GRADE AND TONNAGE DATA FOR BRITISH COLUMBIA MINERAL DEPOSIT MODELS

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Contribution to the Mineral Potential Project, funded in part by the Corporate Resource Inventory Initiative (CRII)

KEYWORDS: mineral deposits, grade, tonnage, resource assessment

INTRODUCTION

The Mineral Potential Project currently being undertaken in British Columbia requires estimation of unknown mineral resources. The method of resource assessment known as the BC Mineral Resource Assessment Process [1993], is described by Kilby (1995, this volume) and in Grunsky *et al.* (1994). The method is based on the three-part assessment methodology developed by the United States Geological Survey (USGS) as documented in Singer (1975), Singer and Ovenshine (1979), Drew *et al.* (1986), Root *et al.* (1992) and Singer (1993). An essential component of predictive resource estimation is the creation of mineral deposit models and associated grade and tonnage data. In this study, resource estimation experts rely on geological and mineral deposit models to assist in their predictions. From the evaluation of models, quantitative estimation can be carried out on the basis of grades and tonnages of known deposits.

BACKGROUND OF MINERAL DEPOSIT GRADE AND TONNAGE DATA

It has been well established that resource estimation can be carried out using statistical procedures (cf. Allais, 1957; Harris *et al*, 1971; Whitney, 1975; Agterberg *et al.*, 1972). The use of grade and tonnage data was originally employed by Lasky (1950) who showed an inverse relationship between average grade and the log cumulative tonnage of porphyry copper deposits.

Estimation of resources generally involves a prediction on the size and grade of a mineral deposit. Such predictions are best based on knowledge of the frequencies of grades and tonnages that characterize such deposits. The distributions that comprise the grades and tonnages represent a stochastic model that can be viewed as probability density functions. Grade and tonnage models have the form of frequency distributions of size and average grades of well explored deposits for each type of mineral deposit model (Singer, 1993). The use of the compiled grade and tonnage data forms the basis for quantifying the predictive estimates. The BC Mineral Resource Assessment Process follows the same estimation technique as in the three-part assessments of the USGS, employing a Monte Carlo simulation using estimates of numbers of deposits and grade and tonnage distributions.

The compilation of information about mineral deposits is a crucial feature of resource estimation. The USGS has compiled extensive descriptions and characteristics for a wide range of mineral deposit types from global sources (Cox and Singer, 1986; Bliss, 1992). The models contain two main components; the descriptive features that characterize the deposits in terms of geology and tectonic setting, and grade and tonnage distributions which characterize the size and grades of known deposits from around the world. Singer (1993) describes the basic concepts in the three-part quantitative assessment methodology for undiscovered resources used by the USGS. The paper also describes the requirements for compiling and scrutinizing grade and tonnage data.

BRITISH COLUMBIA GRADE AND TONNAGE DATA

During the course of mineral deposit model selection for the mineral potential project, mineral deposit models from the USGS (Cox and Singer 1986) were reviewed. The review concluded that many of the USGS resource data sets were not suitable for describing the grade and tonnage of deposits that were likely to exist in British Columbia. In addition, many of the mineral deposit types in British Columbia were considered to be sufficiently unique to warrant distinctive descriptions together with grade and tonnage distributions. As a result, a compilation of mineral deposit models together with descriptions and grade and tonnage data was carried out (Lefebure *et al*, 1994; 1995, this volume). Geologists from the British Columbia Geological Survey Branch, the mining industry, the Geological Survey of Canada, and the USGS compiled deposit model descriptions for deposit types that are likely to exist in British Columbia. Grade and tonnage data were compiled by Stonehouse

Group consultants (Stonehouse Group, 1993) for 435 large deposits that were listed as producers, past producers, and those with proven reserves. Stonehouse used a classification scheme that was modified from Cox and Singer (1986). The classified deposits were subsequently reviewed against an alternative classification scheme developed for British Columbia deposits (Lefebure *et al.*, 1994, this volume). Both classifications, the modified USGS and the British Columbia classification scheme, were assigned to the mineral deposit data. At this time no studies have been carried out that detail the differences between USGS and British Columbia mineral deposit models.

