



O T H E R I N V E S T I G A T I O N S

MULTIPLE REGRESSION, A USEFUL QUANTITATIVE APPROACH IN EVALUATING
PRODUCTION DATA FROM VEIN-TYPE MINING CAMPS,
SOUTHERN BRITISH COLUMBIA

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INTRODUCTION

Relatively little has been published on the development of quantitative mineral resource models of direct use in mineral exploration and evaluation. Nevertheless, an interesting array of literature pertaining to British Columbia has appeared since the late 1960's. An early study by Kelly and Sheriff (1969) was concerned with estimating the economic mineral potential of 20 by 20-square-mile cells over the entire Province in terms of gross dollar value of all contained mineral deposits. A comparable methodology was applied on a different scale and with more detailed geological information (4 by 4-square-mile cells) in the Terrace area by Sinclair and Woodsworth (1970). Most recently this 'cell' approach was applied by Godwin and Sinclair (1979) in an evaluation of a single porphyry-type deposit, the Casino copper-molybdenum deposit in Yukon Territory, based on a 400 by 400-square-foot cell size. All these studies related some measure of cell value (the dependent variable) to a variety of geological and other attributes of the cells (independent variables) by a multiple regression relationship.

Multiple regression has also been applied to the development of quantitative models for the relative worth of individual deposits within a mining camp (Orr, 1971; Orr and Sinclair, 1971; Sinclair, 1979; Sinclair, 1982). Models derived from these latter studies have a relative value measure for deposits (such as log of production tonnage) as the dependent variable and logarithm of average grade figures for several metals, such as silver, lead, zinc, and gold, as independent variables. The most extensive test to date by Sinclair (1982) for the Slocan silver-lead-zinc-gold camp suggests several important applications of the method:

- (1) Newly located deposits can be sampled and the average grades used to estimate potential size (value), thus providing a quantified target for further exploration.

- (2) A statistical model will isolate those deposits that do not fit the general model. In particular, deposits with low recorded production that have grade characteristics of large deposits warrant further detailed examination.
- (3) In some mining camps it may be useful to contour 'values' calculated according to a multiple regression model as one means of examining systematic variations of relative worth in order to delimit areas for detailed exploration.

PROCEDURE

A necessary precursor to the multiple regression approach to exploration model development is the availability of appropriate production information. For this purpose, computer files, developed or improved, were used as follows: Slocan, Slocan City, and Ainsworth camps - Orr (1971) and Orr and Sinclair (1971); Zeballos camp - Sinclair and Hansen (1983); Trout Lake camp - Read (1976) and Goldsmith (1984).

The multiple regression method involves selection of a value measure for each deposit for which production data are available. \log_{10} production tonnage was selected as a satisfactory relative value measure based on results by Sinclair (1979). Similarly, dependent variables were mostly logarithms of average deposit grades (silver, lead, zinc, gold) derived from total recorded production. The general form of the model is

$$\log (\text{tons}) = B_0 + \sum [B_i \log M_i] + e$$

where M_i represent gold, zinc, silver, copper, and lead. Logarithmic transformations are necessary to produce near-normal probability density functions. These data were treated by a multiple regression package which is available through the University of British Columbia Computing Centre. In particular, the backwards stepwise option was used, which rejects variables whose regression coefficients cannot be distinguished from zero at a specified level of significance ($\alpha = 0.05$, in this case).

SLOCAN (SANDON) CAMP

Slocan mining camp has been an important silver producing region since the Nineteenth Century. More than 200 individual silver-lead-zinc-gold veins are known from which some production has been obtained (Orr and Sinclair, 1971). These deposits have been divided into two groups for purposes of quantitative modelling (Sinclair, 1982). The western two-thirds of the camp provided a training set (138 deposits) with which quantitative models were established as summarized in Table 1. These models were then used to estimate potential of deposits in the eastern group for which production tonnages were known. An example is shown plotted on Figure 132, where the scatter is comparable to the standard error of the model. Such a result provides validity for the general

approach. Unfortunately, calculated tonnage by the four-variable model could be compared with only 19 known production tonnages because gold contents were not recorded for most of the 65 deposits in the eastern group. Obviously, gold is an important component in such a model (compare standard errors of the two models in Table 1).

