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GRADE AND TONNAGE MODELS FOR COEUR D'ALENE-TYPE POLYMETALLIC VEINS

by

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INTRODUCTION

Mineralization in the Coeur d'Alene mining district, Shoshone County, Idaho consists principally of galena-sphalerite- and tetrahedrite-veins that have produced significant amounts of silver, lead, and zinc with lesser amounts of copper, gold, cadmium, and cobalt since the 1880s. The district has produced in excess of 31,000 metric tons of silver, more than any other mining district in the world except perhaps Cerro Rico de Potosí, Bolivia (30,000 to 60,000 metric tons; Whitney & Whitney, 1989). These veins are considered to be a distinct type unique to the district. The U.S. Geological Survey (USGS) has not attempted a quantitative estimate of undiscovered resources of these metals in the district, or in other regions favorable for the discovery of Coeur d'Alene-type polymetallic veins, due to the lack of descriptive and grade-tonnage models. This study, which presents grade-tonnage models for the various sub-types of Coeur d'Alene-type polymetallic veins, accompanies a new descriptive model (White, in press).

Polymetallic veins in the Coeur d'Alene district are hosted by several clastic units of the Proterozoic Belt Series, principally the Prichard, Burke, Revett, and St. Regis Formations (Fryklund, 1964). The veins consist of two major types: (1) galena-sphalerite-; and (2) tetrahedrite-veins, which are spatially distinct and may not be of the same age. Galena-sphalerite veins are further divided into those hosted by quartzite lenses within the argillaceous Prichard Formation, which are significantly smaller than those hosted by the Burke, Revett, and St. Regis quartzite units. Economic tetrahedrite veins are found only in the Revett and St. Regis Formations.

Tonnage and grades for these deposits were calculated or estimated from an exhaustive compilation of production, mill performance, and reserve data for the entire district. Data sources, too numerous to cite, were principally annual production records reported to the USGS and U.S. Bureau of Mines, previously released by Mitchell and Bennett, 1983, company annual reports to stockholders and other corporate records, contemporary technical literature and press reports, and other historical records. Tonnages and grades reported here are in-place values that include a normal allowance for dilution with waste or low-grade rock during extraction.

DEPOSIT DEFINITION

Coeur d'Alene-type polymetallic vein deposits are mainly structurally- and bedding-controlled replacement veins. Stockwork-like or disseminated mineralization, sometimes forming substantial orebodies, occurs in some favorable structural environments. Veins commonly pinch and swell, form splits, contain multiple orebodies in their hanging walls and foot walls, and commonly occur as closely spaced parallel structures. Individual orebodies, one or more to a vein, are typically much longer in their dip directions than along strike.

Deposits are defined here as one or more orebodies related by a common structure or set of structures, physically distinct from other sets of structures. No proximity rule is used to define physical distinctness because post-ore faulting has clearly brought different deposits into close proximity. The rationales for individual deposit definitions are given in Appendix I. The deposit definition used here is analogous to the definition of an oil and gas field in petroleum geology.

Tonnage and grade data, derived mostly from individual mine data, had to be adjusted to conform to deposit definitions. Property boundaries between mines do not generally correspond to geologic boundaries between orebodies. Over time, many mine properties have consolidated to form larger operating units. In general, historical production data from many mines had to be combined to account for the tonnage and grades of a particular deposit. Only in a few cases did a mine property cross deposit or deposit subtype boundaries.

DEPOSIT SUBTYPES

Although all of the deposits in the Coeur d'Alene district are related by a common genesis, and are essentially similar in character, they can be divided into a number of subtypes whose tonnage and grade must be modeled separately. The first division is that between galena-sphalerite- and tetrahedrite-veins whose different mineralogy results in different economic metal contents (Pb-Zn-Ag and Cu-Ag, respectively). Galena-sphalerite veins, as shown by Mitchell and Bennett, 1983, can be further divided into deposits within the Middle Prichard Formation, within the Prichard-Burke Formations transition zone, and within the Revett-St. Regis Formations transition zone, which differ markedly in terms of tonnage and grade.

Statistically, each of these subtypes form a homogenous subpopulation whose characteristics and differences have been investigated in detail using some statistical methods not previously applied to grade-tonnage modeling. Tonnage and grade data for each deposit in each subtype are listed in Appendix II. Summary statistics for each subtype are shown in Table 1.

From Table 1 a number of important differences among the various subtypes are readily apparent. All four subtypes show striking differences in mean and variance of tonnage and silver grades. Middle Prichard galena-sphalerite veins are substantially smaller, lower in silver and lead, and higher in zinc grade than Prichard-Burke and Revett-St. Regis galena-sphalerite veins. Mean lead and zinc grades for Prichard-Burke and Revett-St. Regis galena-sphalerite veins are similar but Prichard-Burke veins have a larger variance for lead and zinc grades, lower silver grades, and smaller tonnages.

Vein subtype	Number deposits	Tonnage 10^3 metric t	Ag grade grams per metric t	Pb grade percent	Zn grade percent	Cu grade percent
Galena-sphalerite veins						
Middle Prichard	27	218 ± 318	57 ± 46	5.3 ± 4.0	6.0 ± 3.6	
Prichard-Burke	16	1520 ± 2000	144 ± 92	8.9 ± 3.2	3.0 ± 2.5	
Revett-St. Regis	12	7850 ± 15100	250 ± 119	8.0 ± 2.0	3.0 ± 2.0	
Tetrahedrite veins						
Revett-St. Regis	7	3520 ± 5000	704 ± 155			1.0 ± 1.0

Table 1. Summary statistics of tonnage and grade (mean ± one standard deviation) for each subtype of Couer d'Alene polymetallic veins.

The statistical significance of these differences was evaluated using the Tukey-Kramer Honestly Significant Difference (HSD) test (Kramer, 1956) for the means and a one-way Analysis of Variance (ANOVA) for means and variances. Figures 1 to 4 provide a visual comparison of the natural logarithm of mean tonnage, silver grade, lead grade, and zinc grade among the three types of galena-sphalerite veins. Tukey-Kramer HSD test statistics at the 95 percent level for the means are presented in Table 2. Test statistics from the one-way ANOVA among all three subtypes are given in Table 3.

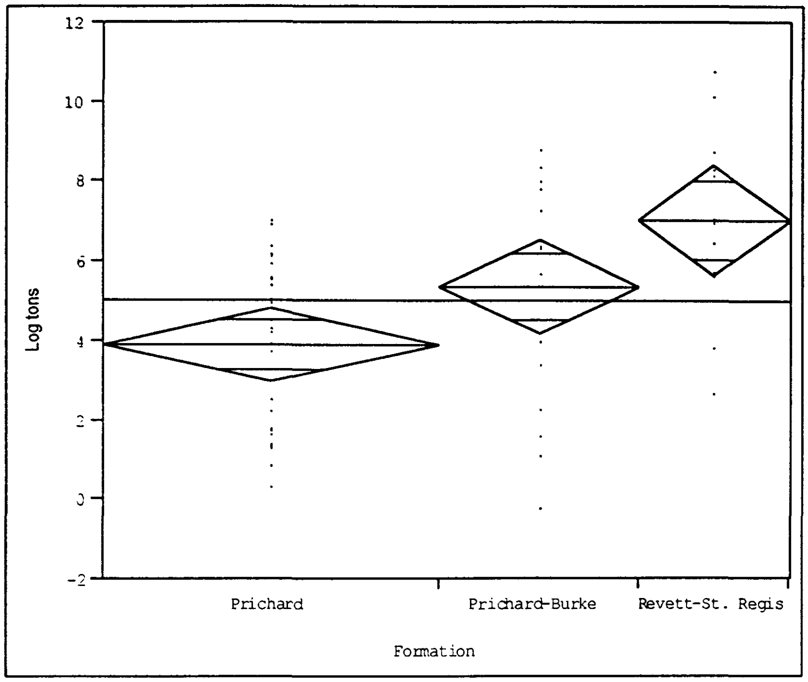

Figure 1. Comparison of the natural logarithm of mean tonnage among the three sub-types of galena-sphalerite vein. The line across each diamond is the group mean, the vertical span of each diamond is the 95 percent confidence interval, and the width of each diamond is proportional to sample size.