The nature of deposit classification is to some extent subjective. Not all geologists can agree on classification designations for some deposit types. Through an iterative process, the deposits that were compiled by Stonehouse were classified and reclassified by geologists in the British Columbia Geological Survey Branch until a consensus was reached on most deposits. Deposits about which there was uncertainty or disagreement, were not classified and thus left out of the grade and tonnage curves.

In many cases there were too few deposits to adequately define a grade and tonnage profile or there were simply no data available. In these cases, we adopted the grade and tonnage distributions that were kindly provided by the USGS (Singer *et al.*, 1993). Singer has emphasized (Singer and Orris, 1994) that there are many serious pitfalls in the construction of grade and tonnage curves. In any resource assessment methodology that requires the use of such data the following requirements must be met:

- The geology of the tracts of ground being considered must be permissive for the deposit type.
- Grade and tonnage models must be consistent with the descriptive deposit models.
- Grade and tonnage models must be consistent with known deposits in the area being considered.
- The estimates of unknown deposits must be consistent with the grade and tonnage model.

GRADE AND TONNAGE DATA COMPILATION

Grade and tonnage data are compiled with the following assumptions:

- The deposit is correctly classified (*i.e.* no mixed deposit types).
- The grade and tonnage represent the complete *in situ* resource (production + reserves).
- The data represent grade and tonnage from a single deposit or a group of small deposits designated as a single deposit.
- The number of deposits that define a grade/tonnage curve are a reasonably complete representation of the resource.
- The grade represents the average grade for each commodity.
- The tonnage represents the tonnage of production plus reserves and resources.
- The grade and tonnage data are based on the lowest possible cutoff grade.

There are several sources of errors that create difficulty in constructing grade and tonnage curves as outlined by Singer (1993) and Singer and Orris (1994). These include:

- Mixed geological environments.
- Poorly known geology.
- Data recording errors.
- Mixed deposit/district data.
- Mixed mining methods.
- Incomplete production and resource estimates.

In addition to these errors Chung *et al.* (1992) have shown that in at least one case the construction of grade and tonnage curves is influenced by the timing of discoveries. A study of mercury deposits in California, in which the dates of discoveries were known, has shown that the largest deposits were discovered first. It follows from this that, for certain deposit types, if an area is incompletely explored, grade and tonnage curves may suggest a greater endowment than is actually present. However, this conclusion may not be universally accepted without thorough geological knowledge and a thorough history of exploration. There is an inherent bias in grade and tonnage data in that they represent only deposits that have been discovered and have been economically evaluated. Another bias in the creation of the data is that the information is knowledge and technology dependent.

If the knowledge of the geology associated with a particular class of mineral deposits changes it may result in an amalgamation or a division of deposits.

Other problems that create difficulty are:

- Grade and tonnage data that are not lognormal.
- Grade and tonnage data that have significant correlations. Most deposit models show little or no correlation between grade and tonnage (see Figure 1).
- Grade and tonnage data where groups of deposits form clusters within a particular mineral deposit model.
- The standard deviation for log-transformed data exceeds a value of 1.0.

The above criteria define standards for the creation of accurate and meaningful grade and tonnage data. The compilation and evaluation of the data attempt to meet all or most of these criteria. Once the data have been compiled, the evaluation of the actual grade and tonnage data requires several steps. An example given here is for calcalkalic porphyry copper deposits that occur in British Columbia. This deposit model is classified as Model L04 (Lefebure *et al.*, 1994) which incorporates USGS models 17, 20 and 21 (Cox and Singer, 1986). Table 1a summarizes the reserves data for the deposits used to characterize the grade and tonnage. The table is listed in increasing tonnage. Table 1b contains deposits that have been classified as calcalkalic porphyry copper deposits but do not fit well on the grade and tonnage curves. These deposits were excluded because the data provided for them were considered not to be a reasonable representation of the resource.

