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Practical Applications of a Computer Orebody Modelling System on the Broken Hill Mine, Black Mountain, Aggeneys

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Day-to-day operations on the Broken Hill mine of the Black Mountain Mineral Development (BMMD) Company require a detailed knowledge of the distribution of the ore minerals within the orebody.

The data are acquired by systematic underground diamond drilling of the orebody and subsequent geological and analytical borehole logging. These data are then captured onto a database, available for further analysis. Before mining commences in a mining block, copper, lead, zinc, silver and bismuth assay values, and the specific gravity of each sample, are extracted from the database. 3-dimensional variogram and kriging calculations are performed for each geological zone, for all the metals of interest.

A computer representation of the mining block in the form of an ore model is then built using these kriged data. From these ore models information is extracted as required by the Geology Department on the mine, and used in numerous operations. These include: daily grade control to supply optimum feed grades to the treatment plant; the compilation of short, medium and long term production schedules; orebody outline definitions for the detailed planning of mining operations; ore resource calculations.

The system has been modified and updated since its inception and provides timely information in a production environment.

Introduction

The strictures of operations in the planning, mining and ore beneficiation on the Broken Hill Mine of the Black Mountain Mineral Development Company (Pty) Limited at Aggeneys (see Figure 1) require a detailed, accurate knowledge of the structure of the orebody and the distribution of metals within it.

Schedules are required in the short term for mining sequences, and feed grade to the concentrator plant; in the medium term for marketing of largely exported concentrates; and in the long term for life-of-mine economic projections.

Daily grades of feed to the plant must be predicted for each metal for optimum recovery operations in the concentrator.

Planning of mining methods, layout design for access development and rock mechanics considerations all require an accurate definition of the orebody, the limits of which are not always geologically precise.

The data from which all this information is derived are from systematic underground diamond drilling. The core from this process is logged, assayed and the information captured onto a database,

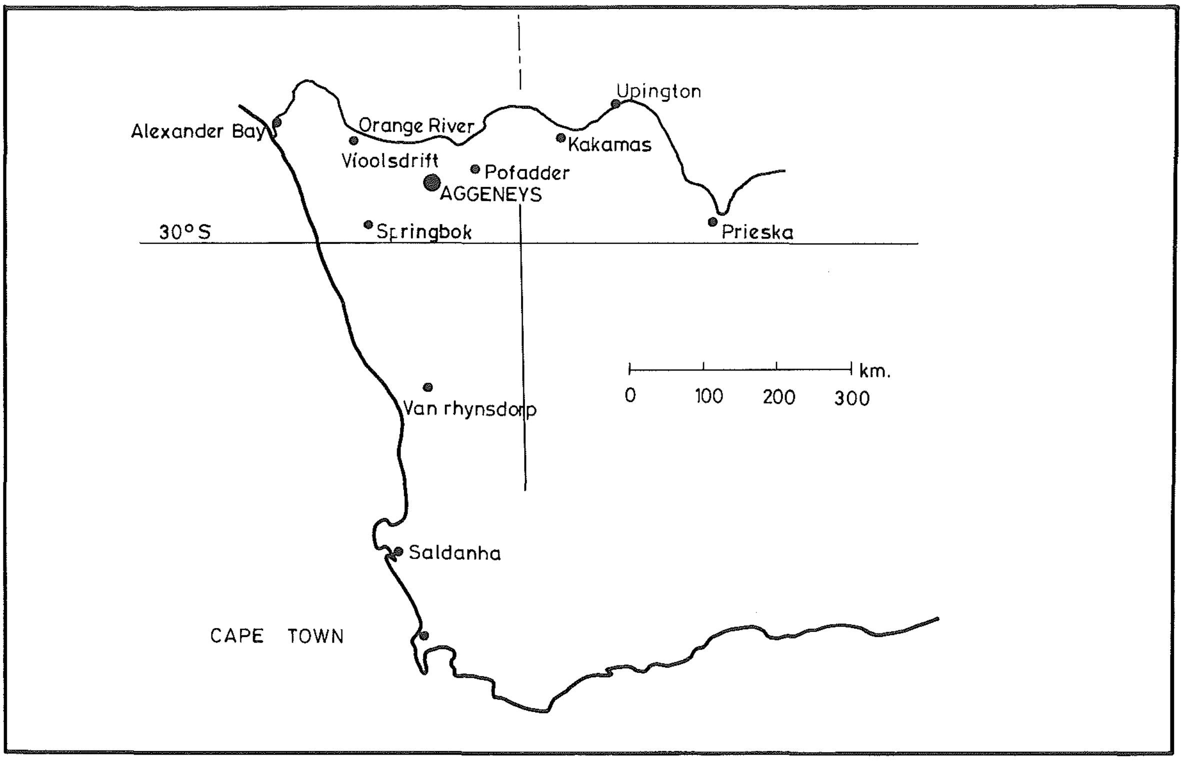

FIGURE 1. Location map of the mine at Aggeneys

where it is then available both for geostatistical analysis and more direct data retrieval.