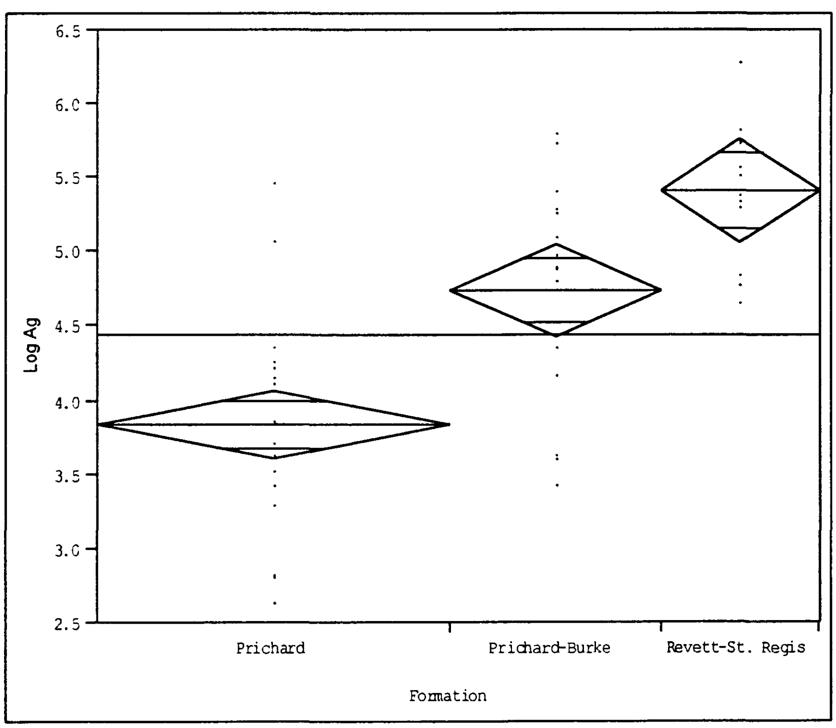

Figure 2. Comparison of the natural logarithm of mean silver grade between the three sub-types of galena-sphalerite vein. The line across each diamond is the group mean, the vertical span of each diamond is the 95 percent confidence interval, and the width of each diamond is proportional to sample size.

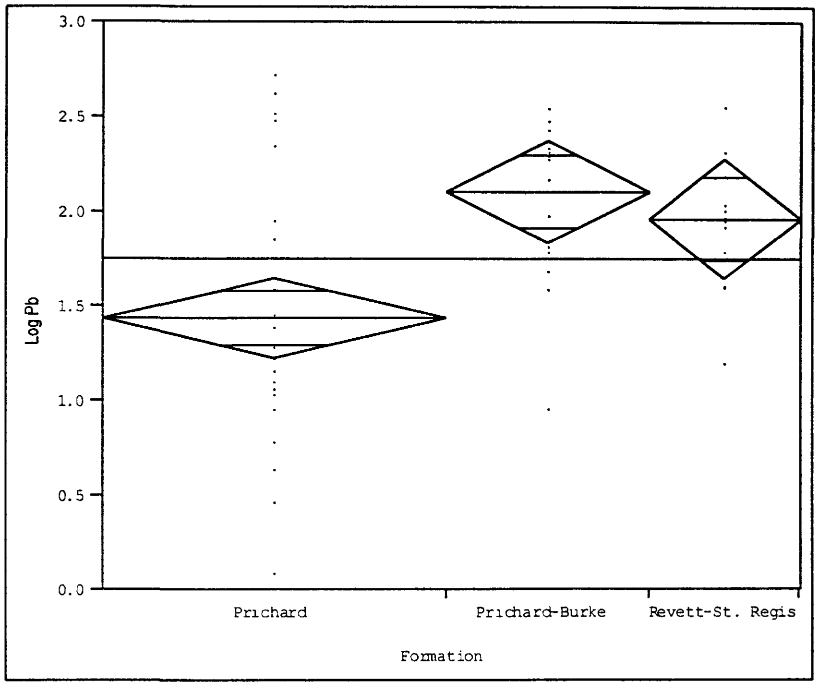

Figure 3. Comparison of the natural logarithm of mean lead grade between the three sub-types of galena-sphalerite vein. The line across each diamond is the group mean, the vertical span of each diamond is the 95 percent confidence interval, and the width of each diamond is proportional to sample size.

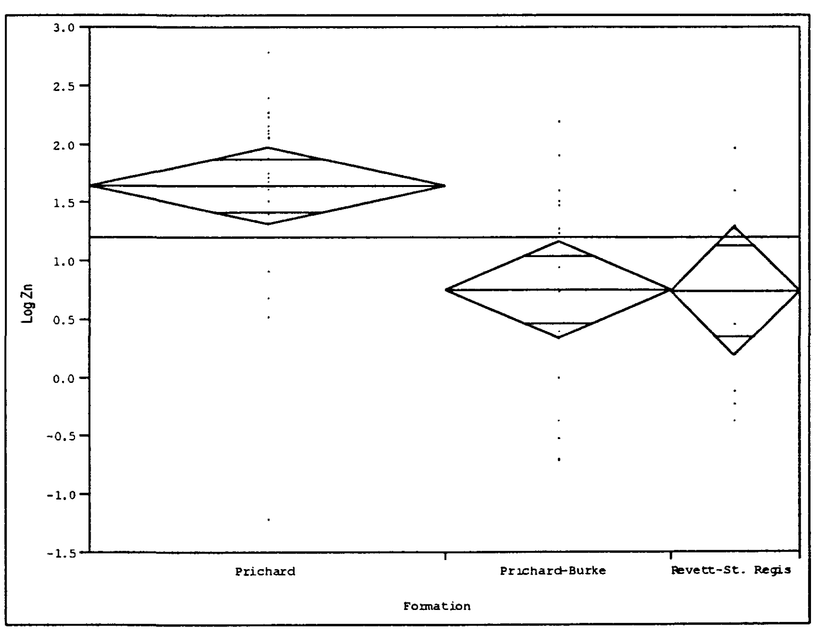

Figure 4. Comparison of the natural logarithm of mean zinc grade between the three sub-types of galena-sphalerite vein. The line across each diamond is the group mean, the vertical span of each diamond is the 95 percent confidence interval, and the width of each diamond is proportional to sample size.

COMPARISON	TONNAGE	AG GRADE	PB GRADE	ZN GRADE
Prichard vs. Prichard-Burke	-0.408	0.430	0.248	0.243
Prichard vs. Revett-St. Regis	1.121	1.060	0.065	0.119
Prichard-Burke vs. Revett-St. Regis	-0.516	0.102	-0.368	-0.830

Table 2. Results of Tukey-Kramer HSD comparison test at the 95 percent level between mean tonnage, silver grade, lead grade, and zinc grade for the three subtypes of galena-sphalerite veins. Positive values indicate pairs of means that are significantly different. Analysis performed on log-transformed variables.

	MEANS		VARIANCE	
	F Ratio	Prob > F	F Ratio	Prob > F
Tonnage	7.87	0.0023	2.16	0.125
Ag Grade	38.18	0.0001	1.06	0.355
Pb Grade	8.20	0.0013	2.66	0.080
Zn Grade	6.95	0.0049	0.10	0.901

Table 3. Test statistics (Welch's test for means, Welch, 1951; O'Brien's test for variances, O'Brien, 1979) for a one-way Analysis of Variance on the three subtypes of galena-sphalerite veins. Probabilities of 0.05 or less are evidence of unequal means or variances across each vein subtype. Analysis performed on log-transformed variables.

No statistical significance can be attributed to observed differences in variances among the three subtypes for tonnage or any of silver, lead, and zinc grades. Significant differences in mean silver grades between each of the subtypes argue strongly for modeling each subtype separately. Were it not for a significant difference in mean silver grades between the Prichard-Burke and Revett-St. Regis deposits, however, these two subtypes could be considered statistically homogenous. Prichard veins have significantly different means for all variables except for tonnage with respect to Prichard-Burke veins.

An important consequence of modeling each subtype separately is the small sample size for each subtype (Table 1). Serious questions should be raised about the robustness of resource estimates based on models with as few as seven deposits (tetrahedrite veins). Unfortunately, no additional deposit data will be available until further discoveries are made.

STATISTICAL ANALYSIS BY SUBTYPES

The grade-tonnage models which follow characterize the distribution of these vein deposits by tonnage and grade. To use these models in a standard three-part quantitative mineral resource assessment (Singer, 1993a) any correlation between tonnage and grade and between grades must be identified and the lognormality of the observed grade and tonnage distributions tested.

Correlation Between Tonnage and Grades

Table 4 shows that no significant correlation exists between tonnage and silver, lead, zinc, and copper grades.

Vein Type	Ag Grade		Pb Grade		Zn Grade		Cu Grade	
	Corr	Prob	Corr	Prob	Corr	Prob	Corr	Prob
Prichard	-0.03	0.89	-0.23	0.26	0.36	0.08		
Prichard-Burke	0.59	0.02	-0.05	0.85	0.19	0.49		
Revett-St. Regis (galena-sphalerite)	-0.56	0.06	0.22	0.49	0.25	0.52		
Revett-St. Regis (tetrahedrite)	0.41	0.36	0.86	0.06			0.06	0.90

Table 4. Correlation between tonnage and silver, lead, zinc, and copper grades for each vein subtype. Corr is the Pearson correlation coefficient and Prob the probability of obtaining, by chance, a larger correlation if no linear relationship exists between tonnage and grade. Analysis performed on log-transformed variables.

Correlation Between Grades

For galena-sphalerite veins, Table 5 shows no significant correlation between silver, lead, and zinc grades. Table 6 shows that no significant correlation between silver, copper, and lead grades of tetrahedrite veins.

