SPOTLIGHT

on grade control

by W.K. BRINSDEN*

The Australian Institute of Geoscientists (AIG) held their fifth successive annual seminar at Observation City, Scarborough, in Perth on 15th November, 1990. The title of the seminar was 'Strategies for Grade Control'. The Seminar attracted 158 delegates, including 10 speakers. In addition to geoscientists, the attendees included mining engineers, metallurgists, and mining analysts.

The welcoming address was given by Rob Duncan, Chairman of the Western Australian Branch of AIG, who said there is a strong demand for this type of seminar in Western Australia (WA). It helps geoscientists to keep up with former colleagues and to keep abreast of technical developments.

Management Structures

Bill Shaw, convenor of the seminar, gave the first paper: 'Management of Grade Control and Mining Geology—An Overview'. His overview showed how mine personnel can maximize the value of the ore mined and fed to a mill. He suggested that all personnel should have

- a clear job description with a list of measurable criteria that are the objectives for that position,
- a chart showing the reporting responsibilities for shared processes such as grade control,
- an awareness of all the factors that contribute to reduced risk in grade control and mining geology: people, money, time, information, skill, and luck.

A discussion of various management structures for mining geology and grade control followed, and this generated considerable discussion by subsequent speakers and from the floor.

Shaw concluded by stating that grade control is not the specific function of one person, but is a shared process across many professions at a mine, including surveying, mining geology, mining engineering, and metallurgy. Nevertheless, accountability and responsibility for various aspects of grade control must be clearly defined and delegated by the mine manager.

New Celebration

The next presentation was 'Grade Control Practices at New Celebration' by Andrew Richards. New Celebration gold mine is located 35 km southeast of Kalgoorlie. The leases cover 119 km^2, and are part of a joint venture between Newmont Australia as manager and Mt Martin Gold Mines. Mining began in August 1986, and produces 115 000 ounces per annum from 8 pits. It has a resource of 23,5 Mt at 2,19 g/t. Ore is milled in a carbon-in-leach plant at a rate of 1,7 Mt per annum.

The mill feed is classified onto 8 stock piles according to grade and metallurgical performance, and is blended through the crusher to maximize the throughput while maintaining the grade.

At present, pit sampling employs ditchwitching, blastholes, and inclined RC and percussion drilling, depending on the situation and cost. A VAX/VMS computer system is employed on site, and Datamine software is used for most data handling.

The reconciliation between grade control and calculated head values since January 1989 has been around 1 per cent. This success has been achieved by concentrating on the quality of the sample produced through good communication between all departments, and by involving production geologists in all aspects of ore production, including operating techniques and ore-contact supervision. The ore blocks at New Celebration are mined selectively, and all production involving a high-grade contact is supervised by a geologist.

All the information collected by a geologist in the pit is available for the exploration and resource sections of the geology department. Data from grades, blasthole logging, face mapping, and general observation are communicated to these sections on a regular basis. Ore-reserve adjustments take into account the grade-control data on each bench.

Richards also pointed out that, for grade control, geology is probably supreme: a production geologist can work under a mining engineer, but it is easier to maintain a healthy independence by having him report to a chief geologist.

Richards concluded by emphasizing

- the importance of geological input to the mining of ore
- good communication between all departments
- the maintenance and improvement of sample quality
- the monitoring of the performance of different ore sources (New Celebration has many) through the mill.

The system of sampling and reconciliation scheduling of ore sources created some interest, with requests for Richards to detail the sampling setup in particular. He pointed out that New Celebration is different because it has scrapped a lot of rig add-ons (such as cyclones and hoses) that people are accustomed to using because they came with the rig. He added that diagrams and specifications can be obtained from Newmont at New Celebration.

Sampling

'Statistical Determination of a Safe Grade Control Sampling Protocol:Case Studies at Granny Smith and Big Bell, WA' was the title of the paper given by David Keough and Steven Hunt.

A study to quantify the heterogeneity of gold is an inescapable step in any gold project to ensure effective grade control and exploration. The requirement is to determine the sampling constant (the measurement of

* Client Advisor, Trent Securities Ltd, 41 St George's Terrace, Perth 6000, Australia.

gold heterogeneity) so that an effective sampling protocol can be designed. Without such a statistical study, a large fundamental sampling error (the error generated by the difference in content between individual fragments) will result.