The system has been in operation for some 4-5 years,[1] and since the initial setting up of the process it has been refined both at the technical and practical levels.

Broken Hill orebody

The Broken Hill orebody forms part of the Aggeneys Ore Formation of the Bushmanland Group of the Namaqualand Metamorphic Complex.

Geology

The orebody consists of two mineralised lenses, termed the upper and lower orebodies from their present structural aspects. These lenses are included in a sequence of schists and quartzites, underlain by basal gneisses. From regional considerations it is thought that the sequence as shown in Figure 2 is overturned.

There are three other base metal occurrences in the immediate area, two - Black Mountain and Big Syncline on the same property - and the third, Gamsberg, some 15 km east. They all appear to be in the same stratigraphic position.

Both upper and lower orebodies show broad similarities, though they differ in detail. Each consists of a central core of massive sulphide, more or less surrounded by an envelope of magnetite-rich rocks. The ore minerals are Galena-PbS, Sphalerite-ZnS, and Chalcopyrite-$CuFeS_2$, with Silver occuring in a number of phases. These occur mainly in the massive sulphide, but variably within the magnetic halo, generally decreasing in abundance away from the massive sulphide.

The region has been subjected to metamorphism of upper amphibolite grade - approx. 650°C and 4,5 kb pressure - and has undergone a series of deformational phases. These, some five of which have

