Using Geological Models Created with Recoverable Resources Estimation (RRE) Techniques in Whittle 4-X

J L Pretorius & L F Baars

J L Pretorius

Qualifications: B Sc (Eng) Mining – University of Pretoria 1971; MDP (AAC) Unisa 1986; Mine Manager's Certificate of Competency – Metalliferous Mines (RSA); Mine Manager's Certificate of Competency – Fiery Mines (RSA).

Memberships: SAIMM.

Experience: Copper, Gold, Coal, Dolomite & Iron ore mining; operational, management and technical responsibilities.

Currently: Senior Divisional Mining Engineer, Anglo American Corporation of South Africa Ltd – Technical Director's Office, Johannesburg, RSA; en route to Chile as Senior Group Mining Engineer for Minorco South America.

L F Baars

Qualifications: M Sc (Mining Engineering, Delft) – 1963; Executive Development Programme at Wits Business School – 1971; Mine Surveyor's Certificate of Competency (RSA); Mine Manager's Certificate of Competency – Metalliferous Mines (RSA); Mine Manager's Certificate of Competency – Fiery Mines (RSA).

Memberships: Fellow of SAIMM; Member of Koninklijk Instituut van Ingenieurs (Holland).

Experience: Phosphate, Gold, Diamonds & Coal mining, operational, management and technical responsibilities.

Currently: Consulting Mining Engineer, Anglo American Corporation of South Africa Ltd, Technical Director's Office, Johannesburg, RSA.

Introduction

The recoverable resources estimation (RRE) technique to create geological and grade estimation models is used extensively within the New Mining Business Division of Anglo American Corporation of South Africa Ltd. The RRE technique has been applied to gold and base metals deposits within South Africa and further afield in Africa with what we consider to be great success. At the moment the RRE technique is the de facto standard for creating geological and grade estimation models within the Group.

In this paper we discuss how geological modelling developed, the origins of the block model as we know it today and the ramifications to mining engineers using geological models created with RRE techniques.

The Description of Ore Bodies Before the Advent of Computers

The use of a block model to represent an orebody is nowadays taken for granted. Until fairly recently great emphasis was placed on understanding the geometry of a deposit in terms of geometrical expressions. At the SAIMM ***Planning Open Pit Mines*** conference held in Johannesburg in 1970 several papers were presented in which the authors expressed the shape of an orebody in geometrical terms. In the documented proceedings of this conference one can plough through the geometry of orebodies described as pipe-like, tabular, etc. From these geometrical descriptions instantaneous - overall - and incremental stripping ratios plus final pits could be calculated by merely substituting the relevant factors in the formulae, using a few strokes of a slide-rule.

The Origins of the Classical Geological Model

A block model is the representation of the physical world in terms of a data set made up from a series of three-dimensional blocks or cells - cubiod - cells that fit snugly on the X, Y and Z axes of a Cartesian co-ordinate system. The manuals that are supplied with mine planning systems will give more detailed descriptions of this method as well as descriptions of the naming conventions particular to that system.

We tried to investigate when this system was first used to describe an orebody or mineral deposit and could not find any mention of this method before the most common reference and pioneering paper of Lerchs and Grossmann in 1964. There is no doubt that the use of the three-dimensional axis with cells to describe the physical world must have been known to mathematicians for centuries and that there is a description of this method buried somewhere in the copious volumes of Euler. In 1982 W P C Stokes gives the honour of first describing the use of the three dimensional computerised block model to Fairfield, J D and Leigh, R W A, for a paper published in 1968, four years after Lerchs and Grossmann!

The Shape of the Computerised Model

The debate continued as to what the shape of the cell should be to represent the physical world in the computer. The rectangular shape was not immediately accepted, even though it was one of the first mooted. In 1984 Peter Stokes mentioned some very interesting shapes: honeycombs, pyramids, curvilinear polyhedra etc., but continued to state the case for the cubiod sub-cell structure.

