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OPEN PIT PLANNING WITH THE AID OF A COMPUTER DESIGN SYSTEM

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ABSTRACT

Computer techniques have become increasingly important in planning open pit mines. This article describes a computer system for the design of open pits to mine stratiform orebodies. The system incorporates a modified version of the Open Pit Design Program developed by Rio Tinto Zinc Consultants Ltd.

The particular requirements of such a system, for example, the accuracy of representation of geological detail and the ability to follow footwalls, are described in this paper together with the methods that have been adopted to satisfy them.

A description of how the computer design program was used to develop the medium and long term mining plans for the Nchanga Open Pit is included.

INTRODUCTION

Technological developments in the engineering field have had a significant effect on the economics of open pit mining. In recent years mineralised zones that would previously have been considered as uneconomical or as underground mining ventures only, have become amenable to open pitting. These orebodies are more marginal and the scale of operations is very large. It is therefore more essential than ever that the evaluation and planning of the operations should arrive at the best economic solution.

The very first aim in planning any open pit venture is the outline of the final pit design, since it forms the basis of all mining operations. Once this pit has been defined, then the intermediate pit designs can be incorporated within the frame work of the final pit. This is a long and tedious process due to all the parameters that have to be considered, such as metal prices, costs and slope angles. The work involved in planning a large orebody could take a planning engineer up to several months of calculations.

With the aid of computers, calculation time can be shortened considerably, thereby increasing the number of alternative designs that can be examined. However, it should be realised that a computer design system is only an aid to open pit planning, and that the final plans still have to be designed by hand.

With this in mind, it was decided to apply an Open Pit Design System to the stratified orebody of Nchanga Open Pit. This pit is the major producer of the five open pits currently being mined by the Chingola Division of N.C.C.M. Ltd.

THE GEOLOGY AND DESCRIPTION OF THE NCHANGA OPEN PIT

The copper orebodies exploited at the Chingola Division of N.C.C.M. Ltd. are contained within the pre-Cambrian sediments of the Lower Roan group of the Katanga system. These sediments overlie a basement complex of granites, quartzites and schists. The stratigraphic succession is shown in table 1. In general the ore mineralization is closely associated with synclinal fold structures. The main syncline is the Nchanga Syncline which is about 7 miles long and plunges westwards at about 15°. The orebodies which

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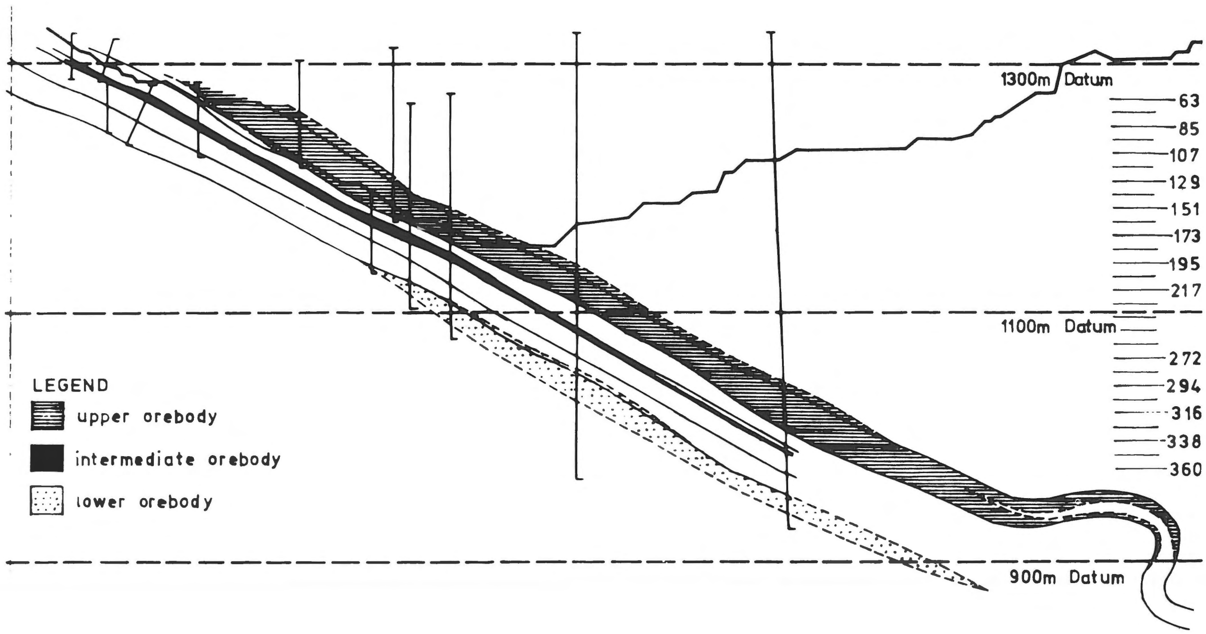

Fig. 1
Typical section through Nchanga Open Pit.

are mined in the Nchanga Open Pit (N.O.P.) lie in strata in the shallow dipping southern limb of this syncline (fig. 1). The general dip of this limb is 30°. Secondary folding does exist.

