Unrolling of Copperbelt Orebodies

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SYNOPSIS

The ore deposits of the Zambian Copperbelt occur in sedimentary strata that have been subjected to relatively mild, flexure-type folding. *Unrolling* serves to reconstruct the original depositional geometry of the folded sedimentary strata and is in common usage on the Copperbelt both for geological analysis of drill hole data and in routine ore reserve estimation.

A computerized method of unrolling was introduced at Roan Consolidated Mines in 1969 based on a standard contouring program. A contour map of the geological structure is drawn from a regular grid of elevations, interpolated from the original, irregularly-spaced intersections. Unrolling is performed across this grid, perpendicular to one or two axes specified by the geologist. Each intersection is unrolled independently, and the new co-ordinates are subsequently processed to produce unrolled maps.

The technique has been used successfully at RCM over the last two years in both the estimation of ore reserves and exploration planning.

INTRODUCTION

The *unrolled plan* or *palinspastic base map* was designed by Kay (1954) as a means for reconstructing original pre-tectonic conditions in areas of marked crustal shortening. Such crustal shortening occurred in the Copperbelt region during the Lufilian orogeny that succeeded the deposition of the sediments of the Katanga sequence. The lower portion of this sequence, the Lower Roan group, is of particular interest because virtually all the economically important copper ore deposits of the region occur within this group.

Stratigraphic marker horizons are commonly present in the Lower Roan throughout the Copperbelt, and much of the crustal shortening has been taken up in the form of simple, flexure-type folding. In these circumstances, unrolled plan construction becomes feasible and, in fact, unrolled plans are in common usage, both in the geological analysis of drillhole data and as a base for ore reserve estimation.

Conventional unrolling by hand is carried out either from structural sections or from a structure contour map of the particular marker horizon to be unrolled. In both cases, the objective is to reconstruct the original relative position of selected control points, for example, drillhole intersection points. It is assumed that the marker horizon formed a horizontal plane in its pre-tectonic state, and that the unrolling reproduces this plane.

The use of computerized methods arose as part of a research project on evaluating ore reserve techniques. The program, see Appendix A, was written in 1969 to give more objective results and speed work on the project. It has subsequently been used operationally both in exploration and for ore reserves, and is fully documented by Annels, *et al* (1970).

UNROLLING PROCEDURE

The basic information required to perform unrolling on a computer is a machine-processable description of the underlying structural surface. In the cases studied in this paper a regular grid of elevation values was used. This arises automatically when using computerized contouring methods. The first stage of contouring a structure map comprises reading in the co-ordinates and structure slopes at each drill hole intersection, then interpolating from these irregularly-spaced values to produce a regular grid of elevations. The interpolation procedure used depends on the particular contouring package and the options chosen, see Appendix A. The production of a contour map follows as a process of calculating and drawing the required smoothed contours across this grid. The choice of the grid size obviously affects the detail of the map produced and the subsequent accuracy of unrolling. The grid can be retained and used as the basis for unrolling once the contour map produced from it has been verified by the geologist.

In addition to using recorded intersection points and slopes, the geologist can include interpretive values to incorporate additional information into the structure map. Having verified the map, the geologist will specify two axes for unrolling, generally the geological fold axes. Each of the original intersection points will then be unrolled independently across the structure grid. The unrolling will be performed perpendicular to each axis as shown in Fig. 1 for an intersection point P.

