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A METHOD FOR THE

THREE-DIMENSIONAL STUDY

OF BEDDED DEPOSITS

(Application to the Hat Creek Coal Deposit)

16095

Respectfully submitted,

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Montreal, August 25th, 1978

FOREWORD

This report gives the results of research completed by Prof. J.M. Rendu during his appointment as Visiting Professor with the Department of Mineral Engineering of Ecole Polytechnique. The aim of this research was to develop a general geostatistical methodology for the three-dimensional estimation of bedded mineral deposits, and to test this methodology using data from the Hat Creek Coal Deposit. These aims have been successfully reached. The methodology and the results of its application are presented here.

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1 - INTRODUCTION TO THE PROBLEM

The problem of interest is the evaluation of bedded deposits. Typically, this problem is treated as a two-dimensional problem, as illustrated in Fig. 1. A reference plane X Y is chosen parallel to the coal bed mineralization, and a point in the deposit is defined by its X and Y coordinates, and its distance Z from the reference plane. (For convenience, we will assume that the reference plane is the horizontal plane, the Z coordinate being the point elevation.) The deposit is then divided in blocks of fixed size in the XY plane (e.g. block EFGH in Fig. 1), but of variable size in the Z direction (block ABCD). The average grade μ_B of such a block is calculated by a formula of the form :

i.e. coal its not mineralized!!

$$\mu_B = \sum_{i=1}^{I} b_i \mu_i \tag{1}$$

where I is the number of boreholes used for valuation, μ_i is the mean grade of the samples in the i-th borehole, and b_i is the weight given to the i-th borehole. The weights b_i are calculated by kriging, or more traditionally by inverse power of the distance.

Even though the thickness of mineralization (AB in Fig. 1) may be much larger than the height of a mining bench, all the mining blocks whose projection on the XY plane falls within the limits EFGH are given the same value μ_B. The position of a mining block with respect to the footwall (F/W) and hanging wall (H/W) of the mineralization is ignored.

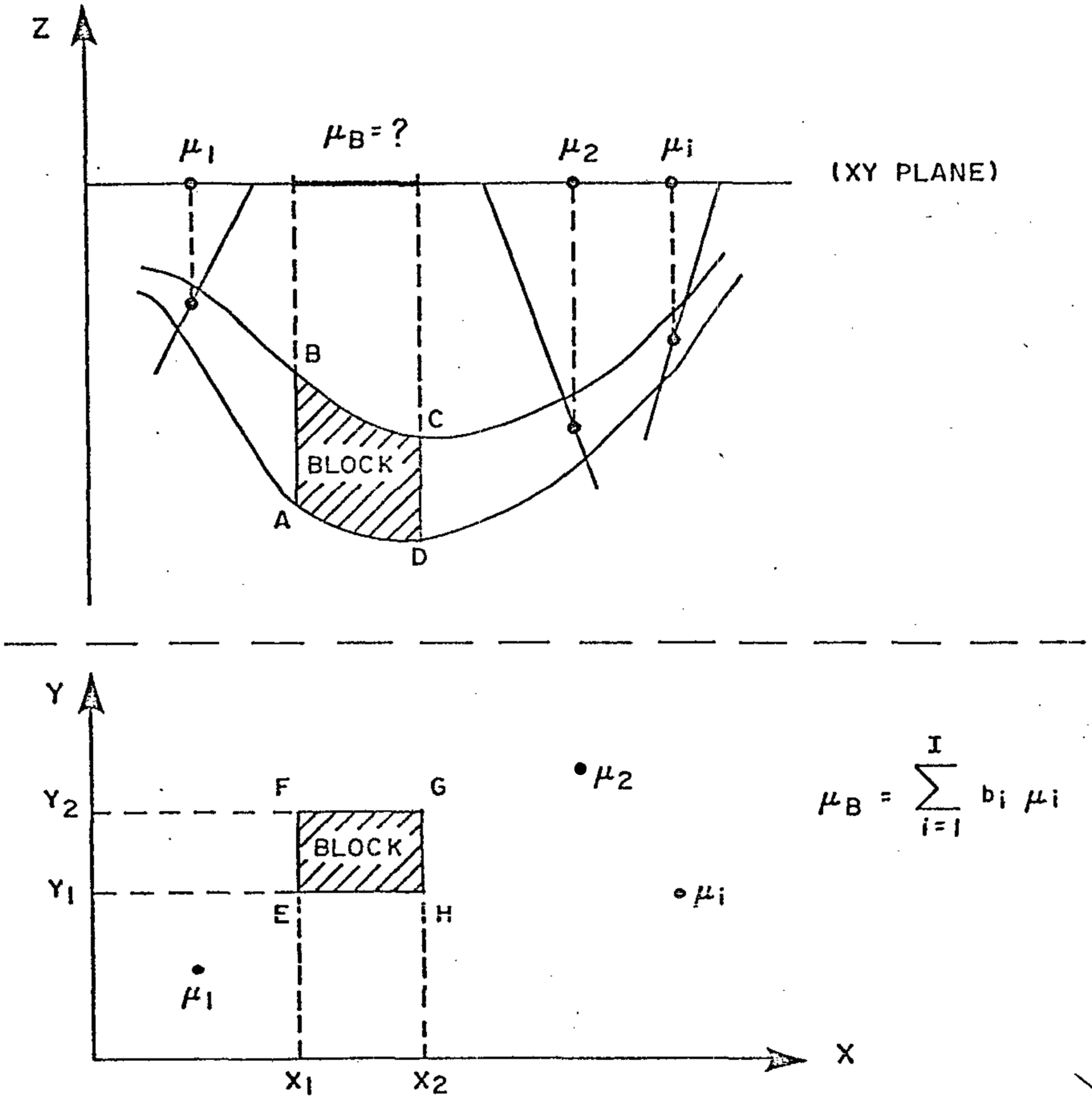


FIG. 1 : REDUCTION OF A THREE DIMENSIONAL PROBLEM TO TWO DIMENSIONS

This traditional approach is acceptable provided no pattern can be recognized in the vertical change in grade between F/W and H/W. If such a pattern exists, and this is usually the case (e.g. a systematic increase in grade towards the F/W, or a decrease in grade towards the limits of the mineralization), this pattern should be taken into consideration for mine valuation. The vertical changes in grade can be divided in two components, a smooth component (or vertical drift) and a random component (usually with correlation). In this report, we present a methodology for the analysis and estimation of the vertical drift in bedded deposits, and for the evaluation of the average grade of a mining block, taking into consideration the block position, not only in the XY plane, but also in the Z direction, with respect to the F/W and H/W of the mineralization. This methodology has been successfully applied to the Hat Creek coal deposit.

2 - DESCRIPTION OF THE METHODOLOGY

2.1 General Description

The method consists of the following steps:

- one-dimensional study of the drift within each borehole. Each borehole is studied successively. The borehole average grade is calculated, and the drift is represented by a polynomial.

- two-dimensional study of the horizontal changes in borehole mean and vertical drift. The spatial distributions of the borehole means, and of the coefficients of the polynomial, are studied in the horizontal plane, using the semi-variogram.

- estimation of the vertical drift at a point X_0Y_0 in the XY plane. The mean of a fictitious vertical borehole at a point X_0Y_0 is estimated from the known borehole means by point kriging. The coefficients of the polynomial representing the vertical drift at X_0Y_0 are estimated from the known coefficients by point kriging. The profile of values which should be expected if a borehole was drilled at X_0Y_0 is thus obtained.

- estimation of the average grade of a block with coordinates X_1X_2, Y_1Y_2, Z_1Z_2. The average value of such a block is equal to the average value of the intersections with the block of all the fictitious vertical boreholes located in X_0Y_0, when X_0 varies from X_1 to X_2 and Y_0 from Y_1 to Y_2. To calculate this average value it is necessary to know the position of the F/W and H/W of the mineralization within the horizontal limits of the block: the F/W and H/W surfaces must have been digitalized, or a mathematical model for these surfaces must be available. Approximation formulae have been developed to estimate a block average grade, whatever the shape of the block.

2.2 One-dimensional Study of Each Borehole

The first step consists in studying each borehole individually. The borehole mean μ is estimated by the average value of the samples in the borehole. If M is a point between F/W and H/W along the borehole (Fig. 2), the following model is used to represent the value $v(M)$ of the mineralization at point M:

$$v(M) = \mu + u(h) + \varepsilon(h) \tag{2}$$

$v(M)$ = grade at point M

μ = borehole average grade

$u(h)$ = drift component of the difference $(v(M) - \mu)$

$\varepsilon(h)$ = residual of the difference $(v(M) - \mu)$

h = d/D

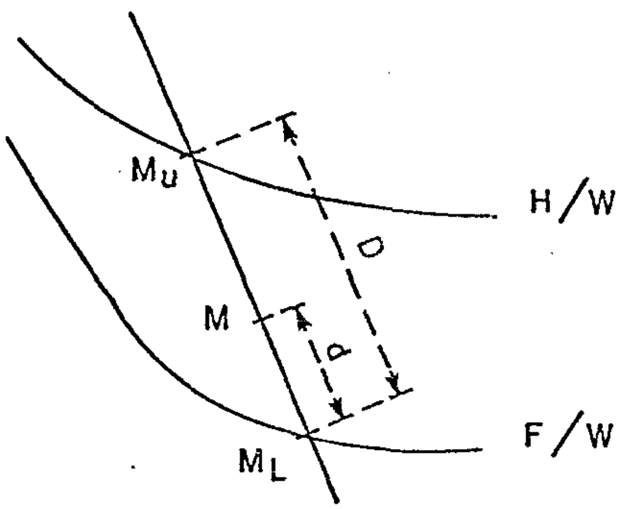
d = distance between M and the F/W intersection along the borehole

D = distance between H/W and F/W intersection along the borehole.