TABLE 1
Stratigraphic succession of principle ore bearing rocks at Chingola.

UPPER ROAN GROUP

LOWER ROAN GROUP
- Upper Banded Shale
- The Feldspathic Quartzite
- Band Sandstone (Upper)
- Pink Quartzite
- Shale Marker
- Banded Sandstone (Lower)
- Transition Quartzite
- Transition Sandstone
- Arkose
- Basal Conglomerate

PRE-KATANGA
- Basement

There are three orebodies which are treatable by current metallurgical methods, the Upper, Intermediate and Lower Orebodies.

The Upper Orebody is the major orebody in the area of the pit and the only one currently being mined by open pit methods. Host rocks are The Feldspathic Quartzite and the Lower part of the Upper Banded Shale. The orebody covers a strike length of some 4800 metres and extends down dip to about 450 metres below surface. The average thickness is about 30 metres, the average grade around 3.0% – 3.5% TCu and the acid soluble ratio about 55%.

The Intermediate Orebody has an average thickness of only 6 metres with an average grade of approximately 3.5% TCu and an acid soluble ratio of about 55%. The host rocks are the Pink Quartzite and the Shale Marker. Most of the orebody lies between 30 and 300 metres below surface and extends over a strike length of 1800 metres.

The host rocks for the Lower Orebody are the Lower Banded Shale, the Transition and the Arkose. The orebody has its sub-outcrop about 200 metres below surface and extends down dip to a depth of over 600 metres. In the area of the pit it averages

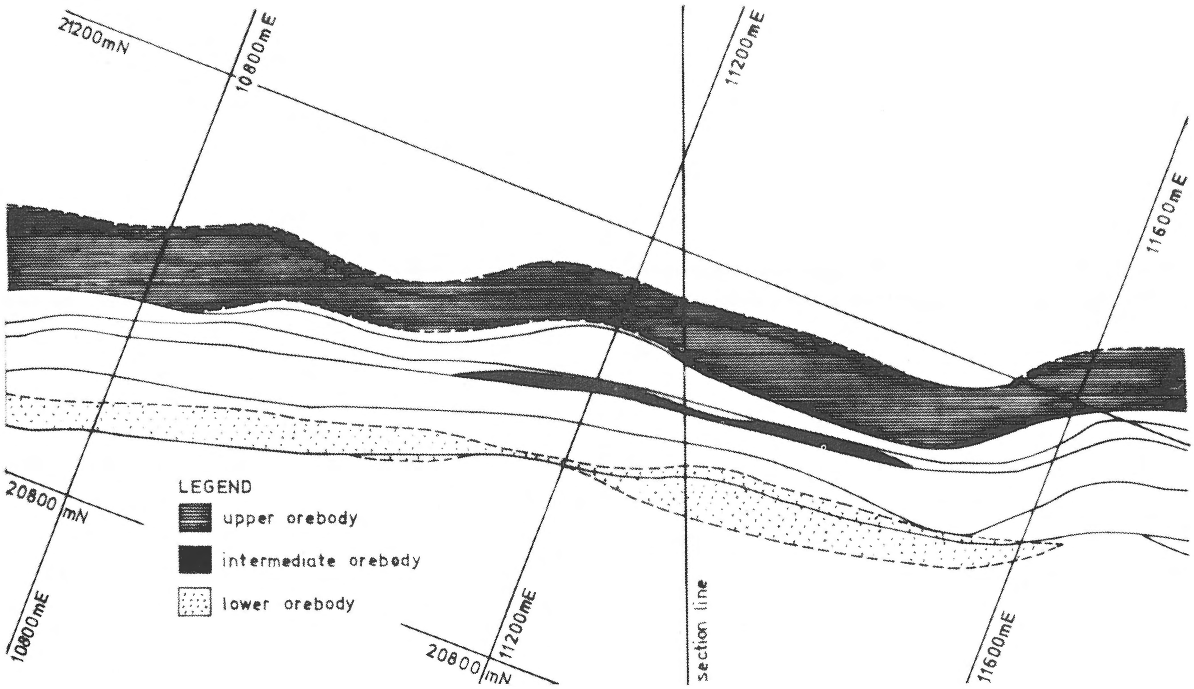

Fig. 2
Bench plan of the Nchanga Open Pit showing the three orebodies.

around 20 metres in thickness and 4% in total copper grade, 40% of which is acid soluble.

