

Ore Reserve Estimation and Ore Body Modelling

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Abstract: This study involves the study of ore reserve estimates and the modelling of ore body (Use of SRPAC). The importance of accurate ore reserve estimates has always been recognized in the past. Mining companies obviously need accurate ore reserve estimates since the quality of the estimate may directly affect the company's profitability. Accurate ore reserve estimates are also becoming increasingly important to, governmental bodies that must make policy decisions regarding nonrenewable natural resources. The paper also explains the methodology of orebody modelling and estimation of ore reserves carried out, which is explained in brief in section III The main benefit of using SURPAC Software includes: i) Drillhole data management, ii) Geological modelling, iii) Block modelling, iv) Geostatistics, v) Resource estimation and mine design, etc. Till now so many methods of reserve estimation had been used like Polygon method, IDS, or its improved method ELIP, Contour, cross-section and many more. But in the recent scenario the Geostatistical method is of more importance, which is followed by Krigging Procedure. In this paper we mainly focused on geostatistical method and further it is compared with other methods to obtain a suitable analysis.

Index Terms – Reserve, Ore body Modelling, Drillhole, Contour, Krigging, ELIP, and IDS.

I. INTRODUCTION

The appraisals for ore reserves depend on the outcomes and investigation of the examples from which they were inferred. On the off chance that a reserves isn't completely created (and still, after all that to a lesser degree), there must be sure suspicions with respect to the coherence and level of the ore between uncovered features or examined drill holes. The designer needs to translate all accessible data in making these suppositions and the precision of the final products is to a great extent dependent on his experience and the adequacy of his judgment. He should join the example esteems effectively, however he should likewise think about the impact of basic conditions, translate the land criteria and think about the impact of auxiliary conditions on congruity and grade of metal, the plausible loss of mineral in mining, the weakening with waste (which, thus, may rely upon the mining technique utilized or to be utilized), and the expense of mining and processing, which might be a significant factor in deciding the base evaluation of shake that can be classed as metal.

Ore reserve estimation is utilized to decide and characterize the ore tonnage and grade of a geological deposit, from the developed block model. There are diverse estimation techniques utilized for various situations subordinate upon the ore limits, deposit geometry, grade fluctuation and the measure of time and cash accessible. Typical resource estimation includes the development of a geographical and asset model with information from different sources. They might be made by inspecting engineers as a reason for putting an incentive on a mining property regarding writes about benefit of proprietors or merchants, from one perspective, or for forthcoming buyers or residents, on the other. They are made for charge purposes and now and then regarding mergers of at least two organizations or with case.

II. USE OF COMPUTER SOFTWARE FOR ORE BODY MODELLING

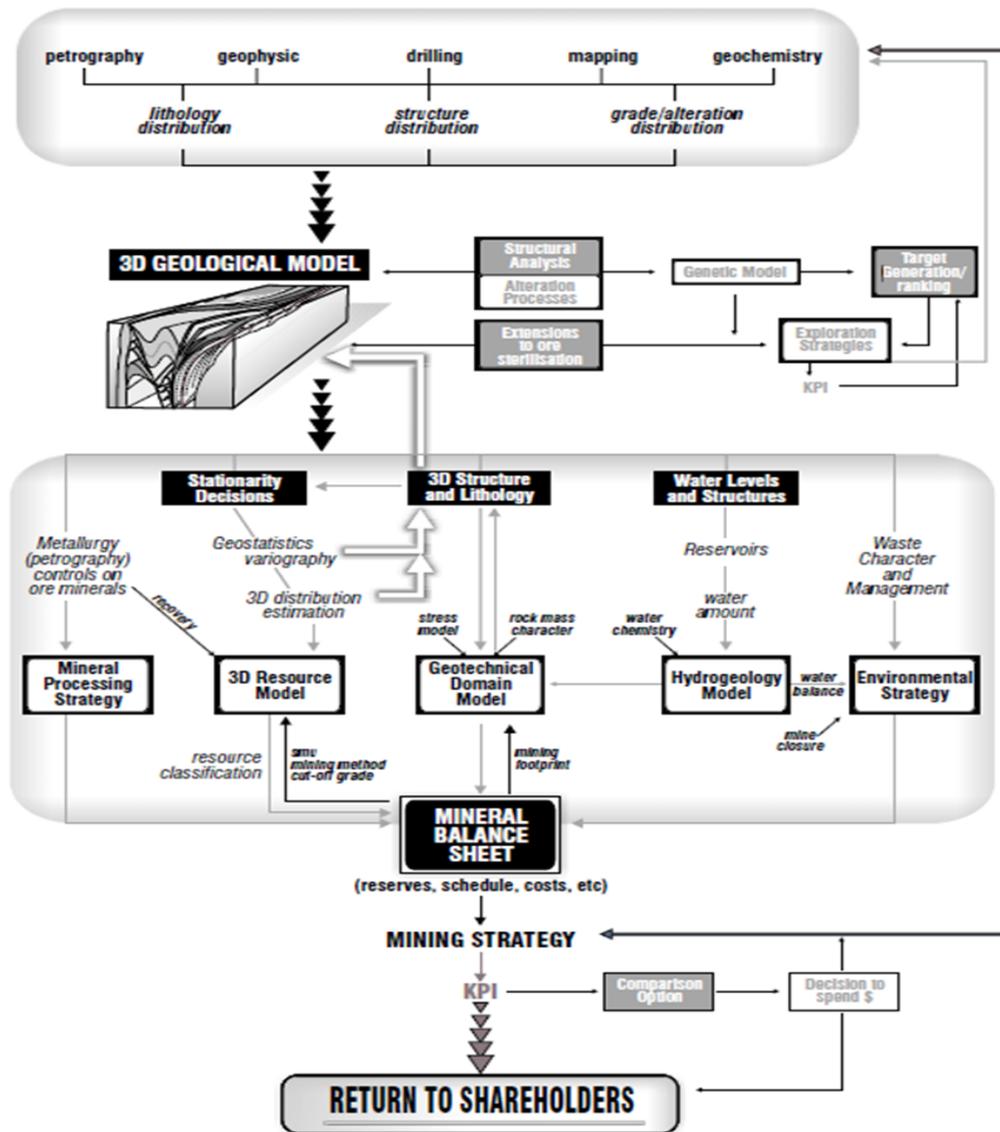
Ore body modeling may be a reflection of geologic and geometrical reality of an ore deposit. Geologists and mining engineers will enjoy such an integrated modeling approach by conformation the deposit earth science, understanding the distribution and accentuation the spatial continuity studies. The model will act as principal guides for development of mineral inventory model and grade-tonnage curves that ultimately will result in a worth model in terms of economic extraction of the ore body. Generally, size of the info is simply too large to manage studies with hand effort. Thus, numerical algorithms and mathematical approaches necessitate laptop applications to beat immense machine time and processes. Currently, several laptop motor-assisted systems and software system serve for geologic modeling. The accuracy and speed of computers alter analysis of varied situations at intervals fairly short times. Computer programs are prepared for ore body modeling once building a healthy info structure. Visual look of earth science body is supported by numerical knowledge like ore reserve quantity and quality composition, that are very important parameters for mine style and programming. Thus, pc systems are vital for mining and earth science studies. So, during this project we have a tendency to primarily target on SURPAC package for the modelling of ore body.