Early Pioneers

The application of computerised mine planning using block models was started at big copper open pits. The funding for the development of these computerised models appears to have been buried within the mine planning departments of these large open pit mines. It is worth noting that many persons involved in the pioneering work of computerised mine planning were either employed by the companies operating large open pits or closely associated with them. A surprising number of these early pioneers were mathematicians that formulated the tools and concepts for mine planning that mining engineers are using today.

Narrow Reef Developments

Mine planning for narrow seam or reef deposits did not slavishly follow the three-dimensional block model route. In the South African deep level gold mines CAD based systems prevail to this day. Reef or panel grades are calculated independently using specialised geostatistical programmes. Using the ability of CAD systems to assign attributes to a drawn object, a mine plan is created where the block values are not directly linked or changed when the spatial position of an object is altered. The traditional mine planning systems and the CAD based system are converging and the possibility of a single mine planning system embracing the best of both approaches is within grasp.

Acceptance in Open Pits

Open pit mine planners have accepted the concept of a computer block model describing a mineral deposit and the use has spread to the dimension stone and quarry industries. There are moves afoot to teach undergraduate mining engineering students the rigours of mine planning based on the three-dimensional block model. Is this how the Ptolemaic system started?

Limitations of the Classical Approach

The classical computer model ascribes a unique grade to a block. In 1964 Lerchs and Grossmann specified v (x.y.z) as the mine value of ore per unit of volume. Depending on the size of the cells used in a block model, we may end up with a piece of ground that is up to 50 metres by 50 metres by 50 metres (125 000 cubic metres) and all the material in this cube is supposed to be of a uniform grade. Nature never works this way. The result obtained from mining is therefore in most instances difficult to reconcile with the original block model. Small wonder that computerised mine planning is suffering from a credibility crisis in some quarters.

In the debate about what method to use to represent the physical world of an orebody we seem to have lost track of the fact that we do not know what ore the orebody contains until we have mined it out. There are papers that supply ore reserves reconciliation at the end of the life of a mine or business development plan. For instance, in 1993, Cameron J Schubert and Richard A Crookes stated that the Tick Hill pit yielded 26 percent more gold than forecasted but required 30 percent more ore to be fed to the plant to achieve this.

In an article in the 'Financial Times' of 21 February 1992, Kenneth Gooding gives a run down of what went wrong at Placer's and ACM Gold's Big Bell mine in Western Australia. He quotes in Placer Dome's in-house magazine 'Prospect' that *"in many ore bodies the grade varies by gradual increments from lower to higher values. At Big Bell ore and waste are mixed in an inconsistent jumble."* Again we see the pernicious influence of the big copper mines manifesting itself when an unconnected and remote gold mine in the outback of Australia is evaluated and modelled.

The Reasons for Changing

The discrepancy between what the geological model predicts and what is encountered in practice is well documented. David, M (1988) states that *"the common plea of the mining industry is that (the) production grade is not (as) was expected in the feasibility study"*. David continues to state four reasons which, in his opinion, contribute to this problem:

1. The size effect - selectivity achieved during the mining operation.
2. The information effect - the degree of sampling.
3. The continuity of the ore - spotty or homogeneous mineralisation.
4. Relative positions of cut-off with respect to mean with no cut-off.

There are examples of each of these factors in the technical literature. Alan J Coles et al explained in 1993 how the ore control was improved at Kundana Gold mine by improving grade control sampling, blasting and loading and, consequently, method practices. In 1985 Taylor HK states that it is his impression that *"many cut-offs do tend to be located at or near the population medians"*. If the cut-off selected is too high the mineralised material scatters and it is difficult to lump parcels of ore together for sensible mining practices.

The ore body models that we use for mine planning are our interpretation of the geological exploration data at our disposal. What if there is more than one way to interpret the data? Is the geologist that is the most vocal, or the more senior, necessarily correct?

