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Computer-assisted evaluation and planning of a china clay pit

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This paper describes the geological modelling and conceptual pit design for a china clay deposit in Cornwall. The work was carried out using the DATAMINE mining software system. Initial data consisted of cored drillhole results and a plan of the surface topography. Two of the sampled variables, bleached brightness and yield, were multiplied by the corresponding percent clay values to create accumulations. Statistical and geostatistical analysis of the principal variables allowed semi-variogram models to be determined. A block model was created, with subcells being generated at the surface to accurately reflect topography. Kriging was used to interpolate grades throughout the model. The most economically optimum pit that could be mined was determined, based on slope constraints and supplied cost information for a minimum required bleached brightness. The proposed pit expansion was evaluated, producing a full volume, tonnage and grade breakdown for the complete design.

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Introduction

As the market for kaolin increases and broadens, it is also becoming more demanding in terms of specification tolerances. Simultaneously, pressure upon the south-west England china clay industry is being felt from a wide range of outside influences. Decision making at senior management level involves increasingly larger capital sums and once a course of action has been embarked upon it is often difficult to change. These factors, together with increasing competition in the white pigment market generally and from alternative supplies of kaolin specifically, dictate that the efficient husbandry of china clay resources is optimised. The foundation for this optimisation is effective mine planning, which should ideally encompass the complete spectrum of effort involved in supplying the customer.

The mine planning challenge has been more effectively met by E.C.C. International since the early 1980s with the in-house development of a computerised reserve evaluation system (Howe et al. 1986). However, additional requirements not currently available within this system have led E.C.C. International to examine a range of alternatives, one of which has been the appraisal of the DATAMINE mining software system. Some of the facilities within DATAMINE explored during this appraisal are discussed in this paper, describing the geological modelling and conceptual pit design for a china clay deposit in Cornwall. The work was carried out using DATAMINE on a microcomputer, in conjunction with E.C.C.

The DATAMINE software system

DATAMINE is an integrated mining software system, which has been developed by Mineral Industries Computing Ltd. The system is built around a relational database core, and has a variety of data processing, ore reserve evaluation and mine planning facilities. Most of the work for this project was undertaken using DATAMINE on a PC/AT compatible microcomputer, which has a 640Kb working memory and a 40Mb hard disk.

The database

Three sources of data were used to create an initial working database for the project:

- (i) Cored borehole collar co-ordinates and downhole core recovery and percent clay values.
- (ii) Test results for each hole, containing for each clay sample the values of bleached brightness, iron oxide, viscosity, and associated yield figures.
- (iii) A topographic plan of the pit area showing the existing bench layout, with spot heights along bench toes and crests, together with other scattered spot heights.

The borehole and test results data were merged into a single file, containing values for each sample interval of bleached brightness, its associated yield, and percent of clay. These were the three variables studied in detail. A total of 154 holes were used for further processing.

Spot heights on the plan were digitised, elevations being keyed in to generate a three-dimensional survey-point location file. Bench toes and crests were digitised as strings and perimeters.

Statistical analysis

Exploratory data analysis was carried out on the raw drillhole data and on derived 'accumulation' fields which were to be used in generation of the block models. These derived fields were:

- (i) The product of percent clay and bleached brightness.
- (ii) The product of percent clay and the yield associated with bleached brightness.

These derived accumulation quantities were necessary because the interpolation techniques used (including kriging) are all essentially averaging operations, and correct weighting of samples can only be achieved by inclusion of the percent clay. It is analogous to the use of seam accumulations as discussed by David (1977).

The bleached brightness and recovery values, together with the accumulations, and the percent clay figure, were all analysed using statistics and geostatistics. When analysing the spatial distribution of a variable, each observation used should carry equal weight - i.e. should represent the same volume of space. One method of producing samples of at least near-equal weighting is to average sample values over fixed intervals. This compositing process is effectively a weighted average computation, using the sections of adjacent samples which lie within each defined composite interval. In this study, the accumulated data and percent clay sample data were composited over 18m bench intervals, based on the average pit bench height.

