THE USE OF PRODUCTION DATA AS AN EXPLORATION GUIDELINE FOR Ag-Pb-Zn-Au VEIN AND REPLACEMENT DEPOSITS, NORTHERN KOKANEE RANGE, SOUTHEASTERN BRITISH COLUMBIA (82F, K)

By Georges Beaudoin
University of Ottawa
D.F. Sangster
Geological Survey of Canada

KEYWORDS: Economic geology, vein, silver, lead, zinc, Sandon, Ainsworth, Slocan, production data, exploration, Kokanee Range

INTRODUCTION

In a series of papers Orr (1971), Orr and Sinclair (1971), Sinclair (1974, 1979, 1982), Goldsmith and Sinclair (1985), and Goldsmith *et al.* (1986) used production statistics to investigate metal grades, metal ratios, and deposit density zonations on a mining-camp scale and attempted to define statistical relationships between metal grades and the size of an orebody using multiple regression and discriminant analysis. Goldsmith and Sinclair (1985) found that statistical models differed significantly from camp to camp and standard errors could be reduced using multiple independant variables (*i.e.* metal grades). The most important variable controlling the variance of their models, although different from camp to camp, in each case was negatively correlated to tonnage and of minor economic importance.

In the present study, we investigate the use of production data as guidelines to the exploration for new mineral resources in a formerly very active mining area. The study area is located north of the city of Nelson, southeastern British Columbia, between Slocan and Kootenay lakes and comprises the old mining camps of Slocan, Slocan City and Ainsworth. The deposits consist of silver-lead-zinc-gold veins and replacements which occur in all sedimentary and intrusive rocks outcropping in the area, with the exception of a few of the Eocene lamprophyre dikes which are post mineralization. The deposits consist mainly of: veins and lenses in fault zones of various widths and fabrics, where mineralization typically displays open space filling textures and is commonly brecciated and deformed by later fault movements; and massive replacements of limestone surrounding fractures. Although replacement deposits are less numerous than vein deposits, they account for about 55 per cent of ore production in the study area, with the Bluebell replacement deposit representing 46 per cent of total production. Mineralogy is predominantly galena and sphalerite with accessory pyrite, pyrrhotite, chalcopyrite and a variegated suite of silver minerals and sulphosalts in a gangue of siderite, dolomite, calcite or quartz. The reader is referred to Cairnes (1934, 1935), Hedley (1945, 1952), Little (1960), Brown and Logan (1989), Beaudoin (1990) and Beaudoin and Sangster (1990) for more details of individual deposits and regional geology.

Cumulative production data for the study area are presented in Table 2-2-1. Metals such as zinc were not mined in the early years because their occurrence in the ore concentrate resulted in a penalty from the smelter. Zinc production data must therefore be used with caution and we have limited its use to a minimum in this study. Similarly, cadmium data are suspect because of the close association of the metal with sphalerite. Copper was recovered from only a few deposits and was not deemed to be sufficiently ubiquitous to warrant investigation in this study. Additionally, in small operations rich ore shoots were mined selectively, thus tending to increase overall ore grades. Accordingly we tried to avoid the use of grades in our study and, instead, used cumulative tonnages of ore mined, metal recovered, and metal ratios. Data for silver, lead, zinc and gold were selected for this study.

The British Columbia Ministry of Energy, Mines and Petroleum Resources MINFILE database was used as our source of production data. Each of the 272 deposits selected produced more than one tonne of ore. No attempts were made to verify the accuracy of individual records except for the Silvana mine of Treminco Resources Limited, the only current producer in the area, for which cumulative production to 1988 was used.

TABLE 2-2-1
CUMULATIVE PRODUCTION FROM THE NORTHERN KOKANEE RANGE

Tonnage	10 432 412 tonnes
Pb	530 240 663 kg
Zn	505 399 616 kg
Cu	2 867 915 kg
Cd	1 771 485 kg
Ag	2 623 406 019 g
Au	961 483 g
Cumulative metal ratios[1]	
Pb/(Pb+Zn)	0.51
(Ag·1000)/[(Ag·1000)+Pb]	0.83
Ag/[Ag+(Au·1000)]	0.73