Vein Type	Ag vs Pb		Ag vs Zn		Pb vs Zn	
	Corr	Prob	Corr	Prob	Corr	Prob
Prichard	0.55	0.003	0.06	0.766	0.27	0.200
Prichard-Burke	0.35	0.187	-0.23	0.386	-0.74	0.001
Revett-St. Regis (galena-sphalerite)	0.24	0.454	-0.40	0.285	0.19	0.617

Table 5. Correlation between silver, lead, and zinc grades for the three subtypes of galena-sphalerite veins. Corr is the Pearson correlation coefficient and Prob the probability of obtaining, by chance, a larger correlation if no linear relationship exists between tonnage and grade. Analysis performed on log-transformed variables.

Vein Type	Ag vs Cu		Ag vs Pb		Cu vs Pb	
	Corr	Prob	Corr	Prob	Corr	Prob
Revett-St. Regis (tetrahedrite)	-0.67	0.097	0.81	0.095	-0.73	0.165

Table 6. Correlation between silver, copper, and lead grades for tetrahedrite veins. Corr is the Pearson correlation coefficient and Prob the probability of obtaining, by chance, a larger correlation if no linear relationship exists between tonnage and grade. Analysis performed on log-transformed variables.

Lognormality of Tonnage and Grades

Lognormality of the tonnage and grade distributions for each vein type was evaluated by applying the Shapiro-Wilk test of normality to log transformed data (Table 7). The distribution of zinc grade of Prichard veins deviates significantly from lognormality due to the inclusion of five deposits which had lost most of their zinc content by oxidation of galena-sphalerite to lead carbonates. Removal of these five deposits results in a lognormal distribution of zinc grades. The hypothesis of lognormality was accepted for all other tonnage and grade distributions.

VEIN TYPE	VARIABLE	*W*	*P* VALUE
Prichard	Tonnage	0.927	0.064
	Ag Grade	0.950	0.236
	Pb Grade	0.952	0.256
	Zn Grade	0.862	0.002
Prichard-Burke	Tonnage	0.900	0.081
	Ag Grade	0.942	0.364
	Pb Grade	0.869	0.026
	Zn Grade	0.957	0.583
Revett-St. Regis (galena-sphalerite)	Tonnage	0.979	0.948
	Ag Grade	0.957	0.682
	Pb Grade	0.937	0.428
	Zn Grade	0.933	0.499
Revett-St. Regis (tetrahedrite)	Tonnage	0.937	0.627
	Ag Grade	0.971	0.911
	Cu Grade	0.973	0.920
	Pb Grade	0.935	0.637

Table 7. Test for lognormality of distributions of tonnage and silver, lead, zinc, and copper grades for each subtype of Coeur d'Alene polymetallic vein. The test statistic is Shapiro-Wilk's *W* (Shapiro and others, 1968) which tests the hypothesis that the observed distribution is a random sample from a normal distribution. If the *p* value is greater than 0.01 then the test statistic *W* is not significant and the hypothesis of normality is accepted. The smaller the *p* value the stronger the evidence against normality.

GRADE-TONNAGE MODELS

Tonnage and grade distributions have traditionally been modeled as lognormal survival distributions (Cox and Singer, 1986). The cumulative proportion of deposits (survival function $S(x) = 1 - F(x)$ where $F(x)$ is the empirical cumulative distribution function) is plotted using a logarithmic scale for tonnage or grade and fitted with a curve representing a lognormal distribution with the same parameters (mean and variance) as the empirical distribution.

Quantiles from these fitted lognormal distributions are used for quantitative mineral resource assessments.

These traditional models, unfortunately, are impossible to plot with currently available software. As an alternative, standard normal quantile plots of log-transformed tonnage and grade data are presented here. These plots have the advantage of presenting the data as a linear model, allowing visual inspection of the correspondence of the fitted lognormal distribution to the empirical data. Table 8 lists estimated parameters (*m*, *s*) of the fitted lognormal distributions. Table 9 lists the mean and most commonly used inverse quantiles (1-*F*(x)) calculated from the parameters of the fitted lognormal distribution from Table 8.

VEIN TYPE	VARIABLE MODELED	*m*	*s*
Prichard galena-sphalerite	Tonnage	3.937	2.084
	Ag Grade	3.838	0.609
	Pb Grade	1.442	0.669
	Zn Grade[1]	1.876	0.410
Prichard-Burke galena-sphalerite	Tonnage	5.370	2.924
	Ag Grade	4.743	0.738
	Pb Grade	2.111	0.442
	Zn Grade	0.760	0.904
Revett-St. Regis galena-sphalerite	Tonnage	7.082	2.390
	Ag Grade	5.421	0.476
	Pb Grade	1.970	0.345
	Zn Grade	0.744	0.852
Revett-St. Regis tetrahedrite	Tonnage	6.819	2.302
	Ag Grade	6.535	0.228
	Cu Grade	-0.367	0.405
	Pb Grade	-1.738	0.05

[1] Model excludes lead carbonate deposits.

Table 8. Estimated parameters (*m*, *s*) of fitted lognormal distribution for grade-tonnage models of each subtype of Couer d'Alene polymetallic veins.

VEIN TYPE	VARIABLE	PROPORTION OF DEPOSITS		
		0.90	0.50	0.10
Prichard galena-sphalerite	Tonnage 10^3 metric t	28	51	754
	Ag Grade grams/metric t	21	46	102
	Pb Grade percent	1.8	4.2	10.0
	Zn Grade[1] percent	3.8	6.5	11.1
Prichard-Burke galena-sphalerite	Tonnage 10^3 metric t	5	215	9,339
	Ag Grade grams/metric t	44	115	297
	Pb Grade percent	4.7	8.3	14.6
	Zn Grade percent	0.7	2.1	6.9
Revett-St. Regis galena-sphalerite	Tonnage 10^3 metric t	55	1,190	25,980
	Ag Grade grams/metric t	122	226	418
	Pb Grade percent	1.7	7.2	11.2
	Zn Grade percent	0.7	2.1	6.3
Revett-St. Regis tetrahedrite	Tonnage 10^3 metric t	47	915	17,833
	Ag Grade grams/metric t	513	689	924
	Cu Grade percent	0.41	0.69	1.17
	Pb Grade percent	0.05	0.18	0.66

[1] Model excludes lead carbonate deposits.

Table 9. Inverse quantiles (1-*F*(x)) of fitted lognormal distribution for grade-tonnage models of each subtype of Couer d'Alene polymetallic veins.

Reserve Growth

The physical extent, tonnage, and grades of Coeur d'Alene polymetallic veins are not fully delineated by exploration and development until a mined deposit nears exhaustion. The costs of adequately exploring these deep vein deposits is sufficiently high that most operating mines maintain at most ten to twelve years of reserves ahead of current production. Singer, 1993b, has noted the dangers of using deposits that have not been fully explored in traditional grade-tonnage models. Of main concern are the use of tonnage data for deposits which one can reasonably expect to have significant future additions of new reserves. A lognormal distribution fitted to such data will underestimate the true parameters of the population modeled.

Of the four types of Coeur d'Alene-type polymetallic veins modeled, two (Prichard and Prichard-Burke galena-sphalerite veins) use data that consists entirely of deposits that were mined to the economic limits of their known orebodies. The Revett-St. Regis galena-sphalerite vein and tetrahedrite vein models include several deposits that are actively mined with significant recent additions to reserves. To account for potential reserve growth in these deposits, a survival-analysis method of fitting a lognormal distribution to the data was attempted according to the following rationale.

Deposits initially, when discovered, have no delineated reserves. Each successive exploration campaign adds reserves until exploration efforts cease to find new ore. Ignoring depletion of reserves during production, reserves can be thought of as growing from an initial value of zero to the true size of the economic portion of the deposit. At any given time, we observe current reserves of all deposits, and add those reserves to past production to obtain the data on tonnage and grade used for constructing grade-tonnage models. Any deposits whose reserves have not been fully delineated at that time have been *right*-censored. The situation just described is a classic survival or failure-analysis type problem for which a broad range of statistical estimators are available.

The survival-analysis approach is directly applicable to tonnage models, as the tonnage of a deposit will grow over time as new reserves are added. The behavior of grade as reserves are added, however, is not predictable. Grade will vary naturally within a deposit such that as different parts of a deposit are delineated overall known deposit grade may rise or fall. As development proceeds to greater depth cut-off grades may increase, causing overall grade to increase if all other factors that influence deposit grade are unchanged. It may be safe to assume that these effects are random overall and that standard grade models can be used even when tonnages are right-censored.

Lognormal distributions were fitted to tonnage data for Revett-St.Regis galena sphalerite and tetrahedrite veins using the Kaplan-Meier product-limit method (Le, 1997) assuming that the survival function is lognormal. Estimated parameters and computed mean and inverse quantiles for the fitted lognormal distributions are shown in Table 10. Note that the estimated parameters of these fitted lognormal distributions are considerably larger than those for the fitted distributions ignoring right-censorship presented in Table 9.

