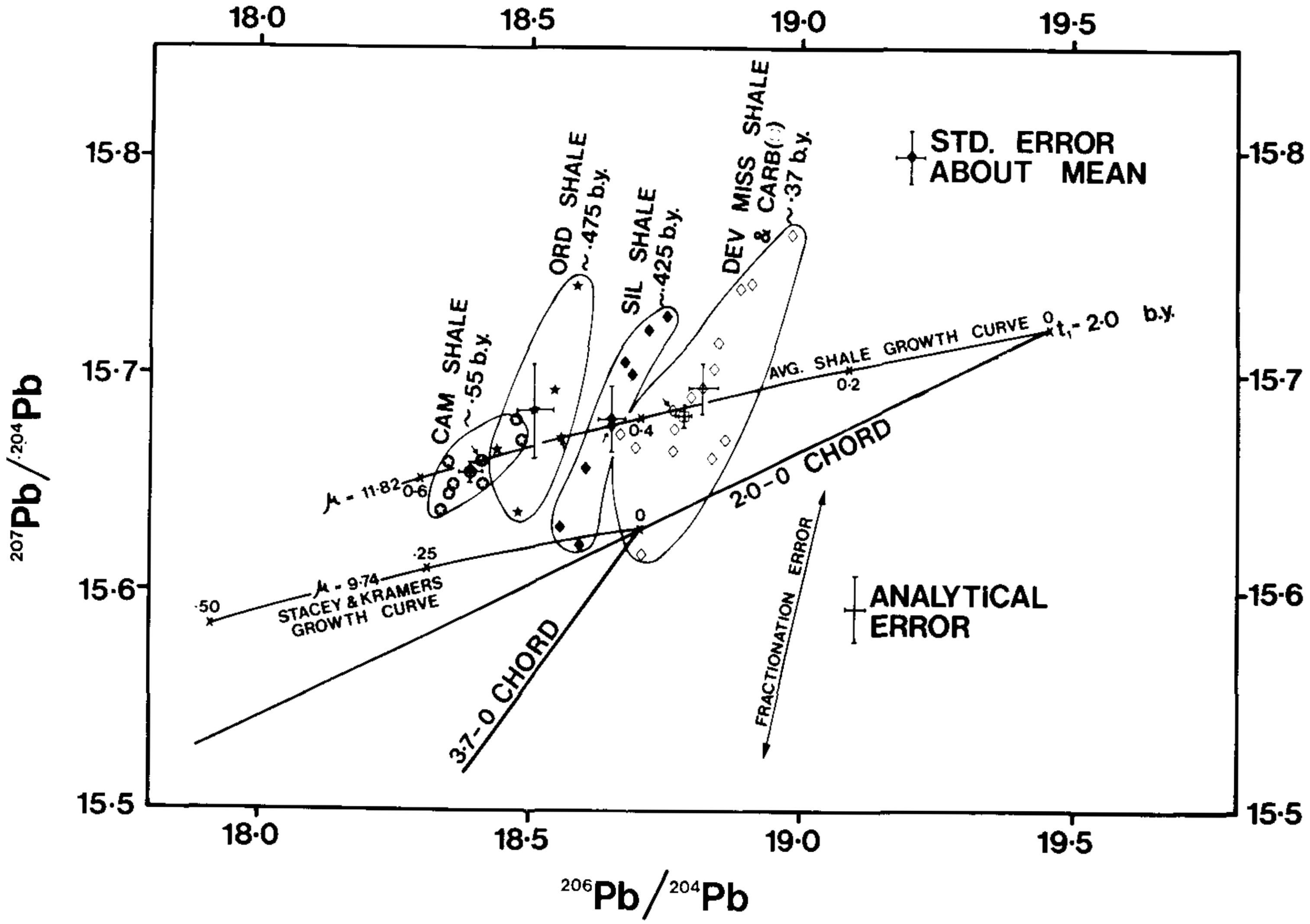

Figure 71. Detailed plot of isotopic ratios in Table 1 from shale-hosted deposits grouped from Cambrian to Devono-Mississippian in age. Stacey and Kramers' growth curve and our average shale growth curve for the northern Canadian Cordillera are defined.