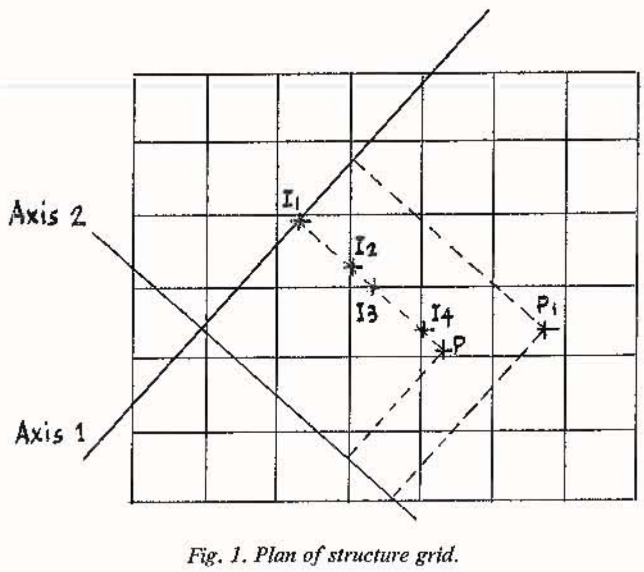

Fig. 1. Plan of structure grid.

A perpendicular from P to axis 1 is drawn. The intersection points of this line with axis 1 and the grid lines are then evaluated (I1, I2, I3, I4) and elevations at these points calculated from the known values at each grid corner.

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The distance d1, across the section I1, I2, I3, I4, P is then calculated based on straight line segments as shown in Fig. 2.

The same evaluation is done for the second axis (distance d2). The point P is then unrolled to the position P′ perpendicular distances d1 and d2, respectively, from each axis. The original data values for the point P are then recorded with the new co-ordinates of P′ and the process repeated for subsequent points. These unrolled points can then be contoured to give unrolled maps of the values recorded, for example, of percentage copper. Ore reserves can also be calculated from the unrolled values by any of a number of conventional planar methods.

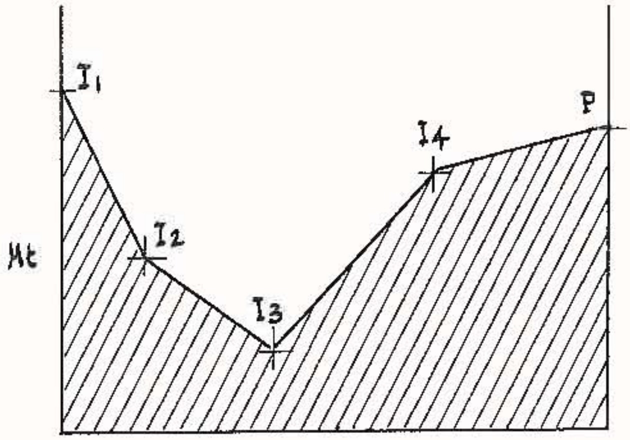

Fig. 2. Section through I1 P.

APPLICATIONS

Palinspastic base maps are inevitably subjective. Whereas the subjectivity introduced by an experienced geologist might often add to the value of the manually unrolled plan, there are circumstances in which a less sophisticated, but unbiased and reproducible unrolling procedure would be preferred.

This is generally the case when the unrolled plan is to serve as the basis for ore reserve estimation. Estimates of ore volume and tonnage are sensitive to errors in the area calculations. It is essential in this work to ensure that the estimates are objective, reproducible and conservative rather than optimistic.

ORE RESERVE ESTIMATION

The present system was developed as a side-line to a research project on different methods of ore reserve estimation and their performance in a typical Copperbelt situation. For the purpose of the ore reserve study, computer programs were established that performed the necessary calculations with great accuracy and according to the strictly defined rules of each method. A manually unrolled plan was used as the geometrical basis for these experimental ore reserve calculations. The introduction of computerized methods for the actual ore reserve calculations served to expose the unrolling procedure as a subjective, time-consuming, and error-prone stage in the otherwise well-defined progression from prime drill hole data to final ore reserve estimates.

The area serving as testing ground for the ore reserve project was the Muliashi South area of the Roan Antelope deposit at Luanshya. A computer-produced structure contour map of the RL6/RL7 marker horizon at Muliashi South is shown in Fig. 3. Very little modification was required to the first structure contour map produced by the computer. This was due mainly to the exceptionally high drill hole density in this particular area.

The manual unrolling had been based on structural sections oriented North-South, a horizontal fold axis in the East-West direction being assumed. Inspection of the structure contour map of Fig. 3 will show the deformation in the area to be explained more satisfactorily by assuming two axes of folding, the directions marked Axis A and Axis B in Fig. 3.