Note that h varies between $h=0$ when M is at the F/W intersection, and $h=1$ when M is at the H/W intersection. The drift component $u(h)$ is represented by a polynomial of order K as follows:

$$u(h) = \sum_{k=0}^{K} a_k \, h^k \tag{3}$$

By hypothesis, the residual $\varepsilon(h)$ has zero expectation and presents a semi-variogram along the borehole, with nugget effect. The optimal coefficients a_k ($k=0-K$), which give an unbiased, minimum error estimate of the drift, are obtained from the sample values in the borehole by universal kriging.



$$v(M) = \mu + u(h) + \epsilon(h)$$

$$h = d/D$$

$$u(h) = \sum_{k=0}^{K} a_k h^k$$

FIG. 2 : ONE DIMENSIONAL STUDY OF DRIFT ALONG BORE HOLE

Note that the average value of $v(M)$ when M varies from the F/W ($M=M_L$ and $h=0$) to the H/W ($M=M_U$ and $h=1$), is the average value of the orebody between F/W and H/W (Fig. 2). Hence:

$$\frac{1}{D} \int_{M=M_U}^{M_L} v(M)\, dM = \mu \tag{4}$$

This can be written:

$$\sum_{k=0}^{K} \frac{a_k}{K+1} = 0 \tag{5}$$

or:

$$a_0 = - \sum_{k=1}^{K} \frac{a_k}{K+1} \tag{6}$$

If I boreholes are available, with index i=1-I, we calculate for each borehole:

- the borehole mean μ_i
- K coefficients a_{ki}, k=0-K
- the coordinates $X_i Y_i Z_i$ of the middle of the borehole ore intersection.

2.3 Two-dimensional Study of Changes in Borehole Mean and Vertical Drift

The semi-variogram of the borehole means μ_i is calculated in the XY plane (eventually taking into consideration changes in the

Z coordinate). The K semi-variograms of the coefficients a_{ki} (k=0-K) are also calculated.

2.4 Estimation of the vertical drift at a point X_0Y_0

If we were to drill a vertical borehole at point X_0Y_0, the sample values obtained along this hole would follow a profile which we can estimate by kriging.

The mean μ_0 of this fictitious borehole is estimated by two-dimensional kriging of the known borehole means μ_i (i=1-I), in the XY plane. The drift coefficients a_{k0} (k=1-K) are estimated by two-dimensional kriging of the known drift coefficients a_{ki} (i=1-I, k=1-K), in the XY plane. To ensure that no bias is artificially introduced, the coefficient a_{00} is calculated using equation (6) :

$$a_{00} = - \sum_{k=1}^{K} \frac{a_{k0}}{k+1} \tag{7}$$

If the F/W and H/W surfaces have been digitalized, or can be represented in any other way, the F/W Z-coordinate (Z_L) and the H/W Z-coordinate (Z_U) can be estimated at X_0Y_0 (Fig. 3). The grade v(M) at a point M at depth Z between Z_U and Z_L is estimated by:

$$v(M) = \mu_0 + \sum_{k=0}^{K} a_{k0} \, h^k \tag{8}$$

where

$$h = \frac{Z - Z_L}{Z_U - Z_L}$$

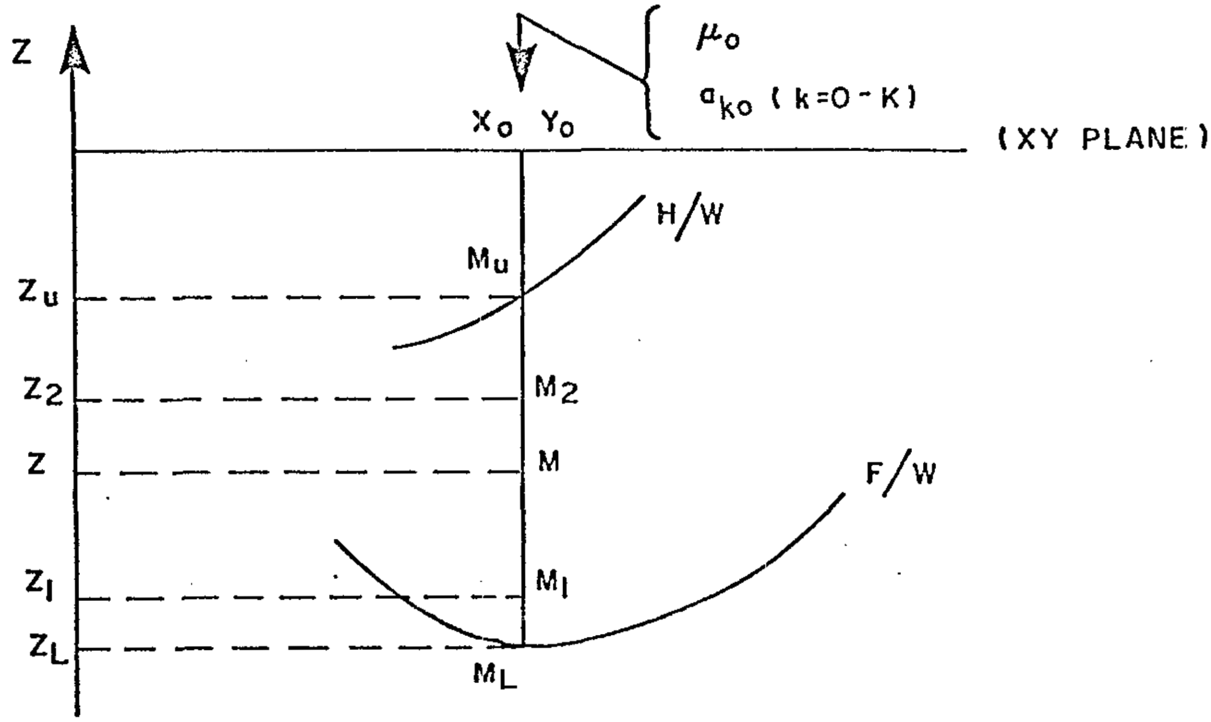


FIG. 3 : ESTIMATION OF THE VERTICAL DRIFT AT POINT $X_o Y_o$

The average grade $v(M_1M_2)$ between two points M_1 and M_2 with Z coordinates Z_1 and Z_2 respectively is estimated as follows:

$$v(M_1M_2) = \frac{1}{M_1M_2} \int_{M=M_1}^{M_2} v(M)\, dM \qquad (9)$$

which can be written:

$$v(M_1M_2) = \mu_0 + \frac{1}{h_2 - h_1} \sum_{k=0}^{K} a_{k0} \frac{h_2^{k+1} - h_1^{k+1}}{k+1} \qquad (10)$$

where:

$$h_2 = \frac{Z_2 - Z_L}{Z_U - Z_L}$$

$$h_1 = \frac{Z_1 - Z_L}{Z_U - Z_L}$$

2.5 Estimation of a block of ore with coordinates X_1X_2, Y_1Y_2, Z_1Z_2

In this section, we study the problem of estimation of a rectangular mining block, included entirely or partly between the limits of a bedded mineralization (Fig. 4). The theory can easily be generalized to any shape of block. Let X_1X_2 and Y_1Y_2 be the limits of the block in the XY plane, Z_2 the elevation of the top of the block and Z_1 the elevation of the bottom of the block. If M is a point with coordinates XYZ inside the mining block, and $v(M)$ the grade at point M, the block average grade V is equal to the average value of $v(M)$ when M takes all possible positions in the block. We already know how to calculate the average value of $v(M)$ when X and Y remain constant

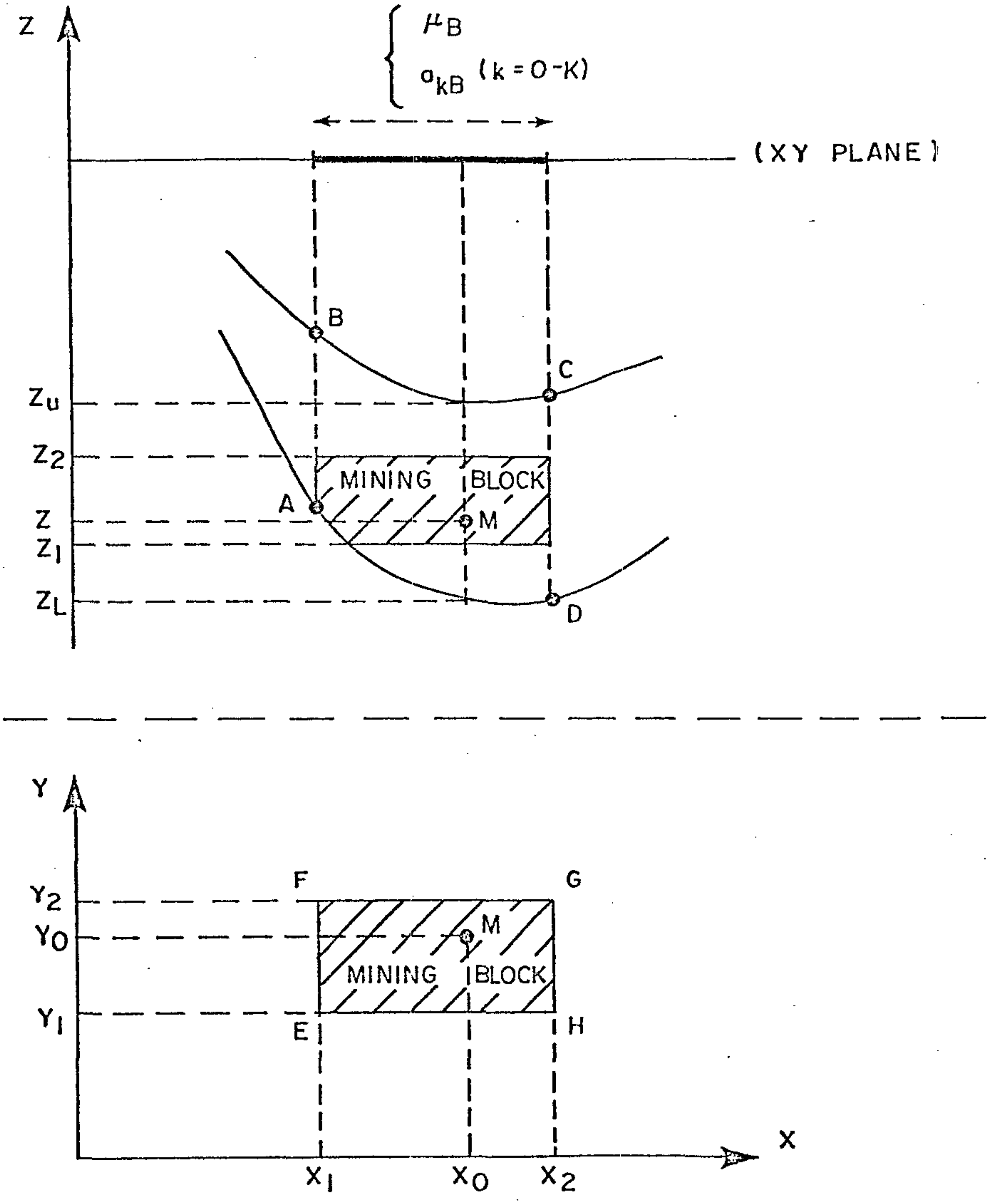


FIG. 4 : ESTIMATION OF A MINING BLOCK

($X=X_0$, $Y=Y_0$) and Z varies from Z_1 to Z_2 (equation 10). We must now integrate this expression with respect to X and Y. Note that μ_0, Z_U, Z_L, Z_2, Z_1, a_{k0} (k=0-K), h_2 and h_1 in equation 10 are all functions of X_0 and Y_0, and an exact integration would be extremely complex. Two different approximations can be used depending on the block size and the variability of the vertical drift in the XY plane. Both approximations assume that the F/W and H/W surfaces of the orebody have been digitalized.

