# Geological Modelling

**Chairman: Professor H. S. SICHEL**
**Rapporteur: Miss M. I. WATSON**

*Papers:*

**Unrolling of Copperbelt orebodies** by J. H. E. Perry and V. H. Wiik

**An exploration model for tabular orebodies** by G. S. Koch and R. F. Link

**Harmonic analysis of copper and gold occurrences in the Arbitibi area of the Canadian Shield** by F. P. Agterberg and A. G. Fabbri

**Mathematical models of orebodies** by M. J. Newton and A. G. Royle

**Estimation of lateritic-type orebodies** by A. Journel

In his presentation Mr Wiik said that unrolling could be regarded as a reversal of the natural process of folding, so that the aim of an unrolling procedure would be the reconstruction of original pre-tectonic conditions. While simply formulated, this aim might not always be achieved. The geometrical relationship between points on the deformed surface and corresponding points on the original surface is process-dependent, and a true reconstruction could be achieved only if the deformation history were known in detail.

In this computer unrolling procedure all these complexities were ignored. Referring to one particular marker horizon, Mr Wiik said that it was assumed in the procedure that this marker was deposited as a horizontal stratum and that it had subsequently been deformed by simple flexure-type folding.

The procedure allowed the geologist to incorporate his knowledge and conception of the deposit through repeated re-contouring with dummy points. This 'manumatic' aspect of the procedure had proved invaluable, not only in resolving specific unrolling problems but also in making the system more acceptable to the geologists in general.

Unrolling served towards removing what might be termed 'tectonic noise' superimposed on the primary distribution patterns for regionalized variables such as metal content and orebody thickness. From this point of view, variograms derived on the basis of unrolled-plan co-ordinates should be more meaningful in terms of depositional environment than are variograms calculated from a normal map projection.

Mr M. M. Oosterveld remarked that it appeared from the paper that there were problems in applying the unrolling technique to ore reserve calculation, and asked whether there were not other methods that might be used for that purpose.

Mr Wiik replied that at present unrolling played only a minor role in practical ore reserve estimation within Roan Consolidated Mines, Limited. The techniques currently in use differed from one orebody to another, but in general they involved projection onto a vertical longitudinal section or a horizontal plan, with subsequent grid interpolation by means of a standard computer contouring package.

As a further step along this line, their computer department had evolved the block allocation technique described by D. A. Phillips at this Symposium. In a different approach, the Geological Research Department were investigating the geostatistical characteristics of RCM's different orebodies. They had also developed an 'ellipsoidal weighting' procedure for block grade estimation in three-dimensional space. This ellipsoidal weighting procedure was strongly 'manumatic' and allowed the geologist to incorporate geological information over and above the mere assay data. In early stages of exploration, this procedure would be strongly biased by the geologist's interpretation of the particular deposit. It was hoped that as the density of assay data increased, they would be able to replace the geologist's subjective assessment by geostatistical parameters and thus arrive at unbiased and efficient estimates of block grade and associated error, by a kriging procedure.

Professor Journel said that unrolling seemed a promising method of decreasing the uncertainties of a variogram based on nominally equal sampling intervals, where flexure of the reef would lead to physical irregularities in the spacing.

In presenting his paper, Professor Koch gave further information about the circumstances of the particular application. The ore came in small shoots around fissure veins, and these were difficult and expensive to find; but being quite rich they might be well worth finding. The upper levels were completely mined out, so that, on the assumption that the pattern revealed there would continue on the lower levels, a model could be chosen for the natural variables and parameters estimated for it.

The program was not designed for a direct attack on optimizing the controllable variables; the process envisaged was rather one of a sequence of intelligent trials. If, for instance, a particular layout was found to give high probabilities of discovering whatever was there, a cheaper one might be tried.

Professor J. W. Harbaugh asked two questions. To the first, on the extent to which economic aspects were considered, Professor Koch replied that the costs of a particular layout were considered in detail, but that returns were not estimated, the evaluation of targets hit being regarded as belonging to a second phase.

The second question was, could the program be used to handle sequential decisions, for instance, to assess strategies of further exploration to be followed when an orebody had been discovered? Professor Koch said that at present the facility of altering the layouts could be turned to this purpose; one might, for instance, try the effect of starting with a cheap layout, and going on to a more elaborate one if a target or

two were hit. A more formal approach to the question was, however, being considered.

Dr Agterberg showed a number of slides among which there were in particular some showing further aspects of the geology of the area.

Professor Harbaugh asked whether the phase diagrams might be useful to guide prospecting, as, for example, where a peak on the complexly corrugated surface lay over an area made unavailable to prospecting by the presence of a lake or swamp, or of glacial deposits.

In a written reply Dr Agterberg said: 'The technique can be useful for prospecting. In order to illustrate this, the following artificial experiment was done. Dots were scattered at random in zones around two sets of equidistant parallel lines. Application of the method gave a power spectrum with peaks indicating periodicity and direction of the zoning.