VEIN TYPE	NUMBER DEPOSITS CENSORED	m	s	MEAN	PROPORTION OF DEPOSITS		
					0.10	0.50	0.90
galena-sphalerite	3	7.615	2.720	82,000	61	2,030	67,800
tetrahedrite	5	9.227	2.418	189,000	449	10,200	230,000

Table 10. Estimated parameters, mean, and inverse quantiles (1-F(x)) of lognormal distributions fitted by the Kaplan-Meier product-limit method to tonnage in thousand metric tons of the two-types of Revett-St. Regis polymetallic veins.

Estimates of the mean and 0.90 inverse quantile are considerably larger than the largest data value (both censored), for Revett-St. Regis galena-sphalerite and tetrahedrite veins, 50 million and 13.7 million metric tons respectively. If the fitted lognormal model is correct, then considerable potential exists for expanding reserves at active mines. Any of the currently mined deposits, or any newly discovered deposits would have the potential of being much larger than the largest known deposits. The 95 percent confidence intervals on the parameter estimates for the fitted lognormal distributions are quite large however. For the parameter *m*, 95 percent confidence bounds are (5.932, 9.607) and (6.904, 18.565) for galena-sphalerite veins and tetrahedrite veins, respectively. Small sample size is likely the most important factor in this uncertainty, particularly for tetrahedrite veins with a sample of seven deposits, five of which are censored. It may also be possible that the lognormal model is inappropriate for modeling tonnage as a survival distribution. In any case, most geologists familiar with Coeur d'Alene-type polymetallic veins will likely find these estimates excessive.

CONCLUSIONS

Of the four types of Coeur d'Alene polymetallic veins examined, two have been modeled successfully: Prichard and Prichard-Burke galena-sphalerite veins. Models for Revett-St. Regis galena-sphalerite and Revett-St. Regis tetrahedrite veins are problematic because not all deposits considered have been fully explored. The Revett-St. Regis tetrahedrite vein model is doubly problematic due to the small sample size of seven deposits. An attempt to fit a lognormal model to tonnage of the two Revett-St. Regis vein-types, assuming that not fully explored deposits are right-censored, yielded excessively large estimates with very wide confidence bounds. The right-censored tonnage models for these vein types, although conservative, will be more useful.

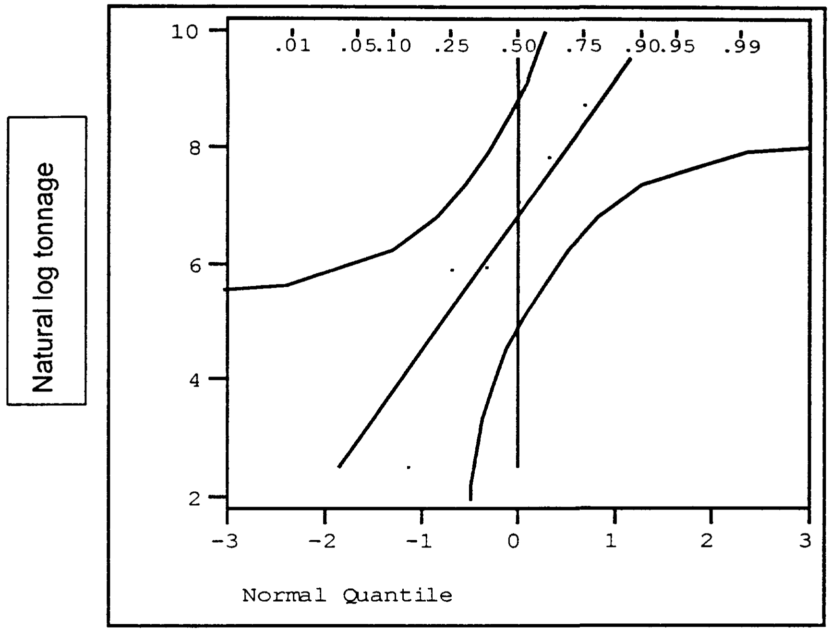

Figure 5. Tonnage model for Revett-St. Regis tetrahedrite veins. Model is the fitted line representing a lognormal distribution with parameters (*m*, *s*) of the observed sample (Table 8). Lillifor's confidence bounds for normality are also shown.

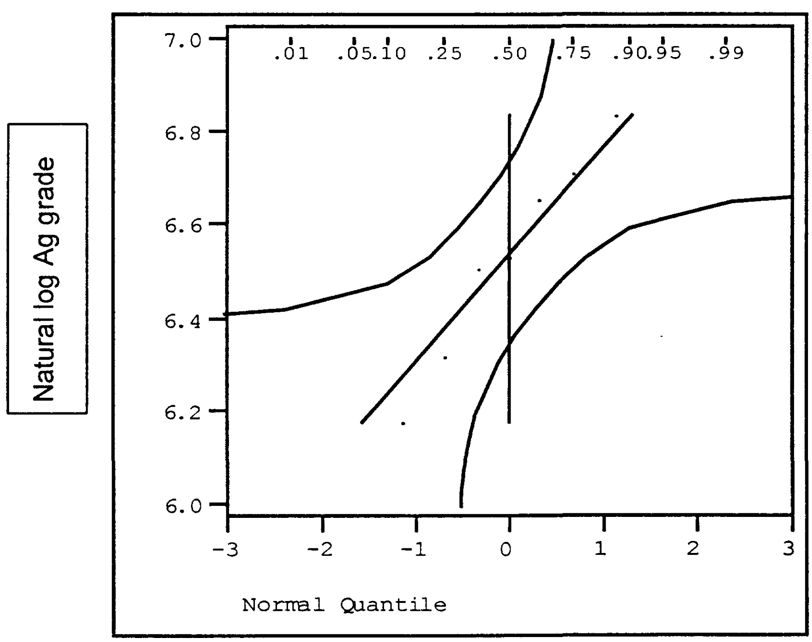

Figure 6. Silver grade model for Revett-St. Regis tetrahedrite veins. Model is the fitted line representing a lognormal distribution with parameters (*m*, *s*) of the observed sample (Table 8). Lillifor's confidence bounds for normality are also shown.

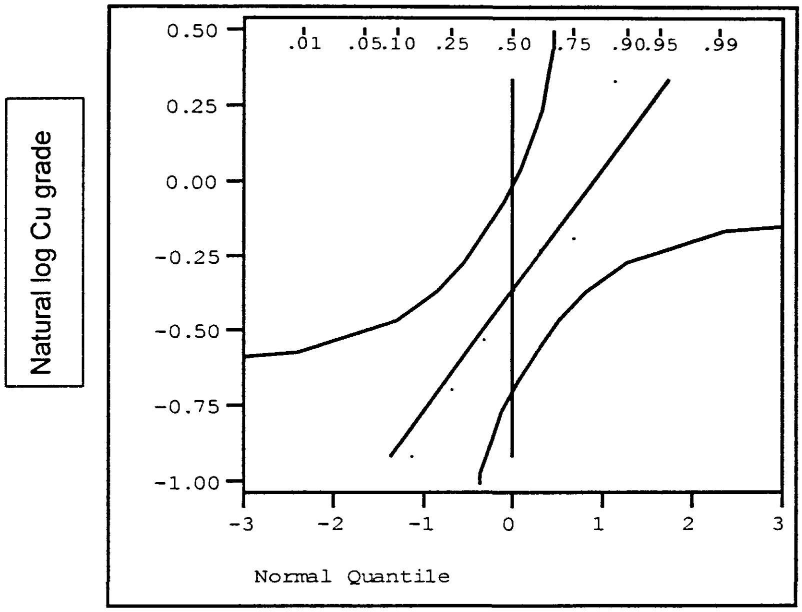

Figure 7. Copper grade model for Revett-St. Regis tetrahedrite veins. Model is the fitted line representing a lognormal distribution with parameters (*m*, *s*) of the observed sample (Table 8). Lillifor's confidence bounds for normality are also shown.

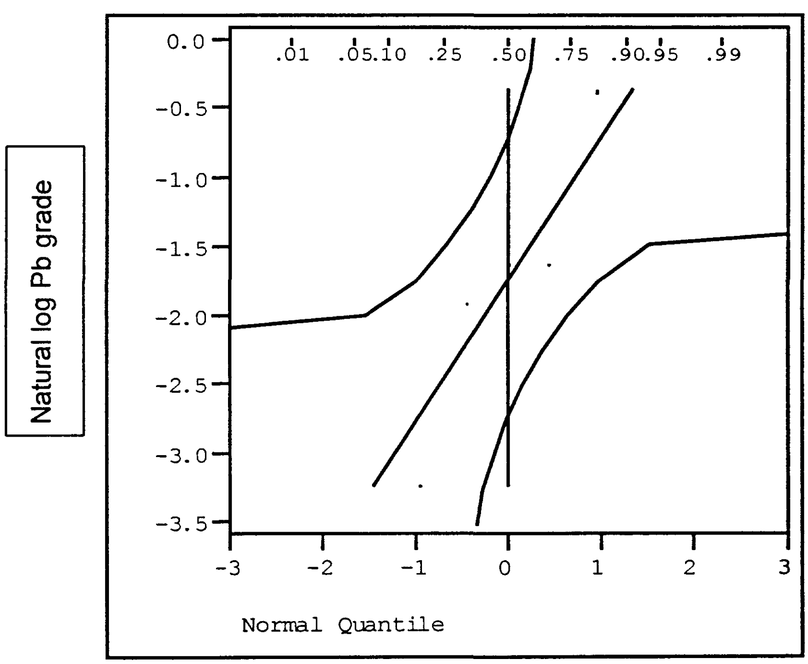

Figure 8. Lead grade model for Revett-St. Regis tetrahedrite veins. Model is the fitted line representing a lognormal distribution with parameters (*m*, *s*) of the observed sample (Table 8). Lillifor's confidence bounds for normality are also shown.