2.5.1 Approximation 1: large block and rapid horizontal changes in the vertical drift

If we want to estimate a large block, such that significant changes in the vertical drift may occur within the horizontal limits of the block, the values Z_{Uj}, Z_{Lj}, Z_{2j}, Z_{1j}, a_{kj} (k=0-K), h_{2j}, h_{1j} will be estimated at J equally spaced points (j=1-J) in the rectangle EFGH (Fig. 4):

Z_{Uj} = Z-coordinate of H/W at point j

Z_{Lj} = Z-coordinate of F/W at point j

Z_{2j} = Z-coordinate of top of mining block at point j

Z_{1j} = Z-coordinate of bottom of mining block at point j

a_{kj} = value of k-th coefficient of drift polynomial at point j

$h_{2j} = (Z_{2j} - Z_{Lj}) / (Z_{Uj} - Z_{Lj})$

$h_{1j} = (Z_{1j} - Z_{Lj}) / (Z_{Uj} - Z_{Lj})$

How to calculate Z_{2j} and Z_{1j} is illustrated in Fig. 5. We will also estimate the average grade of the block B defined by the rectangle EFGH in the horizontal plane, and limited by the F/W and H/W of the mineralization (block ABCD in Fig. 4). This average grade μ_B is obtained by two-dimensional block kriging in the XY plane.

The value V of the mining block is then given by:

$$V = \mu_B + \sum_{j=1}^{J} \{(Z_{Uj}-Z_{Lj}) \sum_{k=0}^{K} a_{kj} \frac{h_{2j}^{k+1} - h_{1j}^{k+1}}{k+1}\} / \sum_{j=1}^{J} (Z_{2j}-Z_{1j}) \qquad (11)$$

If the mining block is entirely included within the mineralization, then $Z_{2j} = Z_2$ and $Z_{1j} = Z_1$ for all j, and the average grade V is given by:

$$V = \mu_B + \frac{1}{J} \sum_{j=1}^{J} \{ \frac{1}{h_{2j}-h_{1j}} \sum_{k=0}^{K} a_{kj} \frac{h_{2j}^{k+1} - h_{1j}^{k+1}}{k+1} \} \qquad (12)$$

If the block is parallel to the mineralization, and the mineralized thickness is constant, we have:

$$Z_{Uj} - Z_{Lj} = Z_U - Z_L \quad \text{for all } j$$

$$h_{2j} = h_2 \quad \text{for all } j$$

$$h_{1j} = h_1 \quad \text{for all } j$$

and:

$$V = \mu_B + \frac{1}{h_2-h_1} \sum_{k=0}^{K} \{(\frac{1}{J} \sum_{j=1}^{J} a_{kj}) \frac{h_2^{k+1} - h_1^{k+1}}{k+1}\} \qquad (13)$$

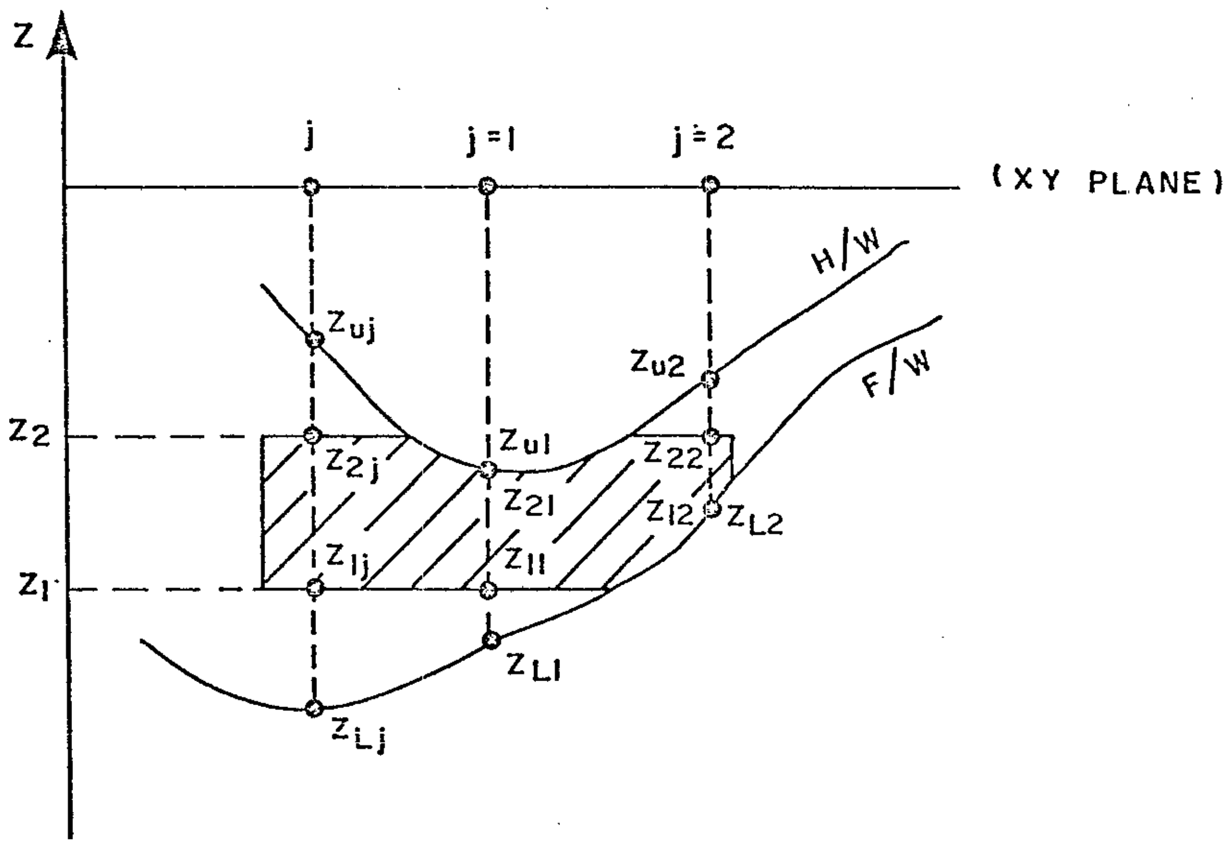


FIG. 5 : MINING BLOCK INTERSECTING THE F/W AND H/W SURFACES

In this particular instance, it is recommended to calculate the average drift coefficients a_{kB} in the block B by two-dimensional block kriging, and to use the following equation:

$$V = \mu_B + \frac{1}{h_2 - h_1} \sum_{k=0}^{K} a_{kB} \frac{h_2^{k+1} - h_1^{k+1}}{k+1} \tag{14}$$

This formula is described in more detail in section 2.5.2.

2.5.2 Approximation 2: small block or slow horizontal changes in the vertical drift

If the vertical drift can be considered a constant within the horizontal limits X_1X_2, Y_1Y_2 of the mining block (Fig. 4), the following method is recommended:

- estimate the mean μ_B of the block ABCD, EFGH with horizontal limits X_1X_2, Y_1Y_2 and vertical limits, the H/W and F/W of the mineralization (Fig. 4). This estimation is done by two-dimensional kriging of the rectangular block EFGH, using the borehole values μ_i.
- estimate the mean value a_{kB} (k=0-K) of the k-th coefficient of the vertical drift in the block EFGH. This is done for k=1-K by two-dimensional kriging of the rectangular block EFGH, using the borehole coefficients a_{ki}. For k=0, equation 6 is used:

$$a_{0B} = - \sum_{k=1}^{K} \frac{a_{kB}}{k+1} \tag{15}$$

- consider J equally spaced points in the rectangle EFGH. At each point ($j=1$-J) calculate Z_{Uj}, Z_{Lj}, Z_{2j}, Z_{1j} and obtain h_{2j} and h_{1j} (see section 2.5.1). The value V of the mining block is obtained as follows:

$$V = \mu_B + \sum_{k=0}^{K} \{ a_{kB} \sum_{j=1}^{J} (Z_{Uj}-Z_{Lj}) \frac{h_{2j}^{k+1} - h_{1j}^{k+1}}{k+1} \} / \sum_{j=1}^{J} (Z_{2j}-Z_{1j}) \qquad (16)$$

This approach is recommended as it is much less costly than the one described in 2.5.2. If the mineralization is of constant thickness ($Z_{Uj} - Z_{Lj} = Z_U - Z_L$ for all j), and if the mining block is parallel to the mineralization ($Z_{2j} - Z_{1j} = Z_2 - Z_1$, $h_{2j} = h_2$ and $h_{1j} = h_1$ for all j), *this equation can be written:*

$$V = \mu_B + \frac{1}{h_2-h_1} \sum_{k=0}^{K} a_{kB} \frac{h_2^{k+1} - h_1^{k+1}}{k+1} \qquad (17)$$

We recognize equation 14.

3 - APPLICATION TO THE HAT CREEK COAL DEPOSIT

3.1 General Description

The methodology described in section 2 has been successfully tested using drill hole data from the Hat Creek coal deposit (Campbell, Jory and Saunders, 1977). Four main geological zones are present in the deposit, two of which have been studied in this report, i.e. zone D and zone B. Zone D was chosen first because of its known continuity which promised to give good results. After the successful study of zone D, zone B has been processed, which is characterized by a much higher variability in both horizontal and vertical grade distribution. As expected the study of zone B proved to be more difficult, and indicated the need for careful data screening before analysis. In spite of these difficulties, it is shown that the methodology can be applied to zone B. The results of these analyses are given below. The tests have been made on the B.T.U. content only.

3.2 Study of B.T.U. in Zone D

3.2.1 One-dimensional study of each borehole

A computer program PROFL3 has been written to perform the following operations:

- For any specified borehole, read the value and size of all the samples falling within a given geological zone (e.g. zone D). This information was read from the individual sample file on tape EX5546 dated May 1978 (MINTEC name: BCHTAP.DAT).

