The use of geographical information systems in the integration and visualization of mining data

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Synopsis

Geographical information systems (GISs) provide sophisticated functionalities that can be used by the personnel in many aspects of the mining industry to visualize, analyse, and manipulate spatial and tabular data. This paper presents an experimental case study for Hartebeestfontein Gold Mine. It shows how data from different computer systems can be brought together into a GIS by use of the Arc/Info and ArcView programs.

Introduction

Hartebeestfontein Gold Mine is a deep-level gold mine situated near Klerksdorp in the North-West province. The mine derives its revenue from the exploitation of the gold-bearing Vaal Reef, which is a tabular orebody extending over a wide area, with little variations in width and an average dip of 10 degrees.

The mining lease covers a surface area of 63 km^2. Five shaft complexes are currently in operation. A conventional breast-stope layout is used, with 30 m long faces and an inter-raise spacing of 150 m. All the development access is in the footwall of the orebody.

There are a number of specialized computerized systems on the Mine, each with its own database. The data stored generally have spatial and tabular components, and are therefore very suitable for integration into a geographical information system (GIS).

A GIS can bring different components of the mine environment together and display them in any combination desired. In a GIS, a map is a querying tool—not just a data-presentation device. Points, lines, and polygons can have data attached to them. Clicking with a mouse on any of these on the screen opens a window showing the underlying data. An example of such a query is shown in Figure 1.

GIS applications in the mining industry have generally been limited to mineral exploration and, to a lesser extent, to environmental management. However, there are a very few examples of the application of GIS to underground mining.

It is important to note that most GISs are designed to handle two-dimensional data, although they have limited three-dimensional capabilities such as digital terrain modelling. These GISs are therefore less suitable for use with massive orebodies.

Setting up of a GIS

This paper shows how a GIS can be set up from data currently available in a digital format. The data include the following:

- sample data
- face outlines
- the ore-resource system
- peg data
- seismic events
- scanned images
- data from the Cost and Production Management (CPM) System.

A number of Turbo Pascal programs were developed for the pre-processing of the data prior to their importation into the GIS. Arc/Info, one of the leading GIS products, is used in the project described here. ArcView, its sister product, is also used—for visualization and querying.

Sample data

Mine personnel sample the stope faces and development ends at regular intervals to control the grade of the ore being mined, to reconcile the production results, and to estimate the mineral resources. The sampler captures the data directly by means of a customized sample-data capturing and computing system. In addition to sample information, face details are also captured.

Before sample information can be imported into a GIS such as Arc/Info, the spatial (x and y co-ordinates) and tabular (attributes) components are separated and stored in two appropriately formatted files. The two components