Statistics and histograms were also produced for the composited variables. The effect of averaging to create the composites caused a reduction in the variance of the composites. However, it was evident that the nature of the original distributions had been preserved, thus validating the use of the composited values for further interpolation. Geostatistical analysis was used to determine model variograms for the required parameters. No anisotropy was indicated in the grade distributions.

Topographical modelling

A DATAMINE block model consists of a regular three-dimensional cuboid structure of cells in space, each of which can have a large number of properties or grades (typically up to 30-40) associated with it. It is also possible to split each one of these cells as often as required into sub-cells, each of which can be quite different in size. No records are stored for cells in which no grade or value information is available, allowing a consequent saving of storage and increase in processing speed. In the generation of any geological deposit model the physical boundaries must first be defined, followed by the definition of localised grade variations.

In this project the most significant boundary is the existing surface topography, as the lateral and downward limits of the deposit are defined by grade rather than geology. Topographic modelling is considered in isolation; the two possible methods being described below.

Surface interpolation from point data

DATAMINE was used to interpolate the surface from all of the available spot-height data, automatically subdividing and truncating cells according to a supplied threshold elevation difference. The basic cell size was 24 x 24 x 18m, which allowed a good representation of the available data and meant that a cell divided in two (in plan) corresponded to the minimum bench width of 12m. The block height of 18m was again chosen to correspond with the average pit bench height. A section through the resulting block model is shown in Fig. 1. This diagram clearly shows the sub-cells created by cell-splitting and truncation at the surface.

Digital terrain modelling

For comparison, an alternative method of surface modelling was also carried out, employing triangulation. In this method, surface data points are first linked into an irregular triangular mesh, which is then intersected with the required block model structure to generate the required model. This method uses string and perimeter constraints to control triangulation, which prevents unwanted

interpolation across known linear changes in slope, such as bench toes and crests. An isometric view of the resulting block model surface is shown in Fig. 2. The existing features of the pit are clearly shown, verifying the accuracy of the generated block model.

Grade modelling

DATAMINE allows grades and many other resource qualities to be interpolated in a number of different ways. For the purpose of comparison, in this project, three methods of interpolation were applied to determine the grades of the three main variables in each cell and sub-cell of the previously created topographic model.

Kriging interpolation

The variogram model parameters determined from the structural analysis were used for kriging interpolation. Values of bleached brightness and yield were then computed from the interpolated accumulation values, by dividing by the corresponding interpolated percent clay values. This model was then used for subsequent mine design, as the structural analysis indicated it to be the most reliable. A horizontal section through the kriged model is shown in Fig. 3A, indicating the percentage of clay along this plane.

Inverse power of distance weighting

Another model was produced using inverse squared distance weighting interpolation. A horizontal section through this model, again indicating percent clay, is shown in Fig. 3B.

Polygonal weighting

A section through the model produced by polygonal weighting is shown in Fig. 3C, again indicating percent clay. In polygonal weighting, the value inserted into each block is the value of the nearest sample to the block centre. Both polygonal and inverse power of distance weighting may optionally (though not in this case) be distorted to model known grade anisotropy.

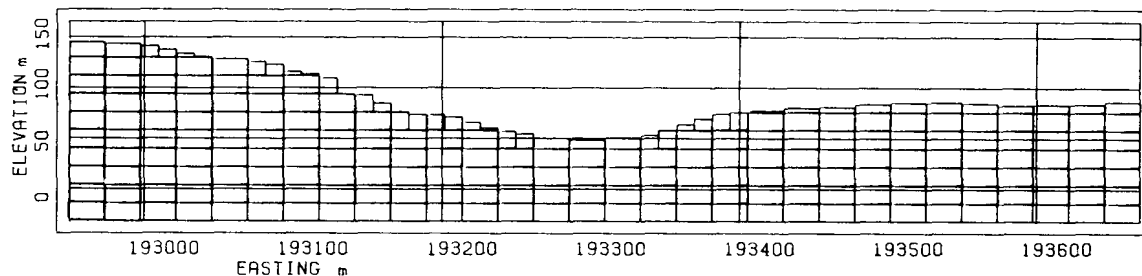


Figure 1. A typical vertical W-E section through the block model, showing the size and structure of the cells and sub-cells.

