A PRELIMINARY REPORT ON RESOURCE ESTIMATION USING GRIDDED GEOLOGICAL DATA I: GUICHON CREEK BATHOLITH (92I/6, 7, 10, 11)

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INTRODUCTION

Many quantitative resource-oriented studies are based on geological variables quantified with respect to cells of a regular grid superimposed on a geological map of an area. Cell size of the grid varies with the purpose and scale of a study as well as the detail with which geological information is known. In a regional study of British Columbia copper resources Kelly and Sheriff (1969) used a 20 by 20-square-mile cell whereas Sinclair and Woodsworth (1970) used a 2 by 2-square-mile cell size for an estimation of vein potential in the Terrace area of northern British Columbia, and Godwin and Sinclair (1979) extended the methodology to a grid cell size of 400 by 400 square feet over the Casino porphyry copper-molybdenum deposit, Yukon Territory.

The types of variables we are concerned with in quantitative, geology-based regional resource studies include:

(1) percentage of a cell underlain by a particular rock type,
(2) distance from cell centre to a specific geological feature,
(3) spatial density of dykes, fractures, and other features,
(4) lengths of contacts, dykes, and fractures contained within a cell,
(5) surface area of the contiguous mass of a given rock type nearest a given cell.

Agterberg (1981) discusses the form of the probability density functions of these types of variables. One of their principal features is the large number of zero and 100 per cent values that result for variables of the type involving 'per cent of a cell underlain by a specific rock type'.

The present study has two specific goals:

(1) to develop a general, computer-based approach for the estimation of quantitative geological variables as a basis for studies of regional mineral resource potential, and

(2) to apply the foregoing computer-based methodology to the Guichon Creek Batholith, host for an important proportion of known copper resources in British Columbia.

PROCEDURE

A general procedure for a quantitative computer-based approach is given by Sinclair and Bentzen (1983). Two general stages are as follows:

(1) quantification of geological variables using a computerized approach, and
(2) application of an appropriate mathematical approach to an evaluation of the quantitative data base.

The former step involves digitizing and editing of map information, and application of a series of computer programs to measure geological variables relative to an arbitrary grid. The latter step depends to a considerable extent on subjective decisions. A general methodology for quantification of geological variables, illustrated by Sinclair and Bentzen (1983), emphasizes the digitizing and calculation phases.

The principal advantages of a computer-based procedure are its consistency, the ability to build in a variety of editing procedures to detect errors in the data base, and the ease with which new variables can be added or old variables changed. The ease with which a completely new set of variables can be generated for a new cell size or a new grid origin of a grid is particularly noteworthy.

Once the data are available a set of control cells must be selected; these are used to generate a mathematical model for value or potential in terms of the measured geological variables. Multiple regression, discriminant function analysis, and a variety of probabilistic procedures have been used as a means of developing such models (Agterberg, 1981). Here we will stress a multiple regression model in which known mineral resources within a cell represent the dependent variable and our measured geological variables (appropriately transformed if necessary) are the independent variables. Once a satisfactory model has been established for the control cells, it is applied to the remainder or target cells as a means of estimating their mineral potential.

DIGITIZING GEOLOGICAL INFORMATION

Digitizing of geological information (outlines of areas underlain by rock types, linear features, etc.) proceeds as follows:

(1) In general, a contact is traced with the digitizer cursor completely around a given geological feature.

(2) Enough points are digitized so that the resulting polygon appears to be a smooth representation of the original outline when plotted at the original scale.

(3) Each polygon is numbered and catalogued.

(4) The number of a polygon is placed in the comment field of the first point of that polygon.

(5) If any point along a polygonal outline represents an intersection or 'meeting' of contacts, that point is labelled as a node in the comment field.

If a digitizing error is made by an operator it is often possible to return to the nearest node, begin digitizing again, and edit out the error segment.

A digitizing program was written in FORTRAN IV using University of British Columbia system subroutines to read the cursor of the digitizer. The program corrects for displacement from the origin and for skewness (where the map has not been placed parallel with the x and y axes of the digitizer). A digitized point is read into memory where it is stored until output as a file. Each digitized point corresponds to a record consisting of four fields as follows:

FIELD	DESCRIPTION
1	4 characters (MOVE, DRAW, or SAME)
2, 3	x and y coordinates written in FORTRAN FORMAT (2G15.7)
4	Comment field of 8 characters

The operator can choose freely when to use the comment field.

EDITING OF POLYGONAL (DIGITIZED) INFORMATION

Three procedures are used for editing digitized polygonal information. Two, ADEND and EDTEK, are programs written by one of us (A.B.), the third is the text editor supplied by the operating system (MTS). In a digitizing session a number of polygons normally would be placed in the same file. The first part of the editing process is to assign polygons to separate rock type files.