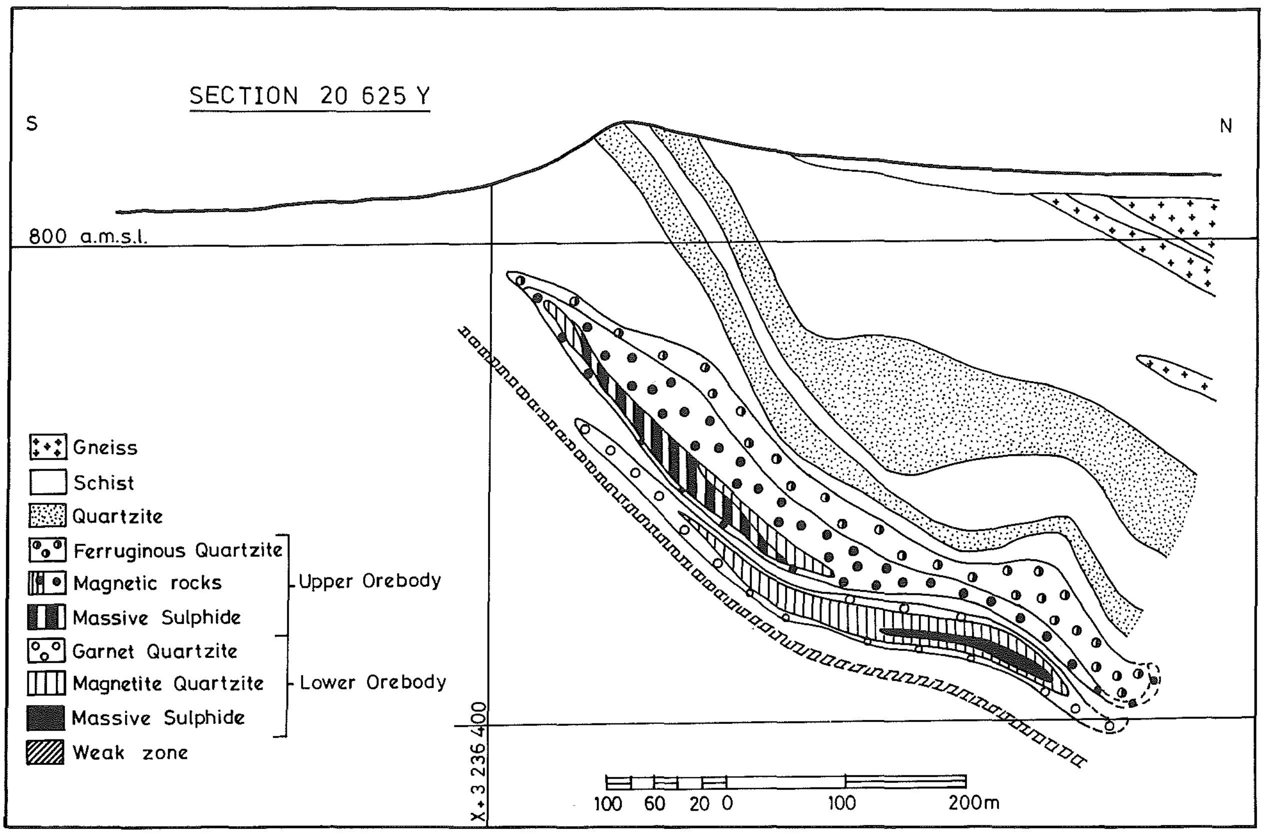

FIGURE 2. Generalised cross section through the Broken Hill orebody

been recognised, occurred under varying conditions of temperature and pressure, which influenced the manner in which the orebody and host rocks responded.

The result today represents the deformation of an essentially strata-bound orebody by folding, thrusting and, to a lesser extent, faulting.

Mining

The principal mining method at present in use is cut and fill with some variations[2]. This method has advantages in terms of flexibility of face and stope outlines, but is more costly than the mass-mining methods previously employed. This more labour -, equipment - and capital-intensive method requires a greater degree of control of mining outlines to ensure minimum dilution, and most cost-effective use of resources.

The ore definition is rarely a sharp geological discontinuity. In certain areas, the footwall contact is a distinct change from ore to total waste rock, but the hangingwall contact is never as easily defined.

The distribution of the four ore metals - lead, copper, zinc and silver - varies in complicated fashion with respect to each other. This is dependent upon original depositional features and also subsequent metamorphic and structural history. Thus, it is impossible to arrive at a metal grade cut-off. The revenue received for each metal also varies in terms of the concentrate sales contracts and the pure metal prices. This makes a cut-off based on any one metal inappropriate.

The method used is to ascribe a Rand value to each metal based upon its intrinsic worth in situ, i.e. metal price less refining and transport charges etc.

A total Rand value can then be ascribed to any particular sample according to its metal grades.

A Rand cut-off, equivalent to prevalent working costs, is used to define economic ore. This can be changed, within limits, as necessary.

Concentrator plant

The ore is sequentially separated after comminution using selective froth flotation.

The process is largely automated and computer controlled for optimum economic efficiency[3].

The complex nature of the ore, and the production of three separate concentrates require an intricate, complicated sequential flotation process. The more consistent the feed grades, the more stable all the conditions in the process become. This concerns not only the actual grades of the metals, but also the relative ratios between them.

Steady feed grade conditions affect most of the operations within the process, from reagent consumption, contamination of concentrates, overall recoveries, and even manpower utilisation.

These all affect the overall profitability of the operation, reducing expenditure and maximising revenue derived from the sale of concentrate. Penalties for instance are paid for lead and zinc contamination of the copper concentrate.

Drilling and data capture

The basic data for the entire 3-dimensional geostatistical system are obtained from systematic diamond drilling and logging of the core.

The drilling is done on north/south sections 20 m apart and is laid out to cover the entire orebody. Levels are 35 m apart and normally four or five holes are fan-drilled per level on each section. Some 1 900 holes were drilled to the end of 1986, which, together with the 168 surface boreholes, form the database of the system. There are in excess of 40 000 samples.

The logging system is as described by Chunnet[1] for the most part. However, it has since been automated by the introduction of a specifically designed data capture system, written for an IBM microcomputer. The system has input screens that correspond exactly to the logging sheets used in the core logging procedure.

To obviate any bias introduced by the inhomogeneity of the mineral content across geological strata, the orebody is zoned by the logging geologist. Some 15 zones are designated; in simplified form these are basically: alternating waste, magnetite-rich rocks and massive sulphides for the two orebodies.

Three-dimensional geostatistical system

The system consists essentially of three sub-systems with a mainframe database at its core. The Generalized 3-dimensional Variogram and Kriging sub-systems perform the geostatistical data processing. An Ore Model sub-system provides a means of representing the results in a form that can be used for further analysis.

The system caters for analysis and processing of up to twelve homogenous zones and metal grades.

Mainframe database

The BMMD Geological Database is an IDMS network database. Retrieval is performed using its Querymaster which invokes CAFS (Content Addressable Filestore System).