In terms of occurrence and economics it is possible to divide this complex of orebodies into three main parts, a Western, a Central and an Eastern section. In the Western section, with a strike length of some 1200 metres, the Upper Orebody extends from close to surface to its greatest depth. The reserves for this orebody are good both in volumes and grades from the upper to the lower cut-off. The Intermediate and the Lower Orebodies are also fully present. The overall stripping ratio in this section is relatively low.

In the Central section, with again about 1200 metres strike length, the Upper Orebody commences at a greater depth and does not extend as deep as in the Western section. The ore volumes are small in the up-dip section, but increase with depth and the overall grade is good. There is little Intermediate or Lower Orebody in this section. Both the overall stripping ratio and the pre-production stripping, i.e. the initial stripping which has to be done to expose the sub-outcrop of the orebody, are high in this area.

In the Eastern section, with around 2400 metres strike length, the Intermediate and Lower Orebodies do not exist at all. The Upper Orebody commences close to surface but does not extend to a depth of more than 200 metres. The ore tonnages are large but the average grade is lower than in the other areas. The overall stripping ratio again is relatively low.

The Banded Sandstones, which lie between the three ore deposits, carries copper values which are in some areas above 2% total copper. However, the mineralization is of a refractory nature, with the copper mainly present in the form of cupriferous mica and wad. This refractory ore is untreatable by current metallurgical processes. The same applies to the Mica Schist immediately overlying the Upper Orebody. When the refractory ore has to be extracted in the course of mining the Upper Orebody, it is then stockpiled for future possible treatment. The overburden, on the hanging wall side of the Upper Orebody, consists mainly of schists, dolomites and argillites.

After it was decided in 1955 to mine the Upper Orebody by open pit methods, the initial pit was planned and actually started in the Western section.

This decision was influenced mainly by the obvious economic advantages of a minimum of initial stripping, low mining ratios and good grades. Another reason was the fact that a pit in that area would be situated close to the existing underground mine, which could provide a good means of dewatering the area of the pit to a level below the final pit bottom. It would also result in shorter haul distances to the mill.

Since the commencement, the Nchanga Open Pit has been steadily increasing in strike and depth. The pit is at present about 3000 metres long and 1000 metres wide, and a depth of approximately 270 metres will be reached during 1972. The ore is mined by 4.6 m^3 shovels and 45 ton trucks at the rate of around 360,000 – 400,000 tonnes per month. Overburden and stockpile material is removed by 11.5 m^3 shovels, supplemented by 65 ton and 100 ton trucks at the rate of some 2 million bank m^3 per month. Soft material on the upper benches is removed by bucket wheel excavator and scraper in certain areas. The volumetric stripping ratio is currently 13 : 1.

PREPARATION OF THE MINERALIZATION INVENTORY

The Open Pit Design Program used at Nchanga is a modified version of that written by Rio Tinto Zinc Consultants. The program which is later described in more detail, requires that the orebodies and surrounding waste material be divided into a large number of small rectangular blocks, each identified by its co-ordinates and rock type.

This division into blocks is achieved by dividing the rock mass firstly into a series of levels or benches, at intervals such that the representation of the geology is sufficiently accurate. For each level a bench plan is drawn, showing lithological and assay contacts, at the mid-bench position. Each of these bench plans are then sub-divided into a large number of rectangles. As can be seen from the bench plan shown in fig. 2, to obtain a reasonable accurate representation of the fairly thin horizons, it is necessary to have a small rectangle (or block) size. In the case of the Nchanga Orebodies, a rectangular unit of 12 metres long and 6 metres wide with a bench height of 11 metres, was decided upon, even though a smaller block size would have been better. However, the chosen block size has already resulted in a total of 90,000 blocks per bench, and this number is rather large for most computers if, as in the case of the Open Pit Design Program, all data of one level is held in core at the same time.