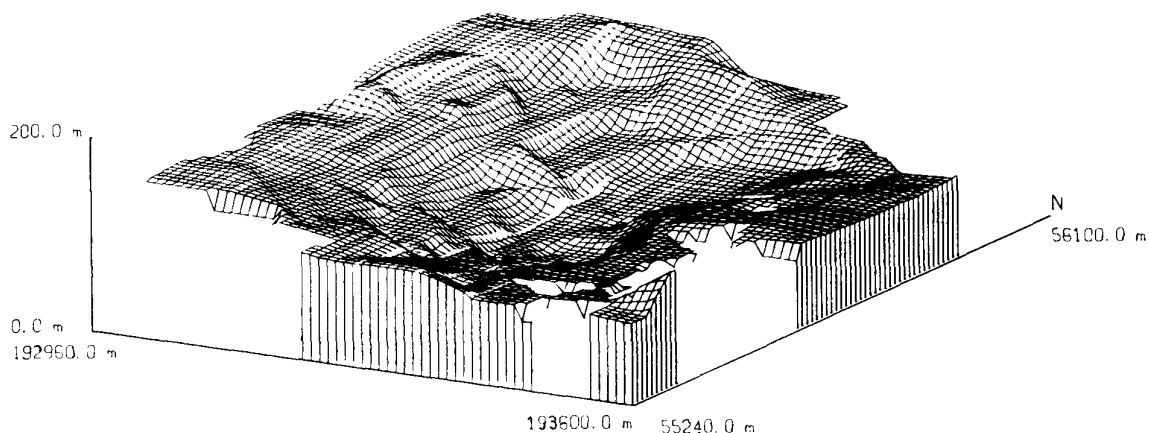


Figure 2. Isometric view of the block model surface viewed from the south-east.