- Fit a polynomial of specified order to these sample values, using universal kriging (see Appendix in Krige and Rendu, 1975, and Chapter 12 in Rendu, 1978). Calculate the coefficients of this polynomial. A polynomial of order 4 has been used. The assumption was made that the residuals $\varepsilon(h)$ (equation 2 in section 2.2) have a linear semi-variogram with nugget effect. This assumption was made after it was verified that a nugget effect of 0.0 gave unsatisfactory results. The linear semi-variogram was chosen because of its simplicity.

- The coefficients a_k (k=0-4) are printed and saved on file.
- The profile of the sample values, and the value of the polynomial at the center of the sample, are plotted. The results are given in Appendix 1.

A polynomial of order 4 gives a good estimation of the drift in most boreholes. However, significant errors may occur near the extremities of the borehole. This border effect is likely to be most significant if the extreme samples are very large, as the shape of the polynomial is controlled only by the coordinates at the center of the sample.

A computer program MRGCOO has been written, to read the output file created by PROFL3, and calculate the three coordinates of the center of zone D. The coordinates are obtained from the first composite file on tape EX5546 dated May 1978 (MINTEC name: COMLODVD). An output file is created, containing the following information (see Table 1):

- Line 1:
  . borehole number
  . number of coefficients in the polynomial
  . X, Y and Z coordinates of the center of the borehole intersection with zone D
  . mean value of the borehole

23	5	557(	24131.4	777.2	.87384E+04
.11379E+03	.50052E+04	-.91209E+04	.10520E+04	.79304E+03	
25	5	6295.7	23766.4	616.6	.92118E+04
-.65554E+03	.18199E+05	-.66377E+05	.95688E+05	-.51233E+05	
38	5	6118.7	24393.2	623.8	.99381E+04
-.16968E+04	.23244E+05	-.59096E+05	.49964E+05	-.13602E+05	
39	5	6178.3	24677.8	796.8	.96074E+04
-.10260E+04	.17601E+05	-.49824E+05	.47366E+05	-.15055E+05	
43	5	5313.2	24076.5	902.4	.78510E+04
.90710E+03	.14711E+05	-.65385E+05	.92226E+05	-.47711E+05	
44	5	5630.2	23469.1	464.0	.87028E+04
-.60958E+03	.27144E+05	-.10129E+06	.13001E+06	-.58699E+05	
46	5	5774.2	24131.4	631.5	.94215E+04
-.12133E+04	.18279E+05	-.29807E+05	-.12056E+05	.25137E+05	
50	5	5505.3	24376.1	848.1	.86222E+04
-.11648E+04	.28642E+05	-.10052E+06	.12350E+06	-.52761E+05	
51	5	5485.4	23461.1	645.2	.74849E+04
.14633E+04	.12656E+05	-.57347E+05	.68654E+05	-.29254E+05	
53	5	5366.0	23797.9	852.0	.81175E+04
.34536E+04	-.20696E+05	.46992E+05	-.57851E+05	.28657E+05	
106	5	5867.4	23782.1	452.9	.93657E+04
-.58331E+03	.27373E+04	.32703E+05	-.94287E+05	.59488E+05	
124	5	5497.0	23794.2	776.1	.86504E+04
-.52096E+03	.18166E+05	-.60418E+05	.69021E+05	-.28418E+05	
127	5	5193.1	23798.9	920.5	.82269E+04
-.10772E+04	.16919E+05	-.14565E+05	-.37805E+05	.34606E+05	
132	5	5199.4	23492.9	917.9	.85457E+04
-.30355E+04	.36960E+05	-.12721E+06	.17537E+06	-.84659E+05	
135	5	5914.1	23668.8	427.9	.81766E+04
.10063E+02	.31959E+05	-.13033E+06	.17982E+06	-.87510E+05	
136	5	5950.4	23949.2	504.9	.97136E+04
-.45970E+03	.18232E+05	-.65639E+05	.79215E+05	-.32906E+05	
137	5	5340.5	23494.1	850.0	.80744E+04
-.11583E+04	.31789E+05	-.93762E+05	.85123E+05	-.23831E+05	
138	5	5944.4	24697.3	734.4	.94021E+04
-.44827E+03	.18931E+05	-.77293E+05	.10008E+06	-.41378E+05	
152	5	6021.9	25020.5	811.2	.99369E+04
-.13967E+04	.17831E+05	-.49139E+05	.47892E+05	-.15575E+05	
158	5	5463.8	24091.7	837.0	.81935E+04
.10605E+04	.40747E+04	-.11841E+05	-.15146E+04	.61321E+04	
161	5	5654.6	24404.9	788.4	.90049E+04
-.11960E+04	.32389E+05	-.12546E+06	.17508E+06	-.84781E+05	
166	5	5349.8	24407.8	899.9	.75082E+04
-.11320E+04	.66058E+05	-.29315E+06	.43058E+06	-.20934E+06	
169	5	5186.4	23961.0	928.0	.86989E+04
-.55568E+03	.12100E+05	-.27732E+05	.10460E+05	.56621E+04	
171	5	5185.9	23635.6	914.5	.87861E+04
-.12215E+04	.11192E+05	-.33197E+05	.51203E+05	-.30713E+05	
176	5	5191.5	23340.0	937.4	.83420E+04
-.36749E+04	.62673E+05	-.24093E+06	.33685E+06	-.15805E+06	
179	5	5334.9	23176.8	795.6	.63163E+04
.93659E+02	.25626E+05	-.92170E+05	.10162E+06	-.37979E+05	
180	5	6411.1	23790.3	767.5	.93548E+04
-.68470E+03	-.20390E+05	.11395E+06	-.16974E+06	.76664E+05	
187	5	6254.8	24249.0	760.3	.10008E+05
-.16786E+04	.28893E+05	-.10904E+06	.14184E+06	-.59405E+05	
188	5	5343.3	24249.3	904.7	.78907E+04
.17226E+03	.25388E+05	-.10614E+06	.14647E+06	-.70581E+05	
190	5	5655.2	24254.8	741.5	.96055E+04
-.52507E+03	.71341E+04	-.42537E+04	-.17613E+05	.13890E+05	
191	5	5937.5	24223.6	581.1	.90790E+04
-.39153E+04	.57669E+05	-.19252E+06	.23505E+06	-.97598E+05	
193	5	5797.5	24560.7	760.3	.99487E+04
-.10979E+04	.16337E+05	-.35945E+05	.17751E+05	.23596E+04	

TABLE 1. Results of drift analysis along boreholes,
PTU zone D

194	5	599	25120.8	830.2	.10251E+05
.51159E+03	.19842E+05	.93134E+05	-.14045E+06	.67532E+05	
196	5	5947.6	24565.9	691.9	.93643E+04
-.28130E+04	.41639E+05	-.13429E+06	.15651E+06	-.61902E+05	
198	5	6120.8	24560.6	688.3	.92686E+04
-.14058E+04	.25244E+05	-.59301E+05	.38506E+05	-.54911E+04	
199	5	6111.2	24255.6	576.1	.98331E+04
-.15230E+04	.20045E+05	-.58409E+05	.63669E+05	-.24760E+05	
200	5	5640.3	23929.7	694.3	.88185E+04
-.79846E+03	.16958E+05	-.44009E+05	.38730E+05	-.13486E+05	
202	5	5488.1	24254.6	840.3	.88359E+04
.66182E+02	.16491E+05	-.61145E+05	.70396E+05	-.27644E+05	
204	5	5663.9	24554.2	811.6	.82492E+04
-.30530E+03	.21816E+05	-.48262E+05	.20231E+05	.21267E+04	
205	5	5808.6	24240.8	630.9	.97371E+04
-.18516E+04	.33284E+05	-.11052E+06	.12995E+06	-.52221E+05	
208	5	5487.4	23940.0	801.7	.86472E+04
-.52744E+03	.28776E+05	-.12197E+06	.17465E+06	-.84372E+05	
240	5	5490.3	23651.0	783.7	.84875E+04
-.11403E+03	.19594E+05	-.72276E+05	.82455E+05	-.31033E+05	
247	5	5921.8	24103.1	567.9	.92884E+04
-.16939E+04	.38847E+05	-.15795E+06	.22275E+06	-.10390E+06	
248	5	5336.2	23629.7	854.3	.77029E+04
-.82261E+03	.32470E+05	-.12321E+06	.16395E+06	-.76717E+05	
259	5	5501.9	23484.8	644.1	.76422E+04
-.42450E+03	.26725E+05	-.99385E+05	.12490E+06	-.55199E+05	
263	5	6271.4	23943.9	630.5	.95391E+04
-.13335E+04	.20746E+05	-.55325E+05	.56035E+05	-.23052E+05	
265	5	6208.0	24405.1	720.9	.99321E+04
-.10029E+04	.15253E+05	-.47608E+05	.55731E+05	-.23448E+05	
266	5	5638.5	24096.6	712.4	.90091E+04
-.51881E+03	.16210E+05	-.40808E+05	.23311E+05	.94087E+03	

TABLE 1. (concluded) Results of drift analysis along boreholes, BTU, zone D.

- Line 2:
  . 5 coefficients a_0, a_1, a_2, a_3 and a_4.

A statistical analysis of these coefficients showed that a_1, a_2, a_3 and a_4 are very strongly correlated (correlation coefficients with absolute value 0.9 and above) while a_0 is not well correlated with the other coefficients. A satisfactory explanation of these high covariances remains to be found, but it is due in part to the similarity between drifts.

Scatter diagrams have been used to graphically analyse the relationship between coefficients. It was observed that the drift coefficients for boreholes 166, 176, 180 and 194 were either exceptionally high or exceptionally low. This can be easily explained by the fact that in these boreholes the upper part of the D zone is missing.

3.2.2 Two-dimensional study of changes in borehole mean and vertical drift

The program MAREC2 (David, 1977) has been used to calculate the directional semi-variograms and average semi-variograms for the following variables:

- the borehole mean
- the drift coefficients a_k (k=0-4).

All the values given in Table 1 have been used. The semi-variograms are given in Appendix 2. We observe that:

- The semi-variogram of the borehole mean presents a strong anisotropy, the long axis of anisotropy making an angle of 113^{o} with the X axis. The direction of anisotropy is therefore N-23^{o}-W, parallel to the Creek Fault. These results concur with those obtained by David & al. (1978). A linear model of semi-variogram has been accepted with slope 556 in the direction N-23^{o}-W, and 1111 in the direction E-23^{o}-N, corresponding to a ratio of anisotropy of magnitude 2.