Another problem, in terms of required computer space, is the great variation in grades, both in total and acid soluble copper, within the ore horizons. It was found necessary to assign a total and acid soluble copper grade to each individual block within the orebodies, although in practice a group of 4 contiguous blocks may have the same grades. Of course, this detailed information regarding grades is required for the ore blocks only, and the remainder of the matrix consists mainly of large areas of undifferentiated waste.

The preparation of the mineralization inventory falls into two parts. The generation of the rock matrix, and the assignment of grades to the blocks within the orebodies.

The basic information for the rock matrix generation is the bench plan. Each bench plan has to be converted into a form which can be handled by the computer. This is done by means of a "pencil follower", which is a high speed unit able to convert a line on a plan into a list of point co-ordinates punched onto computer cards. The D-Mac pencil follower used at Chingola consists of a reading table, an electronic console and a card punch. The plan is laid on the reading table, and the lines are traced with the "pencil". This pencil consists basically of a coil which is inductively coupled with a detector mechanism on a trolley under the reading surface. When the pencil is moved across the table, the trolley follows the pencil exactly by means of servo-amplifiers and servo-motors. The position of the trolley, and therefore of the pencil, is recorded by means of encoders attached to the servo systems and when required, communicated via the electronics console for output on the card punch. The output of pencil follower co-ordinates is transformed into real map co-ordinates using a special computer program. This transformation program takes into account a uni-directional stretching of the paper on which the bench plans are printed.

The method that has been adopted at Chingola for coding the rock matrix is as follows:

First the bench plans are coded. This coding is done by specifying a list of rock types to be coded and assigning a rock type number to each member of this list. Once the list of rock types has been specified, each rock type area on the bench plan is then identified by its rock type number. If there is more than one area of a given rock type, those areas are then suffixed, so that each area has a unique identifier.

After the bench plans have been coded, each of the separate rock areas are pencil followed as closed polygons. The blocks contained in the polygon are coded with the relevant rock type number and then written into the matrix, overwriting whatever else was stored. By maintaining a certain sequence for the input of rock type areas and by utilising the overwriting facility, it is possible to reduce the pencil following to a minimum, with each contact having to be input accurately only once. If a bench plan is too large to fit on the pencil follower table, then the plan is divided into two or more parts, which are pencil followed separately, and then merged again into one plan.

To ensure that no major mistakes are made during the pencil following procedure, the transformed data is plotted again, using a Calcomp plotter, and checked against the original bench plans.

A proper assignment of grades to blocks within stratiform orebodies is not an easy problem to solve. In the case of the Nchanga orebodies interpolation of grades, geological and mineralogical trends have to be considered. A simple weighting and interpolation method between surrounding boreholes, which is quite often successfully used for massive type orebodies, is completely inadequate. Probably the best method to be used here would be to divide each individual borehole intersection into an equal number of slices and have for each slice a grade interpolation procedure, including directional and distance weighting, which conforms with the trends. However, the development of such a computer program is considered to be time consuming and an easier but still reasonable method was decided upon instead. This method is by grade contouring using a computer contouring package. For each orebody, the average grade of the borehole intersection between assay hanging wall and assay footwall is contoured for total and acid soluble copper grades. The contouring package calculates the grade values for each point of its interpolation grid. Each of these grid points is then taken to have a "zone of influence", i.e. each ore-block will get the grade of the grid point nearest to it. The grade contours are drawn on a plotter as a visual check on the grade data generated (fig. 3). If the grade data is not acceptable, dummy hole values are added to the input data and the interpolation grid is re-calculated. This procedure is repeated until the grade contours are accepted.

After the rock matrix and the grade have been generated, the data is "packed" into a more compact form to save computer space. These packed matrices are then stored on magnetic tape for use by the Open Pit Design Program. It was found by experience that it is essential to check what actually went on the computer and what is finally stored after the generation and packing programs. All Open Pit Design results have to be trusted as being fairly accurate and therefore the mineralization inventory can not be allowed to contain any important errors. A special program for checking the inventory file was written, which produces three types of output. First, the rock and grade matrices are displayed on a line printer, having a different alphameric code for each rock type or range of grades. This is a fairly coarse check and enables major errors, like the omission of a rock type area, to be easily spotted. The second output is a plot of the rock matrix in the same way and to the same scale as the original bench plans. This permits a detailed assessment of the accuracy of representation of the geology by the inventory file. The third sub-routine of the checking program calculates and prints the reserves for all orebodies in the same form as the current manually produced ore reserves. This form of presentation shows the tonnage and grade of the ore for each section on every bench. In general the computer and manual ore reserves for N.O.P. compared quite well, with differences of less than 2% overall for both tonnage and grade. After the checking of the data, a correction program makes the required amendments and creates a new inventory file.