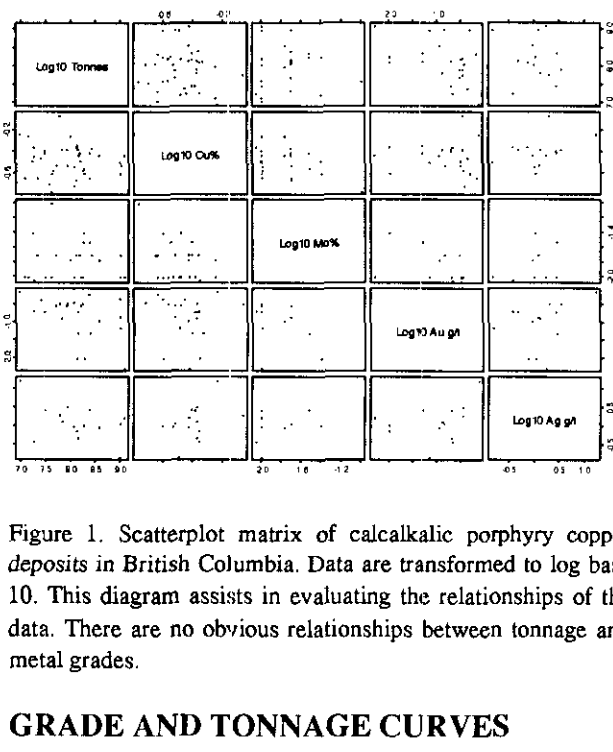

Figure 1. Scatterplot matrix of calcalkalic porphyry copper deposits in British Columbia. Data are transformed to log base 10. This diagram assists in evaluating the relationships of the data. There are no obvious relationships between tonnage and metal grades.

GRADE AND TONNAGE CURVES

Grade and tonnage curves graphically describe the distribution of tonnage and average deposit grades. The process of grade and tonnage curve construction involves the following steps:

- Plot the data are plotted as quantile-quantile plots (q-q plots).
- Plot the data as pairs plots (cf. Figure 1) to examine any possible associations or correlations.
- Calculate basic summary statistics on the data to check for non-normality (log transform) or high variances

Figure 1 shows a scatterplot matrix of the grade and tonnage data. These data have been transformed to log base 10. This plot is a graphically convenient way of examining interactions between the variables. In resource assessment procedures, the commodities and tonnages should be uncorrelated. The application of methods such as scatterplot matrices and regression methods can assist in testing the degree of correlation. From Figure 1 it can be seen that there is little or no correlation between any of the variables. This has been verified using regression methods.

A discussion on the use of the lognormal model is given by Harris (1984). The correct interpretation of the curves is important in applying them to resource assessment. They are plotted as the log (base 10) of grade or tonnage versus the proportion of curve (0-1). Although the distribution of tonnage and grades for metal deposits is generally log normal, this is not necessarily the case for industrial minerals (Singer and Orris, 1994).

Figure 2 shows cumulative probability plots for the porphyry copper grade and tonnage data. Each plot shows the ordered tonnage or grade for each deposit as a point. A theoretical log-normal curve is also plotted on the graph. The curve is derived from the mean and variance of the sample data. Each curve also shows three tie lines at 90, 50 and 10 percentile levels of the curves. The grade or tonnage that is shown at the 50 percentile level indicates the average or mean grade or tonnage for that particular deposit type. The figures can be interpreted as 50 % of the deposits will have a grade or tonnage less than this value, and 50 % of the deposits will have a grade or tonnage greater than this value.

In order to assess data that comprise the grade and tonnage information, various graphical procedures can be applied to test for atypical samples and examine the nature of the population distribution. The plots of Figure 3 show the log (base 10) of tonnage or grade of the deposits plotted against the quantiles of a normal distribution. Such plots can reveal atypical deposits or an unexpected trend in the data. Quantitative procedures can also be applied to determine which transformation best fits the data. Figures 3a and b show quantile-quantile plots for both the raw data and the log-transformed tonnage data. In Figure 3a the four largest deposits appear as outliers. Even after applying a log transform to the tonnage data these four deposits are still noticeably large and possibly atypical. Also, in Figure 3b, there is a change in the slope of the curve where deposit tonnages exceed 100 million tonnes. Such a change in slope suggests two distinct tonnage populations. The cause of