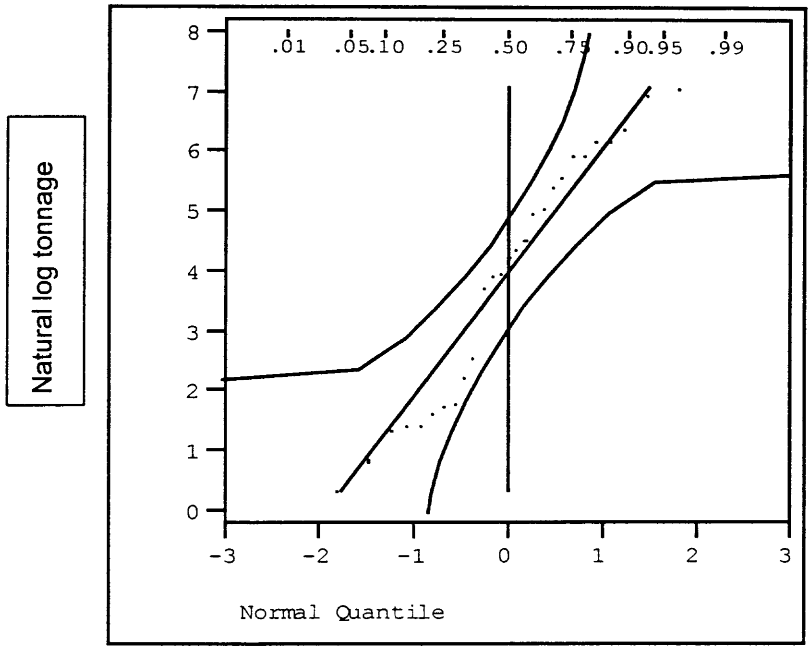

Figure 9. Tonnage model for Prichard galena-sphalerite veins. Model is the fitted line representing a lognormal distribution with parameters (*m*, *s*) of the observed sample (Table 8). Lillifor's confidence bounds for normality are also shown.

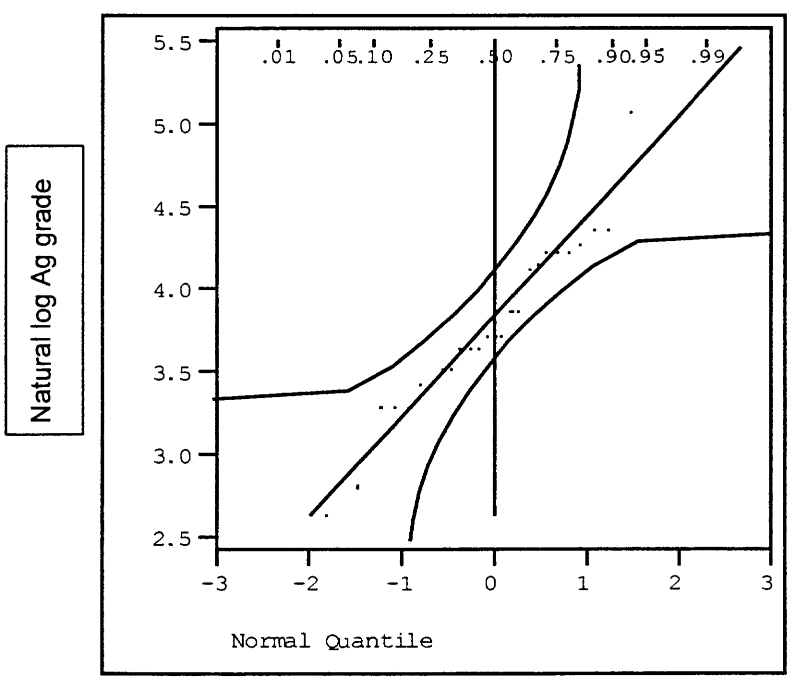

Figure 10. Silver-grade model for Prichard galena-sphalerite veins. Model is the fitted line representing a lognormal distribution with parameters (*m*, *s*) of the observed sample (Table 8). Lillifor's confidence bounds for normality are also shown.

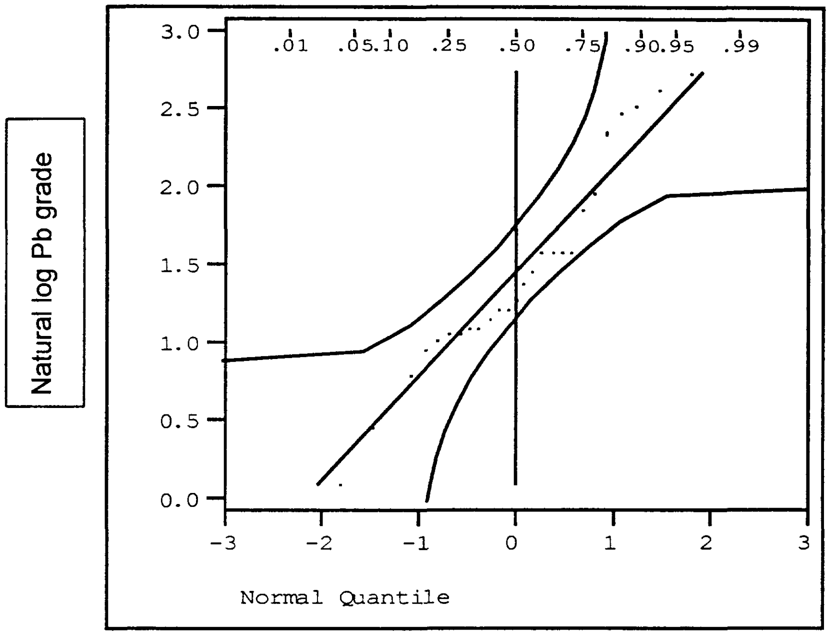

Figure 11. Lead-grade model for Prichard galena-sphalerite veins. Model is the fitted line representing a lognormal distribution with parameters (*m*, *s*) of the observed sample (Table 8). Lillifor's confidence bounds for normality are also shown.

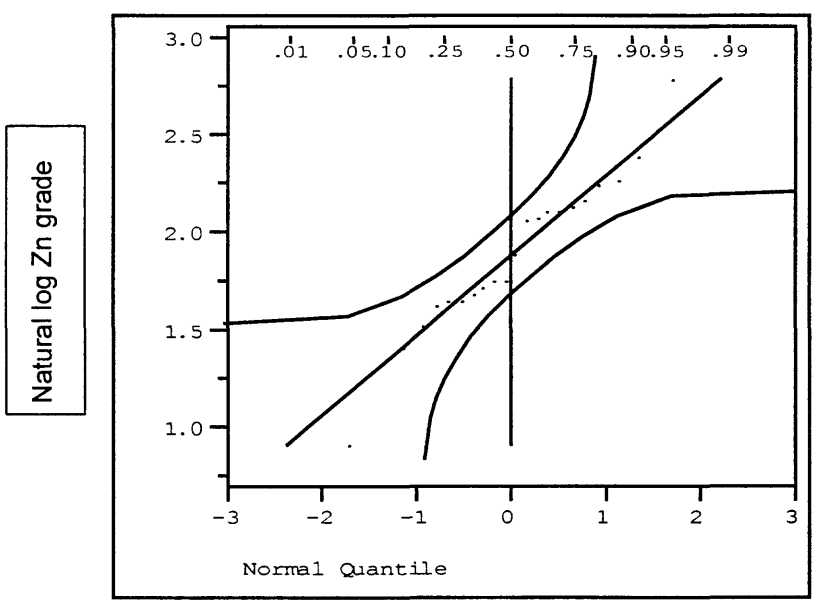

Figure 12. Zinc-grade model for Prichard galena-sphalerite veins. Model is the fitted line representing a lognormal distribution with parameters (*m*, *s*) of the observed sample (Table 8). Lillifor's confidence bounds for normality are also shown.