III. METHODOLOGY

For different purposes in mine, Surpac programming is utilized. Right now, going to talk about just on hold estimation and valuation. Block models are utilized in Surpac for reserve estimation and valuation. To create a block model, Solid model and surface geography are required. In particular, cut-off evaluation is required for valuation of the reserve utilizing block model. Further, to make a strong model, geographical database is to be created. The beginning stage of all mining ventures is the drill-opening information. It proceeds with the bases on which attainability studies and ore reserve estimation is finished. Various tables are remembered for a geographical database, containing various information. Each table contains various fields, having numerous records and with each record containing the information fields. Surpac utilizes a relational database model and supports a few unique kinds of database, for example oracle, paradox and Microsoft access. The economic consequences of the errors in reserve estimation can be very serious. A 10 % mistake in grade estimation is viewed as a minor or little blunder. In the event that creation costs are in any event 50 % to 75 % of the mine site income, a 10 % decline in evaluation can mean a 20 % to 40 % decline in real money activity excess. That can produce a bookkeeping misfortune, contingent upon the proportionate degree of amortization and devaluation charges. It can likewise render a vigorously outfitted task non-suitable. Another consequence of serious error is the necessity of

producing a new estimation that may involve a heavy reduction in the reserve tonnage. Unit capital charges are increased to a level that may generate an accounting loss and a negative return on investment. Some consequences relate to legal liability.

3.1 Disciplines and stages in the mining process, emphasizing major linkages



3.2 Ore Reserves estimation Techniques

As discussed in the flow sheets no. 1, six steps are to be followed in applying the techniques of reserve estimation. These steps are of prior importance as it involves the iteration of technical, financial and risk assessment successively. As a portion of the procedures includes high monetary venture, these emphasis diminishes those impacts which will underpins geologists to do estimation inside upgraded speculation to improve the hierarchical benefits. There are different estimation strategies which are clarified beneath, out of which Matheron's Geostatistical Modelling of much significance which will be talked about in explained way right now. Right now, SURPAC programming has been utilized to characterize the model and to discover their answer in reproduced way to plot appropriate Variogram for the Model. Fundamentally two kinds of model will be talked about to be specific, Solid Model and Block model.

- **Important points considered for applying different techniques**

Tonnage factor: It gives the system to the transformation from volume of ore to weight of ore. In the English framework, the tonnage factor is typically communicated as cubic feet per ton of metal. In the decimal standard, the tonnage factor is the specific gravity of the ore. Presumably the most precise strategy for deciding explicit gravity of a metal is to compute a normal explicit gravity utilizing the particular gravities of individual minerals. For example: If a massive Sulphide ore consists of 10% galena of sp.gr. 7.6, 35% Sphalerite of sp.gr. 4.1, 55% Pyrite of sp.gr. 5.0, the specific gravity of ore is calculated as follows:

$$\begin{aligned}
 7.6 \times 0.1 &= 0.76 \\
 4.1 \times 0.35 &= 1.44 \\
 5.0 \times 0.55 &= 2.75 \\
 &= 4.95
 \end{aligned}$$

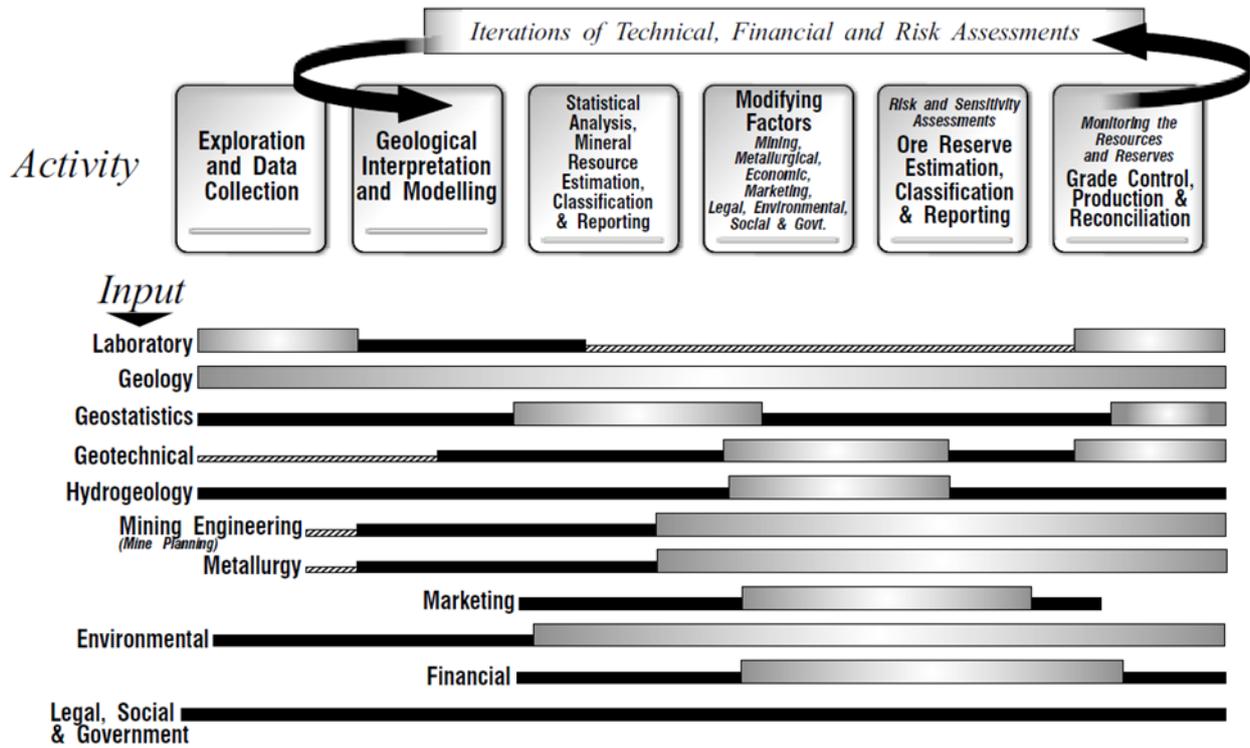
So, the specific gravity of Sulfide ore is considered as 4.95.