In applying the computer unrolling procedure to the Muliashi South area, this two-axes case was investigated along with a one-axis unrolling, using the same axis as was used for the manual unrolling. Plotting the control point positions resulting from the three different unrolling processes verified that all three results were in close agreement over the major central portion of the area, the points produced by two-axes computer unrolling tending to separate from the pair of one-axis points in the peripheral parts of the map area.

The effects of the different unrolling procedures on the ore reserve estimates are shown in Table I. The estimates relate to a stratiform orebody situated within the map area. A computerized version of the conventional 'Triangle' method of ore reserve estimation was used.

TABLE I

MULIASHI TARGET OREBODY

Ore reserve estimates by computerized 'Triangle' method. Program parameters common to all three cases.

	Area	Tonnage	Grade
Comp.-unrolled/2 axes	5 044 429	11 875 302	2.529
Comp.-unrolled/1 axis	4 873 198	11 380 275	2.526
Manual unrolling	4 945 433	11 594 035	2.525

Both cases of computer unrolling yield results that are within about two per cent of the estimates obtained by manual unrolling. As expected, one-axis computer unrolling proved more conservative than the manual unrolling. Two-axes computer unrolling produced the largest orebody area, two per cent larger than that by the manually unrolled plan. Geological reasoning would seem to give preference to the two-axes unrolling as providing the most realistic unrolled geometry.

The results from this exercise indicated that computer unrolling might replace the manual unrolling procedure for the purposes of ore reserve estimation. The system has been applied subsequently to a number of RCM orebodies and exploration targets. In areas with relatively simple structure, such as the main orebody at Chibuluma, the system has been found to perform very satisfactorily. It is now being used on a regular basis for updating and revision of their Class III ore reserves. Attempts have also been made to apply the system to areas of a more complex structure, for example, the underground extension at Chambishi. This has proved less successful, the main difficulty being to establish a satisfactory structure contour map that may serve as basis for the unrolling program.

EXPLORATION

Development of the computer unrolling system was also motivated by the data processing requirements of the RCM Prospecting Department. Unrolling is often used in the interpretation of geological observations from exploration drill holes. As updating and re-interpretation are required frequently between the completion of one drillhole and the positioning of the next, an efficient computer system for unrolling and contour map plotting would offer great advantages in this field.

This system was first applied as an experiment to an exploration area in the Ndola region of the Copperbelt. In this area, copper-bearing quartzites occur in a predominantly arenaceous succession of Lower Roan sediments. Diamond drilling had indicated considerable relief in the pre-Katangan Basement topography, with corresponding local variation in the thickness of the Lower Roan sediments that fill up the valleys and depressions of the old Basement surface. All significant relief had probably vanished by the end of the Lower Roan time, and the distinct boundary between the arenaceous Lower Roan and the dolomites of the Upper Roan may reasonably be assumed to have represented a horizontal plane prior to the Lufilian orogeny.

By constructing a structure contour map of the now-folded Upper Roan/Lower Roan contact and using this as a basis for unrolling, the original basement topography could be reconstructed in the form of an unrolled isopachyte map of Lower Roan thickness. A geological analysis of this kind was pertinent in the present case, because important relationships between occurrence of economic mineralization and thickness of the Lower Roan sediments had been established for this particular area.