Once the data are transferred from the mine via a synchronous link to the ICL 2988 mainframe in Johannesburg, they are subjected to further validation tests before being loaded onto the database. Any errors detected after loading can easily be corrected by editing the data in the database.

Variogram subsystem

The Variogram system provides a generalized method of calculating 3-dimensional variograms. In general, two of the main directions are aligned with the layering of the orebody. The direction of best continuity is always found to be aligned with the plunge direction of the orebody. If the principal directions of continuity in the orebody are known from geological considerations, a facility is available to calculate the relevant planar variograms directly. If not, a general 3-dimensional calculation facility is available to detect the main variogram directions. Tolerance angles on the plunge and azimuth for planar variograms can vary between 0° and 90°.

The following variograms are normally calculated: four in the plane of the orebody and one perpendicular to the plane.

The 15 homogeneous zones that are logged are replications of only four basic zone types as far as variograms are concerned. With five metal grades and specific gravity to be forecast for the Broken Hill orebody, this leads to the production of some 120 planar variograms.

In general the regional geology clearly indicates the plunge of the orebody, which corresponds to the direction of best continuity, and thus planar variograms are calculated directly. A few general 3-dimensional variograms are also calculated as a check to see whether this plunge was determined correctly.

Variogram interpretation

The spherical model seems to fit the experimental variograms well (see Appendix A). The variograms have their maximum ranges of influence down plunge and their minimum range perpendicular to the plane (layering) of the orebody, which is what could be expected geologically. Typical ranges of influence are 60 m to 90 m down plunge, around 30 m perpendicular to the plunge, but in the plane of the orebody, and between 5 m to 11 m perpendicular to the plane of the orebody. Thus, the total zone of influence resembles an oval sardine tin, aligned with the layering in the deposit and pointing down plunge. It is also found that the nugget effect is the same in all directions.

Kriging subsystem

The generalized 3-dimensional Kriging system performs 3-dimensional ordinary kriging,[4] to estimate metal grades and specific gravity within a block. It has the ability to handle multiple homogeneous zones, i.e. different geological zones are treated separately.

The limits of mining blocks, alignment with the layering of the orebody and the density of drilling determine the dimensions and orientation of so-called 'krige' and 'classification' blocks. The dimensions of the former are 5 m x 5 m x 1 m to fit into classification blocks of 10 m x 10 m x 4 m. Thus, a classification block contains 16 krige blocks.

Within the system all the krige blocks within a classification block are estimated using the same sardine tin shaped neighbourhood of samples. This approach is not as rigorous as classic search strategies, but does have benefits in the amount of computer time used and little loss in accuracy of kriged values.

Once the kriging is completed, the results are archived to tape in a form that can be used to build ore models.

Ore model subsystem

The Ore Model system is a generalised storage and retrieval system for data, stored in 3-dimensional spatial form. It was designed as a general purpose utility, relatively independent of the source or type of data stored on it. In the case of Broken Hill the kriged grades are generated for a system of blocks aligned with the tilted orebody. The Ore Model system uses mathematical transformations to rework these data into a horizontal 3-dimensional block system aligned with mining blocks. An ore model for economic calculations has only to be built once because kriged data are based on grade information, independent of economic factors such as metal prices and cut-off.

'Portions' of the ore model, representing an area of the orebody, can easily be accessed in a form that can be used on the mainframe or downloaded to the mine for local processing.

Applications of the ore models

The ore models are used to enable the tonnage and grade to be estimated for various volumes of the orebody. However, owing to mining considerations, analysis is performed on mine blocks whose dimensions are 3 x 3 m on plan and 4 m in elevation. The results of the analysis can be used in day-to-day operations, in short-, medium- and long- term plans and schedules, or for ore reserve calculations.

Daily grade control

The Grade Control system was developed on the mine microcomputer to aid the grade controller in maintaining steady feed grade to the concentrator plant.

A particular lift outline is presented on the screen with the mine block outlines superimposed. The actual blocks can then be 'mined' and the grades calculated automatically. This new mined outline is then filed for use after the next mining shift. This procedure is carried out for all the stopes where kriged information is available.

The system enables management to monitor progress and alter mining sequences should the grades require it. It also gives the plant management an indication of the feed grades expected over the next few shifts, to enable blending of the ore if possible to achieve an optimum steady feed grade.