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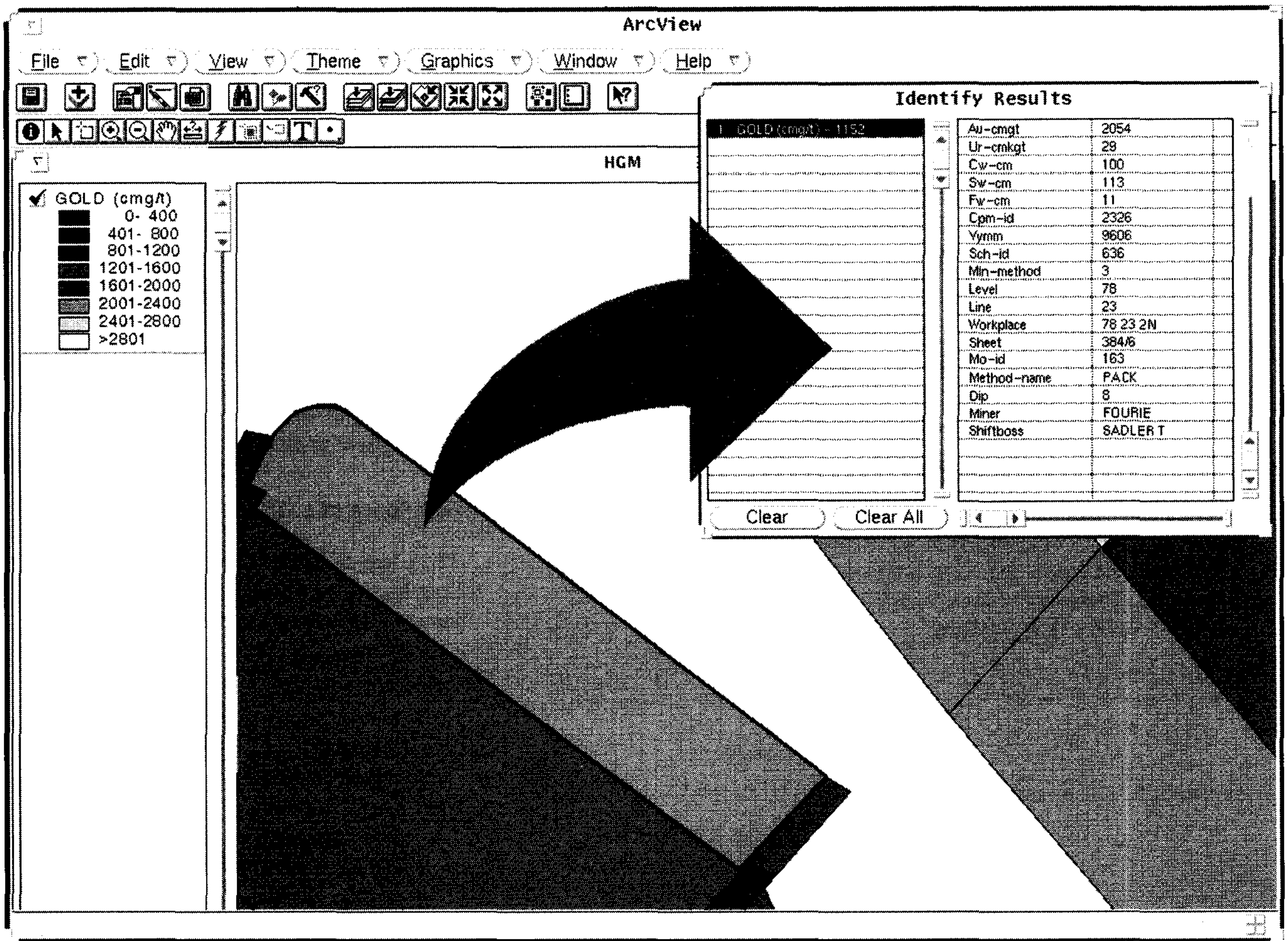

Figure 1—A GIS screen showing the underlying data

remain linked by means of a unique identification number. Spatial and attribute data are imported and processed separately by the GIS. The result is a point coverage linked to a relational database containing the attributes of each point.

With ArcView, the sample information can now be displayed and queried. Points can be shown as symbols whose colour and size are functions of any of its attributes. It is possible to select and display only those samples which meet some specific requirements. For example, it is possible to show all the samples in which reef has been left in the footwall and which have been sampled after a certain date.

GIS also allows for the conversion of a point coverage to an area coverage by means of Thiessen polygons (Figure 2). A Thiessen polygon defines an area that is closest to a specific point. Each polygon inherits the attributes of the point within its boundaries. Queries can now be carried out on polygons rather than on points. Polygons with identical attributes can be merged to form new polygons. For example, it is possible to merge all the polygons that have the same panel identification number (Figure 3) or that have been sampled during a specific year.

Face attributes are extracted and processed separately from sample attributes. The combination of face identification number and month generates the primary key, which relates the face attribute table to the sample attribute table.

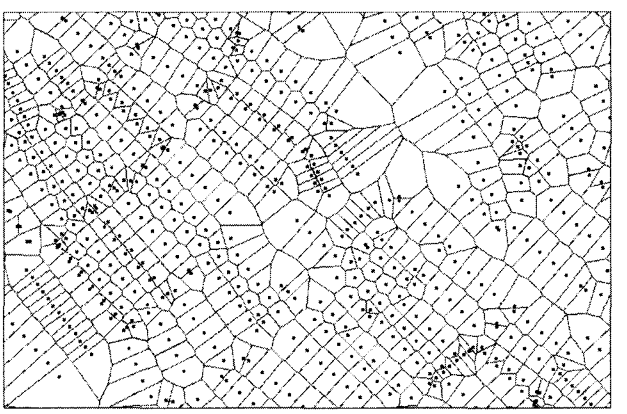

Figure 2—Thiessen polygons

Face outlines

Face positions are measured once a month from survey pegs placed in the gullies. These measurements are used in the calculation of the miners' contract payments, as well as for reconciliation purposes. The new face outlines are plotted on stope sheets so that the area mined since the previous measurement can be estimated.