- The semi-variogram of the drift coefficients a_k (k=1-4) are all proportional to each other. This is due to the very high covariance between these coefficients. Only one model of semi-variogram need be used for all these coefficients. An isotropic model has been retained, made of the combination of two spherical models (Fig. 6):

$$\gamma(h) = C \{ 0.8 * (\frac{3}{2}\frac{h}{300} - \frac{1}{2}(\frac{h}{300})^3) + 0.2 * (\frac{3}{2}\frac{h}{900} - \frac{1}{2}(\frac{h}{900})^3) \} \quad (18)$$

The sill C is equal to the variance of the corresponding coefficient, e.g. $C = 5 * 10^9$ for a_2.

The semi-variogram of a_0 is not well correlated with the other semi-variograms, but since a_0 will not be estimated directly, but rather through equation 7, this is of no consequence.

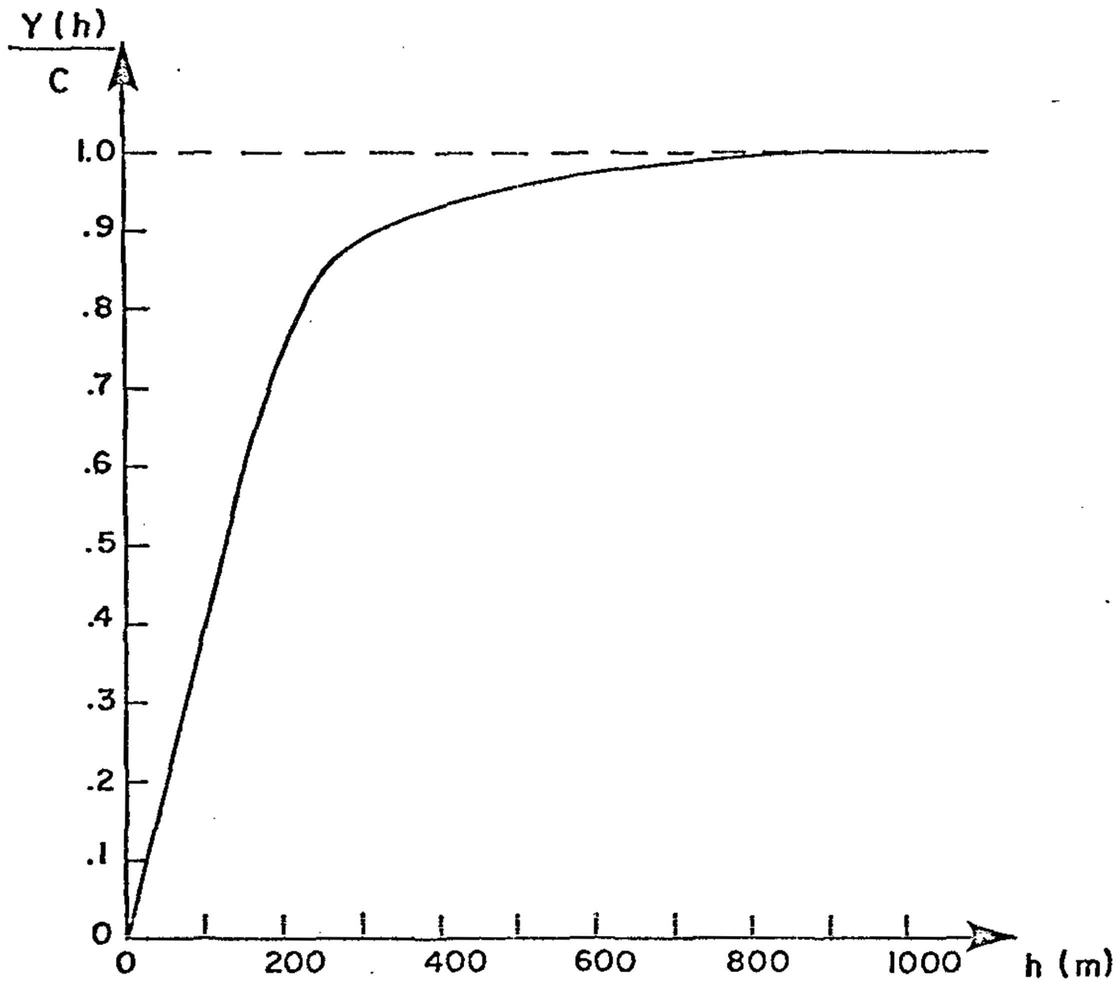


FIG. 6 : SEMI-VARIOGRAM OF DRIFT COEFFICIENTS — BTU — ZONE D —

Note that the maximum distance of influence of the vertical drift is 900 m, but very poor estimation of the drift can be expected for distances of 200 m or more. It appears that the present grid spacing (about 150 m) is sufficient to ensure good estimation of the drift at any point between boreholes.

3.2.3 Estimation of the vertical drift at a point X_0Y_0

The drift has been estimated at points located at 50 m interval on section X = 5350 E, from Y = 23150 N to Y = 24400 N (approximatively on geological section 15, from section W to section N). The mean μ_0 at point X_0Y_0 has been obtained by point kriging, using program KRIGBL1 (IREM-MERI, 1978) after modification for point kriging. The coefficients a_{10}, a_{20}, a_{30} and a_{40} have been obtained, using program KRIGBL1 modified for simultaneous point kriging of the 4 coefficients, using a single semi-variogram.

A program, KPROFL, has been written to calculate the coefficient a_{00} using equation 7, and to draw the estimated value profiles. The results are given in Appendix 3. One should compare the estimated profiles with the B.T.U. values in the neighbouring boreholes, more specifically the following:

Borehole n^{o}	X	Y
179	5335	23177
137	5341	23494
248	5336	23630
53	5366	23798
43	5313	24077
188	5343	24249
166	5350	24408

Note the rapid change in profile when approaching borehole n^{o} 53 (with an unusual increase in value near the H/W) and the abnormal borehole n^{o} 166.

3.2.4 Estimation of a mining block

All the blocks of size 75 m * 75 m * 15 m, located within zone D, between X1 = 5300 E, X2 = 5375 E and Y1 = 24075 N, Y2 = 24150 N have been estimated using equation 16 (section 2.5.2). Due to computer failure at the time, the necessary program has been written on an HP97 calculator.

The mean μ_B has been calculated using the program KRIGBL1. The coefficients a_{1B}, a_{2B}, a_{3B}, a_{4B} have been calculated simultaneously using a modified version of KRIGBL1. The coefficient a_{0B} has been calculated using equation 15. The values obtained were:

$$\mu_B = 7920$$
$$a_{0B} = 938$$
$$a_{1B} = 12700$$
$$a_{2B} = -54100$$
$$a_{3B} = 71700$$
$$a_{4B} = -35900$$

The corresponding profile is given in Fig. 7.

The position of the mining blocks with respect to the F/W and H/W of zone D is given in Fig. 8. The numerical results are analyzed in Table 2.

Block n^o	volume (m^3)	average value V (B.T.U.)	$V-\mu_B$ (B.T.U.)	$100*(V-\mu_B)/\mu_B$ (%)
1	11250	4225	-3695	-47
2	33750	5196	-2724	-34
3	57375	5972	-1948	-25
4	79125	6665	-1255	-16
5	84375	7741	-179	-2
6	84375	8665	745	+9
7	84375	9336	1416	+18
8	75000	9540	1620	+20
9	35437	9446	1526	+19
10	2437	9076	1156	+15
Weighted average		7920	0	0

TABLE 2: Value of mining blocks in area $X_1 = 5300$ E, $X_2 = 5375$ E, $Y_1 = 24075$ N, $Y_2 = 24150$ N.

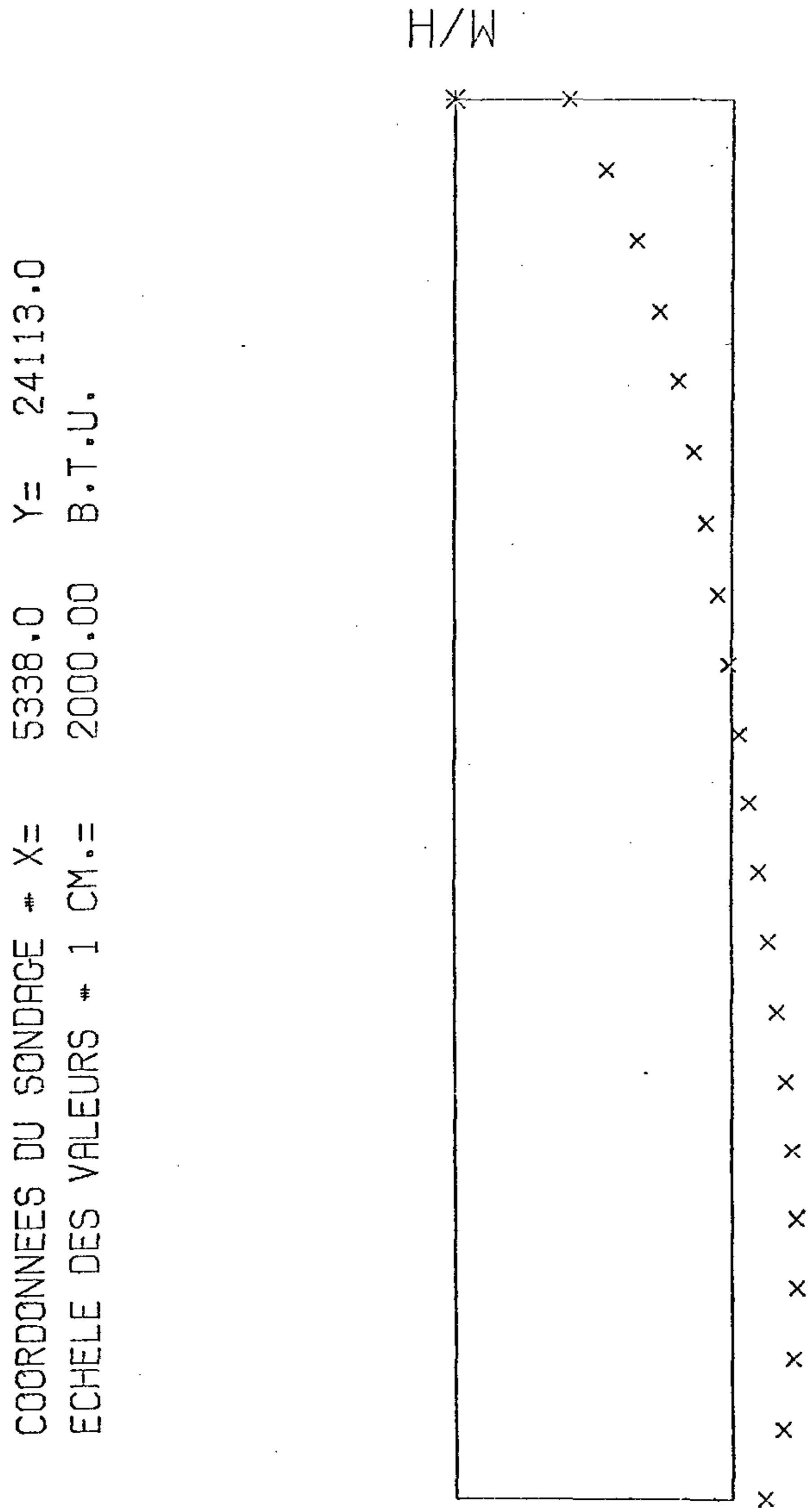


FIGURE 7. Estimated average drift in block $X_1 = 5300$ E, $X_2 = 5375$ E, $Y_1 = 24075$ N, $Y_2 = 24150$ N.