Monthly forecasting

Prior to the beginning of each month the exact mining position in each stope is known. A monthly forecast is compiled to determine, within practical considerations, what tonnage should be trammed from each stope in the ensuing month. This is achieved by obtaining the relevant mine block data from the ore models and performing average grade and tonnage calculations.

In addition to the information from the ore models, the plant requires data on the amount of oxidised ore, and the quantities of pyrrhotite and pyrite as these affect the flotation process.

This information is not available from the kriging, but is all in the database.

Ore reserve calculations

One of the important uses of the system is to determine the ore reserve at the relevant metal prices by utilising one of the facilities available from the Ore Model system. Section plots are produced with the Rand value of each borehole sample plotted - see Figure 3. From these it is a simple matter to determine the economic ore outlines using the relevant cost cut-off.

The outlines are then transformed into horizontal plans, digitised and superimposed onto ore models. The grade/tonnage parameters are extracted for each plan, summed and total reserves derived.

Production schedules

From the ore reserve parameters detailed production schedules can be produced. These take into account mining sequences, overall block reserves, feasible mining rates and other practical strictures. Eventually a life-of-mine schedule is produced using average mine block grades.

For day-to-day monitoring the ability of the ore models to generate character plots of different parameters is used for ore delineation. Thus, each block in a lift can be ascribed a certain character dependent upon, for instance, its Rand value at certain metal prices - see Figure 4. Should there be a major fluctuation in the metal prices, revised prices can be input and, using the cut-off cost as a division or contour, revised ore outlines can be generated. In this manner the sensitivity at any particular stage to fluctuations in metal price, or Rand/U.S.$ exchange rate can be monitored.

Production sampling

Prior to September 1984, sampling of mined ore was carried out. This entailed systematic grab sampling and assaying of broken ore. A double system was thus kept of calculated grades and assay sampled grades. It was found, however, that the calculated grades corresponded more consistently with 'actual' millfeed grades. The systematic sampling was thus discontinued once a sufficient history of comparative figures was available. Sampling is now only done if the Grade Controller feels that the calculated grades of an area do not correspond with the apparent observed ore.

In the case of copper grade, Figure 5 shows how calculated, sampled and millfeed grades have varied over the past five years. Notice how the calculated grade corresponds more consistently with the millfeed grade than the sampled grade. Between 1981 and 1984, large amounts of ore were mined from unkriged areas, which introduced bias in the grade calculations. However, since 1984 most of the ore has been mined from kriged areas, and the mine call factor has been consistently around 100% for all the metals mined.

General

The data contained in the ore models have also been used for research work, for instance, the distribution of metals within the orebody. This can be displayed as a character contour plot of any of the kriged parameters.

Conclusion

A flexible and, above all, practically beneficial, system has been set up on the Broken Hill Mine whereby the large amounts of data generated by underground diamond drilling are converted into usable models