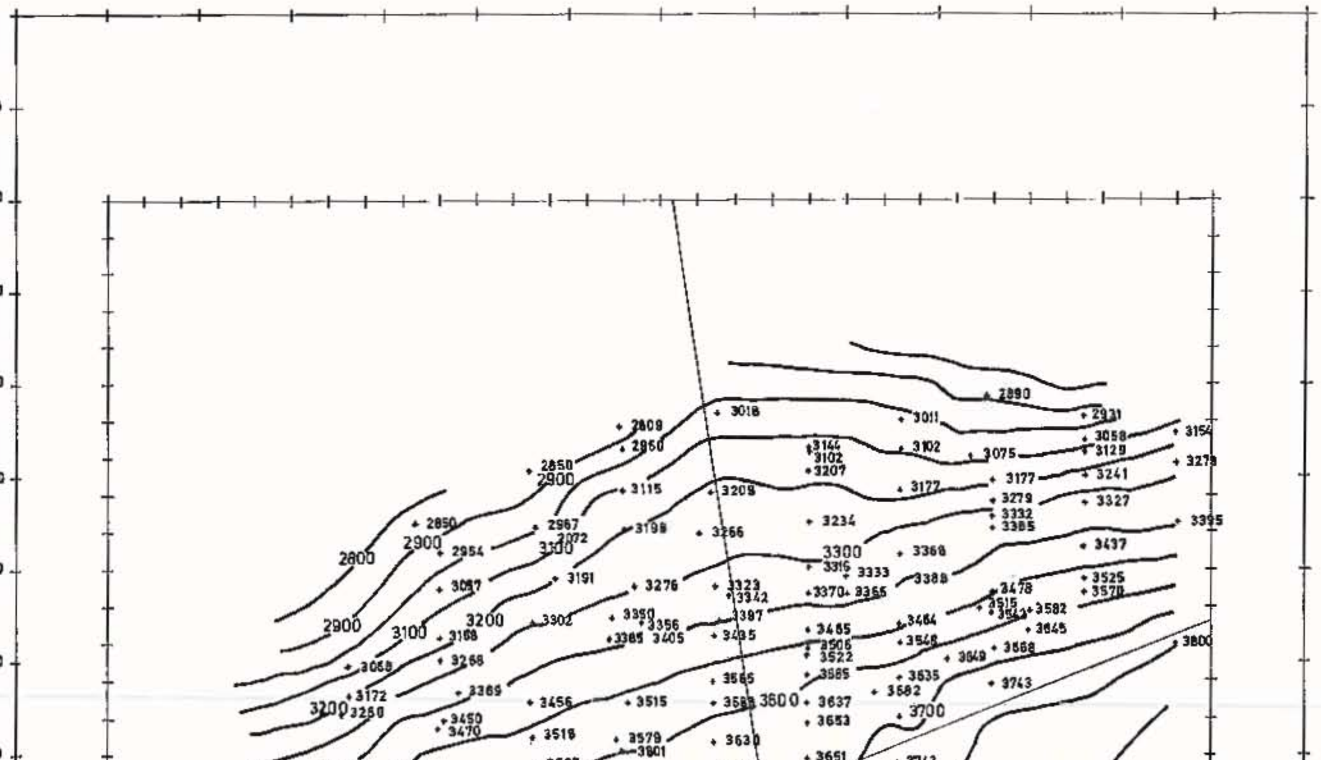

Fig. 3. Structure contour map of the RL6/RL7 contact, Muliashi South.

Using the computer system, a satisfactory structure contour map was established already on the second run of the contouring program. The geologist then specified the axes of unrolling and the variables to be plotted out as unrolled maps. The requested plots were prepared by the computer/graph-plotter in a matter of hours. The computer-produced unrolled maps were found to be of considerable value in the continued exploration of the area and several re-runs were subsequently carried out in order to up-date the maps with the latest drill hole information. The system has also been applied successfully to other exploration areas.

EFFECTS AND CONSTRAINTS OF THE SYSTEM

The use of a straight line segment approximation to the distance across section is necessarily an underestimate. This could be improved by fitting a curve to the intersected points, but in practice reducing the grid size gives the same results. The grid size recommended to give a satisfactory structure contour map proved, on grid reduction, to give unrolled values which could not be extended significantly. The tendency to underestimate lends itself to the natural conservatism inherent in ore reserve estimation.