[1] ratios computed using mass units of cumulative production

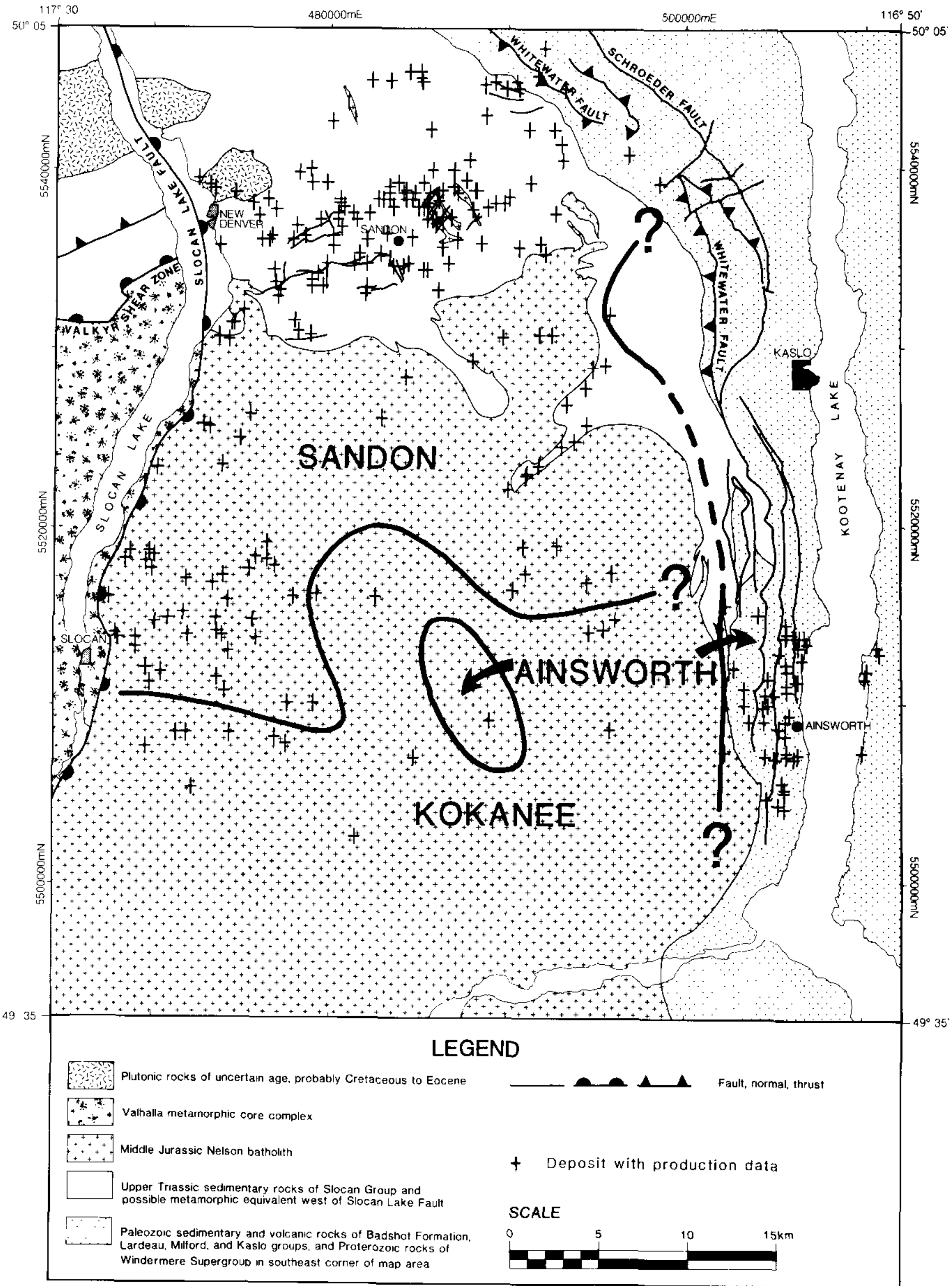

Figure 2-2-1. Location of deposits from the study area with production data recorded in MINFILE database. The areas containing deposits with lead isotope ratios typical of Sandon, Ainsworth, and Kokanee groups are broadly outlined.