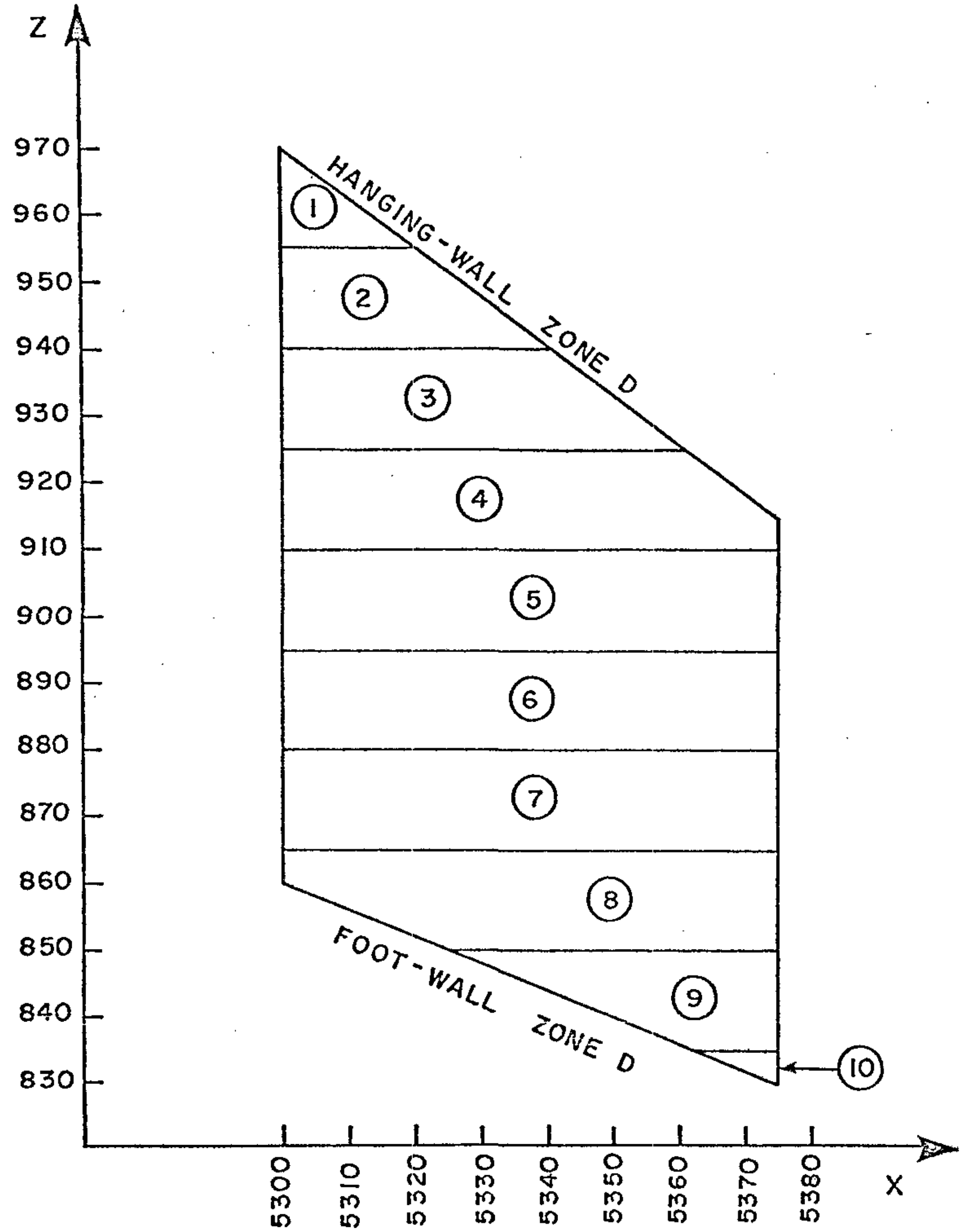


FIG. 8 : POSITION OF MINING BLOCKS IN AREA $X_1 = 5300E$, $X_2 = 5375E$

$Y_1 = 24075N$, $Y_2 = 24150N$.

If the vertical drift had been ignored, all these blocks would have been given the same value of 7920 B.T.U., thus introducing an error exceeding 20% for most blocks.

3.3 Study of B.T.U. in zone B

3.3.1 One-dimensional study of each borehole

The method followed is the one described in section 3.2. The results are given in Table 3 and Appendix 4. The value profiles show a high variability in B.T.U. content. Statistical analysis of the coefficients of the polynomial indicate that they have a higher variance than in zone D. Scatter diagrams have been used to determine the presence of anomalous values.

- The values of the coefficients for hole n^{o} 44 and 193 are extremely different from the others. Hole n^{o} 44 does not contain enough samples to determine the drift correctly. Hole n^{o} 193 intersects only one half of zone B.

- The values of the coefficients for hole n^{o} 200, 203, 147 and 183 are also significantly different from the others. All these holes are on the border of the orebody and intersect only part of zone B.

A study of the geological sections shows that only 28 boreholes intersect zone B, and that 8 of these intersections are incomplete. The incomplete intersections correspond to holes n^{o} 120, 147, 183, 190, 193, 200, 203, and 265.

25	5	6229	23786.4	730.0	.79976E+04
.22208E+03	-.12836E+05	.49244E+05	-.54968E+05	.17626E+05	
38	5	6051.6	24393.2	740.1	.78127E+04
-.34962E+03	-.19671E+04	.18298E+05	-.35343E+05	.20373E+05	
44	5	5718.2	23469.1	616.4	.55840E+04
-.12478E+05	.14175E+06	-.51986E+06	.75130E+06	-.36669E+06	
106	5	5867.4	23782.1	633.7	.71350E+04
-.25383E+04	.12505E+05	-.14796E+05	-.69459E+04	.14857E+05	
120	5	5659.2	23787.6	749.1	.33525E+04
.97797E+03	-.51002E+04	.65410E+05	-.16275E+06	.10231E+06	
135	5	5921.7	23664.5	595.3	.75645E+04
-.25647E+04	.29633E+05	-.10399E+06	.13248E+06	-.53550E+05	
136	5	5952.9	23943.0	650.4	.78035E+04
-.12086E+04	.23611E+04	-.91705E+04	.35554E+05	-.29029E+05	
138	5	5941.6	24701.2	865.1	.82103E+04
-.20795E+04	.30841E+05	-.13288E+06	.21660E+06	-.11614E+06	
141	5	5638.2	23493.2	704.7	.52744E+04
-.29053E+04	.28886E+05	-.10156E+06	.13732E+06	-.60139E+05	
147	5	6414.7	23639.2	828.9	.81253E+04
.17321E+04	-.44636E+05	.17161E+06	-.22433E+06	.97360E+05	
183	5	6259.9	23943.6	842.5	.66193E+04
.13043E+04	-.56778E+05	.24226E+06	-.34172E+06	.15888E+06	
190	5	5655.2	24254.8	936.7	.64726E+04
-.21544E+04	.28535E+05	-.14089E+06	.27589E+06	-.17106E+06	
191	5	5942.5	24233.8	722.5	.74310E+04
-.54621E+03	.13291E+05	-.81409E+05	.16551E+06	-.10186E+06	
193	5	5802.1	24558.5	893.1	.73319E+04
.14679E+05	-.21534E+06	.77453E+06	-.10264E+07	.45891E+06	
196	5	5950.5	24563.7	814.4	.81590E+04
-.12265E+04	.26106E+05	-.13185E+06	.21655E+06	-.11020E+06	
199	5	6114.4	24258.6	731.9	.84651E+04
.15839E+03	-.14425E+05	.83890E+05	-.14886E+06	.81561E+05	
200	5	5636.5	23938.5	931.6	.45616E+04
-.24591E+04	.55310E+05	-.27589E+06	.45904E+06	-.24006E+06	
203	5	6273.5	23615.1	721.8	.74861E+04
-.59276E+04	.76856E+05	-.29684E+06	.43860E+06	-.21640E+06	
205	5	5811.3	24245.4	809.1	.78355E+04
-.11816E+04	-.44679E+02	.13572E+05	-.25845E+05	.15796E+05	
242	5	5763.9	23633.0	622.0	.60199E+04
-.10829E+04	-.11442E+05	.64619E+05	-.93423E+05	.43133E+05	
247	5	5930.8	24106.2	700.3	.79098E+04
-.12189E+04	.12236E+05	-.32988E+05	.26816E+05	-.30242E+04	
250	5	5781.5	23363.7	545.8	.51349E+04
-.52861E+03	-.17692E+05	.90035E+05	-.14045E+06	.72463E+05	
261	5	5799.2	23959.5	712.5	.69301E+04
-.22774E+04	.23793E+05	-.84273E+05	.12413E+06	-.62765E+05	
262	5	6107.9	23634.1	553.9	.75483E+04
-.13900E+04	.17083E+05	-.89169E+05	.16920E+06	-.98686E+05	
263	5	6207.2	23943.9	753.8	.79195E+04
.31410E+03	.98138E+03	-.41541E+05	.11736E+06	-.81517E+05	
265	5	6140.6	24405.1	843.5	.62309E+04
.11774E+04	-.12259E+05	.83092E+03	.43182E+05	-.30596E+05	
266	5	5699.6	24096.6	880.2	.63850E+04
-.14439E+04	-.26714E+04	.47386E+05	-.93735E+05	.52093E+05	
267	5	6153.2	24092.4	705.6	.79375E+04
-.15142E+04	.25586E+05	-.13114E+06	.23178E+06	-.12773E+06	

TABLE 3. Results of drift analysis along boreholes, BTU, zone B.