THE OPEN PIT DESIGN PROGRAM

The original RTZC Open Pit Design Program was mainly developed and used for the evaluation of massive deposits. A detailed description of this program has been published by Fairfield and

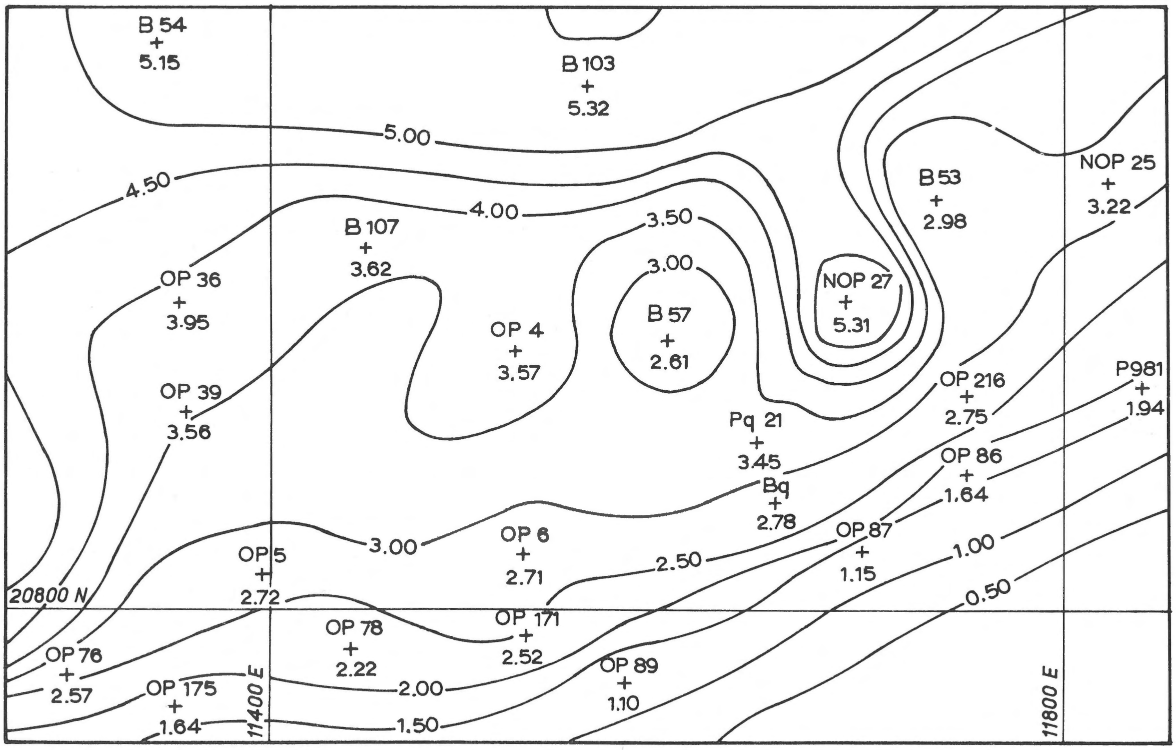

Fig. 3
Portion of an Upper Orebody total copper grade contour plan.

L e i g h (1969). To enable the program to be used on stratiform orebodies like N.O.P., it had to be modified, and this modification was done by RTZC. The major modifications made were the incorporation of the packed matrix concept, the assignment of grades to individual blocks and routines to enable the pit to follow specified footwalls in given areas. The program is, however, still able to handle massive orebodies and to assign uniform grades to individual rock types.

The input data required to run the program is first of all a base perimeter from which to generate the pit, and secondly, a set of features for each rock type, such as the slope angle, the density and the mining costs. The base perimeter is drawn by the designer and then converted to a series of co-ordinated points, either by manual coding the points or by pencil following the perimeter.

With this input the program generates a pit from the base perimeter upwards, bench by bench, until the surface is reached. At every level the perimeter is projected outwards and upwards to the next level, under the relevant slope angle or footwall following controls. When the new perimeter on the next level has thus been generated, two checks are made on this perimeter and adjustments carried out if necessary. First, the perimeter chords are checked to ensure that the chord length is maintained within a specified range; and next the angle between adjacent chords is checked in order to eleminate sharp angles and to avoid the possibility of projected end points crossing over, as in the case of re-entrant angles. The adjusted perimeter then becomes the new base from which the next bench perimeters are generated until the surface is reached.