TABLE 1
SLOCAN (SANDON) REGRESSION MODELS

A:	$\text{Log (tons)} = 1.3789 - 1.1459 \log (\text{Au}) - 0.5544 \log (\text{Pb})$
	$R^2 = 0.59$
	$S_e = 0.8608$
	$n = 62$
B:	$\text{Log (tons)} = 5.4172 - 1.3907 \log (\text{Ag}) - 0.3786 \log (\text{Zn})$
	$R^2 = 0.22$
	$S_e = 1.2490$
	$n = 95$

The number of deposits on which to base a model increases dramatically if only three independent variables are considered and gold is the one omitted. However, the resulting model (model B, Table 1) is very unsatisfactory from a practical point of view because of the large standard error and the very low coefficient of variation. It is evident

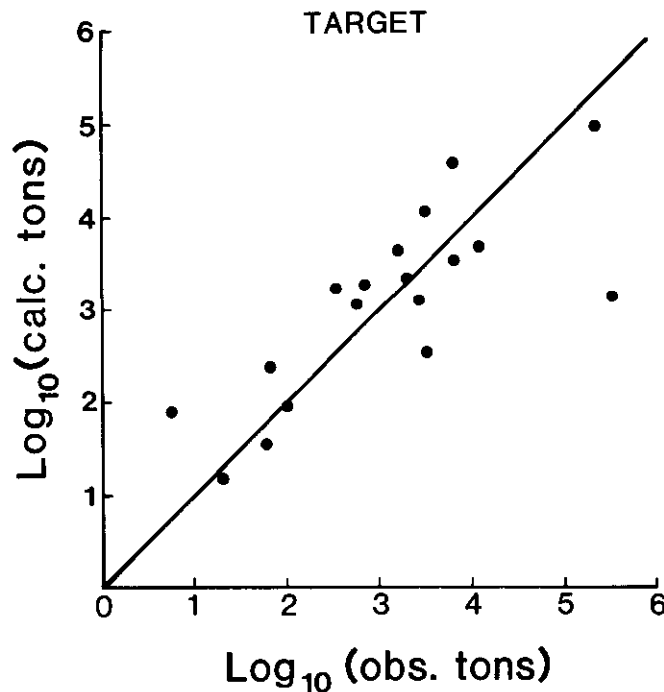


Figure 132. Observed versus calculated tonnages using a multiple regression equation, Slocan camp.

that gold data are highly desirable in such models for Slocan (Sandon) camp. Perhaps the most significant contribution of this study is to stress the importance of gold assays in evaluating vein deposits in Slocan camp.

AINSWORTH CAMP

Of the more than 90 lead-zinc-silver-gold deposits in Ainsworth camp with recorded production, only 13 have average grade information for all four variables. These 'complete' sets of assay data have been used to develop regression model A of Table 2. The multiple regression model has reduced to a simple regression model in this case because lead is a linear combination of other variables and at the 0.05 level silver and zinc were both rejected as not contributing to explaining variability in tons. Clearly gold is an important variable for estimating size potential, but unfortunately is available for few deposits. A much larger data base existed upon which to base a regression model if gold were not included. With this larger data base only zinc was rejected as not contributing to an explanation of the variability of tons. The remaining model (B in Table 2), although statistically meaningful, is of little practical use because of relatively large standard error and low coefficient of variation.

TABLE 2
AINSWORTH REGRESSION MODELS

$$\begin{aligned} \text{A: } \text{Log (tons)} &= 1.5268 - 0.8068 \log (\text{Au}) \\ R^2 &= 0.68 \\ S_e &= 0.6949 \\ n &= 13 \end{aligned}$$

$$\begin{aligned} \text{B: } \text{Log (tons)} &= 3.4067 - 0.5770 \log (\text{Ag}) - 0.8011 \log (\text{Zn}) \\ R^2 &= 0.21 \\ S_e &= 1.1270 \\ n &= 49 \end{aligned}$$

SLOCAN CITY CAMP

Slocan City camp contains 74 small polymetallic vein deposits for which production information is available (Orr and Sinclair, 1971). These deposits are scattered throughout an area of about 115 square kilometres. Of these, only 17 have complete production information for tonnage mined and average grades of silver, lead, zinc, and gold. Data for these 17 deposits were used to develop a regression model (A of Table 3). The model is mediocre, but at that, is substantially better than model B (Table 2) which is obtained when gold is omitted.