At Big Bell, the sampling constant for blasthole cuttings, where the maximum particle size was 1,5 to 2,0 cm, was determined at 814 whereas, at Granny Smith for a similar particle size, the sampling constant was 120. At both deposits, by use of these respective sampling constants and economic considerations, sampling protocols were designed so that the relative standard deviation of the total sampling error would be in the range of 35 per cent. In reality, to achieve the target fundamental error, samples at Big Bell needed to be (26 kg) almost twice the weight of those at Granny Smith (15 kg).

Fundamental errors represent 'feet of clay' in that no amount of geostatistics, good geology, or rules of thumb will correct the bias generated directly as the result of poor sampling techniques.

Geological Mapping

Bob Watchorn of WMC's Hill 50 gave his paper on 'Open Pit Mapping Aspects of Grade Control: Advantages and Techniques'.

It is important to map all relevant details in an open pit such as structured ore zones, lithologies, faults, shear zones, from-the-pit-floor drill holes, and bench faces.

A geologist may have some difficulty in convincing a manager that routine geological mapping is worth while. The manager should be enlightened on how much extra profit can be made from the extra outlay for geological mapping. It is possible for a good mapping geologist to increase the head grade by 0,2 g/t or by a revenue of $3 per tonne, by thorough mapping. A mine's sensitivity to grade is usually much greater than any other factor, i.e. 'Grade is King'. A 1 Mt/a operation could increase its profit by $3 million per annum, and a 2 Mt/a operation by $6 million per annum by increasing the head grade by only 0,2 g/t.

Watchorn concluded by stating that very few open-pit geologists routinely map every bench (fewer than 10 per cent), and that many world-class orebodies in WA do not have good geological maps because managements believe that good mapping does not pay dividends. This view is wrong, and it is never too late for management to recommend the adoption of mapping. The value of systematic geological pit mapping cannot be over-stated from an exploration viewpoint. Senior geologists should be at the highest level of mine management since geological knowledge is usually the initial and ongoing source of a mine's profit.

Deviation of Drill Holes

Michael Ayris of Downhole Surveys Pty Ltd presented a paper entitled 'Determining Drill Hole Deviation'.

Contrary to popular belief, diamond drill holes are generally straighter than RC holes of the same depth. However, drill holes do deviate, as shown by a 50 m underground blasthole that was found to deviate 12 m off target.

Many mining companies on the Goldfields still design pits around unsurveyed RC drill holes. The ramification of unsurveyed drill holes defining an ore zone could be disastrous—even to the extent of finding the ore in the wall or at the bottom of the pit!

The costs of grade control can be reduced by accurate surveying of surface RC and diamond-drill holes defining the ore zone before the pit is mined. The end result is that the ore is found in the correct position, reducing the amount of grade-control drilling required. If a drill hole is to be sampled, it is important to know its exact position. This can be achieved only by a downhole survey.

Surveying underground drill holes is critical to the profitable operation of a mine. Ring-design drill holes should be surveyed to determine the amount of deviation. If these blastholes deviate, they will have a dramatic effect on the blast efficiency, and could cause massive dilution. By surveying each ring, an accurate picture can be drawn, and blasting can be adjusted accordingly to reduce the amount of dilution.

Downhole surveying is rapidly becoming a vital part of drilling programmes as more geologists and engineers realize the need to accurately position their drill holes when defining orebodies.

Mining Policy

The next paper was given by Dr Spero Carras, his coauthors being Michael Wiggin and Ken Denham: 'Grade Control and Mining Policy: Their Effect on Orebodies and Ultimate Reserves'.

Grade control, based on sampling (usually assay information and interpretation), is the process by which a mineable unit is deemed to be above or below a cut-off grade. On this basis, it is mined as run-of-mine ore, low-grade ore, or waste.

Mining policy is that set of parameters, including operating costs, profit margins, cash-flow requirements, and available start-up capital, which are used to determine the required metal production for a given project. Mining policy therefore affects the selection of mining equipment, the production rates, and the mining capacity for the project.

Inherent in the process of selective mining is the importance of the cut-off grade, the internal and edge dilutions, and the minimum grade necessary to sustain the viability of the project. It is important that the persons responsible for grade control are constrained by the parameters inherent in the mining policy.

The paper described the importance of a structured orebody, which is one in which a geologist must place interpretive lines. These lines reflect a geological control, and form a predictive pattern that enables a clear differentiation to be made between ore and waste. The ore and waste have a meaningful degree of continuity and can be mined separately.

An unstructured orebody is defined as one in which ore and waste positions are located randomly and show no predictability or constancy with increasing information. The ore and waste boundaries have no continuity, and hence interpretive lines have no real meaning because a separation of discrete ore and waste zones is not possible.