3.3.2 Two-dimensional study of changes in borehole mean and vertical drift

The directional and average semi-variograms have been studied under different hypotheses:

- -Taking all 28 boreholes into consideration, the results for the borehole means were acceptable (Appendix 5). The results for the coefficients a_k were meaningless.
- -Eliminating boreholes n^o 44 and 193. Again the results were meaningless for the polynomial coefficients.
- -Eliminating all 6 abnormal boreholes (n^o 44, 147, 183, 193, 200, 203). The results are given in Appendix 5.

We observe that:

- -The semi-variogram of the borehole mean is anisotropic, with long axis in the direction N-22^o-W. A linear model with ratio of anisotropy with value 2 has been accepted.
- -The semi-variograms of the coefficients a_k are similar to each other but poorly defined (this is due to insufficient data). The model used for zone D (equation 18, section 3.2.2) gives a good representation of coefficients a_3 and a_4, provided we use:

$$C = 1.10 * (\text{variance of } a_k)$$

The same model will be used for a_1 and a_2.

Given the limited information available, we conclude that the models used in zone D can be accepted for zone B. Note however that the difference between true sample value and drift value can be very significant. This is due to the presence of numerous sterile zones, with extreme changes in sample values from sample to sample.

3.3.3 Estimation of drift at sampled points

To verify that we are able to estimate the drift at a point $X_0 Y_0$ with acceptable precision, the following test has been completed on the 22 boreholes retained. Each sampled point has been considered successively (a sampled point is a point at which a borehole is located). The drift at each one of these points $X_0 Y_0$ has been estimated, using the neighboring boreholes, but eliminating the borehole located at $X_0 Y_0$. Typically the closest borehole available for estimation was located at a distance of 150 m, and very poor estimation was expected.

The estimated drift at all 22 points is given in Appendix 6. These profiles should be compared with the observed profiles along the corresponding boreholes (Appendix 5). Most boreholes are as well or better estimated when the drift is taken into consideration. The most significant improvement is for hole n° 263. Most other improvements are marginal. However, for 6 boreholes, the introduction of the drift significantly increases the error of estimation. These boreholes are n° 190, 191, 199, 205, 247 and 266. All these boreholes are located in the same area, namely on geological sections

P and Q. The poor estimation always occurs near the H/W, the estimated drift indicating an incease (decrease) in value when the samples actually show a decrease (increase) in value. The boreholes which appear to be responsible for most of the problems in the estimation of this area are hole n^o 190 (the upper part of zone B is missing in this hole, and the first sample in zone 211 has an extremely low value) and hole n^o 199 (with a very sharp increase in grade near the H/W).

The results of this test confirm what was expected, namely that point estimation of the drift at distances of the order of 150 m is likely to be meaningless. A more interesting conclusion is that *if the vertical drift is to be taken into consideration in the study* of zone B, more samples intersecting the entire zone should be taken, or a method to correctly estimate the drift in incomplete boreholes should be developed. Such a method is proposed below.

4 - ANALYSIS OF INCOMPLETE HOLES

4.1 General considerations

Consider a hole which intersects a mineralized body whose upper part has been eroded, such that only the lower part of the intersection remains. Sample values can be obtained from this lower part, but a polynomial fitted to these values will not be representative of the vertical drift through the entire mineralization. The polynomial coefficients will not be comparable with the coefficients obtained in other holes with complete intersection, and calculation of the semi-variogram using those coefficients will be meaningless. This can be clearly observed when scatter diagrams of pairs of coefficients are drawn: on these diagrams incomplete holes often give points outside the cloud of points corresponding to complete intersections, thus indicating anomalous values. Clearly the same problem will occur if a hole is drilled through the upper part of the mineralization, but was interrupted before reaching the F/W of the orebody.

In the above analysis of the D zone in the Hat Creek deposit, the influence of incomplete holes has been ignored. This could be done because the vertical drift is remarkably constant, and the number of incomplete holes is small enough not to affect the analyses. In the B zone, however, incomplete holes represent a significant part of the information available, and the structural analysis proved to be only partly successful. This critical situation highlighted the need to develop a procedure to study incomplete holes.

4.2 Description of the method of analysis

To determine the drift coefficients in an incomplete hole, the following steps will be followed:

4.2.1 Do a structural analysis of all complete holes (sections 2.1, 2.2, 2.3 above).

4.2.2 Using the results of this structural analysis, estimate the value profile at the position of all incomplete holes (section 2.4 above). This estimation is made from complete holes only. Let $\hat{\mu}$, $\tilde{a}_k$ (k=0-K) be the estimated mean and drift coefficients at the location of an incomplete hole. The following steps are repeated for each incomplete hole.

4.2.3 Estimate the percentage of the mineralization which has been sampled. If P% has been sampled and L' is the sampled length, the complete length of ore intersection (if the whole mineralization had been sampled) would have been:

$$L = L' * 100 / P \tag{19}$$

The missing length is:

$$L'' = L - L' = L' \left(\frac{100-P}{P}\right) \tag{20}$$

4.2.4 If n' is the number of samples in L', the average sample length is L'/n' and in the missing part of the orebody we could have taken n" samples of (approximatively) the same length:

$$n'' = \frac{L''}{L'} n' \tag{21}$$

4.2.5 The problem is to estimate what would have been the value of these n" samples if they had been taken. If we ignored the fact that n' samples have been taken along the borehole, our best estimate of the n" samples would be given by the estimated drift obtained in 4.2.2 above. If M is the point at the center of the sample to be estimated, and M_L the point where the borehole intersects the F/W of the mineralization, the sample value is estimated as follows:

$$v(M) = \hat{\mu} + \sum_{k=0}^{K} \hat{a}_k h^k \tag{22}$$

where $h = MM_L/L$.

We must however take into consideration the fact that n' samples have been taken, with average value μ' representing P% of the mineralization. If these P% were taken near the F/W of the orebody, their estimated average value using equation 22 would be:

$$\hat{\mu}' = \frac{1}{P} \int_{h=0}^{P} v(M)\ dM = \hat{\mu} + \sum_{k=0}^{K} \hat{a}_k \frac{P^k}{k+1} \tag{23}$$

If the P% were taken near the H/W of the orebody, their estimated average value using equation 22 would be:

$$\hat{\mu}' = \frac{1}{P} \int_{h=1-P}^{1} v(M)\ dM = \hat{\mu} + \frac{1}{P} \sum_{k=0}^{K} \hat{a}_k \frac{1-(1-P)^{k+1}}{k+1} \tag{24}$$

Usually, the value of $\hat{\mu}'$ will not be equal to the average sample value μ', and using equation 22 to estimate the n" missing samples will introduce a bias. Rather we will use the following equation:

$$v(M) = \mu + \sum_{k=0}^{K} a_k h^k \tag{25}$$

where

$$\mu = \hat{\mu} * (\mu'/\hat{\mu}')$$

$$a_k = \hat{a}_k * (\mu'/\hat{\mu}')$$

The average value of $v(M)$, when M is in the sampled part of the orebody, is equal to μ'.

We can now create n" samples of length L"/n" in the missing part of the bore, and calculate their value using equation 25, where M is the point at the middle of the sample, and $h = MM_L/L$.

4.2.6 We now have a complete borehole, with n' true samples and n" simulated samples. We can use this borehole to complete the structural analysis of the mineralization.

4.3 Example 1: borehole with missing F/W intersection

Borehole n° 203 intersects only sub-zone 211 in zone B. The lower part of zone B (sub-zone 212) is missing. Using only the surrounding boreholes, the value profile at the position of hole n° 203 has been estimated as follows:

$$\hat{\mu} = 7980 \text{ BTU}$$
$$\hat{a}_0 = 333$$
$$\hat{a}_1 = -16\ 900$$
$$\hat{a}_2 = 57\ 500$$
$$\hat{a}_3 = -55\ 800$$
$$\hat{a}_4 = 14\ 500$$

The average value of the 9 samples taken in sub-zone 211 is $\mu = 7486$ BTU. We estimate that only 50% of the borehole has been sampled (P = 50). Using equation 24 we calculate:

$$\hat{\mu}' = 8643 \text{ BTU}$$

Using the corrective factor $\mu'/\hat{\mu}' = 7486/8643 = 0.8661$ we obtain (equation 25):

$$\begin{aligned}
\mu &= 6\,912 \text{ BTU} \\
a_0 &= 288 \\
a_1 &= -14\,638 \\
a_2 &= 49\,803 \\
a_3 &= -48\,330 \\
a_4 &= 12\,559
\end{aligned}$$

The sampled length is L' = 47.0 m. The missing part is therefore L" = 47.0 m (equation 20). Due to the presence of an exceptionally small sample in sub-zone 211, only n" = 8 samples have been considered in the missing zone. Their values have been calculated using equation 25, and the results are plotted on Fig. 9 (zone 211 contains the true samples, while zone 999 contains the simulated samples). A polynomial has been fitted to the completed borehole, and the following parameters have been obtained:

$$\begin{aligned}
\mu &= 6\,909 \\
a_0 &= -96 \\
a_1 &= -3\,965 \\
a_2 &= -7\,177 \\
a_3 &= 45\,081 \\
a_4 &= -33\,997
\end{aligned}$$