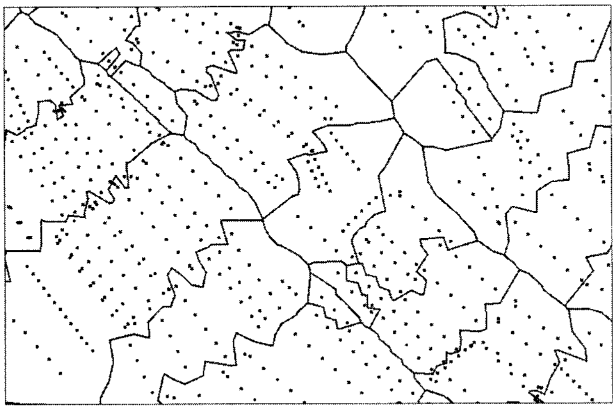

Figure 3—Merged polygons of identical attributes

In the estimation of the tonnage mined and the gold content, an in-house designed program is used. The outlines of each panel mined are digitized and stored on disk. However, the valuation results are not saved. An additional program was developed to reprocess the digitized outlines. For each polygon, the boundary co-ordinates, centroid co-ordinates, and valuation results are saved in separate files in a format that can be imported directly by the GIS. As with the sample data, the spatial and attribute data are linked by means of a unique identification number.

Face outlines are very useful in giving a general picture of the underground workings. However, some cleaning up of the data is required: boundaries between adjacent polygons never fit perfectly, and there are slivers and gaps when polygons do not join or when they overlap (Figure 4). Arc/Info has built-in functions to clean up most of these slivers and gaps (Figure 5).

Face outlines are digitized from stope sheets that present the workings on the plane of the reef on a scale of 1:200. The digitized information is converted to the horizontal plane by means of bench marks. A bench mark defines an average plane for each stope sheet or part of a stope sheet. Significant gaps and overlaps are often encountered at the boundaries of two stope sheets (Figure 6). Unfortunately, there is no straight-forward solution to this problem.

Except for the valuation results and date, face polygons have few useful attributes. A link needs to be built between