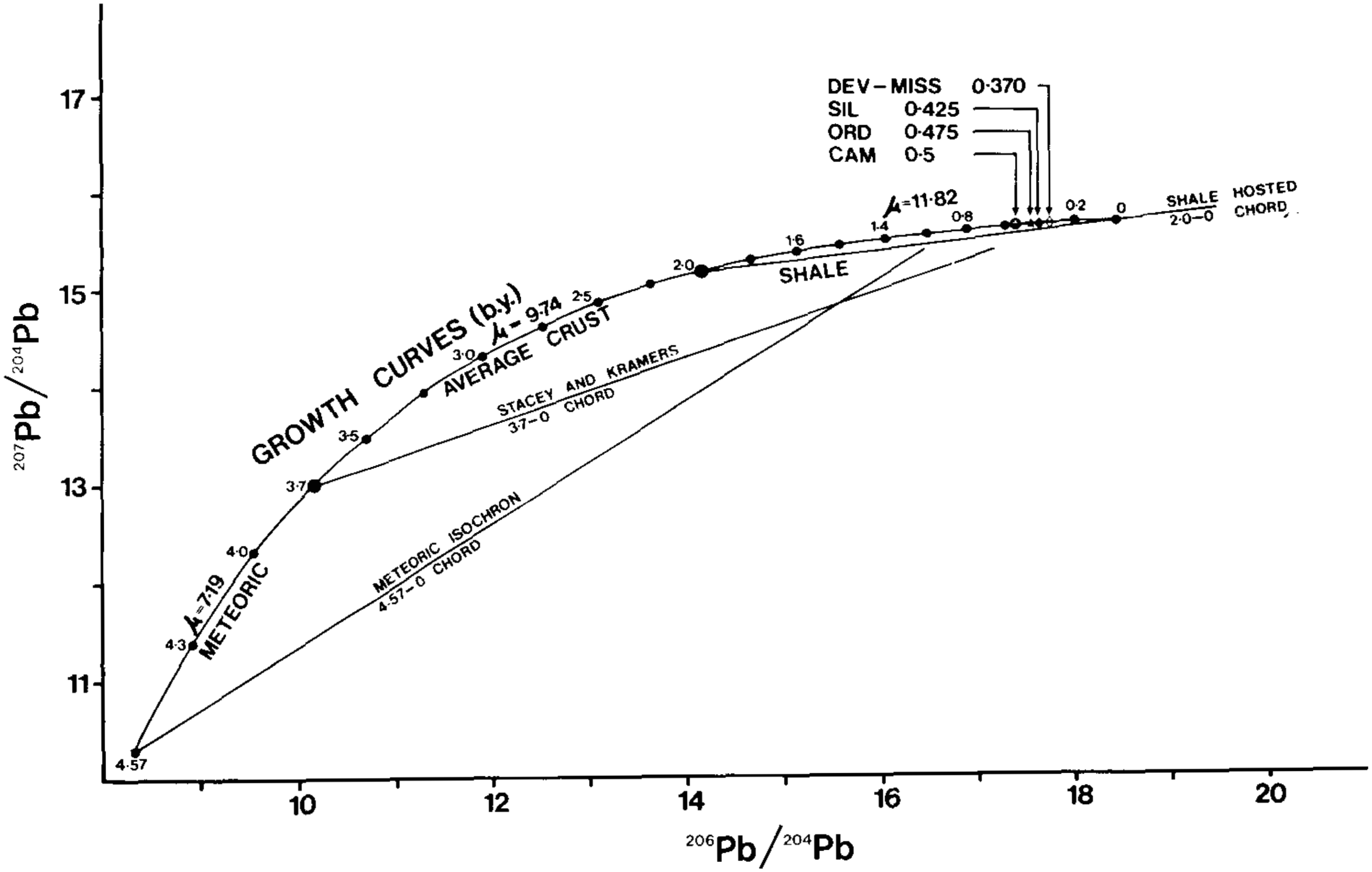

Figure 72. Galena-lead isotope analyses from stratiform, shale-hosted deposits of Cambrian to Devono-Mississippian age in or adjacent to the Selwyn Basin, British Columbia, and the Yukon Territory. A three-stage evolution in the growth curves is implied for the northern Canadian Cordillera (4 300 to 3 700 Ma, 3 700 to 2 000 Ma, and 2 000 to 0 Ma). Note that analyses for labelled deposits fall too close to the 3 700 to 0 cord of Stacey and Kramers to give meaningful ages. Model ages from our average shale growth curve appropriately are between 300 and 600 Ma.