The editing program presents one polygon at a time to the operator and ADEND allows the operator to assign a 'flag' to separate polygons. ADEND is used on a TEKTRONIX 4010. The operator selects the number of points to be displayed on the terminal by a trial-and-error process and isolates a polygon — a flag is then added and the operator continues with the next polygon. During this phase of editing it is possible to 'repair' errors in the digitizing process (for example, the deletion of erroneous segments). In addition, polygons must be closed for future use so it is important to verify that the last and first points are identical. Finally, the nature of area determination program is such that digitizing should be in an anti-clockwise direction. Consequently, at this stage any polygons digitized in a clockwise direction must be reversed.

EDTEK is used on a TEKTRONIX 4010 and permits the display of polygons as well as a limited amount of editing. One point or several points at a time can be moved back and forth through a polygon thus allowing repair of digitized lines. In addition, plotter directives can be changed; for example, 'MOVE' can be changed to 'DRAW'. Another plot directive 'NOPE' (meaning NON-OP) was added which effectively eliminates a point without actually deleting the coordinates.

At this point in the editing there should be one file for each geological variable. In the case of a rock type, the file contains as many polygons as there are separate outcrop areas. A program CHKPL is used to verify that each polygon is constructed in a counter-clockwise manner.

A final editing stage involves the recognition of 'islands' of a second rock category within a polygon surrounding an area of a different rock category. These 'islands' were coded as clockwise polygons attached to the perimeter of the surrounding polygon.

An example of edited polygons is given by Sinclair and Bentzen (1983) for the border phase of the Guichon Creek Batholith.

MEASUREMENT OF GEOLOGICAL VARIABLES

All variables are to be measured relative to individual cells of an arbitrary grid superimposed on a field of geological data. The types of variables referred to earlier (*see* Introduction) include area measurements, length of line segments, and distance to nearest expression of a geological feature, measured respectively by a series of subroutines named AREA, LCON, and DCON.

AREA is an area calculating program that utilizes a 'point counting algorithm'. Each cell of a grid superimposed on the area in question is represented by an array of 400 subcells (points). The program determines for each cell, the proportion of subcells that are contained inside or outside the polygons of a particular rock type. A subcell was assigned '0' if it lies outside a polygon and '1' if it lies within a polygon. The array of 0's and 1's were stored and area calculated by simple counting. In the early stages a listing of the array was used as a check on the procedure and programming. In a few cases of highly irregular outcrop shapes, the inefficiency of the AREA algorithm necessitated subdivision of a complex polygon into several smaller simple polygons.

DCON calculates the distance from the centre of a cell to the nearest contact of a selected rock type. Each cell in turn is checked against a current polygon.

TABLE 1
VARIABLES AND TRANSFORMATION USED IN THE REGRESSION ANALYSIS
(Variables considered but not used are omitted from the list.)

	VARIABLES	TRANSFORMATION	COMMENTS
8	distance[1] to Bx	arith, stand[3]	Breccia
9	distance to 4	arith, stand	Bethlehem phase granodiorite
10	distance to 4a	arith, stand	Bethlehem phase granodiorite
11	distance to 5a	arith, stand	Skeena variety granodiorite
12	distance to 5	airth, stand	Bethsaida phase quartz monzonite to granodiorite
13	distance to 5b	arith, stand	Bethsaida phase quartz monzonite to granodiorite
17	length[2] of 2	arith, stand	Border phase quartz diorite to granodiorite
24	length of 4	arith, stand	Bethlehem phase granodiorite
25	length of 4a	arith, stand	Bethlehem phase granodiorite
26	length of 5a	arith, stand	Skeena variety granodiorite
27	length of 5	arith, stand	Bethsaida phase quartz monzonite to granodiorite
28	length of 5b	arith, stand	Bethsaida phase quartz monzonite to granodiorite
46	area[4] of sum of 2, 2a	arcsine	Border phase quartz diorite to granodiorite
47	area of sum of 3a, 3b, 3c, 3d, 3e	arcsine	Guichon variety, Chataway variety, and Transitional granodiorite
48	area of sum of 4, 4a	arcsine	Bethlehem phase granodiorite
49	area of sum of 5a, 5, 5b	arcsine	Skeena variety granodiorite and Bethsaida phase quartz monzonite to granodiorite
54	distance to Ex4[5]	arith, stand	Bethlehem phase granodiorite
55	distance to Ex5a	arith, stand	Skeena variety granodiorite
56	distance to Ex5	arith, stand	Bethsaida phase quartz monzonite to granodiorite
57	length of Ex2	arith, stand	Border phase quartz diorite to granodiorite
61	length of Ex4	arith, stand	Bethlehem phase granodiorite
62	length of Ex5a	arith, stand	Skeena variety granodiorite
63	length of Ex5	arith, stand	Bethsaida phase quartz monzonite to granodiorite
71	sum of area of 2a, Ex2	arcsine	Border phase quartz diorite to granodiorite
72	sum of area of 3a, Ex3b, 3c, Ex3d, Ex3e	arcsine	Guichon and Chataway variety granodiorite, and Transitional granodiorite
73	sum of area of Ex4, 4a	arcsine	Bethlehem phase granodiorite
74	sum of area of Ex5a, Ex5, 5b	arcsine	Skeena variety granodiorite and Bethsaida phase quartz monzonite to granodiorite
75	distance to Lornex fault	arith, stand	
77	grade of copper of deposits	log	
88	whole rock copper content	log	
89	whole rock zinc content	log	
90	geomagnetic field strength	arith, stand	
94	difference in geomagnetic field strength	log	
95	distance to wallrock	arith, stand	