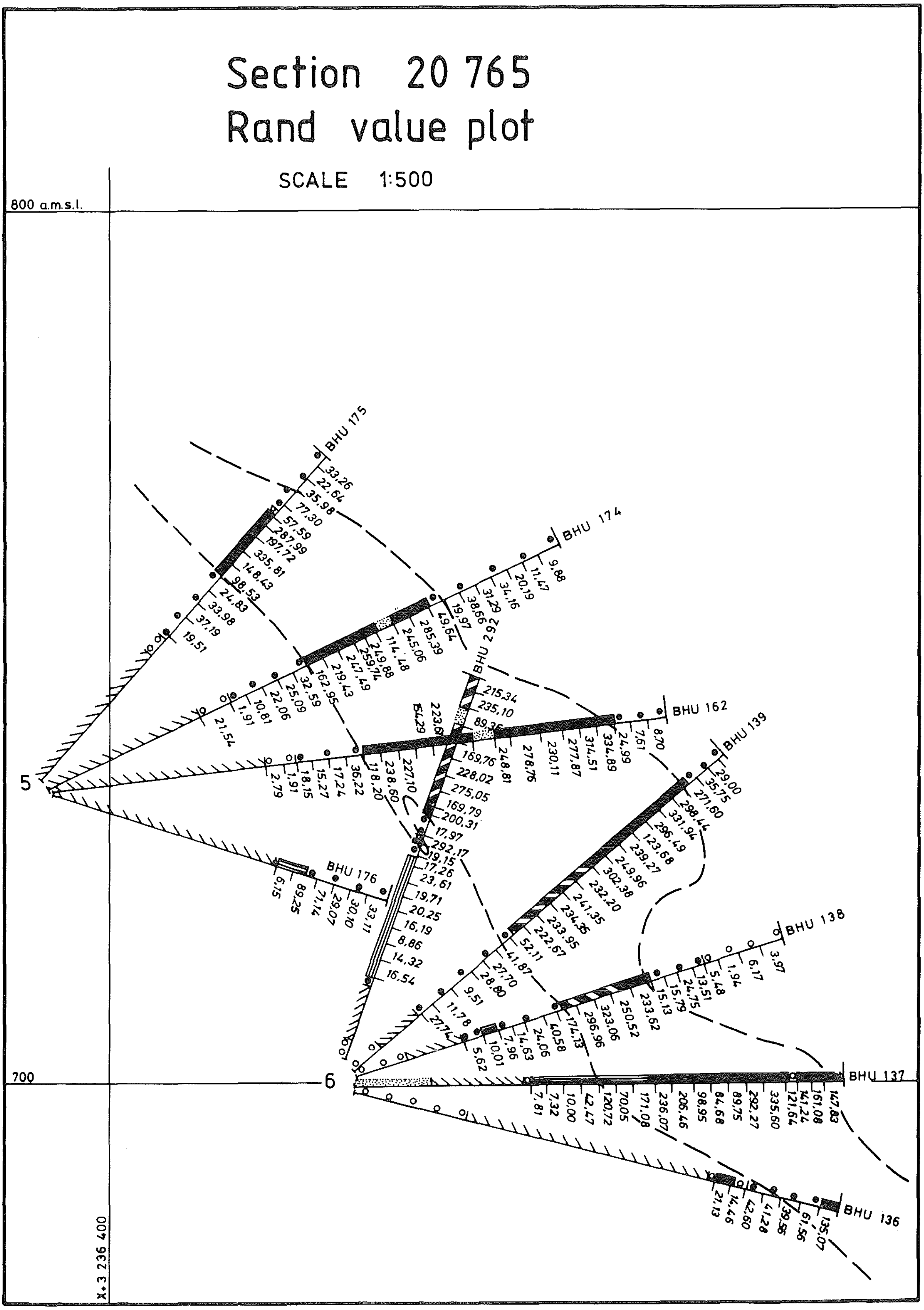

FIGURE 3.: Computer derived section showing Rand values and economic ore outlines