All methods for the calculation of ore reserves make use of two basic principles:

1. Samples taken close to each other are likely to have same value
2. Average grade are calculated using some form of weighted average

$$\bar{x} = \sum_{i=1}^n \frac{x_i w_i}{w_i} \tag{1}$$

Flow sheet 1: Ore Reserve Estimation process



3.2.1 Classical methods:

Among the great measurable techniques, Arithmetic mean and Mean aggregation strategies are by and large and is by all accounts comparable. Their prevalence results from straightforward figuring calculations. Be that as it may, the two strategies contrast in the calculations as well as in the materialness, which, lamentably, is somewhat once in a while checked practically speaking. The two strategies depend on the idea of autonomous estimations (perceptions), which implies simply arbitrary changeability of deposit parameters (i.e., the absence of autocorrelation of specific parameters). If such premise is valid the estimated resources or reserves (Q) for particular Minerals/Ore are given by the following formulae:

1. Arithmetic Mean Method:

$$Q[M] = \bar{M} \times \bar{\gamma}_0 \times F \tag{2}$$

2. Mean accumulation method:

$$Q[M] = \bar{q} \times F \tag{3}$$

Where,

- \bar{M} - Arithmetic mean of thickness measured at observation sites,
- $\bar{\gamma}_0$ - Arithmetic mean of density of a raw-material,
- F - Area of a seam or its part (parameter usually regarded as constant) [m²],
- \bar{q} - Arithmetic mean of unit accumulation determined for n observation sites.

The arithmetic mean method provides correct results only when additional premise is valid: that thickness and density of raw material are independent variables.

3.2.2 Polygon Method of Reserve estimation

Tonnage and mineral quality are being evaluated by weighting the central sample value by the zone of a polygon built around the central sample and extending this half way to adjacent sample sites. Just that part of the polygon correspondent with the region really mines is utilized. The tonnage is evaluated first and afterward the mineral quality is dictated by the sample value by the tonnage. A S.G. of 1.34 is utilized for all evaluated techniques. Polygonal estimation strategy is most regularly utilized for tabular deposits that have been penetrated by a progression of vertical drill openings, and vein-like deposits that have been drilled by angle holes for collecting sample data. This strategy uses the standard of "rule of closest focuses". In the polygonal strategy, the polygons are built by drawing perpendicular bisectors to lines associating all sample points. The volume and grade calculation in this method is straight forward. The volume and the tonnage are then calculated as below:

$$\text{Volume (V)} = \text{Area (A)} \times \text{Height (H)}$$

$$\text{Tonnage} = \text{Volume (V)} \times \text{Tonnage Factor (TF)}$$

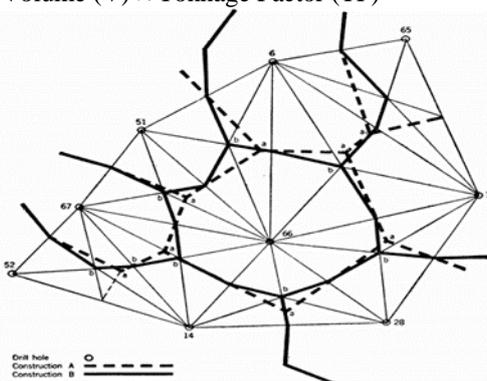


Figure 1 Construction of polygons around drill holes for estimating tonnage and grade of ore

3.2.3 Inverse of the Distance Squared Method (IDS)

With the presentation of PCs in ore reserve computations, the utilization of separation weighting strategies got down to earth. In these strategies the grade assigned to a block is a weighted average of all or nearly all holes surrounding the block. The loads relegated to each gap is a component of the separation between the gap and the focal point of the block. The loads must summarize to one, in this way shaping the direct mix of the evaluations encompassing the block. In the inverse of the distance squared method (IDS) the weights are inversely proportional to the distance squared. Many other variations of the distance weighting have been devised and used.

Modification of IDS Method (ELIP)

This is the second distance weighting tested. The basic difference between IDS and this method is that IDS gives equal weight in all directions for a given distance, whereas with BLIP the weight can be varied for different directions.

3.2.4 Illustration of Kriging procedure

Kriging is a geostatistical interpolation technique used in mining industry for interpolation of input point data and estimation of a block model (mineral resource model). The name ‘‘Kriging’’ was given by Prof. Georges Matheron in honor of the South African mining engineer Danie Krige. Kriging is an optimal spatial regression technique which requires a spatial statistical model, popularly known as a variogram, representing the internal spatial structure of the data. The input data (used to estimate any particular block) are weighted based on the variogram model, search parameters and the number of samples used to Krige or estimate a block. In order to comprehend the theoretical basis of the Kriging procedure, one must be familiar with the following concepts from Matheron’s Geostatistics (or Geostatistics in short).

1. The variogram function (or variogram).
2. Variance of point samples within any size volume v , given as $\sigma^2_{(O/V)}$.
3. Block variance in a deposit, given as $\sigma^2_{(D/V)}$.
4. Krige's Relationship.
5. Extension (or Estimation) variance, given as σ^2_E .

Variogram Models

Variograms calculated for mineral deposits have been found to be adequately described by a few theoretical models (David, 1974, p. 59). The most often used models are the spherical model and the Dewijsian Model. The spherical model is a transitive variogram and is expressed by the equation given below:

$$\gamma(h) = C_o + C \left[\frac{3h}{2a} - \frac{h^3}{2a^3} \right] \text{ For } h \leq a \quad (4)$$

$$\text{And, } \gamma(h) = C_o + C \text{ for } h > a \quad (5)$$

Where, C_o = nugget value

C = sill value minus C_o

h = distance

a = range.