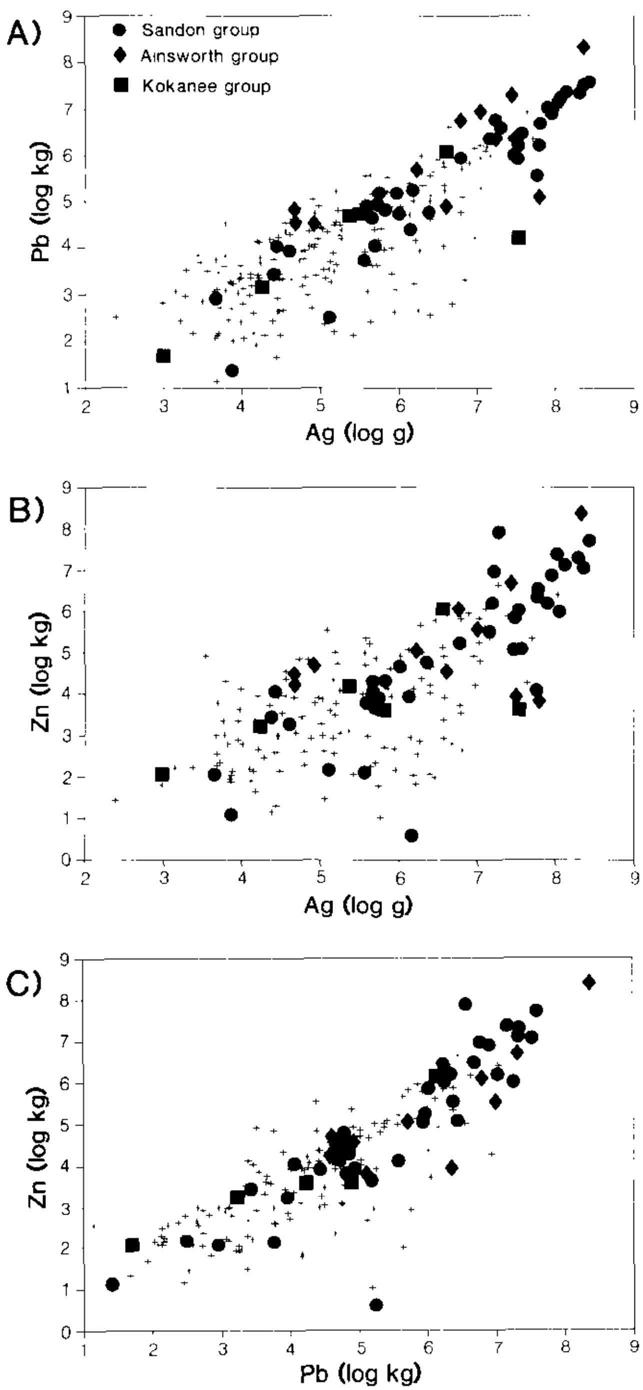

Figure 2-2-2. Log-log scatter plots of total metal production per deposit. See text for discussion. (A) Pb versus Ag. (B) Zn versus Ag. (C) Pb versus Zn.

DESCRIPTION OF CUMULATIVE PRODUCTION DATA

Deposits in the Slocan, Slocan City and Ainsworth mining camps are either hosted by the Middle Jurassic Nelson batholith or occur peripheral to it in sedimentary rocks of the Badshot Formation, Lardeau, Kaslo, Milford and Slocan groups of Early Cambrian to Late Triassic age. Logan *et al.* (1987) found that lead isotope ratios of galena from some of the deposits fell into three groups. This grouping was confirmed using all published galena lead isotope ratios. The three groups of deposits have a distinct geographical distribution and we have used this grouping to study the production statistics. Due to lack of lead isotope data, however, only 24 per cent of the deposits could be assigned to a group. The locations of the mineral deposits for which production data exist are shown in Figure 2-2-1, with a broad outline of the geographical distribution of the three groups of lead isotopes. The three groups of lead isotopes are named Sandon, Kokanee and Ainsworth, and production data will be discussed in relation to the location of the deposits within the areas defined by the three groups.

The three most abundant metals, silver, lead and zinc display log-log linear relationships (Figure 2-2-2). Scatter plots of the log of the amount of metal extracted from each deposit exhibit a sharp upper limit and a convex lower limit. The peculiar half-moon shape of the log-log arrays does not seem to be related to population statistics but to anthropogenic artifacts as discussed below. On each of these plots the three lead isotope groups cannot be distinguished from one another and will therefore be treated as a single statistical population.

In Figures 2-2-2b and 2c the lower limit of the scatter plots comprises deposits with high contents of silver or lead relative to zinc. As zinc was an unwelcome commodity in the early days of mining (backfilling with zinc-bearing waste is reported for the Payne deposit) selective mining probably resulted in lower cumulative production of zinc. The reasons for the irregular lower limit of the array in the log Pb versus log Ag (Figure 2-2-2a) is less obvious as galena was one of the ore minerals specifically sought during mining. For small deposits, it can be argued that selective mining of a specific texture of foliated galena ("steel galena"), considered by miners to be rich in silver, is responsible for the scatter. Visible pyrargyrite is almost always found in foliated, fine-grained galena at the Silvana mine, whereas it is rarely found in large lenses of massive galena. Another explanation for deposits with high cumulative production of silver relative to lead and also zinc, is that these deposits represent the so-called "dry ores" of Cairnes (1934), which are characterized by quartz veins with disseminated silver minerals and sulphosalts and little galena or sphalerite. Their lead isotopes, however, are similar to the other deposits richer in lead and zinc.

Interestingly, gold does not show a linear relationship with either lead, zinc or silver. There is a weak negative correlation between copper and gold. The reasons for the apparently different behavior of gold are unresolved, but may be related to its associated minerals.

EXPLORATION GUIDELINES

Production tonnage is a minimum estimate of the size of a deposit because unrecovered reserves are excluded, and losses during beneficiation must have occurred. To some