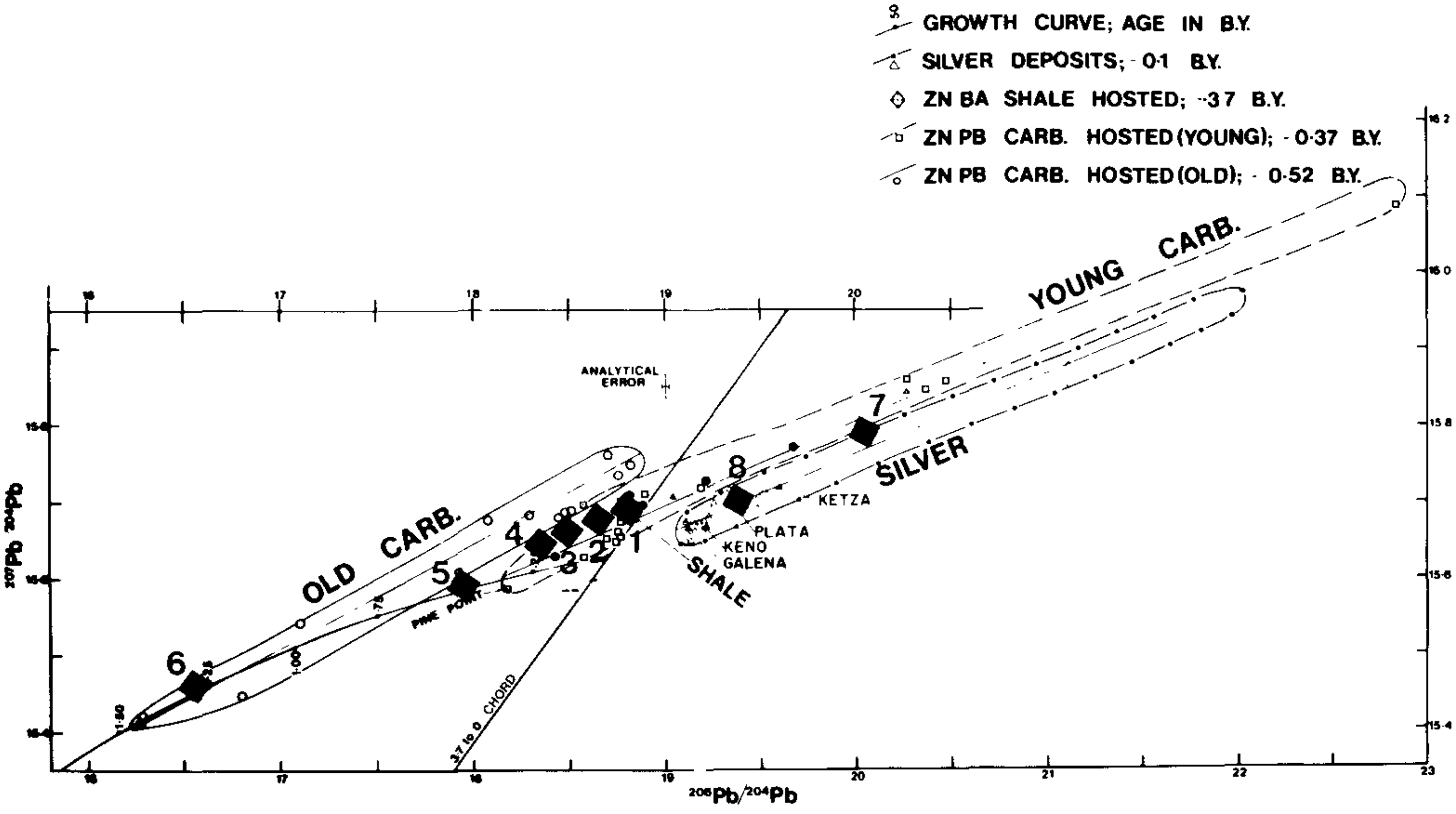

Figure 73. Galena-lead isotope analyses from shale-hosted deposits plotted as large diamonds on a figure adapted from Godwin, *et al.* (in press) which shows fields where most isotope values fall for: (1) pre-Ordovician ('old') carbonate-hosted deposits, (2) post-Cambrian ('young') carbonate-hosted deposits, and (3) vein and skarn 'silver' rich deposits. Numbers on large diamonds are referred to in the text and in caption of Figure 70.