TABLE 1A
CALCALKALIC PORPHYRY COPPER DEPOSITS IN BRITISH COLUMBIA

Deposit	Tonnes (x1000)	Cu %	Mo %	Au g/t	Ag g/t
TASEKO	9,502	0.58	0	0 75	17
IDE - AM	11,481	0.23	0 01	NA	NA
KRAIN	14,000	0.56	0 01	NA	NA
OX LAKE	17,000	0.33	0.04	NA	NA
BIG ONION	18,000	0 36	0	NA	NA
NANIKA	18,144	0 44	0.009	0 21	0.38
REY	21,488	0 23	0.02	NA	NA
RED DOG	25,000	0.35	0	0 44	NA
EAGLE	30,000	0.41	0.01	0.2	2 71
GNAT PASS	30,000	0.39	0	NA	NA
SWAN	36,000	0 2	0	NA	NA
WHITING CREEK	40,000	0.17	0.1	NA	NA
DOROTHY	40,800	0.25	0.01	NA	NA
ANN	43,381	0.27	0	NA	NA
LOUISE LAKE	50,000	0.3	0.02	0 3	NA
KERR	60,000	0.86	0	0.34	2
GRANISLE	66,434	0 42	0	0.13	1.33
HI-MARS	82,000	0.3	0	0.3	NA
MORRISON	86,000	0.42	0	0.34	3 4
HUCKLEBERRY	100,000	0.56	0 017	NA	NA
GAMBIER ISLAND	114,000	0.29	0.01	NA	1
KEMESS NORTH	116,000	0.19	0	0.37	NA
HIGHMONT	125,000	0.22	0 02	NA	NA
BETHLEHEM	134,000	0.44	0	0 01	0.74
CATFACE	138,000	0.46	0	0 05	NA
BELL COPPER	143,000	0.42	0	0.2	0 48
POPLAR	144,000	0.37	0 02	NA	NA
O.K.	155,000	0 39	0.02	NA	NA
POISON MOUNTAIN	159,000	0.33	0.01	0.31	NA
HUSHAMU	173,000	0.27	0.01	0 34	NA
MAGGIE	181,000	0.28	0.03	NA	NA
BRENDA	183,000	0.25	0.04	0.01	1.06
KEMESS SOUTH	230,000	0.23	0	0.65	NA
BERG	238,000	0.39	0 03	0.05	2.84
JA	260,000	0.43	0.02	NA	NA
ISLAND COPPER	373,000	0.37	0.017	0.11	0 94
GIBRALTAR	965,000	0.32	0.01	0.07	0.15
FISH LAKE	976,000	0.25	0	0.48	NA
SCHAFT CREEK	1,000,000	0 3	0.02	0.14	1.2
HIGHLAND VALLEY COPPER	1,200,000	0.372	0.01	0.005	1.73

TABLE 1B
CALCALKALIC POPRHYRY COPPER DEPOSITS NOT USED IN GRADE AND TONNAGE CURVES

Deposit	Tonnes	Cu%	Mo%	Aug/t	Ag g/t
WIZ	294	1.26	0	NA	0.01
G.E.	540	0.27	0	NA	NA
VIMY	819	0 35	0	NA	NA

Note: NA= Missing Values (Data not available)