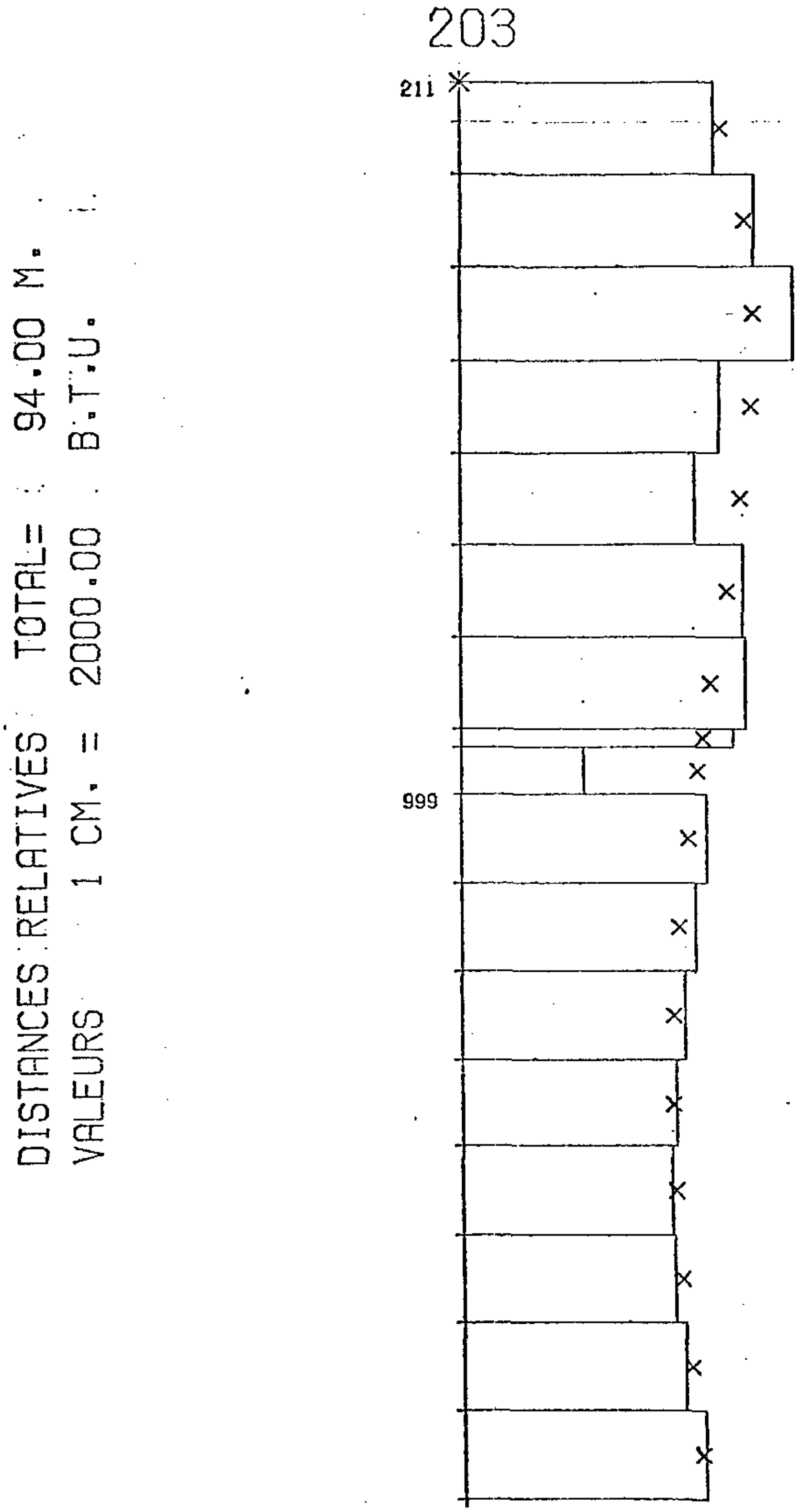


FIGURE 9. Borehole 203 with simulated missing samples (subzone 999).

These values compare favorably with the corresponding values in the surrounding samples. In the original analysis of zone B (see section 3.3.2) hole n° 203 had to be eliminated as an outlier.

4.4 Example 2: borehole with missing H/W intersection

Borehole n° 193 intersects only the lower part of sub-zone 212 in zone B. The upper part of zone B is missing. Using only the surrounding boreholes, the value profile at the position of hole n° 193 has been estimated as follows:

$$\hat{\mu} = 7830 \text{ BTU}$$

$$\hat{a}_0 = -1\,130$$

$$\hat{a}_1 = 17\,300$$

$$\hat{a}_2 = -85\,100$$

$$\hat{a}_3 = 147\,000$$

$$\hat{a}_4 = -79\,500$$

The average value of the 8 samples taken in zone 212 is $\mu' = 7332$ BTU. We estimate that only 37% of the borehole has been sampled (P = 37). Using equation 23 we calculate:

$$\hat{\mu}' = 7\,407 \text{ BTU}$$

Using the corrective factor $\mu'/\hat{\mu}' = 7332/7407 = 0.9899$ we obtain (equation 25):

$$\mu = 7\ 751$$

$$a_0 = -1\ 119$$

$$a_1 = 17\ 125$$

$$a_2 = -84\ 238$$

$$a_3 = 145\ 512$$

$$a_4 = -78\ 695$$

The sampled length is L' = 27.4 m. The missing part is therefore L" = 46.6 m (equation 20). Due to the presence of two exceptionally small samples in sub-zone 212, only n" = 10 samples have been considered in the missing zone. Their values have been calculated using equation 25, and the results are plotted on Fig. 10 (zone 212 contains the true samples, while zone 999 contains the simulated samples). A polynomial has been fitted to the completed borehole, and the following parameters have been obtained:

$$\mu = 7\ 695$$

$$a_0 = -\ 987$$

$$a_1 = -1\ 683$$

$$a_2 = 17\ 716$$

$$a_3 = -18\ 845$$

$$a_4 = 3\ 169$$

These values compare favorably with the corresponding values in the surrounding samples. In the original analysis of zone B (see section 3.3.2) hole n^o 193 had to be eliminated as an outlier.

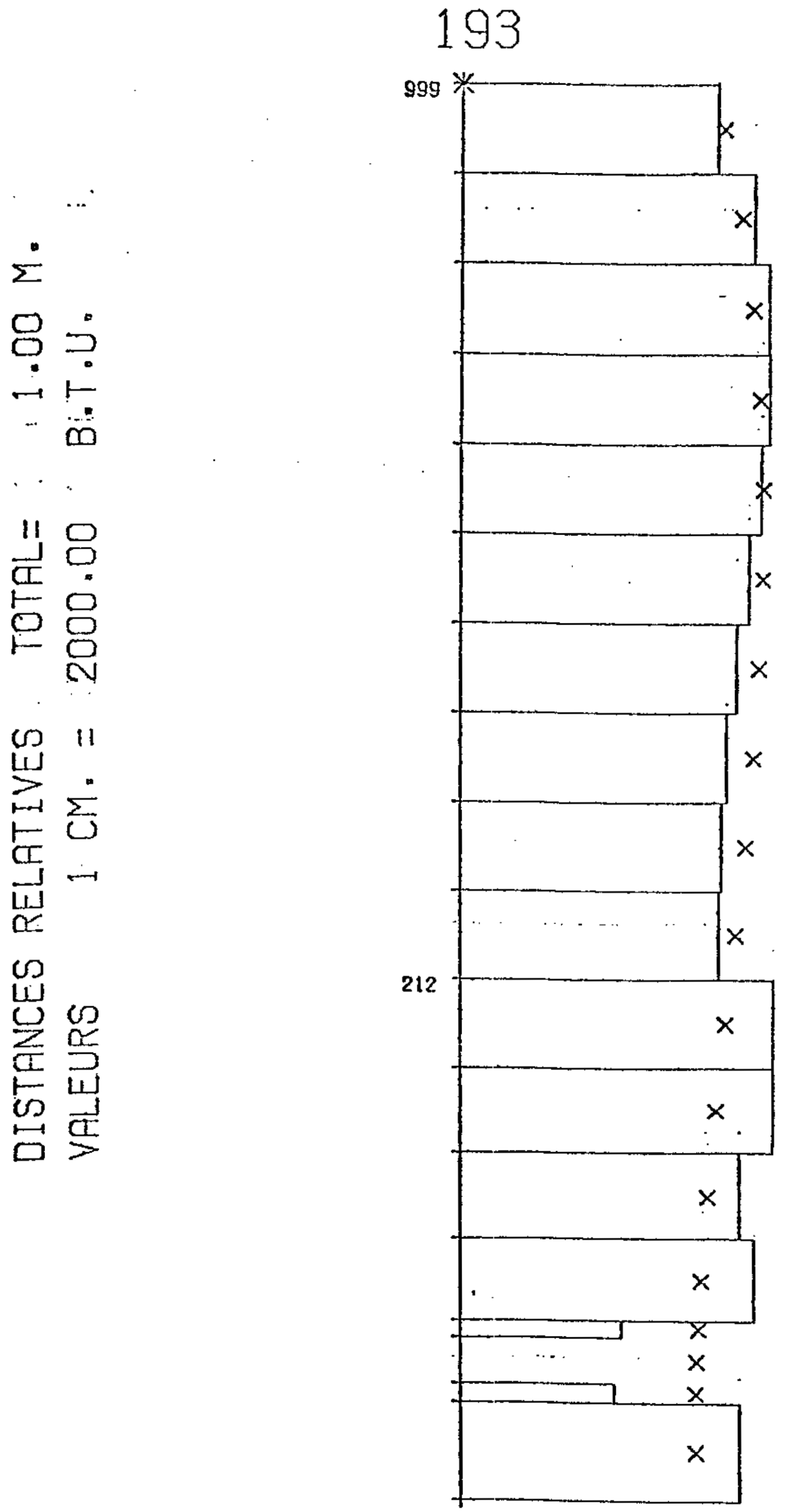


FIGURE 10. Borehole 193 with simulated missing samples (subzone 999).

4.5 Conclusions

This study shows that it is possible to successfully estimate the missing part of a borehole, and to use this simulation for a more meaningful structural analysis of the deposit. The structural analysis of mineralized zones such as zone B, which contain a large percentage of incomplete boreholes, should be made using this approach.

5 - CONCLUSIONS

The most important conclusion which can be drawn from this analysis is that the proposed methodology can be used successfully for the three-dimensional study of bedded deposits. However, significant difficulties can be encountered in the following situations:

- if the number of samples in a borehole is too small (e.g. less than 10 samples for a 4-th order polynomial)
- if the samples near the extremities of the borehole are very large (due to border effects, the extrapolated values beyond the center of the last samples can be meaningless)

- if the value of the samples at the extremities of the borehole are significantly different from the values in neighbouring samples (due to border effects, the extreme samples have a strong influence on the coefficients of the polynomial)
- if the borehole does not intersect the entire geological zone
- if the number of boreholes is insufficient.

More research must be done, to answer the following questions:

- how can we best use the information available in boreholes which intersect only part of the mineralization ? Analysis of zone B using the approach outlined in section 4 to process all incomplete holes will give an answer to this question.
- how can we decrease the border effect, and the resulting instability in the polynomial near the F/W and H/W of the mineralization ?
- what is the meaning of the coefficients a_k ? Why are they correlated ? What is the sensitivity of the estimated drift to changes in the value of the coefficients ?
- what would be the effect of changing the order of the fitted polynomial, and which is the optimal order ?

- what reduction in the error of estimation of a mining block can be expected if the drift is taken into consideration ?
- should the local difference between individual sample values and estimated drift be taken into consideration ?

Analysis of BTU content in zones A and C of the Hat Creek deposit, and analysis of the drift component in values other than BTU content would also be of interest.

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