The present unrolling program recognizes pure flexure folding only as the mechanism responsible for deformation. If applied to areas dominated by slip (shear) folding or plastic flow folding, this program will, therefore, produce distortions, though this might not prove serious and an unrolled map could still be useful for many purposes. Faults and other discontinuities must be identified and corrected for before unrolling by computer. By the nature of the structure grid, overfolding can be neither represented nor handled. Simple cases of overfolding can be dealt with by manually re-shaping the overfold structure into a valley-form structure of identical size prior to computer processing.

The present program unrolls at right angles to the given axes. It would require little modification to handle any angle, though the geological validity of this is questionable. Unrolling across a single axis can be specified by a parameter to the program. Extension of the unrolling procedure to more than two axes is unrealistic without revising the structure map at an intermediate stage. Even in the two-axes case, slight inaccuracies are introduced when the axes are not perpendicular, though this is not significant in practice.

This system necessarily produces an objective and reproducible method of unrolling while incorporating the experience of the geologist in establishing the structure map and defining the axes of unrolling. It also saves considerable effort and possibility of errors on the part of the geologist, and, once established, reduces the time to get results. When additional drill hole values become available these often will not affect significantly the structure maps and can be unrolled directly with the original grid. New unrolled maps and ore reserve estimates can be obtained quickly to aid management decisions and exploration plans.

POSSIBLE EXTENSION TO THE SYSTEM

While the unrolled plan provides useful information for the geologist and enables a total ore reserve estimate to be made, it does not aid the mining engineer directly. He requires the ore tonnage and average grade estimate broken down by mining block. This can probably be achieved best by superimposing on the unrolled plan the reference boundaries for the mining blocks, for example, levels, sections, etc. Integrating between these curves will then give the required block values. Since the original values (elevation, X and Y co-ordinates) can be stored with the unrolled point, they can be mapped as variables on top of the unrolled plan.

The present method of unrolling is based on a structure grid, but there is no reason why other representations of the surface should not be used. If a mathematical equation were definable it would be a simple matter to integrate across the surface in the defined directions.

ACKNOWLEDGEMENTS

We are indebted to Roan Consolidated Mines, Limited, for permission to publish this paper. Our thanks are also extended to Dr A. E. Annels of RCM Prospecting Department, whose initial suggestion gave rise to the present system and who worked with us in the first experimental application of the system to an exploration area. Mr A. R. Wills, formerly of RCM Computer Department, handled all work with the grid-generating and graph-plotting programs. The system would never have become a reality without his enthusiastic co-operation.

REFERENCES

ANNELS, A. E., PERRY, J. H., WIIK, V. H., and WILLS, A. R. (1970). Contouring, unrolling and ore reserve estimation with the aid of computer and plotter. *RCM Company report*.

KAY, M. (1954). Isolith, isopach and palinspastic maps. *Am. Assoc. Petroleum Geologists Bull.* vol. 38, pp. 916-917.

APPENDIX A

TECHNICAL DETAILS OF THE PROGRAMS USED

The original computer-contouring package used was the IBM STAMPEDE system (surface techniques, annotations and mapping programs for exploration, development and engineering). Since then we have transferred to the Calcomp GPCP package (general purpose contouring program) which has provided comparable results, but improved facilities for this application (for example, incorporation of intersected slopes as well as co-ordinates). Both of these programs were run on RCM's computer at Ndola, a 256K IBM 360/40 with IBM 1627 on-line graph plotter.

Full details of the interpolation procedures used in STAMPEDE and GPCP can be obtained from the relevant users manuals provided by the manufacturer. To summarize however, STAMPEDE evaluates the elevation at a grid point by dividing the area around it into octants and choosing the nearest data point in each octant. A weighted average of these elevations based on the inverse square of distance from the grid point is used together with the intersections of each tangent plane (determined by a first-degree finite difference equation). The grid size can be varied by the user.

The GPCP program is similar but considers the nearest n points (user specified) in its evaluation and also allows the user to specify a tangent plane at each point. It will calculate its own tangent plane and average the two according to a user specified weighting.

The unrolling program was written in FORTRAN IV using the IBM G level compiler and can accept grid values in either the Stampede or GPCP format. The execution time for the program is negligible.