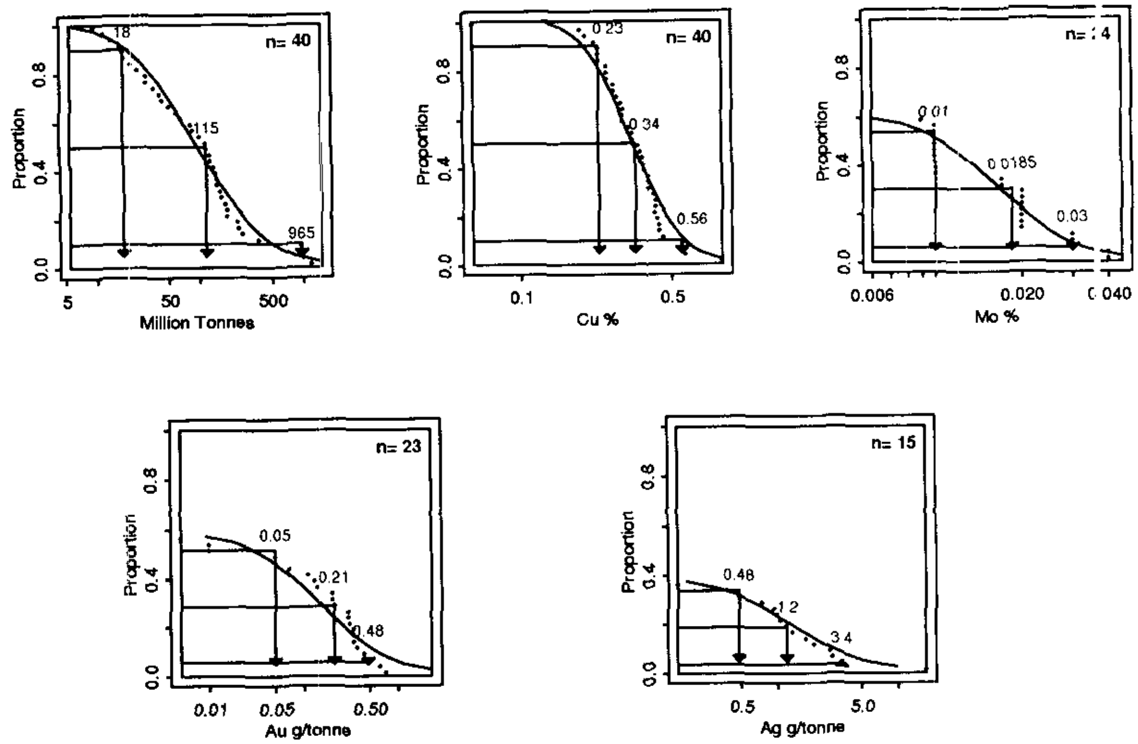

Figure 2: Grade and tonnage curves for British Columbia calcalkalic porphyry deposits.
Individual deposits are shown a dots. The curved line represents a lognormal curve fitted to the mean and variance of the logtransformed data. The tie lines on each graph represent the values of the tonnage or grade at the 90th, 50th, and 10th percentile. The intersection of the data and log-normal curve with the y-axis represents the proportion of data that are greater than zero and/or not missing data (NA in Table 1a). The number of data points for each commodity is shown in the upper right of each figure. No distinction is made between production and reserve data.

these two populations is not clearly understood. Figures 3c and d show quantile-quantile plots for copper. In this case the distinction between the untransformed and transformed data is less obvious. On closer examination however, it can be seen that the log-transformed data provide a better fit in the quantile-quantile plot. The copper data also displays four outliers which represent copper values greater than 0.5%. These data occur within the small to medium size deposits although there is no clear correlation between tonnage and copper grade as shown in Figure 1. The line of points in Figure 3d appears to be nearly a straight line. However, there is a slight change of curvature in the line at about log10 Cu = -0.4 (0.4%Cu) but it is not as nearly pronounced as the tonnage data in Figure 3b. Further study is required to investigate the possible bimodal nature of the calcalkalic porphyry copper deposits.

Finally, summary statistics can be applied to provide some numerical description of the data. These descriptions are best interpreted with the plots as described in Figures 1, 2 and 3. Table 2 shows summary statistics for the grades and tonnages of the porphyry copper data.

CONCLUDING REMARKS

The mineral potential project requires assessments for a wide range of mineral deposit types. For several deposit types, grade and tonnage data have been constructed to meet the requirements for quantitative resource assessment. As outlined above, there are many considerations required in the construction of grade and tonnage tables and curves. With these considerations in mind, mineral deposit resource data can be compiled to meet the requirements of the British Columbia Resource Assessment Process.
For many mineral deposit models, there are an inadequate number of deposits for the construction of grade and tonnage curves. In these cases, and where appropriate, deposit model descriptions and grade and tonnage curves from the USGS have been used. In some cases there are deposit profiles for which there are no grade and tonnage data available. In these special cases, mineral deposit experts were asked to provide examples of expected grades and tonnages, from which curves could be constructed and used in situations where estimates are required.