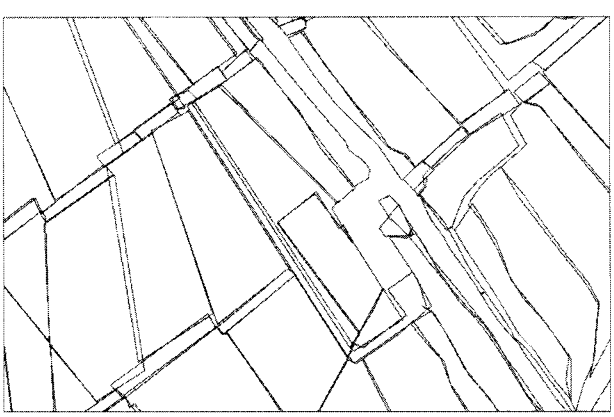

Figure 4—Imperfect fit between adjacent polygons

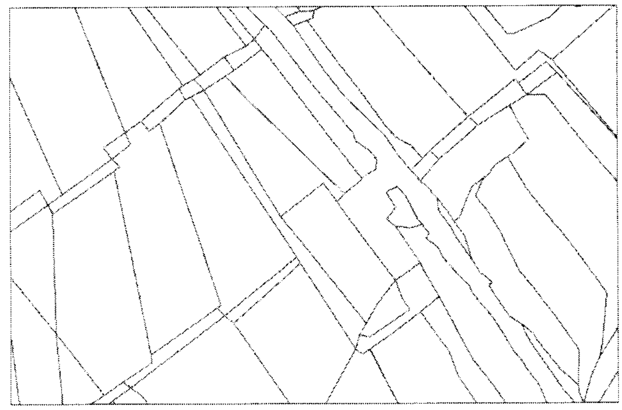

Figure 5—Slivers and gaps between polygons as cleaned up by Arc/Info

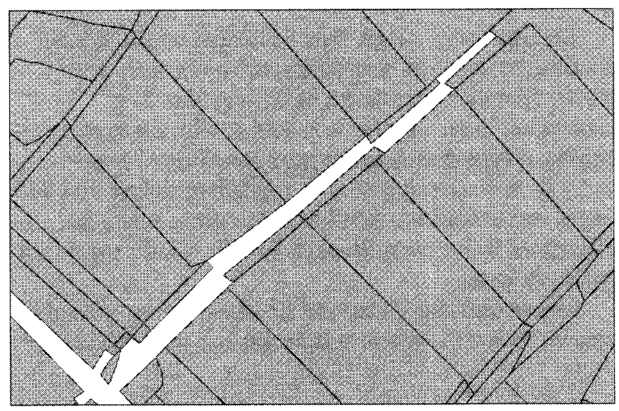

Figure 6—Gaps and overlays often encountered at the boundaries of two stope sheets

the face polygons and the face attributes extracted from the sample data-capturing system. This is achieved by means of a point-in-polygon overlay of the face centroids and polygons generated from the sample points as discussed above. Face centroids are assigned the face identification number of the polygon within which they fall (Figure 7). However, this method occasionally allocates incorrect identification numbers, especially to gullies and sidings.

Again, the combination of face identification number and month is the primary key that connects face polygons and

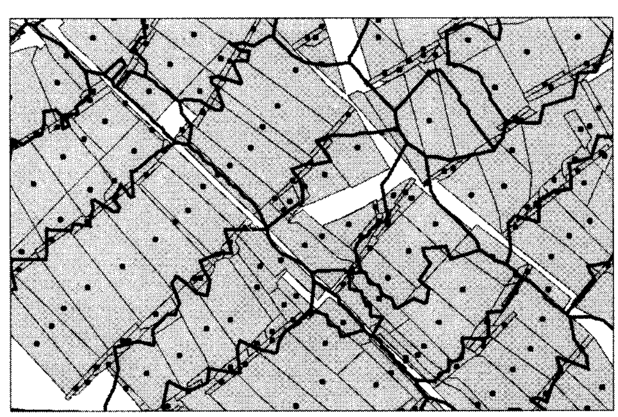

Figure 7—A point-in-polygon overlay

face attributes, even though the two were obtained from different sources.

The program used to capture the face outlines would require some modifications if the problems described earlier are to be avoided and the accuracy improved.

Ore-resource system

The core of the ore-resource system is a database containing over half a million samples, its main function being the valuation of the mine's mineral resources. The valuation process comprises the following steps:

(1) updating of the ore-resource blocks
(2) regularization of the sample data
(3) kriging
(4) integration of the block polygons and kriged output squares
(5) listing of the block values.

The regularized sample data and kriged output squares are ideally suitable for importation into a GIS since they require minimal manipulation before and after their importation. Some cleaning is necessary after the importation of block polygons to eliminate gaps and slivers. Figures 8 and 9 show block polygons with regularized sample data and kriged output squares respectively. The grade trends are highlighted by the assignment of different colours to selected grade categories.

Regularized sample data can be superimposed on kriged squares so that the effects of the valuation algorithm can be inspected. Similarly, block polygons can be viewed together with face polygons so that any significant differences between the estimated block values and the actual block values can be identified.

With a GIS it is possible to intersect two polygon coverages to generate a third that covers the areas common to both input data sets.

The new coverage also inherits their attributes. For example, if blocks are intersected with faces, the resulting coverage will cover the part of the blocks that had been mined since the beginning of the financial year. The new polygons will have both the estimated and the actual gold content as attributes. Furthermore it is possible to calculate a new attribute by dividing the actual value with the estimated value to obtain a block factor. Figure 10 shows the intersection of block and face polygons, where the resulting polygons are shaded according to their block factor. Areas with consistently high or low block factors can now easily be isolated and viewed together with the sample values available before and after the block valuation, and the reason for the discrepancy can be determined.