A third case is where the drilling grid exceeds the size of the structures. This is a common cause of problems.

For the evaluation of structured orebodies, constrained methods are essential, together with geological mapping during grade control.

The smoothing out of such orebodies results in a large amount of internal dilution and low-grade ore being sent to the mill. Such practices, while resulting in an easier job for grade controllers, are detrimental to the head grade.

Geostatistical Analysis

Vivienne Snowden of Mark Thomas & Co. gave the next paper, entitled 'Improving Reconciliation and Grade Control by Statistical and Geostatistical Analysis'.

Accurate estimation of the recoverable resources and good grade-control procedures are the foundation of successful mining ventures.

Many open-pit gold mines in Australia suffer from a lack of reconciliation between the exploration and in-pit estimated head grades and the actual head grades delivered to the mill. Some of the main reasons for erroneous estimation are failure to account for one or many of the following:

- statistical distribution of the sample data
- spatial continuity of the sample data
- relationshp between regression effect and volume variance
- degree of mining selectivity, i.e. the dilution that is practised
- appropriate estimation of the recoverable tonnages and grade.

Although the study described was relatively concise, it demonstrated the ability of these techniques to reconcile production estimates with the kriged recoverable-resource model and grade control outlined.

Effective operational cut-offs can be set on grades estimated for recoverable mining units, and the optimization and understanding of the operation can be improved considerably. An understanding of the grade–tonnage relationship, and the roles of the regression effect and the volume–variance relationship, will considerably aid geologists and mining engineers in calculating recoverable tonnages and grade and in reconciling estimates with actual production.

Determination of Cut-off Grade

Bob Adam of Adam Mining Services gave an address entitled 'Cut-off Grade Determination:Stating the Obvious'.

The term *cut-off grade* is used to define a number of different things in geological and mining projects. Adam described the various meanings of cut-off grade, what and why changes occur, and how to determine the change point. The implication that the structure of an orebody is a function of the grade is often wrong, since the grade distribution is a function of other geological features. However, it is simpler to look at the grade distribution because of the interest in mineral concentration.

The cut-off grade of resources or reserves can be calculated via grade–tonnage curves, which assume that the orebody is the sum of an infinite number of discrete parts, each having a particular grade.

The break-even cut-off grade is the grade required to cover all the operating costs involved in the mining and processing of a tonne of ore. In an open pit, this includes the cost of waste removal. The determination of the break-even cut-off grade is, thus,

$$\frac{(Mc + Wc + Tc + Ac)}{P \times R},$$

where Mc = Cost of mining a tonne of ore and delivering it to the treatment plant
Wc = Cost of mining the waste increment
Tc = Cost of treating a tonne of ore
Ac = Cost of all the overhead charges
P = Price per unit received for the final product
R = Metallurgical recovery.

Adam concluded by stating that the term *cut-off grade* has a number of meanings in different contexts and often creates differences of opinion. It is always better, when one uses the term, to add a qualification, e.g. a cut-off grade of 1,5 g/t based on a gold price of $500 per ounce and estimated operating costs of $22 per tonne.

Mahd Adh Dhahab Mine

Nick Journet of Surpac gave the next paper, which was written by Ross Corben of Surpac: 'Computerized Grade Control in an Underground Mine'.

The Mahd Adh Dhahab Gold Mine in Saudi Arabia contains about 1 Mt of ore grading 30 g/t gold, 120 g/t silver, 2,5 per cent zinc, 0,68 per cent copper, and 0,1 per cent lead. Underground mining is by a combination of cut-and-fill stoping in the larger, eastern veins, and multiple sub-level open stoping in the narrow, high-grade, western veins. The mine has been using Surpac mining software since October 1989 for its underground-survey, geological-modelling, mine-planning, and grade-control functions. One of the main reasons that the software system was implemented was to streamline the flow of information from channel sampling through to mining.

The implementation of Surpac at Mahd Adh Dhahab has allowed for more efficient and accurate grade control. In the past, all the channel-sample data were hand-drafted, and manual grade–tonnage calculations were made for all six elements assayed. This proved to be time-consuming and prone to error, and in many cases the channel and geological data collected for each lift could not be processed before mining in the stope commenced. Ore-reserve updates can now be done using both underground sampling data and drilling data. Mine planning has been simplified since all the survey and geological information is now readily available in the same data format.

The Mahd Adh Dhahab grade-control system is relatively simple in its approach, and more sophisticated techniques such as polygonal kriging could be used with Surpac. However, the level of technology used is suited to the remoteness of the Mahd Adh Dhahab site, where it is important that the system is understood and used by all appropriate mine staff.