The footwall following facility is an important feature in designing pits for mining stratiform orebodies. This facility enables the design to follow up a specified lithological or assay contact when the angle of dip is less than the safe slope angle. For instance, in N.O.P. the safe slope angle for the ore types is about 45°, while the angle of dip of the horizons varies around 30°. When a pit is generated up at a 45° slope angle for the ore and without footwall following, quite an amount of ore is going to be left out of

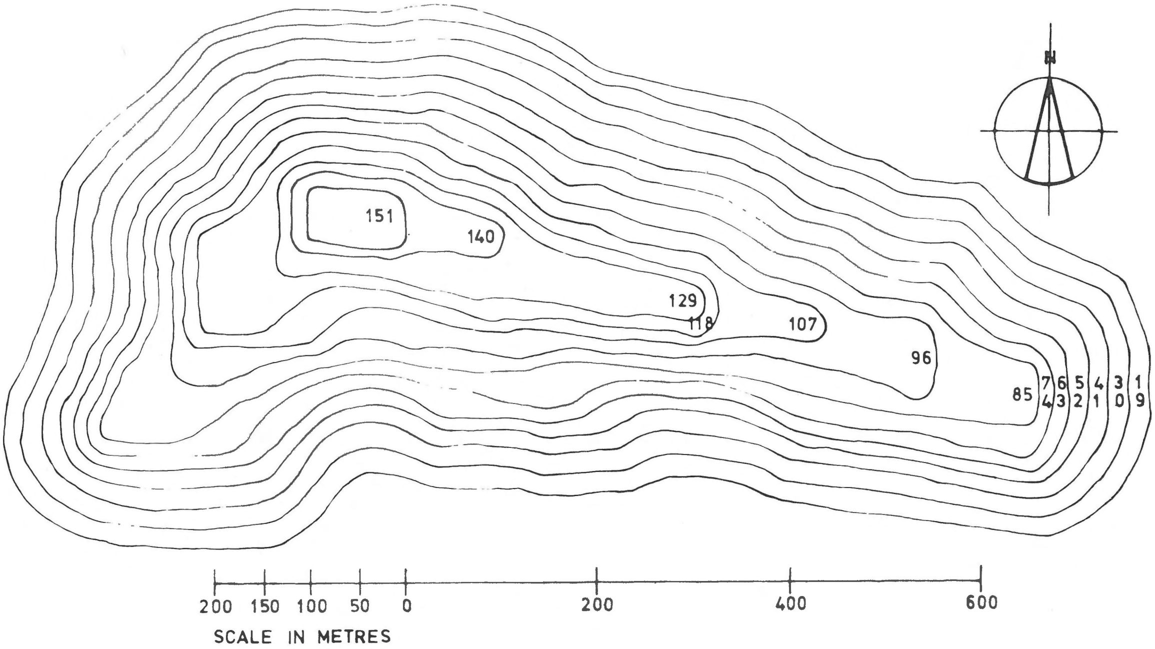

Fig. 4
Example of computer designed pit, showing footwall following on south side, and stepping out along strike.

the pit, and the overall result would be a meaningless design. It is often required that the strike length of ore to be exposed on a bench is longer than for the bench immediately below it. To emulate such a type of design with a computer program, the bench perimeter must be able to step out along strike within a given rock type to a specified limit.

The footwall following is done at each mid-bench, when every perimeter point is checked to see if it is within the user specified area for that bench and also within one of the set of specified rock types. If it is, then the perimeter point is projected outwards up to a given distance. The process is repeated until either the rock type boundary or the specified limit has been reached. The method works very satisfactorily, producing pit perimeters that follow the desired contacts within the discrimination allowed by the blocks, as can be seen in fig. 4.

For every perimeter generated the program calculates the volume, tonnage and grade of each of the rock types and then the total volume, tonnage and grade of ore, total volume and tonnage of waste, the volumetric stripping ratio and the mining cost. Finally, at the completion of the program the same calculations are done for the total pit.

A major use of the system is the designing of medium and long range plans for mining the orebodies, which means that quite often a sequence of pit extensions have to be evaluated. In these cases the computer creates a new inventory file after each pit generation, by changing the "mined out" blocks into air.

In addition to the printed results, it is desirable for the design engineer to be able to see a plan of the total pit resulting from the initial pit, combined with the extensions. The plotting routine developed for use with the program allows him to specify which combinations of pits, from a set of runs, he wishes to see combined and plotted together as composite pits. A general flow chart of the Mineralization Inventory Generation and Open Pit Design System is shown in fig. 5.