We should remember that a geological model could be prepared with two different and opposing objectives in mind. To give a small local error, which can lead to a big error in the global estimate, or to give an accurate global estimate, in which case the local error could be way off the mark.

There is a limit to the usefulness of an orebody model. Geo-statisticians talk about support for estimates, size of error etc. When an orebody model gets passed to the mine-planning engineer these words of caution on using the model are very quickly forgotten. The orebody model is used to give global and local estimates without thought. On some operations the mine planning department reveres it as a shrine whereas the operations department ignores it completely because the attitude prevails of "let the planners plan their pretty mines and we will find out what is really in the ground".

We have seen cases where the first five years of an operation are planned down to monthly levels on an ore resources model with an indicated level of estimates. These mine plans were then duly passed on to a financial model where detailed analysis revealed differences of IRR's of only 0,1- 0,2%.

To bridge this credibility gap the recovered resources technique is available. It gives a good regional and global estimate without compromising the local estimate. Using this technique carries a clear warning - get more information if you want a decent local estimate!

Particularities of the RRE model

What are the particularities of a geological and ore resources model created with the RRE techniques?

1. No attempt to say exactly where the ore will be found in a block – this you have to do later when you do grade and ore control.
2. More than one grade per block is supplied - this is the most confusing aspect of the RRE technique and we will discuss this in more detail.
3. You cannot see the ore in a block - difficult to picture on screen, etc.
4. It is for a specific fleet of equipment - the model is not valid if you decide to increase or decrease the size of the equipment in the fleet.
5. The decision on or selection of equipment must be determined before the model is created. Some advance thought about how, and at what rate, you are going to mine is required.
6. It cannot be created in isolation by the geologist - some pre-consultation is necessary.
7. It requires a user instruction manual – using the model is almost impossible without instructions and some explanation about how the fields were put together.
8. It requires more understanding of the role the different disciplines will play during the extraction process.

The Format of a RRE Geological Model.

The Datamine process SMUMOD, released in 1994, can be used to create a RRE geological model. In Table 1 we show the information for one cell in a RRE geological model created for an open pit gold mine project we were evaluating in 1995.

Note that the user assigns the field names and not the SMUMOD process. In this case we selected field names that can be interpreted by a user who has been exposed to the naming convention years after the event. One hundred percent of the cell tonnage will report a gold grade of 1.139g/t (values for fields OP_0P0 and OG_0P0). Most mining engineers are used to this classical block grade of a block model. In geostatistical terms this is referred to as the block grade estimate and it is calculated with the kriging method applicable to the type of deposit.

Table 1 continues to list ore proportions (the field starting with OP_) and grades (the field starting with OG_) of these respective ore proportions for cut-offs ranging from 0.30 to 1.6 g/t. We can see on inspecting the value of the ore proportions that it decreases as we go down the column, from 100%, when no cut-off applies, to 16.4%, when a cut-off of 1.6g/t is applied.

Conversely we can see that the grade of the ore proportions increases from 1.139 g/t, when no cut-off applies, to 4,876 g/t, when a cut-off of 1,6 g/t is applied. For instance, if we apply a cut-off of 1g/t the ore proportion of this block is 25.2% with a grade of 3.608 g/t.

Field Name	Value	Field Name	Value
OP_0P0	1.0000	OG_0P0	1.1390
OP_0P3	0.5530	OG_0P3	1.9570
OP_0P4	0.4770	OG_0P4	2.2140
OP_0P5	0.4180	OG_0P5	2.4610
OP_0P6	0.3710	OG_0P6	2.7010
OP_0P7	0.3330	OG_0P7	2.9340
OP_0P8	0.3020	OG_0P8	3.1630
OP_0P9	0.2750	OG_0P9	3.3870
OP_1P0	0.2520	OG_1P0	3.6080
OP_1P1	0.2330	OG_1P1	3.8260
OP_1P2	0.2150	OG_1P2	4.0400
OP_1P3	0.2000	OG_1P3	4.2520
OP_1P4	0.1870	OG_1P4	4.4620
OP_1P5	0.1750	OG_1P5	4.6700
OP_1P6	0.1640	OG_1P6	4.8760

Table 1: Block Values of One Cell in RRE Model

This looks very interesting - increasing gold grades without doing anything except changing the cut-off grade! Have we discovered at long last the alchemists' elixir? To see where this increased gold grade comes from we can use the information in Table 1 to construct Table 2.