Basic Concept of Variogram Function:

The variogram is a function that expresses the degree of continuity of a regionalized variable. Thus, it is the basic tool of geostatistics. The variogram describes the average squared difference between samples ‘ h ’ feet apart and is defined by equation given below:

$$2\gamma(h) = \frac{1}{v} \int_V [f(x+h) - f(x)]^2 dx \quad (6)$$

Where, $2\gamma(h)$ = value of the variogram for distance h ,

$f(x)$ = sample value at point x ,

$f(x+h)$ = sample value at point $(x+h)$,

h = distance between samples.

Fig. 2 shows the example of variogram. The variogram is a vector function which generally increases with increasing distance h . The variogram can express the following structural characteristics of the phenomenon under study (Matheron, 1971, p. 58).

1. Continuity: The continuity of the phenomenon under study is reflected by the rate of growth of the variogram near the origin. A high degree of continuity is reflected by a parabolic growth near the origin. Average continuity is expressed by a regular growth from the origin. A discontinuity at the origin is called a ‘‘nugget effect’’ and can have real physical meaning or be due to errors of measurement, recording, or sampling. A completely discontinuous variogram indicates a pure random phenomenon. Fig. 3 illustrates different degrees of continuity expressed by the variogram.

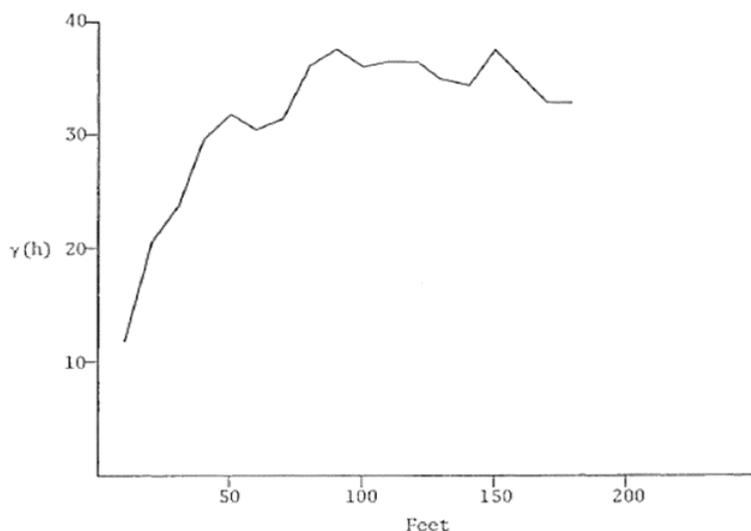


Figure 2 Variogram of a Manganese Deposit

2. Zone of Influence: The variogram gives a concise definition of the notion of zone of influence. Often, beyond a certain distance called the range, the variogram becomes nearly flat indicating that the samples are independent (see Fig. 3.2.4.2). A sample has no influence beyond the range of the variogram. A variogram with a range is called a transitive variogram. In some cases the variogram never reaches a limiting value but instead shows a steady increase with increasing distance. This is an intrinsic variogram and indicates the variogram obeys the intrinsic hypothesis

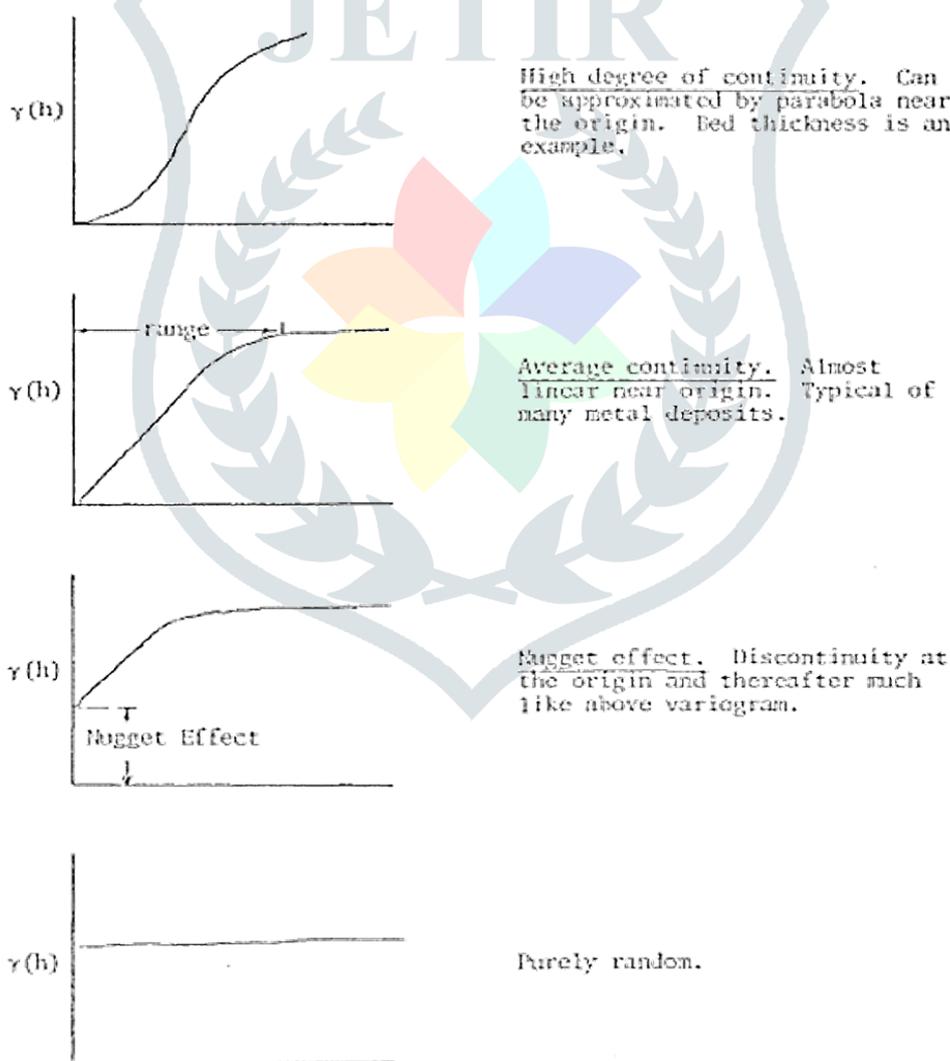


Figure 3 Degrees of Continuity expressed by variogram

3. Anisotropy: Variograms computed in different directions are often different, indicating anisotropy. Fig. 4 shows a hypothetical example of anisotropy. The range of the horizontal variogram is 60 feet and the range of vertical variogram is 30 feet. The anisotropy factor is 60/30 or 2. This means that one foot in the vertical direction is equivalent to two feet in the horizontal plane as far as grade variation is concerned.