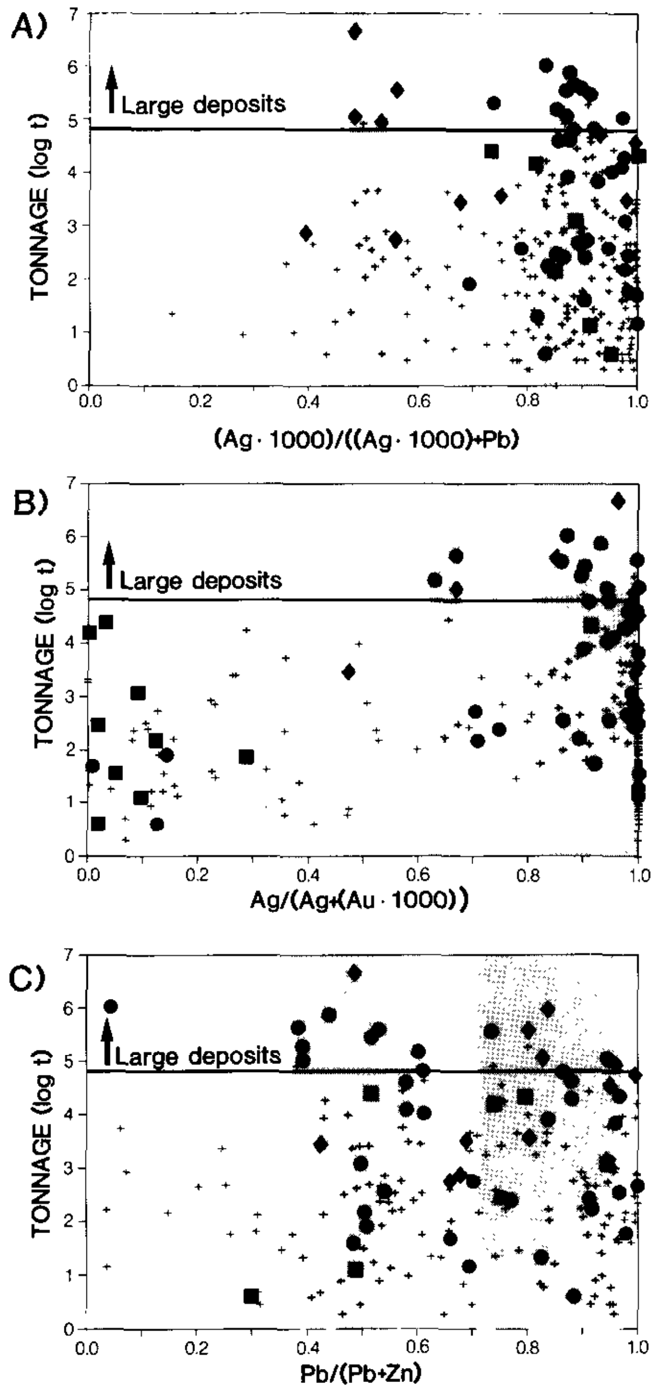

Figure 2-2-3. Log total production tonnage per deposit relative to metal ratios. Shaded areas comprise the ranges of ratios of the large deposits. The horizontal line at 63 000 tonnes separates large deposits from the rest of the data. Symbols as in Figure 2-2-2, all metals in kg. See text for discussion. (A) Tonnage versus (Ag · 1000)/[(Ag · 1000)+Pb] (B) Tonnage versus Ag/[Ag+(Au · 1000)]. (C) Tonnage versus Pb/(Pb+Zn).

extent, production tonnage is also a function of mining methods, especially in districts with a long mining history. For the purpose of this study, large orebodies are defined as those greater than 63 000 tonnes, the 50th percentile value for Canadian lead-zinc vein and replacement deposits (Sangster, 1986). Metal ratios for these large orebodies were used to provide empirical exploration guidelines to identify former small producers that may have potential for being larger. The technique should, of course, be regarded as only one of many tools to evaluate mineral occurrences or past producers. Nevertheless, there is a striking consistency in the metal ratios of large producers and the use of their ratios in assessing mineral exploration targets in the study area is proposed.

Silver:Lead Ratios

The graph of (Ag · 1000)/[(Ag · 1000)+Pb] versus log tonnage (Figure 2-2-3a) demonstrates that most of the large orebodies correspond with two ranges of ratios. The first range, between 0.47 and 0.57, comprises all the large orebodies of the Ainsworth group. The second range, from 0.82 to 0.93, comprises most of the large orebodies from the Sandon group. The Cork-Province deposit (082FNW094) ratio (0.74) is intermediate between Ainsworth and Sandon ranges. This deposit has lead isotope ratios typical of the Sandon group and the reason for its anomalous (Ag · 1000)/[(Ag · 1000)+Pb] ratio remains unknown. The Hewitt deposit (082FNW065), with a ratio of 0.97 is outside the Sandon range but is contained within the same fault zone as the Sandon group Van Roi deposit (082FNW064). Both have similar lead, sulphur, carbon and oxygen isotope ratios (Beaudoin, unpublished data) whereas the Van Roi has a (Ag · 1000)/[(Ag · 1000)+Pb] ratio within the Sandon range. There is thus justification for regarding the Van Roi and Hewitt as parts of the same orebody and calculating a new, weighted, ratio of 0.94. This, in turn, would redefine the Sandon range to extend from 0.82 to 0.95. This results in a Sandon range which excludes only one large orebody (Cork-Province). No deposit of the Kokanee group has a sufficiently large tonnage to qualify as a large orebody as defined in this study. The average (Ag · 1000)/[(Ag ·

TABLE 2-2-2
STUDENT'S t TEST COMPARING THE DATABASE WITH THE AU SUBSET

		Pb/(Pb+Zn)	Ag · 1000/(Ag · 1000)+Pb
1) Database	x[1]	0.69	0.84
	n[2]	195	251
2) Au subset	x	0.67	0.87
	n	114	125
Student's t test	DF[3]	307	374
	t[4]	0.083	0.036
	t_c[5]	2.576	2.576

[1] average
[2] number of observations
[3] degrees of freedom
[4] Student's t test of the ratio after logistic transformation
[5] critical value of Student's t test at a level of significance of $2\alpha=0.01$

1000)+Pb] ratio of the Kokanee group, however, falls within the Sandon group range (Table 2-2-2).