Peg data

Pegs are placed in the hangingwall of development ends and stopes for use as reference points from which the position of the workings can be measured. At Hartebeestfontein, pegs have been stored in a digital format since 1987, and the database contains about 25 000 records.

A special program was developed to extract and filter the peg data. Unfortunately, there is no flag to distinguish pegs placed in the on-reef workings (raises and scraper gullies) from those placed in the footwall developments. Only those pegs which can be placed with certainty in the on-reef workings are used at this stage. Pegs placed in the stopes are identified from their serial numbers, while those placed in the raises can be identified only from the workplace names.

Peg elevations relative to sea level are used to generate a digital elevation model (DEM) of the reef horizon. Arc/Info generates first a triangulated irregular network (TIN) and then a set of contour lines (Figures 11 and 12). These contours can then be superimposed on the face outlines to give an indication of the inclination of the reef.

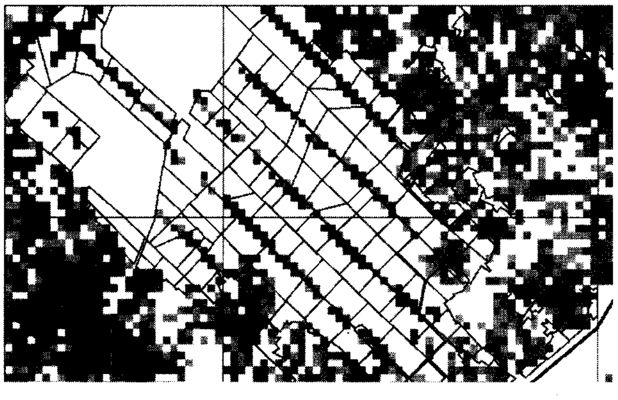

Figure 8—Block polygons with regularized sample data

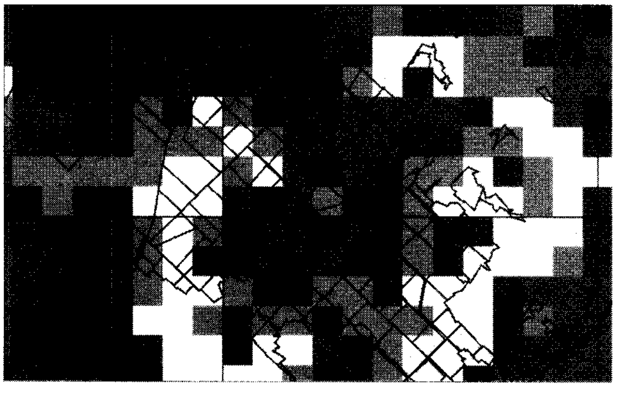

Figure 9—Block polygons with kriged output squares

Figure 10—Intersecting block and face polygons

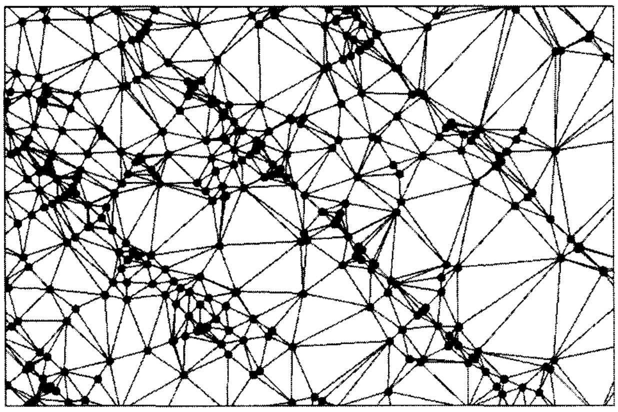

Figure 11—A triangular irregular network (TIN) generated by Arc/Info

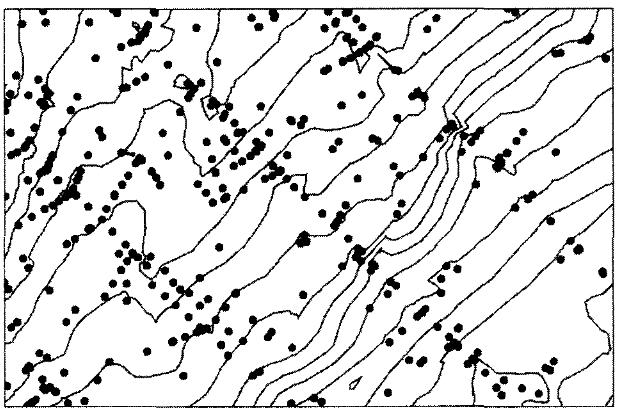

Figure 12—A set of contour lines generated by Arc/Info from the TIN shown in Figure 11

Seismic data

The Klerksdorp regional seismic network is a joint project between Hartebeestfontein and its neighbouring mines. It consists of a network of geophones covering an area of approximately 250 km^2. When a seismic event occurs, its co-ordinates (x,y,z), magnitude, time, and other relevant parameters are computed and then stored in a database. The transfer of data to the GIS is relatively straight-forward.

Although the seismic system has some very useful visualization facilities, a GIS allows for the integration of seismic data with face outlines, the reef surface model, and geological structures. An event can be displayed together with the working places likely to be affected, as well as the faults and dykes present. The distance of an event above or below the reef horizon can be calculated by a comparison of the DEM derived from the pegs and the recorded elevation of the event. It is then possible to highlight those events which are in close proximity to the reef.

Figure 13 shows a number of seismic events that were recorded close to two working panels. The sizes of the dots are related to the magnitude of each event.

Scanned images

The spatial data currently available in digital format cover only a fraction of the mine property. The digitizing of all the mined areas would be a tedious task, and the scanning of