[1] 'Distance' means the distance from centre of cell to nearest contact with one of above rock types.
[2] 'Length' means length of contact of each of above rock types within each cell.
[3] 'Arith, stand' means arithmetic, standardized, that is, the mean value of a variable is subtracted from a given value and the result is divided by the standard deviation.
[4] 'Area' means fraction of area of each cell underlain by each of above rock types.
[5] 'Ex' means that the contact of this rock unit was extensively extrapolated across under or overlying sedimentary and volcanic rocks.

LCON measures the length of a particular rock contact within a given cell. The procedure is to measure the distance between successive pairs of points in a polygon, determine which cell the points are in, and cumulate length until a point is found outside the current cell. For a given variable each polygon is treated in succession, and within each polygon points are examined successively. For two points that straddle the boundary of adjoining cells no attempt is made to distribute the distance between cells. This is not a problem where distance between points is small compared with cell dimensions.

Verification of measured geological variables is achieved by plotter output of the measurements at a scale that can be overlain on the base geological map.

APPLICATION TO THE GUICHON CREEK BATHOLITH

Geological variables for the Guichon Creek Batholith were digitized as outlined previously using as a base the most recent publically available geological map of the area (McMillan, 1978). Variables quantified and found useful are listed in Table 1. All variables were examined as histograms and probability graphs and most were transformed to a closer approach to normality as indicated in Table 1.

A control area consisting of 32 cells was selected to include a geologically representative transect across the batholith that included the major mineral deposits. Measures of cell value were estimated by copper reserves and production taken largely from Sinclair, *et al.* (1982). Within the transect, cells with no known copper content were assigned a value of 1 000 tonnes for most of our studies; a non-zero value was required because the value variable (tonnes of copper) was log transformed.

Backward stepwise multiple regression was conducted for the 32 control cells with tonnes of copper (log transformed) as the dependent variable and various groupings of geological variables (approximately transformed, Table 1) as independent variables. Relatively simple equations were eventually established after considerable trial and error on (1) variations in assumed copper content of 'zero' reserve cells, (2) the effects of different transformations of some independent variables, and (3) sensitivity studies on the inclusion and omission of several independent variables. A final model for this phase of the study is listed in Table 2.

TABLE 2
MULTIPLE REGRESSION EQUATION FOR
COPPER RESOURCE ESTIMATION
GUICHON CREEK BATHOLITH

$$\begin{aligned}\text{Log}^{10}\text{ (tonnes copper)} = 1.2752 &+ 0.7623\text{ (magnetic field relief)}\\ &- 0.8231\text{ (distance to breccia)}\\ &- 1.1351\text{ (area Chataway – Guichon)}\\ &- 0.3509\text{ (length of contact of hybrid phase)}\end{aligned}$$

$R^2 = 0.49$; Standard Error = 0.9117; variables significant at 0.05 level.

The regression model for cell value was then applied to the target cells and cell values were estimated as potential tonnes of concentrated copper. The model was used first to estimate cells underlain by known rock types, and secondly, to estimate copper potential in cells with younger volcanic cover where we had to interpolate geological contacts. Results are summarized on Figure 96. These results are subject to a considerable amount of uncertainty — the standard error of the model is about one order of magnitude, but a major source of unknown error also exists in the basic assumptions that a continuous relationship exists between tonnes of copper and a combination of geological variables, and that the control cells are truly representative. At this stage we can say that the variables included in the model appear reasonable from a geological point of view and that the model reproduces most known large copper reserves reasonably well (that is, within the error limits of the regression equation).