SILVER:GOLD RATIOS

The graph of Ag/[(Ag+(Au · 1000)] versus log tonnage (Figure 2-2-3b) also exhibits two ranges of ratios which contain all the large orebodies. One of the ranges, 0.84 to 1.00, contains a majority of the large deposits of both the Ainsworth and Sandon groups. A large number of deposits possess a ratio of 1.00; this is caused either by very low gold content in the orebody or, more commonly, by the absence of gold production data.

A second range of ratios, between 0.62 and 0.68, includes only three large orebodies. Two of them, the Victor (082FNW204) and Whitewater (082KSW033), are from the Sandon group whereas the other, the Kootenay Florence (082FNE016), is from the Ainsworth group. There is no obvious geographic or geologic reason for their higher gold content.

LEAD:ZINC RATIOS

A graph of Pb/(Pb+Zn) ratios versus log tonnage (Figure 2-2-3c) indicates that this ratio has a wide range, even for large orebodies. All but one large deposit (Lucky Jim, 082KSW023) are contained within two broad ranges extending from 0.37 to 0.61 and 0.71 to 0.97. Both contain deposits from the Ainsworth and Sandon groups.

ANALYSIS OF EXPLORATION GUIDELINES

Based on this analysis of metal ratios and deposit size, it is suggested that those small deposits in the study area which possess all three metal ratios falling within the favourable ranges defined here be considered exploration targets with good potential to contain further, undiscovered, ore reserves.

Gold data are available for 137 of the 272 deposits studied. We tested to see if the deposits with gold data are from a representative subset of the database. We have applied the logistic transformation to (Ag · 1000)/[(Ag · 1000)+Pb] and Pb/(Pb+Zn) ratios since they are constrained between 0 and 1 and have a skewed distribution. Student's t tests indicate that there is no statistical evidence suggesting that the means of the tranformed ratios from the gold data subset come from a different population than does the entire database (Table 2-2-2). Also, there are similar proportions in the gold data subset and the database of deposits within both favourable ranges of (Ag · 1000)/[(Ag · 1000)+Pb] ratios. Accordingly we conclude that the gold data subset is representative of the database.

Within the Ainsworth group, only one deposit falls within the favourable ranges of (Ag · 1000)/[(Ag · 1000)+Pb], Ag/[Ag+(Au · 1000)], and Pb/(Pb+Zn) ratios and hence, by this criterion, would be regarded as potentially larger than its past production would indicate (Table 2-2-3). Within the Sandon and Kokanee groups, 24 deposits are considered to have potential for being larger than their past production (Table 2-2-3). These 24 exploration targets represent 40 per cent of the deposits with favourable (Ag · 1000)/[(Ag · 1000)+Pb] ratios from the gold data subset. They represent 18 per cent of the gold data subset and about 9 per cent of the whole database. If, in fact, the gold data subset is representative of the database, as suggested above, the empirical exploration guidelines proposed in this paper should enable one to select about 18 per cent of the known deposits as potential new development targets in the study area. We suggest that this percentage is also a better estimate than the percentage (0.7%) obtained for the Ainsworth group because of the small number of deposits within the favourable ranges of ratios available in that group.

The efficiency of these exploration guidelines can be checked by verifying the past production of the targets identified in the study area. Of the 25 targets identified, nine (36%) produced more than 10 000 tonnes of ore including one with production over 50 000 tonnes, twelve (48%) have produced between 10 000 tonnes and 1000 tonnes and the remaining four (16%) have produced less than 1 000 tonnes. There are 38 deposits with more than 10 000 tonnes of production in the study area. Excluding the large orebodies as defined in this study, the nine deposits that have each produced more than 10 000 tonnes of ore represent 24 per cent of the deposits within this class of tonnage in the area. The proposed exploration guidelines are not biased by the larger scale mining operations and therefore permit selection of targets which have produced varied quantities of ore.

Figure 2-2-4 shows the locations of the 25 targets relative to the known large orebodies in the area. An obvious feature is the clustering of large orebodies in two relatively small areas; one near Sandon and the other near Ainsworth.