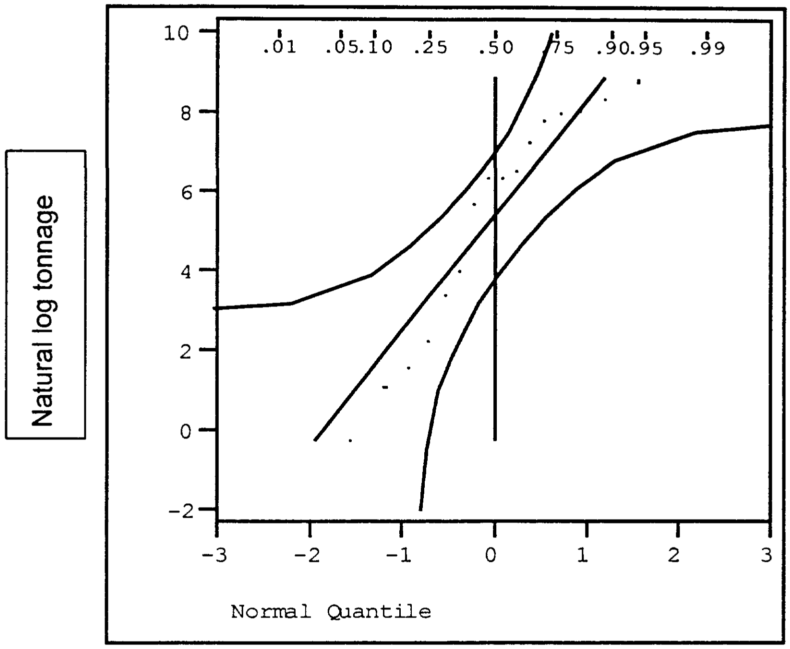

Figure 13. Tonnage model for Prichard-Burke galena-sphalerite veins. Model is the fitted line representing a lognormal distribution with parameters (*m*, *s*) of the observed sample (Table 8). Lillifor's confidence bounds for normality are also shown.

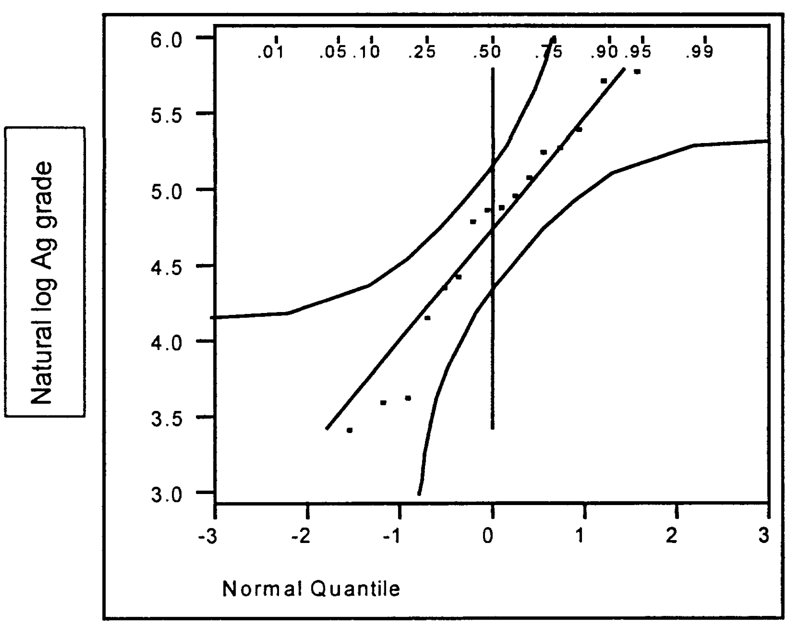

Figure 14. Silver-grade model for Prichard-Burke galena-sphalerite veins. Model is the fitted line representing a lognormal distribution with parameters (*m*, *s*) of the observed sample (Table 8). Lillifor's confidence bounds for normality are also shown.

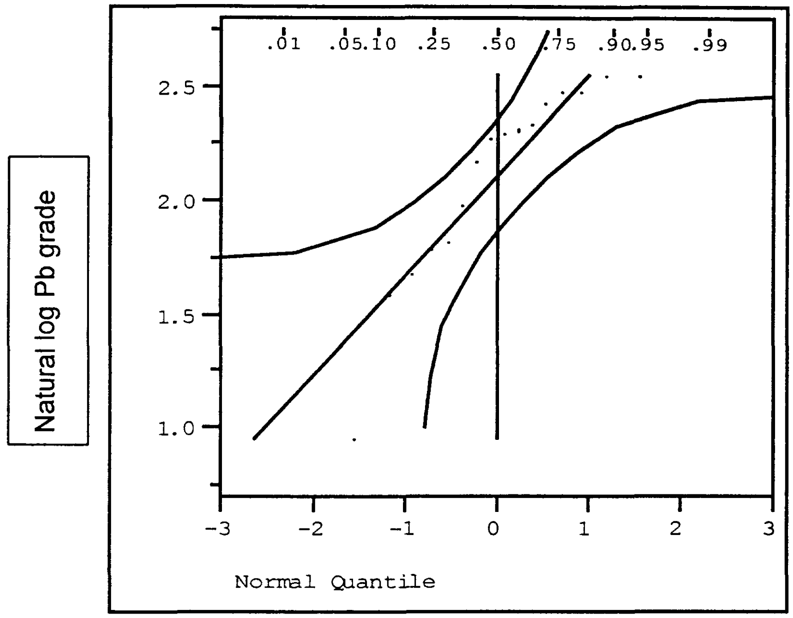

Figure 15. Lead-grade model for Prichard-Burke galena-sphalerite veins. Model is the fitted line representing a lognormal distribution with parameters (*m*, *s*) of the observed sample (Table 8). Lillifor's confidence bounds for normality are also shown.

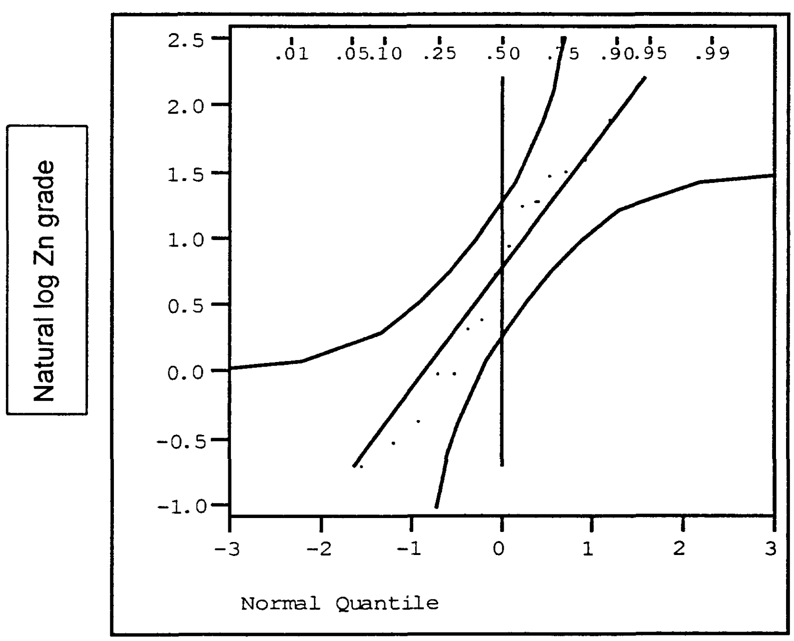

Figure 16. Zinc-grade model for Prichard-Burke galena-sphalerite veins. Model is the fitted line representing a lognormal distribution with parameters (*m*, *s*) of the observed sample (Table 8). Lillifor's confidence bounds for normality are also shown.

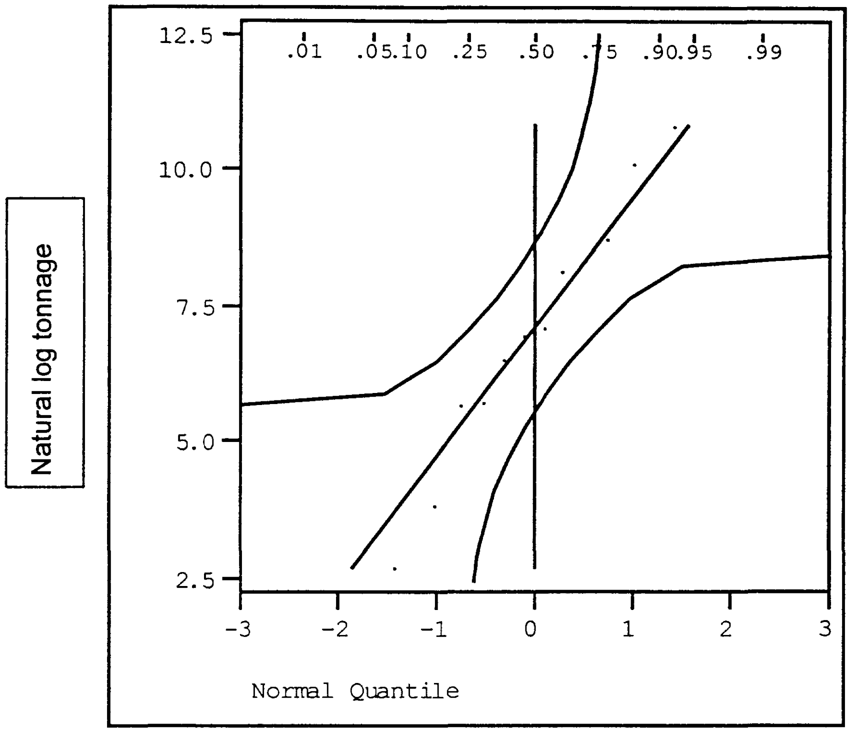

Figure 17. Tonnage model for Revett-St. Regis galena-sphalerite veins. Model is the fitted line representing a lognormal distribution with parameters (*m*, *s*) of the observed sample (Table 8). Lillifor's confidence bounds for normality are also shown.