TABLE 3
SLOCAN CITY REGRESSION MODELS

A: $\text{Log (tons)} = 1.5878 - 0.6085 \log (\text{Au}) - 0.5177 \log (\text{Zn})$
 $R^2 = 0.37$
 $S_e = 1.0700$
 $n = 17$

B: $\text{Log (tons)} = 2.0867 - 0.4508 \log (\text{Zn})$
 $R^2 = 0.14$
 $S_e = 1.1290$
 $n = 33$

TROUT LAKE CAMP

Four grade variables and production tonnages are available for 17 past producer silver-lead-zinc veins. These data were used to establish the following multiple regression model:

$$\begin{aligned} \log (\text{tons}) &= 3.484 - 1.524 \log (\text{Ag}) - 1.821 \log (\text{Au}) + 1.440 \log (\text{Pb}) \\ &\quad - 2.644 \log (\text{Zn}) \\ R^2 &= 0.78 \\ S_e &= 0.867 \end{aligned}$$

All four grade variables have a significant contribution to the reduction of variance in the model, although silver is the single most important variable. Production data span more than five orders of magnitude; consequently, a model that estimates size with an absolute error less than one order of magnitude may have potential in evaluating well-sampled deposits in the camp. Practical application of the model is limited at the moment because for many deposits production data were not recorded for all four metals; zinc data in particular are deficient.

ZEBALLOS CAMP

Production data for 11 vein deposits from the Zeballos gold camp, Vancouver Island (Hansen and Sinclair, 1984), were used to derive the following model:

$$\begin{aligned} \log_{10} (\text{tons mined}) &= 3.09 - 0.97 \log_{10} (\text{Ag}) - 1.67 \log_{10} (\text{Cu}) \\ R^2 &= 0.98 \\ S_e &= 0.41 \end{aligned}$$

where tons mined is short tons of recorded production, and silver and copper are average grades of recorded production in ounces per short ton and per cent respectively. The backwards stepwise procedure removed two potential grade variables, gold and lead, from the model at the 0.05 level.

DISCUSSION

The five examples cited here demonstrate a procedure for developing useful quantitative (regression) models to evaluate size or relative value of polymetallic vein deposits. Each of the examples involves four independent grade variables. Experience with one, two, or three independent variables is that the resulting models have substantially larger standard errors than is the case with four independent variables.

In four cases the calculated models involve silver-gold-lead-zinc deposits. At the fifth camp the metals are gold-silver-lead-copper. The models differ dramatically from one camp to another, a difference that is accentuated by considering the most important single variable in reducing variance in the model. At Zeballos the important element, copper, is correlated negatively with tonnage. In Slocan (Sandon) and Ainsworth camps, gold is by far the most significant independent variable and is also negatively correlated with tons. Silver is important in Trout Lake camp, and is correlated positively with size.

The regression model approach suggests a variety of practical applications:

- (1) The small number of deposits in a camp that depart most from the model may be anomalous. Of particular interest are those deposits with low observed tonnages and very much higher calculated tonnages. Such deposits may fit the model and have relatively large undiscovered tonnages.
- (2) In each camp there are a large number of past producers for which fewer than four metal grades were recorded. In some cases resampling of old workings is possible and such samples, analysed for four variables, could be evaluated by the regression model. Such a program would appear especially viable in the case of Slocan (Sandon) camp where about 270 past producers are known, only 89 of which have data for all four independent variables of the regression model.
- (3) Newly found deposits evaluated by drilling, surface and/or underground sampling may have sufficient data so that weighted mean grades can be substituted in the model for rough estimates of size potential. Of course past producers also can be re-evaluated in this way as additional data become available.

The principal difficulty with the method lies in the substantial amount of information necessary to establish the models. Even in camps with many deposits and a long history of production, much of the production may not have been analysed for enough variables or the appropriate variables to provide an acceptable model. Our work demonstrates that different variables are important in different camps. Furthermore, the most important variable for purposes of estimating tonnage may be of relatively minor economic importance with the result that little or no attention is paid to measuring it. This is true of copper in Zeballos deposits and gold in deposits of the Slocan (Sandon) and Ainsworth camps.

CONCLUSIONS

Multiple regression models relating production tonnages to average grades of production for deposits from polymetallic vein camps appear to have potential as a deposit evaluation technique. In the five camps studied here the models provide tonnage estimates with an error of about one order of magnitude or less, in some cases much less. This error is large, but in the context of range of deposit sizes (commonly over five to seven orders of magnitude) the models can discriminate between small tonnage and large tonnage extremes. In addition, the models provide a basis for a probabilistic approach concerning the chances a deposit has of exceeding a 'minimum conceptual target.'

Despite limitations of the availability of data, the regression method appears to have potential in evaluating new finds in established mining camps and in re-evaluating known deposits for which more comprehensive assay information becomes available.

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