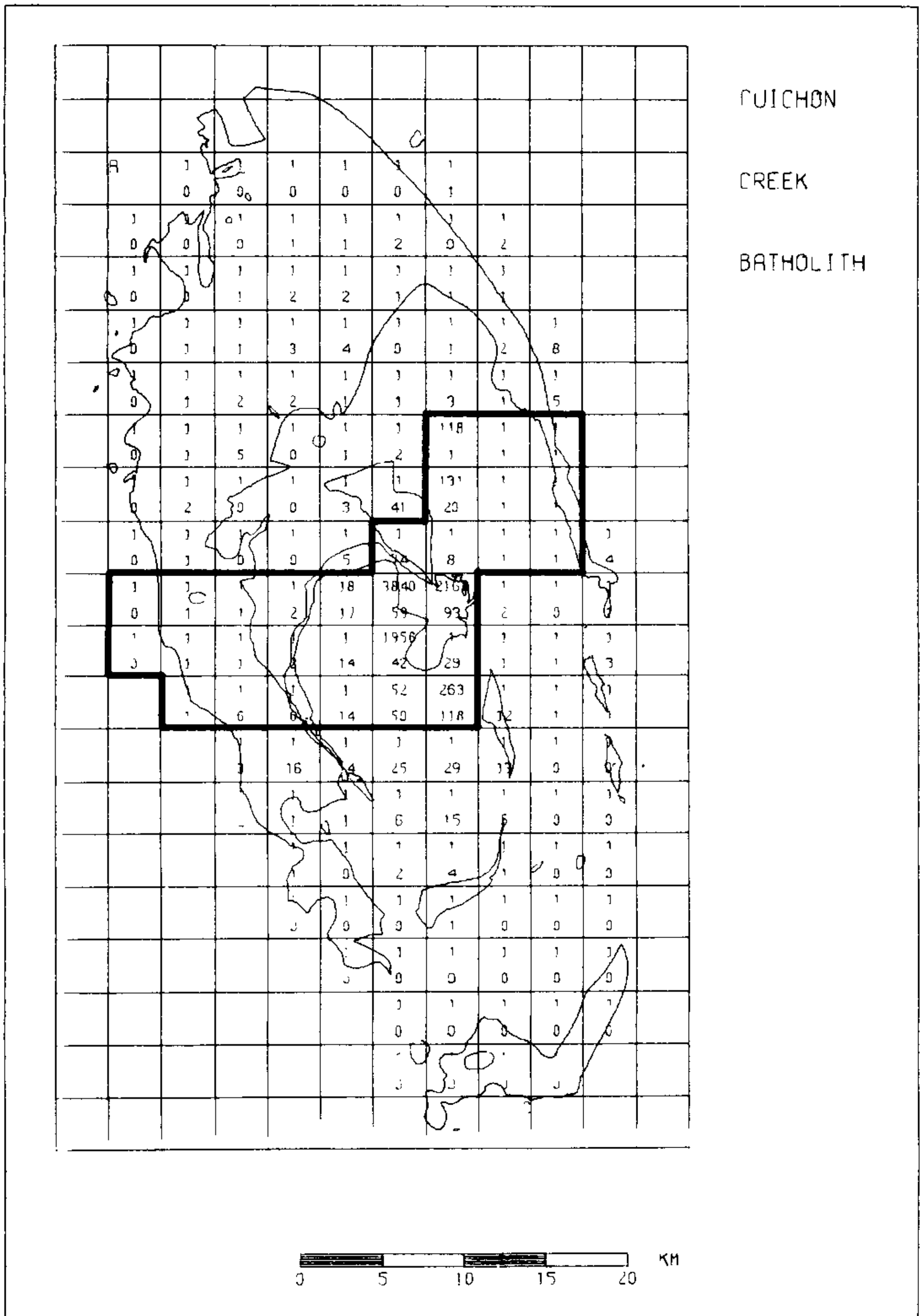

Figure 96. Two by 2-mile-squared grid cells superimposed on the Guichon Creek batholith. Control cells (30) are enclosed by a heavy rectangular outline. Figures in each cell refer to thousands of tonnes of copper observed (upper) and calculated by backward stepwise regression model (lower).

DISCUSSION

This study clearly outlines the copper-rich central part of the batholith but also emphasizes several cells that appear to have high copper potential but no known reserves. One purpose of the study was to develop a methodology for recognizing areas now covered by younger volcanic rocks that have potential. The results are at least partially successful in this regard although unknown factors always leave an element of doubt.

The models we have developed require further testing using sensitivity tests; tests to examine the effects on the model of varying the size of the grid cell and the origin of the grid. Other mathematical models than multiple regression should also be attempted for the Guichon data base.

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