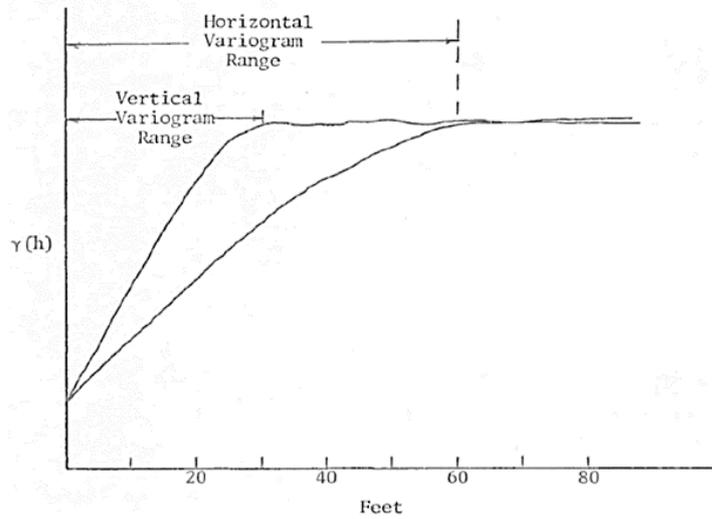


Figure 4 Hypothetical example of anisotropy

Variance of point samples within any size volume V

Bypassing a review on the Variogram function the variance of point samples within any size volume can be defined as:

$$\sigma^2_{o/v} = \frac{1}{v^2} \int_v dx \int_v \gamma(x - y) dy \tag{7}$$

In Equation above, the variables x and y are two dummy variables used for integration of the Variogram function values over the volume of interest. Strictly speaking, the equation corresponds to sextuple integrals, if v is a volume in a 3-dimensional space. On the other hand, it reduces to quadruple integrals when v is reduced to an area.

Extension Variance:

The error made by extending the grade of a sample to another point or to a volume is termed extension variance. It is defined mathematically as

$$\sigma_E^2 = E[Z(V) - Z(V')]^2 \tag{8}$$

Where, Z (V) = the grade of block v that is extended to block V'

Z (V') = the grade of block V'.

The calculation of the extension variance of an ore reserve estimate is one of the main purposes of geostatistics.

Estimation Variance:

The concept of extension variance and estimation variance are the same. However the term estimation variance is used when the extension of several samples to a volume is being made.

Variography

Taking spatial variety and randomness into account, variogram function can reflect spatial variable structure of regional variable. To study the anisotropy of the ore deposit, Variography was done in different directions and dips into ore deposit. After studying of more than 30 variograms it was found that the ore deposit has no anisotropy, because in most of the variograms same ranges and sills

Formula for Estimation Variance:

$$\sigma_E^2 = \frac{2}{NV^2} \int_v \int_v \gamma(x_1 - y) dy - \frac{1}{v^2} \int_v dx \int_v \gamma(x - y) dy - \frac{1}{N^2} \sum_{i=1}^N \sum_{j=1}^N \gamma(x_i - y_j)$$

Peter H., University of Arizona, 1945

were obtained. Variogram analysis of the normal scores data, Fig. 5 of the variogram in different directions does not allow one to detect anisotropy, so only an omnidirectional model (Fig. 6) is considered. Model consists of pure nugget effect with 0.3 plus a spherical scheme with sill 1 and range 150 m. This model is required since ordinary Kriging estimation will be based on.