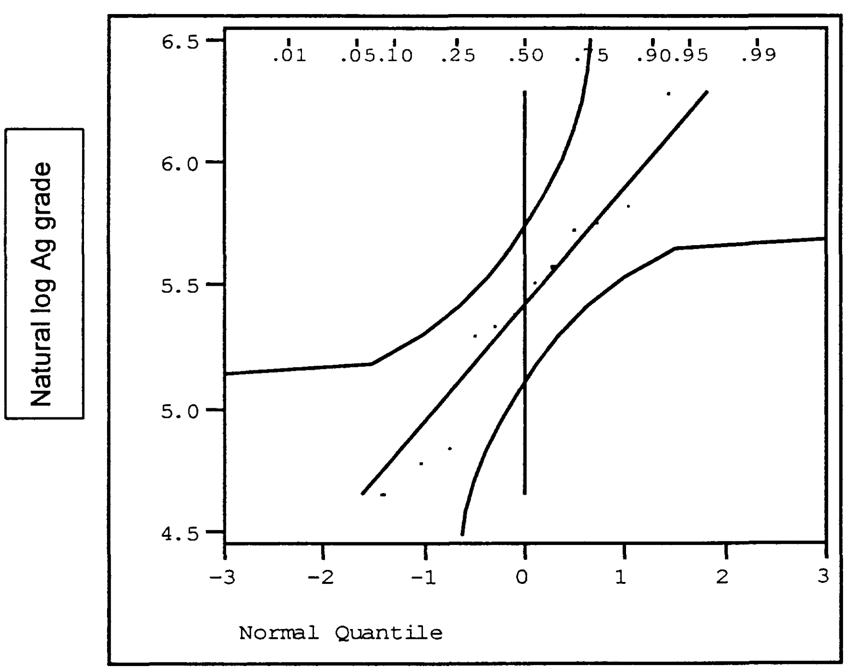

Figure 18. Silver-grade model for Revett-St. Regis galena-sphalerite veins. Model is the fitted line representing a lognormal distribution with parameters (*m*, *s*) of the observed sample (Table 8). Lillifor's confidence bounds for normality are also shown.

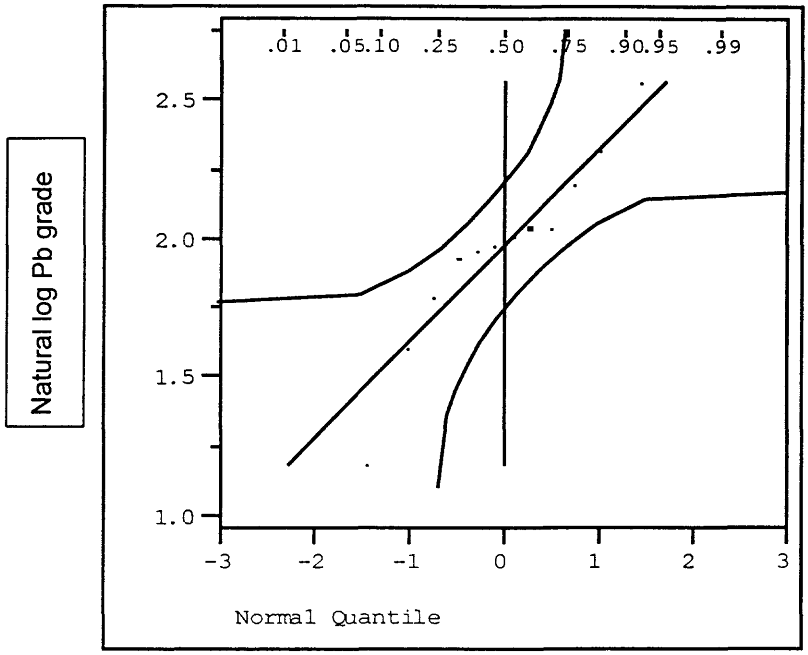

Figure 19. Lead-grade model for Revett-St. Regis galena-sphalerite veins. Model is the fitted line representing a lognormal distribution with parameters (*m*, *s*) of the observed sample (Table 8). Lillifor's confidence bounds for normality are also shown.

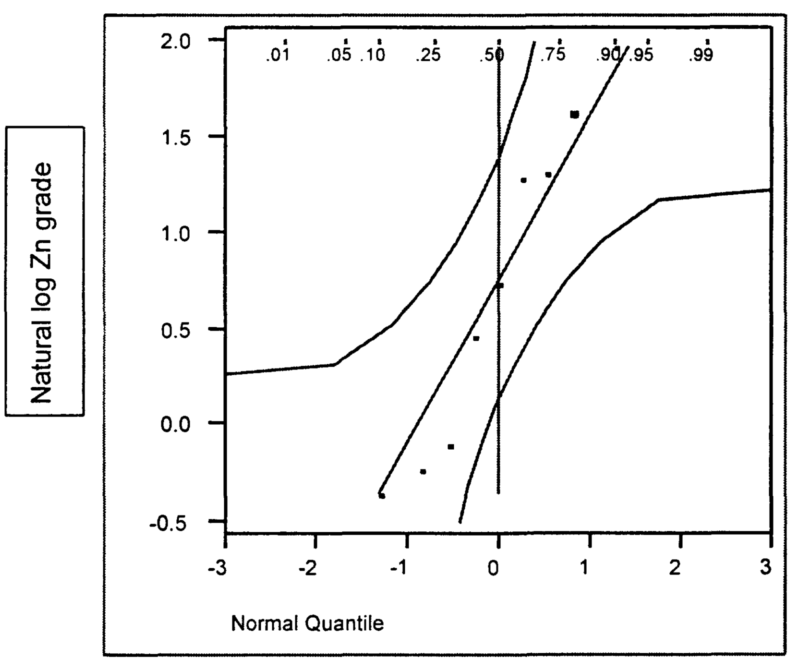

Figure 20. Zinc-grade model for Revett-St. Regis galena-sphalerite veins. Model is the fitted line representing a lognormal distribution with parameters (*m*, *s*) of the observed sample (Table 8). Lillifor's confidence bounds for normality are also shown.

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APPENDIX I. DEPOSIT DEFINITION CRITERIA

Ajax: One orebody on a small vein.

Alhambra: One galena-sphalerite orebody on the Alhambra fault within the Crescent mine property.

Amazon-Manhatten: Two orebodies (West, East) on Amazon-Manhatten vein.

American Silver: One small orebody found to date.

Amy: Several small orebodies along the Amy vein.

Anchor: Several small orebodies along four parallel veins in Summit District.

Anchor: Small vein in Lelande District. Promoted at one time as an east extension of the Hecla but this cannot be confirmed.

Bear Top-Oro Fino-Ione: Three parallel veins. Main ore shoot on Bear Top vein, two small shoots on Oro Fino vein, little ore found on Ione vein.

Benton: Small vein.

Black Bear-Frisco-Gem: Three old mines along the same structure. Two parallel orebodies (North and South) at each mine in the hanging and foot walls of the vein.

Black Horse: Three orebodies on two parallel veins.

Blue Grouse-Mountain Goat: Two orebodies (Blue Grouse, Mountain Goat) on Blue Grouse vein.

Bobby Anderson-Northern Light: Three small orebodies on two or three veins in the same fault zone.

Bunker Hill-Last Chance: Includes production from several old mines that became part of the Bunker Hill, namely the Last Chance, Tyler, and Stemwinder. More than twenty major and many minor orebodies.

California-Black Cloud: Also includes Monarch and Panhandle. One orebody.

CAMP: One small orebody found to date on a substantial vein.

Carlisle-Virginia: Several small orebodies on Carlisle vein.

Cedar Creek: Three orebodies (Cedar Creek, Portland, New Hope) on same vein.

Charles Dickens: Two small orebodies on same vein.

Coeur: Multiple orebodies on many closely-related veins. Actively mined but nearing exhaustion. Current exploration may add to reserves, increasing the known size of this deposit.

Constitution: Two principal orebodies on the same vein.

Crescent: Several orebodies along the Alhambra fault.

Crystal Lead: One orebody on a small vein.

Dayrock: Four subparallel veins, Dayrock, Ohio, Dora, and Panhandle.

Douglas-Marmion: Two parallel veins. Douglas has three orebodies (East, Middle, West).

Evolution: Small vein.

Formosa: Two orebodies (East and West) on Formosa (Canyon Silver) vein.

Galena-Argentine: Mine property includes galena-sphalerite veins in the Lead Zone and tetrahedrite veins in the Silver Vein and Argentine areas. Production and reserves for each vein-type have been broken out for modeling purposes. The Galena is an active mine with substantial new reserves found and reported every year.