Computerized Systems

Malcolm Newton of Datamine gave the next paper: 'A Toolbox Approach To Grade-control Systems'.

The main functions of a computerized grade-control system can be grouped together as follows:

- data entry, validation, and editing
- data processing and management
- graphical presentation
- composite design and evaluation
- reporting of both printed and graphical reconcilation.

Grade control involves large quantities of data. An average of only 50 blastholes per day soon builds up into a large database including the following:

- sample assay data
- blasthole survey data
- geological logging data
- face mapping
- composite (e.g. blast block or pod) evaluation results and survey layout.

It is therefore important to have an efficient database at the core of the grade-control system.

A typical 'toolbox' includes standard relational database commands for functions such as the joining and subsetting of data files, together with more complex operations such as plotting and interactive graphical evaluation. The menu then allows commonly used sequences of processes to be stored and executed at a single command. A toolbox approach provides an ideal method of tailoring a system to specific site requirements. The high-level tools that are available through a menu language enable an experienced user to easily build or modify the system. This method of menu building also ensures that the components of the system are integrated. In particular, the use of a common set of data-handling routines makes it easy to transfer data between parts of a system and others, such as survey or long-term planning.

Metallurgical Accounting

The last paper presented was entitled 'Does the Mill Control the Grade?'. This paper, by Bernie Siddall and Ken Baxter, indicated how practising metallurgists should present a balanced view of metallurgical accounting, but still endeavour to be as accurate as possible. They should also be aware of uncertainties associated with gold assays, tonnage readings, and changes to gold in the circuit.

Most modern semi-autogenous mills have a coarse feed size of at least 150 mm, which is difficult to sample accurately. Weightometers should be checked regularly, and should preferably not be subjected to extremes of heat, or to wet or dusty conditions. Care should also be taken in the sampling of mill feed for moisture determinations.

In gold-in-circuit determinations (GIC), most of the gold (approximately 75 per cent) is usually on the carbon. Gold can also accumulate in the mill liners, gravity circuit, and cathodes. A 5 per cent error in a carbon assay can result in an error of 460 g of gold in the GIC for a 0,5 Mt/a plant, giving an uncertainty of 0,1 g/t in the mill head grade.

Siddall concluded by stating that most of the errors occur because of

- inaccurate assays
- lockup of coarse gold
- failure to account for gold in the liquor returned from the tailings dam
- difficulties in the accurate determination of carbon concentrations in the tanks.

Cross-checks with external laboratories are recommended as a check on the accuracy of the assays, and the gravity circuit should be cleaned up completely each month or period end.

Closure

The Seminar was closed by Dr Rod Marston, an exploration geologist, who thanked the AIG for organizing another superb seminar. He pointed out that grade control is beoming more important every day since costs are rising and revenues may even be falling. It was good to see geologists endeavouring to work closely with mining engineers, mine planners, number-crunchers and, last but not least, metallurgists.

Copies of Bulletin No. 10: *Strategies for Grade Control* can be obtained from Mr Rob Duncan at the WA Branch of the AIG office (Tel: (09) 382 2855, Fax (09) 381 3724) for $35, including postage and packing. Included in the volume are an extensive bibliography on grade control, a checklist for effective grade control, a list of contacts, and a tabulation of grade-control techniques in representative Australian mines.

Computer-aided reclamation design

The Surface Mining Group of the Australian Coal Industry Research Laboratories Ltd (ACIRL) has been awarded a one-year grant by the Australian National Energy Research, Development and Demonstration Council to expand its landform design capacities. The project, which will be completed in December 1991, will develop additional surface design and evaluation tools to allow computer-aided design of mine-reclamation earthworks. Such earthworks are required to treat the post-mining landscape and produce a stable non-eroding landform.

This latest recognition of ACIRL's efforts in supporting open-cut operators with tools that integrate reclamation into mine planning comes after the Surface Mining Group successfully demonstrated the unique capabilities it has developed in digital terrain-modelling applications.

The main thrusts of the development will target the efficient semi-automated generation of a synthetic digital terrain model (design surface) that balances cut-and-fill within the economic transportation distance of the proposed equipment, meets agricultural criteria, and establishes drainage elements. The system will be portable within the Unix environment and, where practical, will utilize the standard mine-planning and terrain-modelling packages as a host system.

On completion of this project, the Surface Mining Group will continue with work aimed at the further optimization of spoil re-shaping and reclamation works.