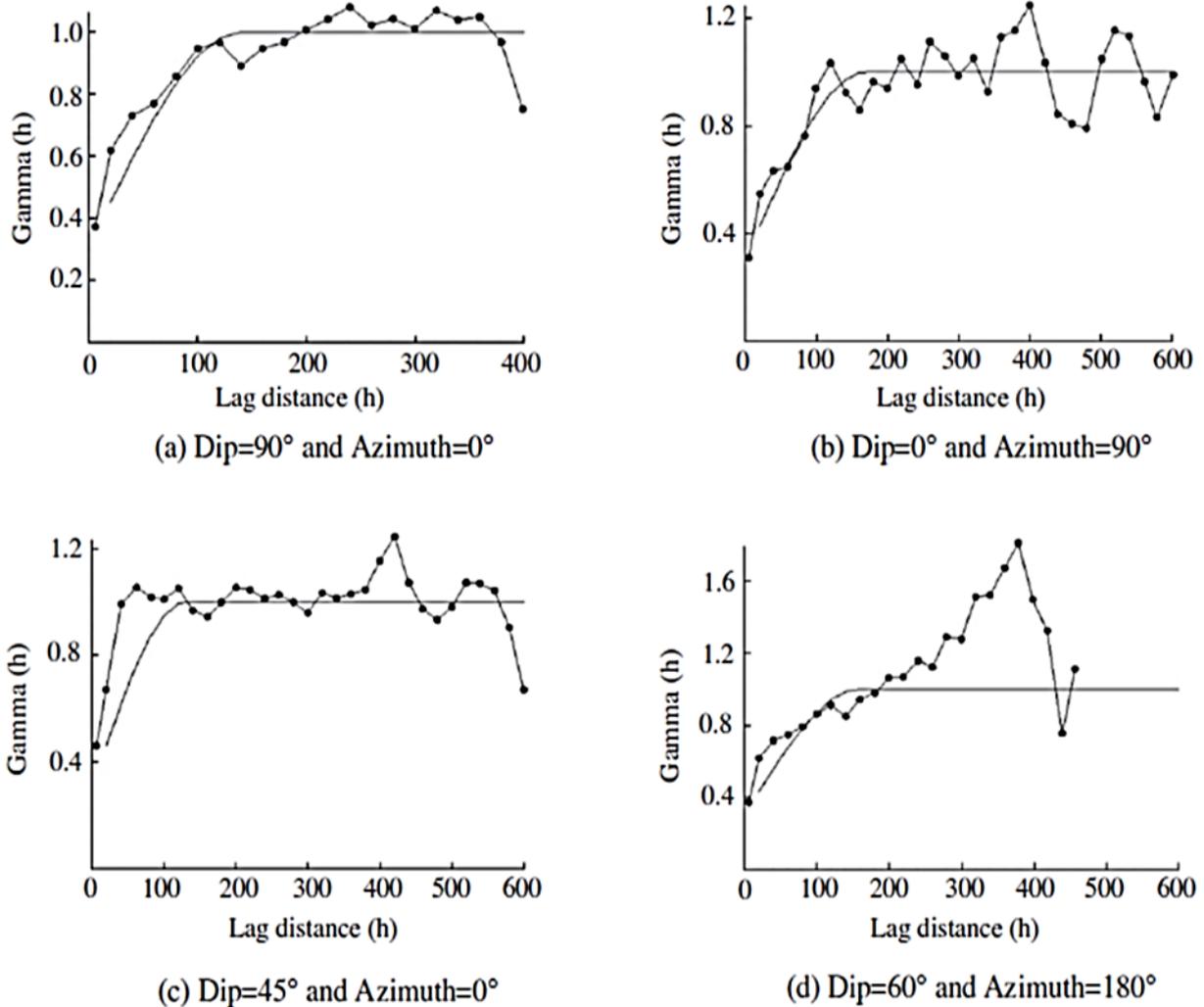


Figure 5 Variography in various directions of Dip and Azimuth

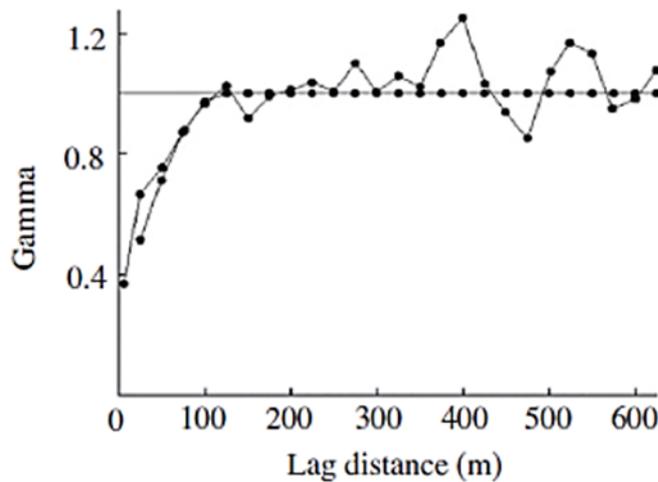


Figure 6 Omnidirectional Variogram of Manganese Ore Deposit

Verification of variogram through cross validation

One of the method to check validity of the results of estimation is cross validation. In order to do that using the fitted variogram, in each step one of the data being removed and its value was estimated based on the other real data of the searched area. Then the difference between the estimated value and the known value was discussed. The correlation coefficient between the estimated points and the known points was 0.773 (Fig. 7).

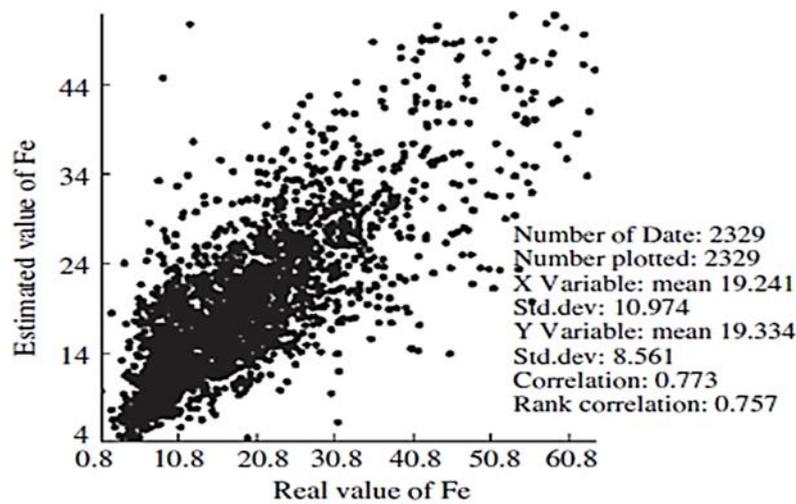


Figure 7 Cross validation diagram for real and estimated values of Mn

Grade-Tonnage Curve

Grade-tonnage curves are one of the tools which enable the mine managers to determine the correct long-time, mean-time and short-time parameters for ore producing. Drawing grade-tonnage curves needs to finding the tonnage of different grades. To find the tonnage of each block, the specific gravity of ore and core recovery percent is required. So according to this data, we could calculate the deposit based on different cut-off grades. Fig. 8 shows the grade-tonnage curve of Manganese deposit. It could be seen that with reducing the cut-off grade of iron the amount of deposit increases and with increasing the cut-off grade the amount of deposit decreases.

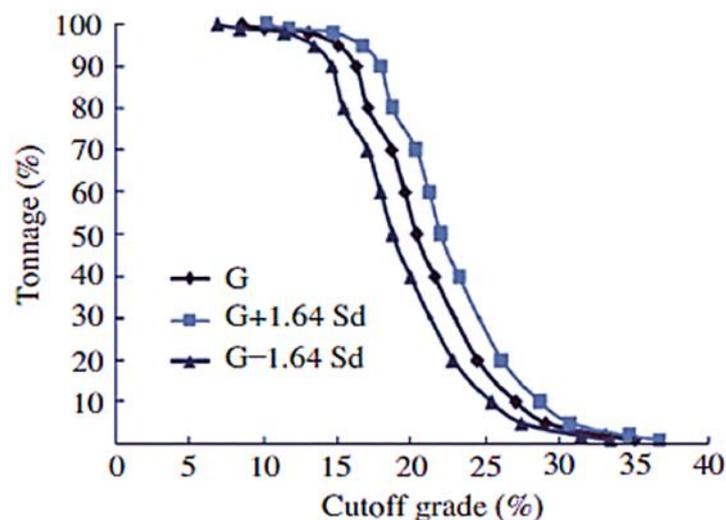


Figure 8 Tonnage grade curve of Manganese ore deposit.