TABLE 2-2-3
LIST OF EXPLORATION TARGETS

MINFILE	NAME	PRODUCTION (Tonnes)
082FNE005	VIGILANT	4684
082FNW008	ALAMO	357
082FNW015	ALTOONA	8041
082FNW020	LAST CHANCE	9445
082FNW021	SURPRISE	44476
082FNW028	BELL	4146
082FNW035	RECO	6697
082FNW036	SLOCAN SOVEREIGN	4539
082FNW037	NOBLE FIVE	39812
082FNW042	ELKHORN	3071
082FNW043	WONDERFUL	28382
082FNW052	RUTH-HOPE	59753
082FNW054	RICHMOND-EUREKA	36651
082FNW057	IVANHOE	40294
082FNW060	MAMMOTH	19283
082FNW063	LUCKY THOUGHT	8951
082FNW068	NOONDAY	572
082FNW083	FLINT	171
082FNW148	ENTERPRISE	10687
082FNW177	MOUNTAIN CHIEF	2989
082FNW181	AMERICAN BOY	5948
082FNW197	CANADIAN	855
082KSW011	ANTOINE	10127
082KSW030	WELLINGTON	1779
082KSW031	CHARLESTON	2324

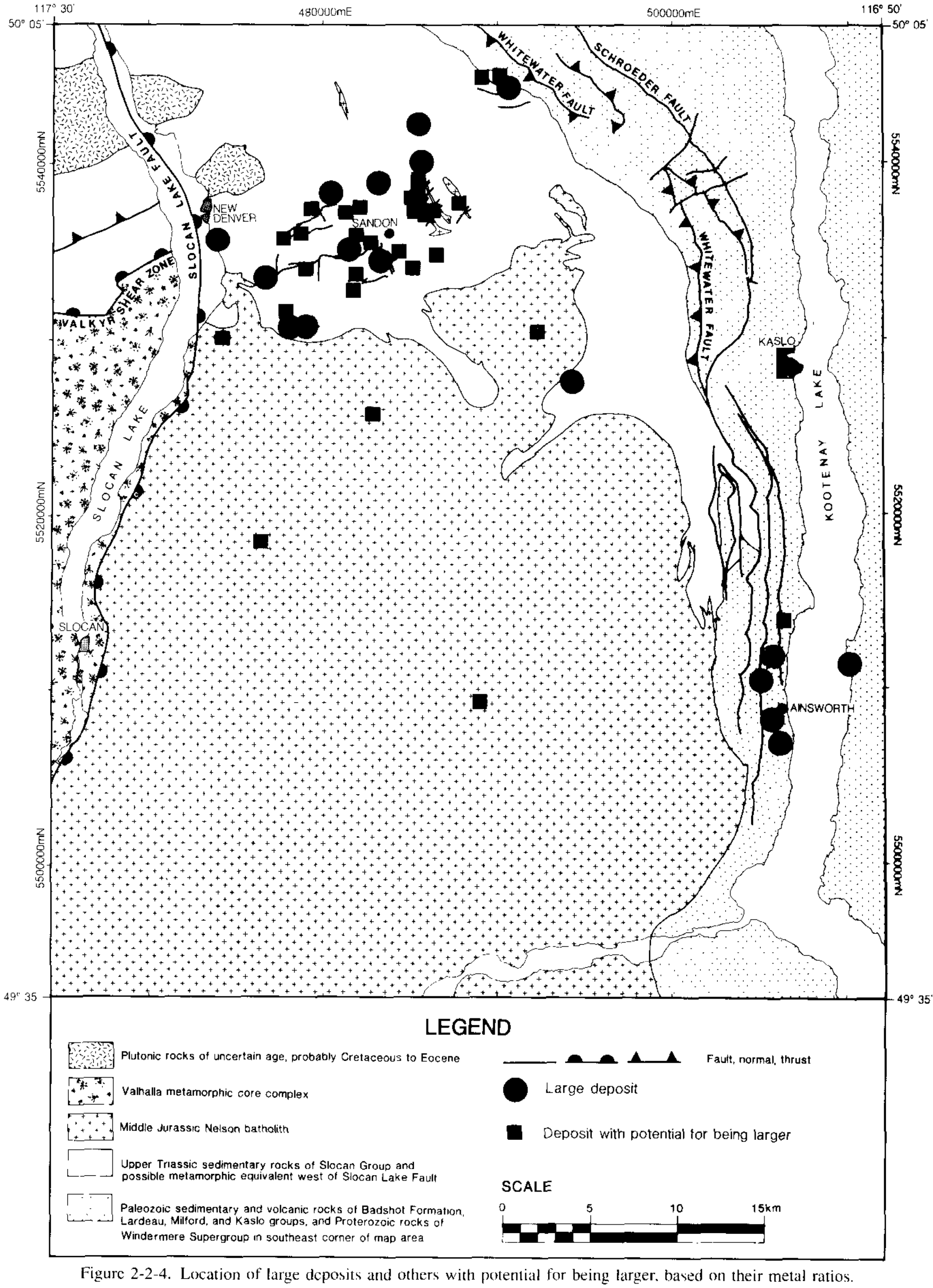

Figure 2-2-4. Location of large deposits and others with potential for being larger, based on their metal ratios.

Almost all the exploration targets are, however, confined to the area near Sandon.