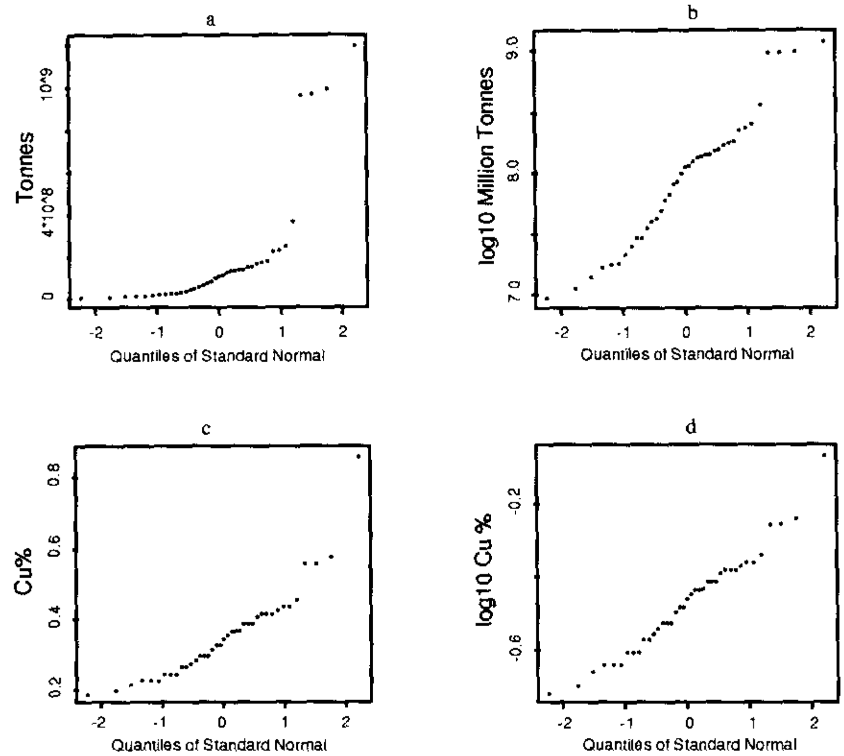

Figure 3: Quantile-quantile plots of British Columbia calcalkalic porphyry copper deposits.. Deposit tonnage and copper grades are displayed as raw untransformed data and as log-transformed values. The use of quantile-quantile plots graphically displays the distributional nature of the data. The tonnage data displayed in raw form (a) show a marked positive skewness. The log-transformed tonnage data (b) display characteristics that are more typical of a normally distributed set of data. Note the 4 outliers in (b). The copper data show a small positive skewness in the raw state (c). This skewness is absent in the log-transformed state (d).

TABLE 2
SUMMARY STATISTICS FOR BRITISH COLUMBIA CALCALKALIC PORPHYRY COPPER DEPOSITS.

	Tonnes	Cu%	Mo%	Au g/t	Ag g/t
Minimum	6.98	-0.77	-2.05	-2.3	-0.82
1st Quartile	7.54	-0.58	-0.2	-1.06	-0.08
Median	8.03	-0.47	-1.73	-0.68	0.07
Mean	7.95	-0.47	-1.76	-0.84	0.11
3rd Quartile	8.24	-0.38	-1.7	-0.47	0.37
Maximum	9.08	-0.07	-1	-0.12	1.23
Variance	0.3	0.02	0.07	0.36	0.22
NA's	0	0	16	17	25

Note: All data transformed to log (base 10)
NA= Missing Values (Data not available)

The compilation, description and refinement of grade and tonnage data is being carried out for all deposit models for which data are available in British Columbia. The resulting models will provide a realistic basis for quantitative resource estimation procedures that form a core part of the British Columbia Resource Assessment Process.

ACKNOWLEDGMENTS

The author wishes to acknowledge the advice and support of Don Singer and Dennis Cox, United States Geological Survey for their invaluable comments and assistance during the initial compilation of the grade and tonnage data used for the BC Resource Assessment Program.

REFERENCES

Allais, M. (1957): Method of Appraising Economic Prospects of Mining Exploration Over Large Territories - Algerian Sahara Case Study; *Management Science*, Volume 3, Number 4, pages 285-347.

Agterberg, F.P., Chung, C.F., Fabbri, A.G., Kelly, A.M. and Springer, J.S. (1972): Geomathematical Evaluation of Copper and Zinc Potential of the Abitibi Area, Ontario and Quebec; *Geological Survey of Canada*, Paper 71-41.

Bliss, J.D., Editor (1992): Developments in Mineral Deposit Modeling; *U.S. Geological Survey*, Bulletin 2004, 168 pages.

Chung, C.F., Singer, D.A., and Menzie, W.D. (1992): Predicting Sizes of Undiscovered Mineral Deposits: An Example using Mercury Deposits in California; *Economic Geology*, Volume 87, pages 1174-1179.