Next, parts of the dot map were eliminated in order to simulate a zone where bedrock was not exposed because of thick glacial cover. The power spectrum again showed peaks for the zoning which was extrapolated across the covered areas.

The new spectrum was different in that these peaks were less well developed and a new peak occurred around the origin corresponding to waves with a long period for the covered areas. It illustrated that periodicities present in parts of an area are extrapolated across the entire area of study and will cross places where bedrock is hidden or exposed but barren. It is useful to investigate the bedrock near crest lines falling on covered areas to see whether favourable host rock with undiscovered deposits does occur. It is noted, however, that the vast majority of copper occurrences used for the present study are too small for mining.'

Mr P. L. Bezuidenhout, expressing some scepticism of the naturalness of consecutive waves, wanted to know why harmonic analysis was used and how the wavelengths were chosen.

Dr Agterberg explained that harmonic analysis was recommended in many cases where the data could be regarded as observations on a random field; it was strongly so in this case because a periodic phenomenon was being looked for, with periodicities that might be obscured by large-scale regional variation on the one hand, and unpredictable small-scale variation on the other. The first would result in a peak around the origin of the power spectrum and the second would raise its overall level; but a sharp peak at some distance from the origin might indicate the presence of the phenomenon sought; wavelength and direction could then be found from the spectral co-ordinates of the peak. In this study a somewhat arbitrary upper limit of 20 miles was put on the wavelength.

The pattern, although periodic, might indeed be poorly approximated by a sine wave; if, however, it had some markedly different shape which it maintained consistently over the area, that should be reflected in harmonics of the primary peak. In the results studied here little could be inferred about shape, and refinement of the basic sinusoids was not possible.

Introducing his paper, Mr Royle said that they wanted sample sets drawn from artificial bodies that would show the same characteristics as those drawn from some real orebodies. Some included features were serial correlation between block means provided by the trigonometric surface; a log-normal distribution of sample values within blocks; and the additive relationship that the overall sample variance should be equal to the sum of the within-block variance and that between block means. The artificial orebodies produced were of types in general difficult to value, because of anisotropies and high random components with short ranges of influence.

Naïve evaluation from the sample values alone produced distortions that increased in severity as the within-block variance was raised: the histogram of values was greatly spread, and curves of tonnage and of mean ore reserve value against cut-off limit were sadly erroneous. By contrast, these last two curves worked on kriged values were much better, following the true block mean curves very closely when the standard error of estimate was small.

Professor M. David suggested an explanation for the discrepancy reported in conclusion (ii) of the paper, namely, that in looking at high- and low-grade *blocks* the wrong regression was being examined. Since the purpose of kriging was to provide an estimator such that at any given predicted value the mean of the corresponding true values would be equal to the prediction, the relevant regression was that of true on estimated values, not that of estimated on true. He suggested further that the discrepancy noted between theoretical and observed kriging standard errors might be due to the simulation method used: the absence of closely-spaced samples from within the same block would blur the approach of the variogram to the origin, hence impeding estimation of the nugget variance.

Dr D. G. Krige suggested a further explanation for the slight over-valuation of low-grade blocks, namely, that if the overall distribution were log-normal, then the regression of sample on true values would probably be curvilinear; but if the weighting coefficients were applied directly to the natural values, then the estimator employed would be linear. Mr Royle confirmed that this was possible, since the sample distributions were three-parameter log-normal, but the weights were estimated from, and applied to, the natural values; appropriate scattergrams were being produced and should soon be available. To a further query from Dr Krige he replied that he was not aware of any similar work on real or artificial orebodies; for real orebodies, indeed, block means known with sufficient accuracy would be very difficult and expensive to obtain.

Professor Journel prefaced his summary of his paper with some remarks on the need for understanding the structure of the problem at hand, and of the available data: blind use of a program package might result in a quite inappropriate analysis.

In response to a request to clarify the relationship between service variables and (i) reality and (ii) the advancing production process, he said that service variables were often used without being described or, indeed, recognized, as such. In data collection the real structure was sometimes partly obliterated: for instance, samples might be taken over a maximum channel width of one foot, even if the stratum of interest were in some places thicker than that. In such a case, the observed values would not fully reflect the true natural relationships, but would be to some extent artefacts of the method of observation. They might then be termed 'service variables', to draw attention to the element of artificiality in the values that were in fact being used.

In the mining process, we cannot know the true grade of a block, in considering whether or not to extract it; but as mining or sampling advance in its neighbourhood, we should be able to form better and better estimates of its grade. We may then use these estimates as service variables to guide the selection.

In reply to a question from Mr Royle, Professor Journel said that they were, for financial reasons, doing the evaluation step by step. They had started relatively cheaply, with two crosses with 20 m intervals for investigation of the fine structure and a 400 m grid for the large-scale variation over the whole orebody. The latter had proved too coarse for useful discrimination between smaller blocks; but as the next step observations had since been taken at 100 m intervals.