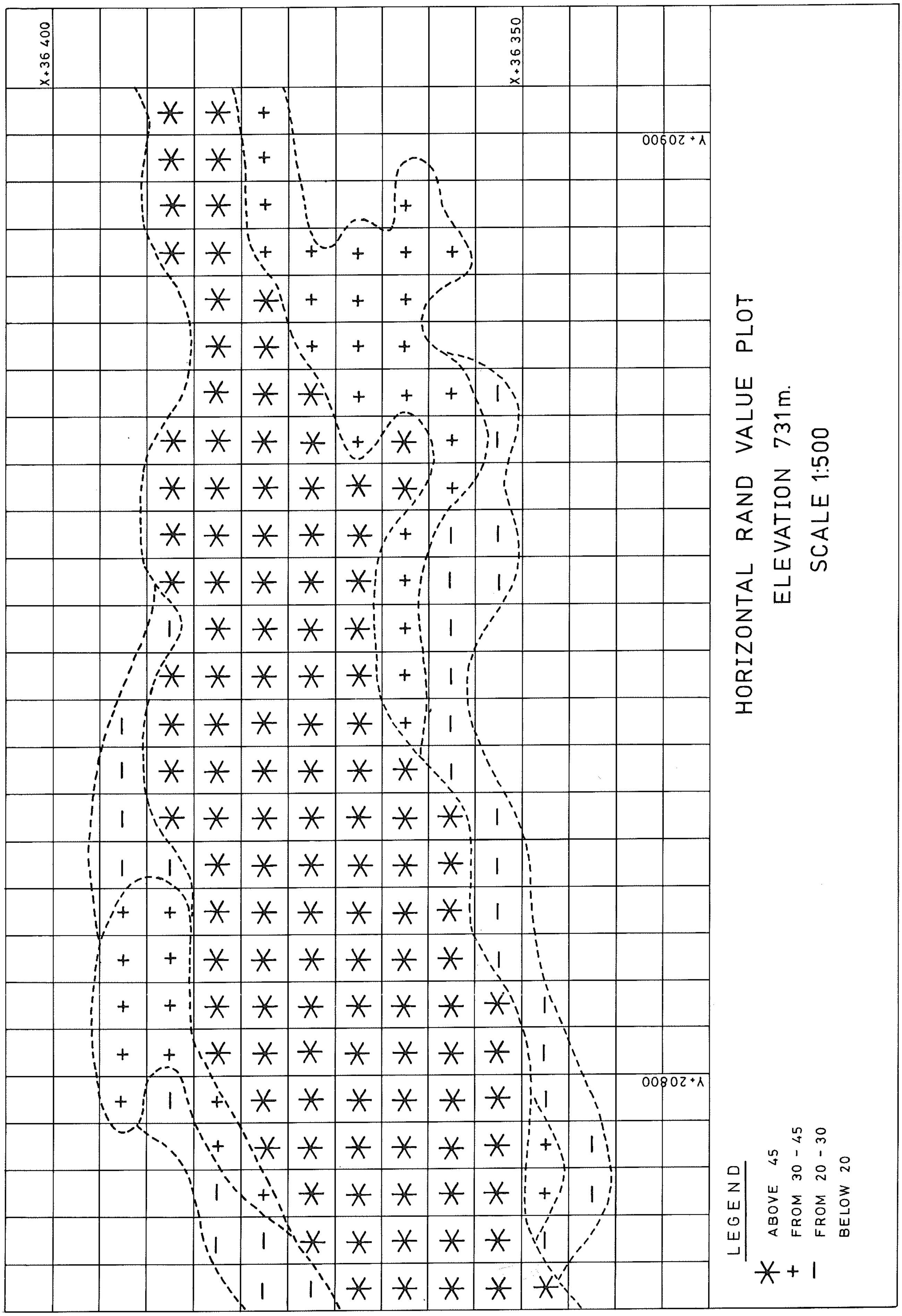

FIGURE 4. Rand value contour plot

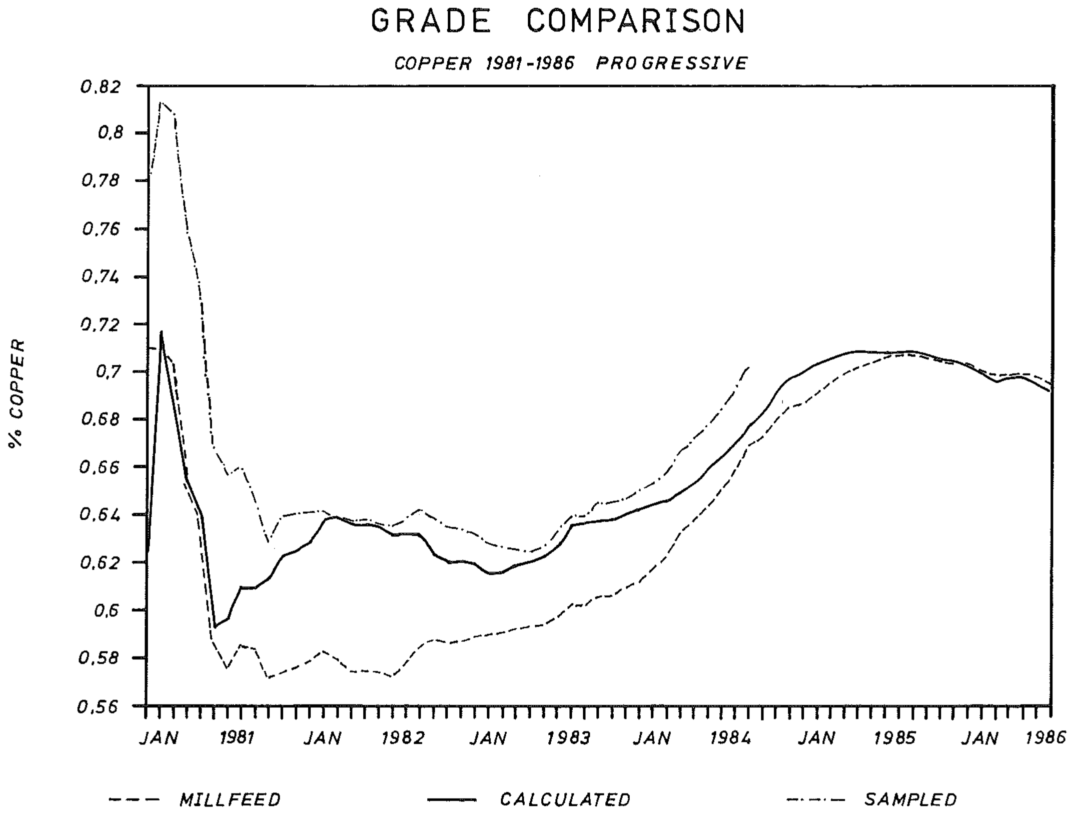

FIGURE 5. Comparison of millfeed, calculated and sampled copper grades

of the orebody.