Cox, D.P. and Singer D.A., Editors (1986): Mineral Deposit Models; *U.S. Geological Survey*, Bulletin 1693, 379 pages.

Drew, L.J., Bliss, J.D. Bowen, R.W., Bridges, N.J., Cox, D.P., DeYoung, J.H., Jr., Houghton, J.C., Ludington, S., Menzie, W.D., Page, N.J., Root, D.H. and Singer, D.A. (1986): Quantitative Estimation of Undiscovered Mineral Resources - A Case Study of U.S. Forest Service Wilderness Tracts in the Pacific Mountain System; *Economic Geology*, Volume 81, pages 80-88.

Grunsky, E.C., Massey, N.W.D., and Kilby, W.E. (1994): Mineral Resource Assessment in British Columbia, The Mineral Potential Project; *Nonrenewable Resources*, Volume 3, Number 4, pages 271-283..

Harris, D.P. (1984): Mineral Resources Appraisal, Mineral Endowment, Resources and Potential Supply: Concepts, Methods, and Cases; *Oxford Geological Sciences Series*, 445 pages.

Harris, D.P., Freyman, A.J., and Barry, G.S. (1971): A Mineral Resource Appraisal of the Canadian Northwest Using Subjective Probabilities and Geological Opinion; *Canadian Institute of Mining and Metallurgy*, Special Volume 12, pages 100-116.

Kilby, W.E, (1995): The Mineral Potential Project: An Overview; *B.C. Ministry of Energy, Mines and Petroleum Resources, in* Geological Fieldwork 1994, Grant, B. and Newell, J.M., Editors, Paper 1995-1, this volume.

Lasky, S.G, (1950): How Tonnage and Grade Relations Help Predict Ore Reserves; *Engineering and Mining Journal*, Volume. 151, Number 4, pages 81-85.

Lefebure, D.V., Simandl, G.J., Ray, G.E., and Alldrick, D.J., (1994): British Columbia Mineral Deposit Profiles, Version 2.0; *B.C. Ministry of Energy, Mines and Petroleum Resources*, unpublished report

Lefebure, D.V., Alldrick, D.J., Simandl, G.J., Ray, G.E. (1995): British Columbia Mineral Deposit Profiles, *B.C. Ministry of Energy Mines and Petroleum Resources, in* Geological Fieldwork 1994, Grant, B. and Newell, J.M., Editors, Paper 1995-1, this volume.

Root, D.H., Menzie, W.D. and Scott, W.A. (1992): Computer Monte Carlo Simulation in Quantitative Resource Assessment; *Nonrenewable Resources* Volume 1, Number 2, pages 125-138.

Singer, D.A. (1975): Mineral Resource Models and the Alaskan Mineral Resource Assessment Program *in* Mineral Materials Modeling - A State-of-the-art Review; Vogely, W.A., Editor; *John Hopkins Press*, pages 370-382.

Singer, D.A. (1993): Basic Concepts in Three-part Quantitative Assessments of Undiscovered Mineral Resources; *Nonrenewable Resources*, Volume 2, Number 2, pages 69-81.

Singer, D.A., Orris, G.J. (1994): Quantitative Estimation of Undiscovered Mineral and Industrial Mineral Resources, Workshop, *International Association for Mathematical Geology*, Annual Meeting, Mont Tremblant, Quebec.

Singer, D.A. and Ovenshine, A.T (1979): Assessing Metallic Resources in Alaska; *American Scientist*, Volume 67, pages 582-589.

Singer, D.A. and Mosier, D.L. and Menzie, W.D. (1993): Digital Grade and Tonnage Data for 50 Types of Mineral Deposits, Macintosh Version; *U.S. Geological Survey*, Open File Report 93-280, 1 disk, 52 files.

Stonehouse Group (1993): MINFILE Reserves/Productions/ Status Audit, *B.C. Ministry of Energy Mines and Petroleum Resources*, unpublished report, Contract No. 93-708.

Whitney, J.W. (1975): A Resource Analysis Based on Porphyry Copper Deposits and the Cumulative Copper Metal Curve Using Monte Carlo Simulation; *Economic Geology*, Volume 70, pages 527-537.

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