Some of the targets are hosted by the same structure as some large orebodies. The most striking example is the "Main Lode" near Sandon. The "Main Lode" has been interpreted by numerous mine geologists and Hedley (1952) as a continuous fault zone containing several large orebodies: the Standard (082FNE180), Silvana (082FNE050) and Silversmith (082FNE053). Two of the proposed targets, the Ruth-Hope (082FNE052) and Richmond-Eureka (082FNE054) are also contained within the "Main Lode" and occur respectively between the Silvana and Silversmith deposits and to the east of the Silversmith deposit.

Metal zoning in the orebodies could reduce the accuracy of these exploration guidelines because a zoned deposit, if partially mined, would yield production metal ratios not representative of the deposit as a whole. Vertical mineralogical zoning is reported in the literature from nine deposits, although there is no quantitative information on this zoning. Metal zoning has also not been documented but would be expected if, indeed, there is mineralogical zoning. Reported vertical mineralogical zoning generally consists of increased abundances of sphalerite or siderite with depth relative to galena or quartz. At Silvana, metal ratios in millhead assays for individual stopes do not show evidence of either lateral or vertical zoning across the orebody. A poorly defined increase of (Ag · 1000)/[(Ag · 1000)+Pb] with depth may be present although detailed study of individual sections through the orebody shows similar, reverse, or nonsystematic variation of the same ratio. Careful investigation of paragenesis has shown neither vertical nor lateral mineralogical zoning at Silvana. Therefore it is concluded that vertical mineralogical and metal zoning, although

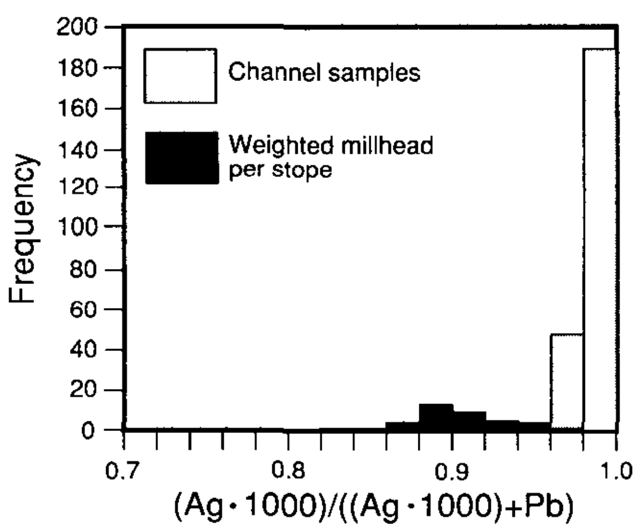

Figure 2-2-5. The histogram of (Ag · 1000)/[(Ag ·1000)+Pb] ratio, using weighted millhead data for each stope, is superposed over a typical histogram of (Ag · 1000)/[(Ag · 1000)+Pb] ratios from channel samples across the lode in stope 45-13-7, 8, Silvana Mine, Treminco Resources Limited.

reported, have not been conclusively demonstrated and, where investigated, have been shown to be nonexistent. Consequently, metal-ratio zoning is unlikely to have influenced the exploration guidelines proposed here.

Systematic channel sampling is a common method employed in the determination of metal grades and has been carried out in some stopes in the Silvana orebody. A typical histogram of (Ag · 1000)/[(Ag · 1000)+Pb] ratios from one of the stopes at Silvana (Figure 2-2-5a) shows that the ratios cluster between 0.97 and 1.00. No sample had a ratio either in the previously determined favourable range for the Sandon group (0.82-0.95) or close to the ratio for cumulative production data at Silvana (0.90). This contrasts with a strong mode for the (Ag · 1000)/[(Ag · 1000)+Pb] ratios of all millhead stope data between 0.88 and 0.90, similar to cumulative production data (Figure 2-2-5). It thus appears that channel sampling within individual stopes or lodes does not produce metal ratios directly comparable with production data. The reasons for the contrast remain obscure. It appears therefore that only production data should be used in conjunction with the exploration guidelines proposed here.

CONCLUSIONS

It is concluded that cumulative production data can be useful to assess the potential of past producers when a large database exists for a group of deposits which may be considered as a single population. In the study area, large deposits have a limited range of silver, lead, zinc, and gold metal ratios. We suggest that these common parameters can be used to identify those past producers which have the potential for being larger than indicated by their production record. The empirical exploration guidelines developed here could be modified by the discovery of new large orebodies with different metal ratios. From the currently available database, we propose that deposits in the study area with metal ratios within the following ranges have potential for being larger:

i) Deposits from the Ainsworth group having (Ag · 1000)/[(Ag · 1000)+Pb] ratios between 0.47 and 0.57 and deposits in the Sandon group having (Ag · 1000)/[(Ag · 1000)+Pb] ratios ranging from 0.82 to 0.95.

ii) Deposits in the Ainsworth and Sandon groups having Ag/[Ag+(Au · 1000)] ratios ranging from 0.84 to 1.00. It is also apparent that some deposits with ratios around 0.62 to 0.68 are also more likely to be large, with the added interest of being richer in gold.

iii) Deposits in the Ainsworth and Sandon groups having Pb/(Pb+Zn) ratios ranging from 0.36 to 0.61 and from 0.71 to 0.97.