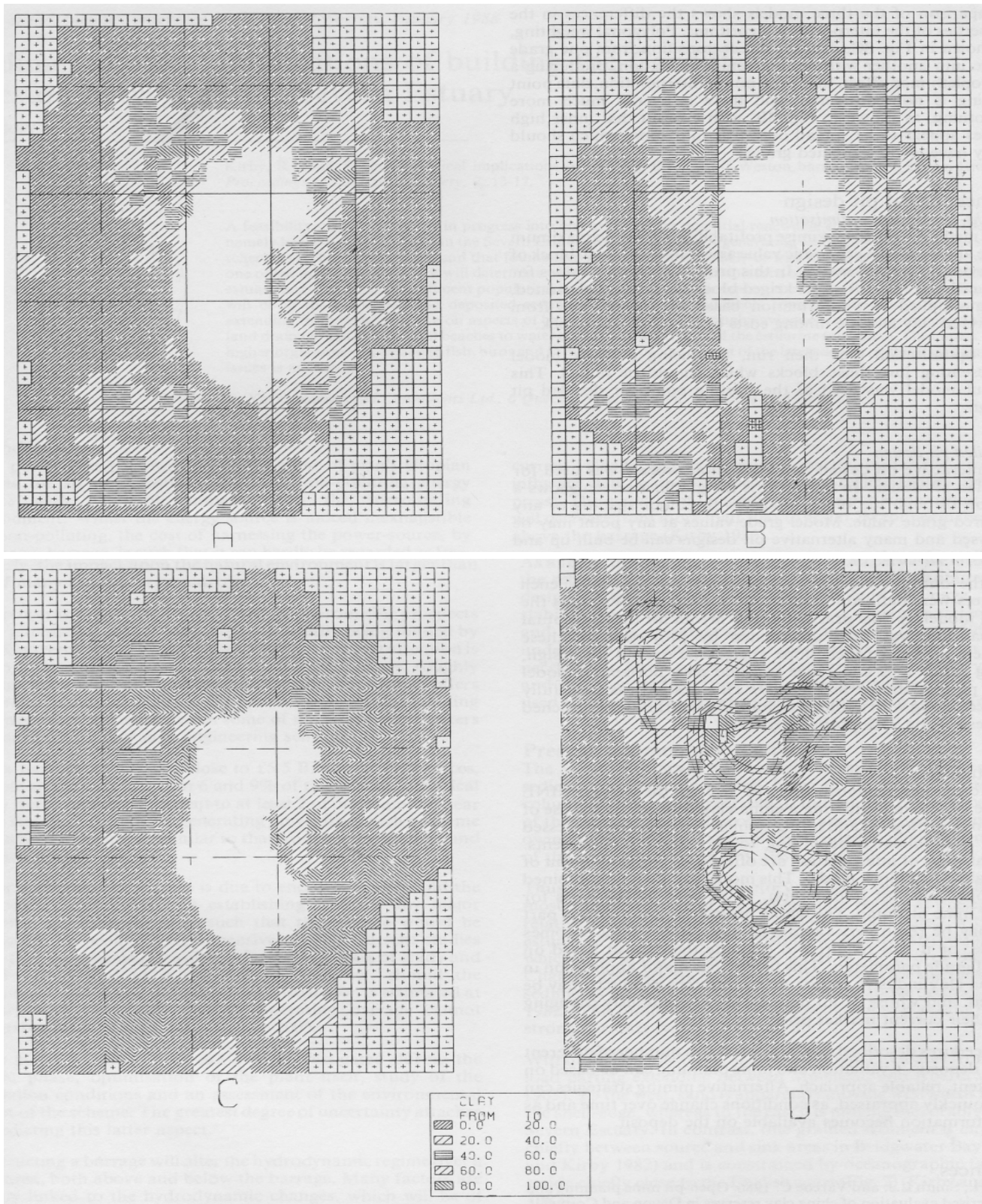


Figure 3. A comparison of the different ways in which the grades of the block model were interpolated. Sections A)B) and C) cut the model at the 65m elevation.

A) Kriging.

C) Polygonal weighting.

B) Inverse squared distance weighting.

D) Kriged model cut at the 49m elevation, with the overall pit design superimposed.

Comparison of the three models shows the differences in the properties of the interpolation algorithms. Polygonal weighting, as shown in Fig. 3C, displays direct transition from one grade range into another with no intervening gradation, producing a choropleth-map effect. In inverse power interpolation, data point spacing is not considered, and there is overall much more smoothing, as shown in Fig. 3B, with a result that inner high grades appear to be spread outwards into zones which should really have lower estimated grades.

Conceptual pit design

Lerchs-Grossmann optimisation

This method seeks to maximise profitability, subject to maximum slope angles and an economic value associated with each block of a previously created model. In this project, economic values for each cell and sub-cell of the kriged block model were generated, using supplied cost information based on the revenue from recovered clay and the mining costs of clay and waste rock.

The optimisation was then run, producing a block model representing just those blocks which should be mined. This output model was used as the starting point for detailed pit design.

Detailed pit design

An interactive pit design and evaluation process was used for detailed pit design. In this process the graphics screen shows a section through the block model, with colour shading of any required grade value. Model grade values at any point may be analysed and many alternative pit designs can be built up and rapidly evaluated.

Using the output model from Lerchs-Grossmann, mid-bench perimeters were defined interactively, and examined against the original model. A final practical bench layout for the conceptual pit expansion was then determined by projection of these perimeters at the required slope angle. The overall pit design, showing bench toes and crests overlaid on a horizontal model section plot, is shown in Fig. 3D. This design was then fully evaluated, along with a tolerance for the mined grade of bleached brightness at the 95% probability level.

Conclusions

This project has demonstrated the use of the DATAMINE software system in evaluating a china clay deposit. By the use of such a tool, geological and topographical data may be processed quickly and validated according to the user's requirements. Different ways of interpolation are offered for the assignment of grade values in a block model. This model can then be combined with slope and cost information, to be used as the basis for efficient mine planning. The whole project, or just a certain part of it, may be rerun very rapidly as more initial data becomes available, or if it is required to evaluate the deposit based on different grade parameters. This facility has major application in the china clay industry, where many different products may be produced, and whose profit margins are continuously changing due to their current market price.

The procedures described can be applied to a number of different types of deposits. Evaluation and mine planning can be based on a consistent, reliable approach. Alternative mining strategies can then be quickly appraised, as conditions change over time and as more information becomes available on the deposit.

References

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