Golconda: Four closely related veins, Golconda, Klondike, Mayflower, and East Mayflower.

Gold Hunter: One large orebody that leans or thins out in many places, in particular between the old upper workings and the newly developed lower workings. Lower levels of deposit being actively explored. The size of this deposit will likely grow substantially as exploration and development proceeds.

Hecla: Six major orebodies (Hecla, Intermediate, Magazine, Ore or No Go, Hecla B, and East) in same vein system.

Hercules-Ambergris: One main orebody on Hercules vein and small orebody on parallel Ambergris vein.

Highland-Surprise-Nevada Stewart: Three mines along same structure. One ore shoot on Highland ground, two on Surprise (No. 1 and No. 2), and two on Nevada Stewart ground (North and South).

Hilarity: Two orebodies on same vein.

Hummingbird: One small vein.

Hypotheek: Two orebodies (East and West) on same vein.

Idora: Small orebody on Idora vein.

Interstate-Callahan-Monitor: Several orebodies (Callahan East, Callahan South) on Interstate-Callahan vein. Monitor is near-surface east extension of Callahan East orebody.

Jack Waite: Many closely-spaced orebodies on same vein.

Little Pittsburg: Little Pittsburg vein with four orebodies, extends onto Nabob ground. Also includes Crystallite vein.

Lucky Friday: One large orebody. An active mine nearing exhaustion. Limited exploration for new reserves is still underway which might add a relatively small tonnage to announced proven and probable reserves.

Mineral Point: One main orebody (Siderite vein) with several small orebodies on adjacent structures (Commodore Truxton, Cross, and Wire Silver veins).

Nipsic: One orebody on Nipsic vein.

Ontario: One small disseminated deposit in fractured Burke Formation quartzite between Saxon and Alhambra faults.

Page-Blackhawk: Production from two parallel veins, Tony and Curlew, which extend into Blackhawk ground.

Paragon: Two orebodies on same vein.

Rex: One orebody on Rex vein.

Senator Stewart-Crown Point: Apparently one main orebody on Senator Stewart vein.

Sherman: Three closely related veins (Sherman, Union, Leary).

Sidney-Denver-Nabob: Three main ore bodies on the Sidney vein (Sidney East, Sidney West, and D-5) which extend onto Denver and Nabob ground. Also includes Denver vein.

Sierra Nevada: Although integrated with the Bunker Hill mine workings, this deposit lies on the opposite side of the post-ore Osburn Fault from the Bunker Hill-Last Chance deposit.

Standard-Mammoth-Green Hill-Cleveland: Green Hill-Cleveland mine worked an extension of the Standard-Mammoth vein.

Star-Morning: Most production from main Star-Morning vein. Several splits and parallel veins including You Like, Noonday, Grouse, and Motor Barn.

Success: One main orebody on Granite vein.

Sunset: Sunset vein on Liberal King property.

Sunset-Portland: Several orebodies in same vein system on Sunset, Portland (Silver Tip), Tuscambia, Sitting Bull, and Parrot properties.

Sunshine-Polaris: A consolidation of all mines along the Sunshine-Polaris vein system. Includes production from the Sunshine, Big Creek Apex, Silver Dollar, Silver Syndicate, Chester, Metropolitan, Silver Summit, Sunshine Consolidated, Polaris, Nellie, and Rainbow properties, most of which are now part of the modern Sunshine mine. Multiple orebodies on five main veins (Yankee Boy-Polaris, Chester, Silver Summit-Silver Syndicate, Yankee Girl, and West Chance). The Sunshine is an active mine with current proven and probable reserves sufficient for another ten to twelve years of operations. Sunshine Mining Company, in its 1996 SEC Form 10K reports and additional resource of 2,127 metric tons of silver which is not included in the tonnage and grade figures used for the Sunshine-Polaris deposit due to the lack of grade information.

Tamarack-Custer: Includes production from Custer, Tamarack, Tamarack & Custer, and Tamarack No. 5 Lease. Several orebodies on several closely related veins, including Custer, North, South, Monroe, Murphy, Chesapeake, Nelson, Thomas, Watson, Snowy Peak, Phoenix, and Wet.

Terrible-Edith: Several small orebodies on same vein.

Tiger-Poorman-Marsh: The Tiger and Poorman mines worked the main Tiger-Poorman orebody which extends onto the Wide West claim of the Hecla mine property. Marsh is a separate orebody on the same structure.

Tough Nut: Small orebody on Tough Nut vein.

APPENDIX II. GRADE-TONNAGE DATA

Middle Prichard Formation galena-sphalerite veins:

DEPOSIT	TONNAGE THOUSAND METRIC T	AG GRADE GRAMS PER METRIC T	PB GRADE PERCENT	ZN GRADE PERCENT
Amazon-Manhatten	501.1	27	1.9	5.2
Amy	4.2	41	4.9	8.4
Anchor	2.4	38	7.1	5.8
Bear Top-Oro Fino-Ione[1]	95.0	27	12.0	2.0
Black Horse	54.0	34	3.0	4.6
Blue Grouse-Mountain Goat	275.2	31	2.2	5.4
Bobby Anderson-Northern Light	42.6	79	6.4	9.7
Carlisle-Virginia	71.9	17	1.6	5.1
Cedar Creek[1]	4.2	237	13.9	negligible
Charles Dickens	13.0	69	4.9	3.8
Constitution	609.0	79	3.6	8.7
Douglas-Marmion	145.4	62	2.9	8.2
Evolution[1]	9.0	34	1.1	0.3
Highland-Surprise-Nevada Stewart	493.0	41	3.4	8.0
Hilarity	3.8	31	3.2	5.2
Hypotheek[1]	80.0	48	12.5	negligible
Idora[1]	5.2	161	10.5	1.7
Interstate-Callahan-Monitor	1,189.0	69	4.9	16.3
Little Pittsburg	391.2	38	3.4	6.6
Nipsic	52.0	38	2.9	8.2
Paragon	6.1	14	3.0	7.9
Rex	161.0	64	4.0	4.1
Sidney-Denver-Nabob	1,065.0	69	4.9	9.4
Sunset	232.6	27	2.8	5.6
Sunset-Portland	393.9	72	4.3	5.8
Terrible-Edith	5.9	48	15.3	11.0
Tough Nut	1.4	41	2.6	2.5

[1] Oxidized deposit consisting primarily of lead carbonate ores.

Prichard-Burke Formations Transition Zone galena-sphalerite veins

Deposit	Tonnage thousand metric t	Ag grade grams per metric t	Pb grade percent	Zn grade percent
Ajax	5	37	9.8	0.7
Anchor	3	31	6.2	3.6
Benton	0.8	123	12.9	0.5
Crystal Lead	10	79	8.8	1.0
Formosa	55	165	12.9	4.4
Gem-Frisco-Black Bear	3,100	133	5.4	3.5
Golconda	310	146	6.0	4.6
Hecla	7,000	195	10.4	1.4
Hercules-Ambergris	3,200	331	12.0	0.6
Hummingbird	31	85	4.9	6.8
Jack Waite	610	38	11.4	2.6
Sherman	601	226	10.2	2.1
Standard-Mammoth-Greenhill-Cleveland	4,500	311	10.0	1.5
Success	730	65	2.6	9.1
Tamarack-Custer	2,600	135	7.3	5.0
Tiger-Poorman-Marsh	1,500	200	12.0	1.0

Revett-St. Regis Formations Transition Zone galena-sphalerite veins

Deposit	Tonnage thousand metric t	Ag grade grams per metric t	Pb grade percent	Zn grade percent
Alhambra (Crescent)	15	317	3.3	2.1
Bunker Hill-Last Chance	50,000	127	7.2	3.6
California-Black Cloud	47	310	9.0	unknown
Dayrock	1,254	209	7.5	0.8
Galena-Argentine	673	202	6.0	0.9
Gold Hunter	3,600	220	5.0	0.7
Lucky Friday	6,550	538	10.2	1.6
Ontario	296	250	7.7	unknown
Page-Blackhawk	4,254	120	6.9	7.2
Senator Stewart-Crown Point	1,100	265	7.8	5.0
Sierra Nevada	320	340	13.0	
Star-Morning	26,100	106	7.1	3.7

Revett-St. Regis Formations Transition Zone tetrahedrite veins

DEPOSIT	TONNAGE THOUSAND METRIC T	AG GRADE GRAMS PER METRIC T	CU GRADE PERCENT	PB GRADE PERCENT[1]	SB GRADE PERCENT[1]
American Silver	13	670	0.50		
CAMP	375	689	0.83		
Coeur	2,600	556	0.70	0.20	0.60
Crescent	1,230	822	0.40	0.20	0.30
Galena	6,300	777	0.80	0.15	0.03
Mineral Point	400	482	1.40	0.04	0.63
Sunshine-Polaris	13,700	932	0.59	0.70	

[1] Lead and antimony grades not modeled due to paucity of data.