From Table 2 we can see that there is nothing untoward about the increased gold grades reported in Table 1. The increased grade is obtained by sacrificing total contained metal.

To visualise this type of model requires a new way of looking at the information. The RRE method hollows out a block or cell but does not tell where the hollowed out bit sits within the model. To find out where the waste sits in the model requires more information than is currently available.

CUT-OFF GRADE	ORE PROPORTION	GRADE (G/T) OF ORE PROPORTION	ORE TONNAGE FOR BLOCK WITH NOMINAL 1000t	CONTAINED GOLD (G)	WASTE TONNAGE (T)	GOLD IN WASTE (G)	GRADE OF WASTE (G/T)
0.00	100.0%	1.139	1000	1139.0	0	0	0.000
0.30	55.3%	1.957	553	1082.2	447	56.8	0.127
0.40	47.7%	2.214	477	1056.1	523	82.9	0.159
0.50	41.8%	2.461	418	1028.7	582	110.3	0.190
0.60	37.1%	2.701	371	1002.1	629	136.9	0.218
0.70	33.3%	2.934	333	977.0	667	162.0	0.243
0.80	30.2%	3.163	302	955.2	698	183.8	0.263
0.90	27.5%	3.387	275	931.4	725	207.6	0.286
1.00	25.2%	3.608	252	909.2	748	229.8	0.307
1.10	23.3%	3.826	233	891.5	767	247.5	0.323
1.20	21.5%	4.040	215	868.6	785	270.4	0.344
1.30	20.0%	4.252	200	850.4	800	288.6	0.361
1.40	18.7%	4.462	187	834.4	813	304.6	0.375
1.50	17.5%	4.670	175	817.3	825	321.8	0.390
1.60	16.4%	4.876	164	799.7	836	339.3	0.406

Table 2: Further Manipulations of the RRE Values Reported in One Cell

This information will be made available by the drilling that will be done as a matter of course during the grade control phase of the operation. We can expect that the grade control department will define the location of the ore and waste before we actually have to load this block.

The Advantages of Using This Method in Pit Optimisation.

The advantages of using the RRE approach in the Whittle pit optimiser can best be demonstrated in a working example. To illustrate how the block value is influenced we continue with the cell information shown in Tables 1 and 2. Table 3 is constructed using the following assumptions:

Block tonnage	Tons	1 000
Ore Mining Cost	US $/t mined	1.50
Waste Mining Cost	US $/t mined	1.35
Processing Cost for ore	US $/t treated	8.00
Gold Price	US $/g	10.00