ACKNOWLEDGMENTS

This study is being funded jointly by Natural Sciences and Engineering Research Council (NSERC) Operating Grant OGP 0038460 to D.F.S., by the Geological Survey of Canada, and by the British Columbia Ministry of Energy, Mines and Petroleum Resources (Geoscience Research Grant RG89-04 and RG89-37). G. Beaudoin is supported by NSERC, Fonds pour la formation de chercheurs et l'aide à la recherche and University of Ottawa scholarships. We wish to express our gratitude to Silvana Division of Teminco Resources Limited for allowing use of their production data. The MINFILE database was provided by the Geological Survey Branch, British Columbia Ministry of Energy, Mines and Petroleum Resources. We wish to thank W.D. Sinclair and R.G. Garrett for reviewing the report.

REFERENCES

Beaudoin, G. (1990): Geological Compilation Map, Northern Kokanee and Southern Goat Ranges, British Columbia; *B.C. Ministry of Energy, Mines and Petroleum Resources*, Open File 1990-18.

Beaudoin, G. and Sangster, D.F. (1990): Preliminary Report on the Silvana Mine and other Ag-Pb-Zn Vein Deposits, Northern Kokanee Range, British Columbia; *B.C. Ministry of Energy, Mines and Petroleum Resources*, Geological Fieldwork 1989, Paper 1990-1: pages 251-255.

Brown D.A. and Logan, J.M. (1989): Geology and Mineral Evaluation of Kokanee Glacier Provincial Park, (82S/11, 14) Southeastern British Columbia; *B.C. Ministry of Energy, Mines and Petroleum Resources*, Paper 1989-5, 47 pages.

Cairnes, C.E. (1934): Slocan Mining Camp, British Columbia; *Geological Survey of Canada*, Memoir 173, 137 pages.

Cairnes, C.E. (1935): Description of Properties, Slocan Mining Camp, British Columbia; *Geological Survey of Canada*, Memoir 184, 274 pages.

Goldsmith, L.B. and Sinclair, A.J. (1985): Multiple Regression, a Useful Quantitative Approach in Evaluating Production Data from Vein-type Mining Camps, Southern British Columbia; *B.C. Ministry of Energy, Mines and Petroleum Resources*, Geological Fieldwork 1984, Paper 1985-1: pages 411-418.

Goldsmith, L.B., Sinclair, A.J. and Read, P.B. (1986): Exploration Implications of Production and Location Data for Ag-rich Vein Deposits, Trout Lake Mining Camp, Southeastern B.C.; *Canadian Journal of Earth Sciences*, Volume 23: pages 1627-1640.

Hedley, M.S. (1945): Geology of the Whitewater and Lucky Jim Mine Areas, Slocan District, British Columbia; *B.C. Ministry of Energy, Mines and Petroleum Resources*, Bulletin 22, 54 pages.

Hedley, M.S. (1952): Geology and Ore Deposits of the Sandon Area, Slocan Mining Camp, British Columbia; *B.C. Ministry of Energy, Mines and Petroleum Resources*, Bulletin 29, 130 pages.

Little, H.W. (1960): Nelson Map-area, West Half, British Columbia (82FW1/2); *Geological Survey of Canada*, Memoir 308, 205 pages.

Logan, J.M., Gabites, J.E. and Brown, D.A. (1987): Galena Lead Isotope Characteristics of Mineralization in Kokanee Glacier Provincial Park, Southeastern British Columbia; *B.C. Ministry of Energy, Mines and Petroleum Resources*, Geological Fieldwork, Paper 1988-1: pages 535-541.

Orr, J.F.W. (1971): Mineralogy and Computer-oriented Study of Mineral Deposits in Slocan City Camp, Nelson Mining Division, British Columbia; unpublished M.Sc. thesis, *The University of British Columbia*, 143 pages.

Orr, J.F.W. and Sinclair, A.J. (1971): Mineral Deposits in the Slocan and Slocan City Areas of British Columbia; *Western Miner*, Volume 44: pages 22-34.

Sangster, D.F. (1986): Classification, Distribution and Grade-tonnage Summaries of Canadian Lead-Zinc Deposits; *Geological Survey of Canada*, Economic Geology Report 37: 68 pages.

Sinclair, A.J. (1974): Probability Graphs of Ore Tonnages in Mining Camps – A Guide to Exploration; *Canadian Institute of Mining and Metallurgy*, Bulletin, Volume 67: pages 71-75.

Sinclair, A.J. (1979): Preliminary Evaluation of Summary Production Statistics and Location Data for Vein Deposits, Slocan, Ainsworth, and Slocan City Camps, Southern British Columbia; *Geological Survey of Canada*, Current Research, Part B, Paper 79-1B: pages 173-178.

Sinclair, A.J. (1982): Multivariate Models for Relative Mineral Potential, Slocan Silver-Lead-Zinc Camp; *B.C. Ministry of Energy, Mines and Petroleum Resources*, Geological Fieldwork 1981, Paper 1982-1: pages 167-175.