One of the major considerations during the development of the system has been that it should be easily useable by planning engineers who are unfamiliar with computers, with minimal involvement

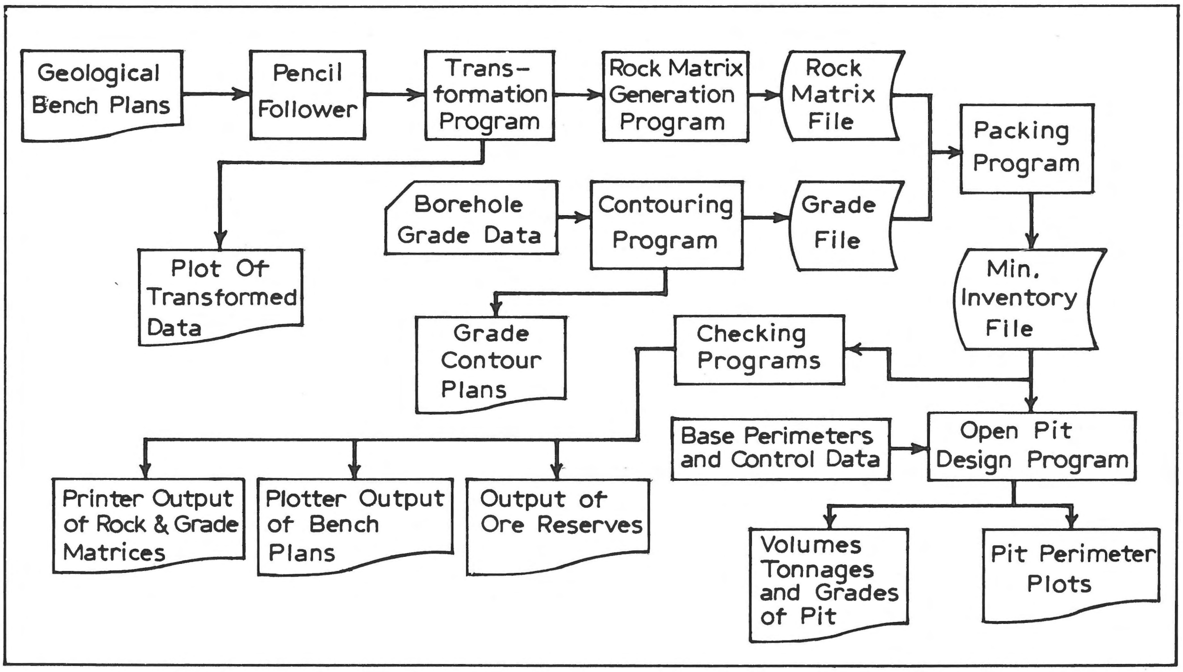

Fig. 5
Flowchart of Mineralization Inventory Generation and Open Pit Design System.

of computer personnel. While the generation of the mineralization inventory file requires programmer assistance, the pencil following and the design of pits are handled routinely by the pit planning department.

USES OF THE SYSTEM

The use of the Open Pit Design Program for the planning of N.O.P. can be divided into three phases:

1) the determination of the depth and limits of the final pit.
2) the determination of the best sequence of mining within the final pit.
3) the establishment of the short term mining programme.

Before describing these phases in more detail, it is worth noting some of the constraints on the planning of the Nchanga Open Pit as it is now.

One of the major constraints is the fact that in the near future underground workings will expand eastwards and will eventually be under the western end of the pit. This necessitates the removal of as much ore as possible from that area of the pit before it is affected by cave cracks. It also requires the mining of a sump in a safe area on a level below this mined out part. Because of this, during the last few years the pit has been deepened, mainly in the western end of the pit, while being extended eastwards along strike.

Two other important constraints, i.e. production rates and cut-off grade, were taken into account when using this system for planning Nchanga Open Pit.

It was decided not to vary the annual ore production rate, since the effect of variations in this tonnage on the total profitability would be meaningless without considering at the same time changes in the mining rates of other operations both at Chingola and other Divisions of N.C.C.M. Ltd. The cut-off grade was kept at 1.5% TCu. In N.O.P. this grade is more or less the "natural" cut-off grade, since very little treatable material with grades below 1.5% TCu is available.