IV. EXPERIMENTATION OF DESIGNED ORE MODEL

4.1 Generalized Solid Model

Creating a solid model in SURPAC involves different steps. First of all we initialize the geology pattern of the drill holes based on ore percentage. Then we go for sectioning of the boreholes. Sectioning involves dividing the entire span of drill holes to different parallel planes spaced equally and along any particular direction (which can be set by user). Each section contains some drill openings (there might be a section which does not contain any drill hole).

Then digitizing was done, one by one, in all the sections. In this process we take the ore which has the ore percentage of our interest. Thus segments are to be created in all the sections. Than all the segments are combined to one string file. After that the string file was checked for any spikes or duplicate points or the rotation of each segment. All the spikes, duplicate points were removed and rotation was set to anticlockwise. The generated solid model report contains the trisolation extents, surface area and volume of the solid. In this project the above properties are found to be:

Trisolation extents

X Minimum: 1130.170
Y Minimum: -500.000
Z Minimum: 679.818
Surface area: 287214;

X Maximum: 1584.023
Y Minimum: -50.000
Z Minimum: 853.191
Volume: 3590520

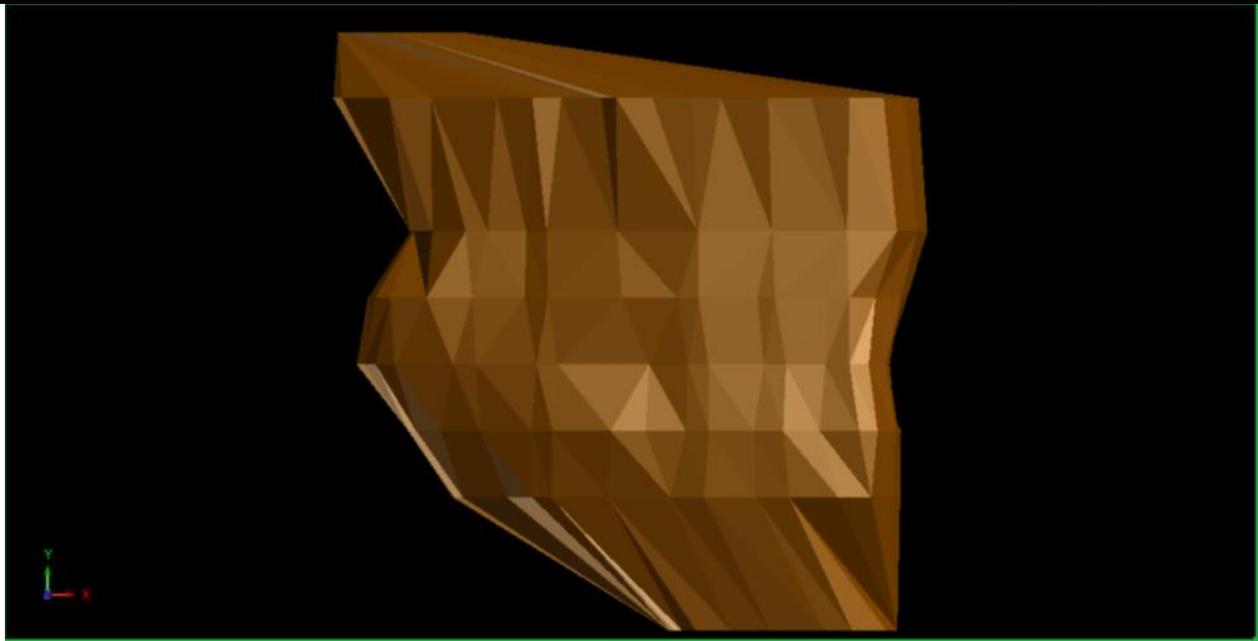


Figure 9 Plan view of Solid Model

4.2 Block Model Geometry

3D coordinates spatially defines the model extents. Block size used for interpolation and reporting. The minimum and maximum coordinates taken are:

X Minimum: 1150

X Maximum: 1560

Y Minimum: -550

Y Maximum: 0

Z Minimum: 690

Z Maximum: 880

Step distance in x, y, z directions are taken as 55, 55, and 10 respectively and the block model is created.

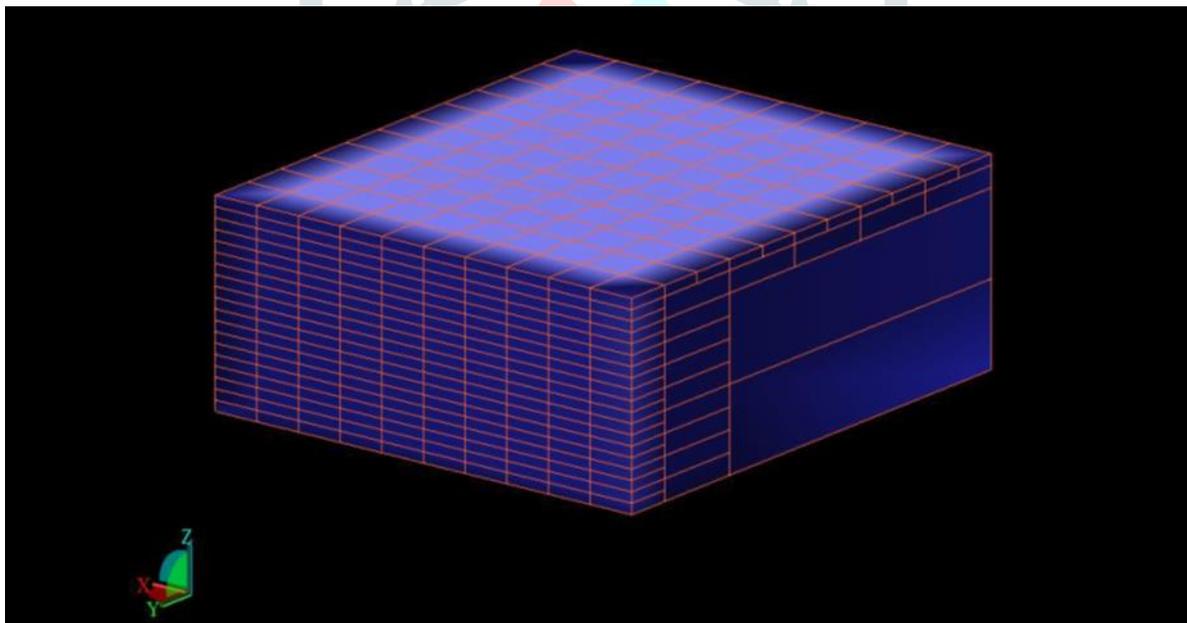


Figure 10 Display of generated Block Model

Now we can create the view of constrained block model by adding different graphical constraints. After adding, the created solid model as a constraint to the block model it took a very different look which is shown below in Fig. 11. Next task was to estimate the ore reserve for each block. It was achieved using three different methods, i.e. (Nearest Neighbor, Inverse distance with power 2 and 3 and Ordinary Kriging). After applying sufficient constraints, estimation reports were generated.