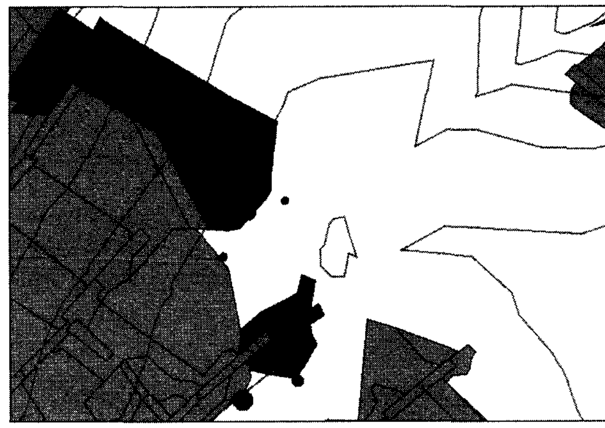

Figure 13—Seismic events that were recorded close to two working panels

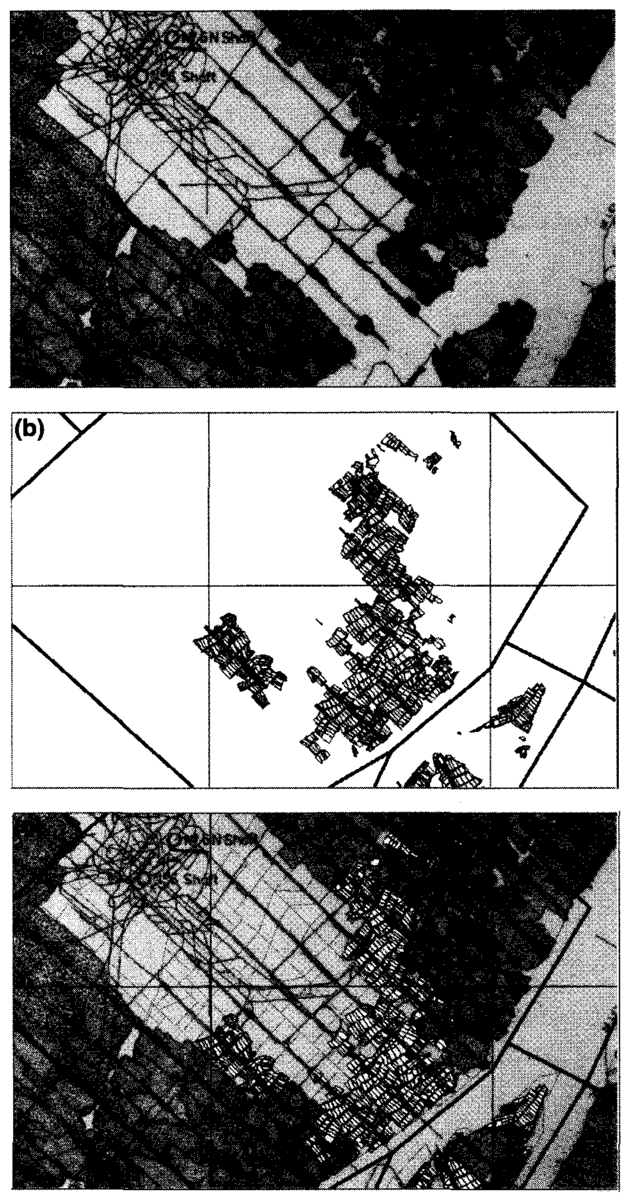

Figure 14—The sequence in which face polygons are superimposed on a scanned image

mine plans is an easy way of providing a raster image of these areas. This image can then be used as a backdrop to any of the data described earlier. Figure 14 shows how face polygons are superimposed on a scanned image. The gridlines on the scanned plan are used as reference points to establish the relationship between the image's pixels and the mine's co-ordinate system.

As scanned images have no attribute, they cannot be used to settle any query. If required, points, lines, and polygons can be captured by the tracing of these features directly from the image on the screen

CPM data

The Cost and Production Management (CPM) System was introduced in an attempt to provide management with information and analysing tools that would assist them in their decision making. At the heart of the system is a central database where planned and actual production information is stored for each face. However, this system has no graphical capabilities, and displays only textual or numerical information. In order to view the workings in their spatial context, one has to refer to the mine plans.

GIS makes it possible to link the face attributes stored in the CPM database with their corresponding face polygons based on a common face identification number. This can be done either by data transfer from one database to the other or by the establishment of a direct interface between the two systems.

Conclusions

In general, data capturing is the most expensive component in the setting up of a GIS. In the case of Hartebeestfontein, significant amounts of data are already available in digital format. In a GIS, these different types of data can be brought together into a coherent system without any major organizational changes. Although the data conversion is relatively complex, it can be automated to a large extent.