This output is used daily for monitoring and scheduling in the short-, medium- and long- term, and for detailed mine planning.

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Appendix A: Three-dimensional model for metal grades

Typical experimental variograms in the 'horizontal' and 'vertical' planes are shown in Figures 6 and 7, respectively. The ranges of influence are denoted as a_x and a_y in the horizontal plane and a_z in the vertical plane. Notice the inherent anisotropy of the deposit as shown by the varying ranges of influence.

Let the distance between samples be denoted by h_x and h_y in the 'horizontal' plane and by h_z in the vertical plane. In the horizontal case the variogram model is given by:

$$\gamma(h_x,h_y) = C_o + C_1\gamma_1(\,|h_1|\,) \qquad , h_1>0$$

$$= 0 \qquad , h_1=0$$

$$\text{where } h_1 = \sqrt{h_x^2+\left[\frac{a_x\ h_y}{a_y}\right]^2}$$

and in the 'vertical' direction by

$$\gamma(h_z)= C_o + C_2\,\gamma_2(h_z) \qquad , h_z>0$$

$$= 0 \qquad , h_z=0$$

Transforming into isotropic space:

$$\delta^2 = h_x^2+\left[\frac{a_x\ h_y}{a_y}\right]^2+\left[\frac{a_x\ h_z}{a_z}\right]^2$$

In the following cases, the 3-D model must give;

Hor. $(h_z=0)$ $:\gamma(h_x,h_y)= Co + C_1\gamma_1(|\delta|), \delta>0$

Vert. $(h_x=h_y=0)$: $\gamma(h_z)= Co + C_2\gamma_2(h_z), h_z>0$

Therefore the 3-D model is given by

$$\gamma(h_x,h_y,h_z)=Co+C_1\gamma_1(|\delta|)+(C_2-C_1)\gamma_2(h_z), \delta>0$$

$$= 0 \qquad ,\delta=0$$

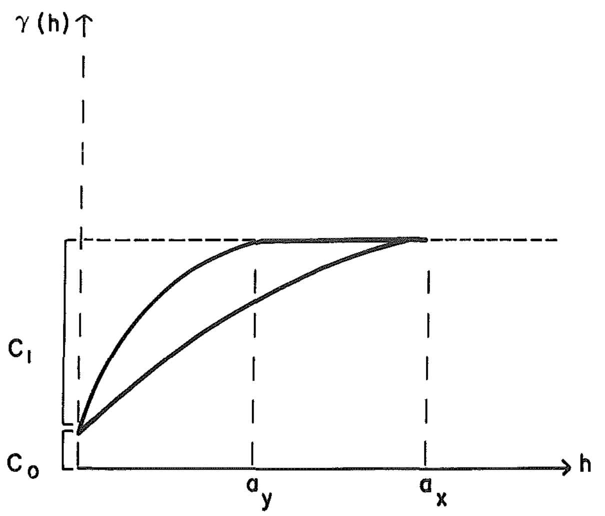

FIGURE 6. 'Horizontal' semivariogram for the Broken Hill orebody

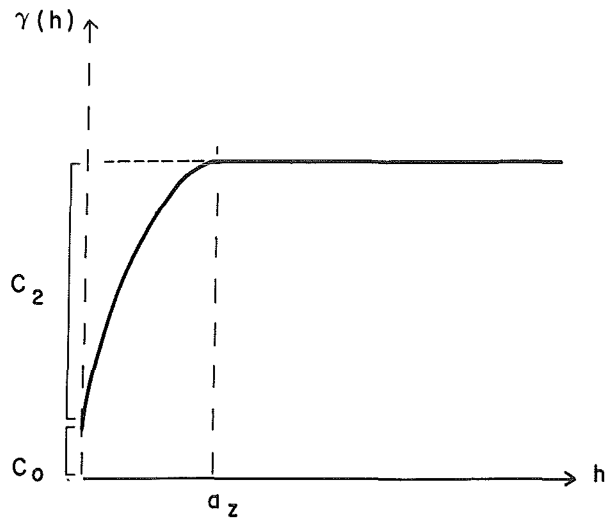

FIGURE 7. 'Vertical' semivariogram from the Broken Hill orebody