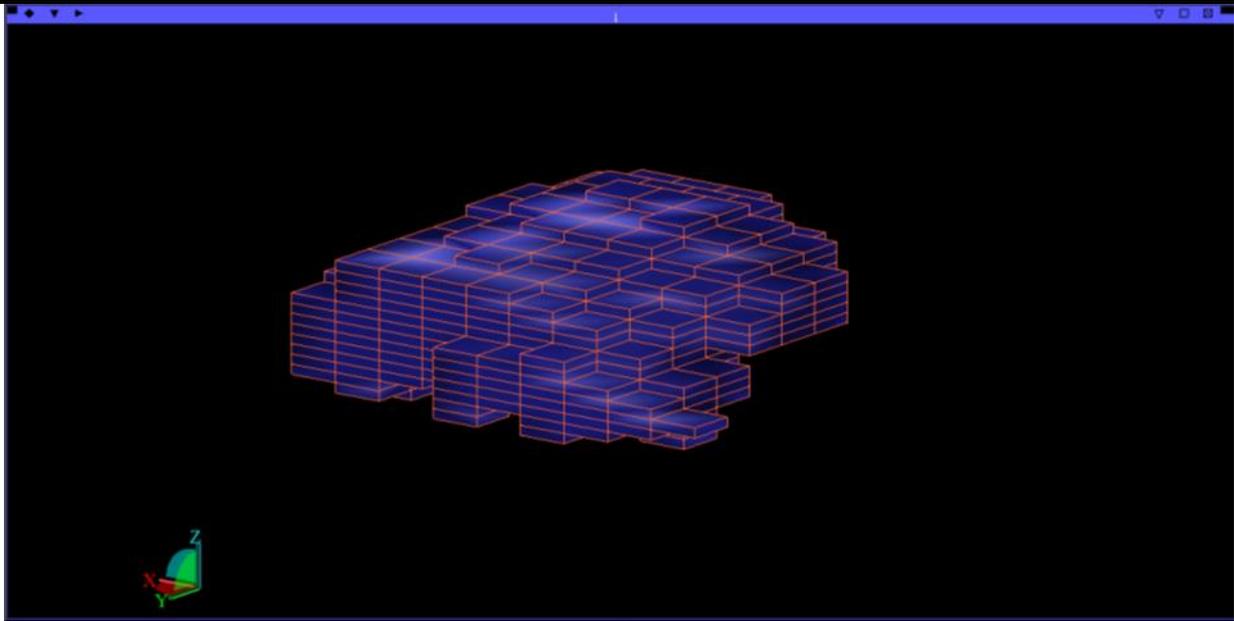


Figure 11 Display of constrained Block Model

V. RESULTS AND DISCUSSION

Here we have assumed ordinary Kriging to be the best estimator. Now the comparison of reserve estimation of other estimators is carried out following the steps given below:

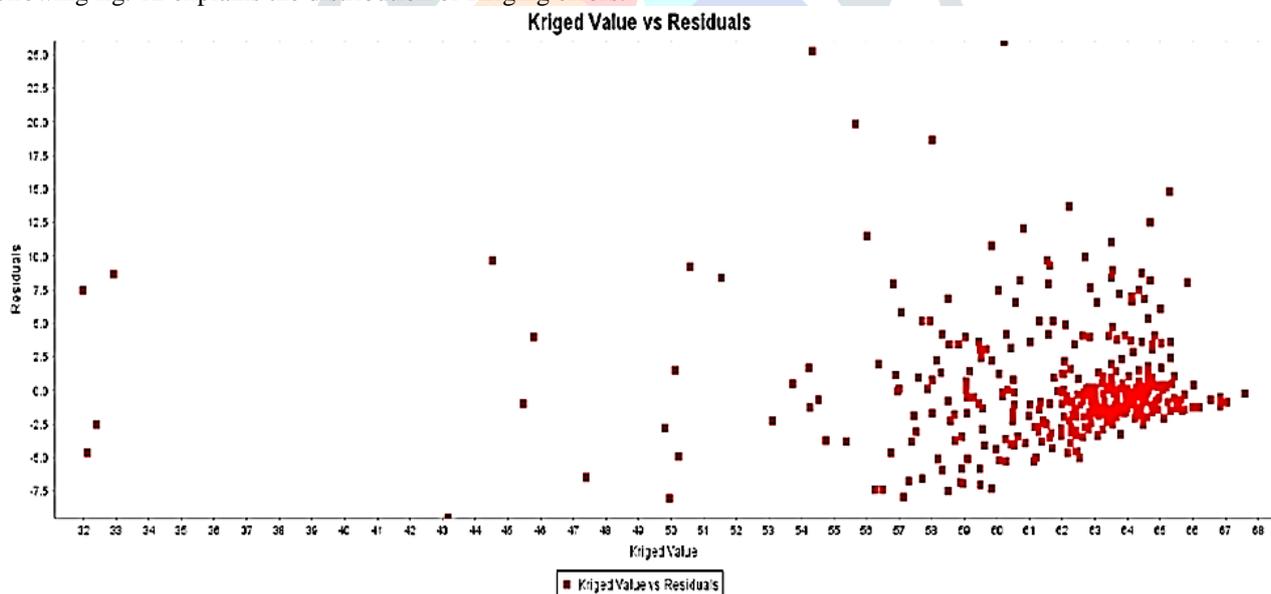
1. The variogram that has been used in the ordinary Kriging estimation was cross validated.
2. Then the results of other estimators were compared with the result of ordinary Kriging.

Cross validation of variogram:

Cross validation permit us to compare estimated and true values using only the available information in the sample data set. Thus it gives the statistics of Kriging errors. The cross validation of the concerned variogram resulted the following:

1. Number of assays = 352
2. Mean of errors = 0.3508
3. Variance of errors = 20.7834

The following fig. 12 explains the distribution of Kriging errors.



VI. ACKNOWLEDGMENT

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