The production areas at Hartebeestfontein are widely dispersed. ArcView could allow the management of the Mine to review the different areas quickly and easily. It provides an intuitive user interface that makes GIS data accessible with minimal training.

Acknowledgements

The authors thank Hartebeestfontein Gold Mine for allowing the use of its data, and the Geology Department of Anglovaal Minerals for the use of its GIS. ◆

Awards to Wits students*

Trevor Shing has won the annual Parson's prize awarded by the Powder Metallurgy Association of South Africa. Trevor, a fourth-year student in the School of Process and Materials Engineering at the University of the Witwatersrand, was awarded a Kruger Rand for an oral presentation on his final-year research project.

The award was made at the Association's annual symposium, at which prizes are awarded for presentations by students countrywide on research related to powder metallurgy. The competition is open to Ph.D., M.Sc., and under-graduate students, and the judging is carried out by the management committee of the Powder Metallurgy Association and the invited overseas speakers present at the symposium. Trevor's presentation, entitled *The Automation of a Magnetometer to Measure the Magnetic Properties of Hardmetal*, was judged the best against competition that came mainly from post-graduate students.

Ian Northrop, Chairman of the Powder Metallurgy Association, (left) congratulates Trevor Shing on his achievement

The runner-up, also from Wits, was M.Sc. student Lineo Makhele of the Department of Physics. Her subject was *The Inhibition of Stress Corrosion Cracking in WC–Co by Means of Ion Implantation*.

Handing out the prizes, the chairman of the Powder Metallurgy Association, Ian Northrop, said the high standard of the winning presentations was a credit to both the academic staff of Wits and the high-calibre students currently studying there. ◆

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