DETERMINATION OF THE FINAL PIT

The main objective of designing a final pit is to establish the total economical mineable reserve, together with the associated overall stripping ratio. Another purpose is the determination of the final pit rim which is required for the location of dumps and surface workings, such as workshops, offices, roads and power lines. Unfortunately, the determination of a once and for all final pit is virtually an impossible task for a pit like N.O.P. where the economic pit bottom is not likely to conform with down dip cut-off of the ore. First of all, the information required is never as sufficiently detailed as one would desire, and also liable to changes as new geological interpretations become available. The decision is also dependent upon factors such as metal prices, operating costs and slope angles, whose values are subject to considerable future uncertainty. Since the start of operations the final depth of the Nchanga Open Pit has been worked out several times, each time resulting in a deeper ultimate pit. One of the objectives of repeating this exercise, with the aid of the Open Pit Design Program, was to review the previous results in the light of more available geological information, changed equipment characteristics, changed costs and a better knowledge of the various slope angles. Obviously it is now possible to evaluate the orebodies in far more detail than previously, with the conventional manual methods.

The procedure adopted was to determine first one overall pit design which is economically feasible. To this overall pit, small extensions were added both in depth and along strike. For each extension the revenue, total costs (including the incremental cost with depth) and profit or loss were calculated. In the case of a profit another extension was added, and so on, until the break-even point was reached. In this exercise no time element was considered. The total procedure was repeated a number of times for different copper prices, costs and slope angles, resulting in a range of possible final pits.

MINING SEQUENCE WITHIN THE FINAL PIT

The medium term planning of a pit has to be done within the frame work of an overall sequence of mining, which leads to the final pit and generates the most advantageous cash flow patterns. However, the planning of the pit to maximise an economic criterion such as net present value can sometimes conflict with the requirements for efficient operation. Quite often a compromise between the "optimal" sequence and practical plans is necessary.

In mining stratiform orebodies with high instantaneous stripping ratios, large earth moving equipment has to be used for the overburden removal and therefore large benches, resulting in good equipment efficiencies and a minimum of shovel moves, are required. It should also be possible to have shovels evenly spread over the total pit to obtain equal travelling times throughout the years. Haul roads should be wide and with a minimum of sharp bends, etc. The result of this is pit designs which tend to overstrip and do not necessarily mine the most profitable areas first.

On the other hand, a policy of maximising discounted profits will result in mining all high grade or low stripping areas during the early stages. This may lead to undesirable designs or rapidly changing stripping ratios during a certain period or even during the total pit life. Also for orebodies with large variations in depth and specifically in grade, it may be more profitable to commence extracting the orebody by a number of small pits rather than one large pit, although the opposite may be much more desirable for a variety of other reasons. In scheduling the mining of the Nchanga orebodies, it was felt that the stripping ratio should stay within a certain range of values for at least a number of years before any substantial increase in stripping would be allowed.

A major use of the Open Pit Design Program to-date has been to establish the varying patterns of cash flows which result from different sequences of mining the Nchanga orebodies. Rather than try to find the best sequence of annual plans, which would involve a very large number of permutations, the approach was to derive at the best sequence of, say, five yearly mining programmes, each programme being mineable as an independent and separate unit. These intermediate pits were all designed with the pit slopes, as for the final pit, at the maximum safe angles, since the cash flows from the different sequences are comparative rather than true economic evaluations of each separate intermediate pit.

The amount of work involved in developing these alternative sequences of mining, although not inconsiderable, is only a fraction of the effort which would have been required if no computer program had been available.

SHORT TERM MINING PLANS

The use of an Open Pit Design Program for short term planning is rather limited. The plans for the next one or two year operations are more heavily constrained than the medium and long range plans and not all constraints can be taken into account when designing a pit by computer. Detailed scheduling of equipment and production becomes important in the evaluation of a design and this can only be done in a proper way from a manually drawn pit, which shows the ramp systems and location of dumps which are going to be used.

The computer can still be of great use by assisting in the examination of many alternative pits in a short period of time. Various comparative test runs have been made to establish the relationship, for the different hanging wall rock types, between the working slope angles including ramps and the maximum safe angles, as a function of pit length and depth. By comparing volumes of manually designed pits with computer simulated designs, it has been found that a sufficiently accurate allowance can be made for ramps if the slope angles are decreased by between 2 and 10 degrees, depending on the ramp system envisaged.

When the computer has generated a series of possible pits, then the most satisfactory plans are drawn up manually and evaluated in more detail. The bench perimeters of the manual plan can be accepted by the Open Pit Design Program instead of perimeters it has generated itself, and thus the planning engineer is able to obtain the volumes, tonnages and grades excavated in this pit extension, and also generate a new inventory file as it would be at that stage of mining.

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