CUT-OFF	ORE MINING COST	WASTE MINING COST	TOTAL MINING COST	PROCESSING COST	TOTAL COST	REVENUE FROM GOLD SALES	BLOCK VALUE
g/t	US $	US $	US $	US $	US $	US $	US $
0.00	1500.00	0	1500.00	8000.00	9500.00	11390.00	1890.00
0.30	829.50	603.45	1432.95	4424.00	5856.95	10822.21	4965.26
0.40	715.50	706.05	1421.55	3816.00	5237.55	10560.78	5323.23
0.50	627.00	785.70	1412.70	3344.00	4756.70	10286.98	5530.28
0.60	556.50	849.15	1405.65	2968.00	4373.65	10020.71	5647.06
0.70	499.50	900.45	1399.95	2664.00	4063.95	9770.22	5706.27
0.80	453.00	942.30	1395.30	2416.00	3811.30	9552.26	5740.96 *
0.90	412.50	978.75	1391.25	2200.00	3591.25	9314.25	5723.00
1.00	378.00	1009.80	1387.80	2016.00	3403.80	9092.16	5688.36
1.10	349.50	1035.45	1384.95	1864.00	3248.95	8914.58	5665.63
1.20	322.50	1059.75	1382.25	1720.00	3102.25	8686.00	5583.75
1.30	300.00	1080.00	1380.00	1600.00	2980.00	8504.00	5524.00
1.40	280.50	1097.55	1378.05	1496.00	2874.05	8343.94	5469.89
1.50	262.50	1113.75	1376.25	1400.00	2776.25	8172.50	5396.25
1.60	246.00	1128.60	1374.60	1312.00	2686.60	7996.64	5310.04

Table 3: Calculating Block Value at Different Cut-off

From inspecting Table 3 we can see the benefits of the RRE technique when using the Whittle optimiser. As the cut-off is raised there is a reduction in mining cost because not all the material in a block carries the ore mining cost. The mining cost starts from a high of US $1500 at no cut-off and drops to a low of US $1374 at a cut-off of 1.6 gram per ton. Less ore is processed and this saves processing costs. When no cut-off is applied all the material in the block is processed and the processing cost is US $8000. The processing cost drops to US $1312 when a cut-off of 1.6 grams per ton is applied. Note that gold is relatively easy to process and the ratio between processing cost and mining cost is not so pronounced as in the case of more complicated minerals like, for instance, nickel and zinc.

Overall, the cost of mining and treating the ore in the block decreases from US $9500 when no cut-off is applied to US $2686 for a cut-off of 1.6 grams per ton. This is quite substantial when the whole model is subjected to the rigors of this exercise.

In our example shown in Table 3 the best operating scenario (marked with an asterisk) for this block is a cut-off of 0.8 grams per ton.

Conclusion

We have illustrated the advantages of using the RRE techniques when dealing with an ore body at the early stages of a project. The method allows the geologists and geo-statisticians to craft a realistic model that does not compromise or stretch the available data set. If the mine planning engineers understand the advantages and benefits of using the RRE technique the pressure to create a geological model with minute cells representing bucket or truck loads is alleviated.

Rectangular blocks are easy to understand and the use of these in mine planning seems to have prevailed as we write, near the end of the 20th century. The use of sub-cells that can be used to describe very complicated geometrical shapes seems to have extended the usefulness of this system of representing the geological world of interest to miners. We can predict with confidence that this type of model, modulated with refinements like, for instance, the RRE techniques, will be around for a fairly long time and well into the 21st century.

References

Plewman, R P, 1970. *The Basic Economics of Open Pit Mining.* Proceedings of the Symposium on the Theoretical Background to the Planning of Open Pit Mines with Special Reference to Slope Stability, SAIMM Johannesburg, pp 1-7.

Lerchs, Helmut and Grossmann, Ingo, F, 1964. *Optimum Design of Open-Pit Mines.* Joint CORS and ORSA Conference, Montreal, May 27-29, 1964. Published in Transactions, C.I.M., Volume LXVIII, 1965, pp 17-24.

Stokes, W P C, 1982. *Computers in Mining: Progress and Pitfalls.* Mining Magazine - December 1982.

Henley, S and Stokes, W P C, 1984. *Improved Geological Modelling Techniques for Mine Planning.* 18th International Symposium on the application of Computers and Mathematics in the Mineral Industries, London.

Stokes, W P C, 1982. *Computers in Mining: Progress and Pitfalls.* Mining Magazine - December 1982.

Lerchs, Helmut, Stokes W P C, Lane, K F and Whittle, J are all Mathematicians by training that have helped shaped mining planning in the late 20th Century.

Henley, S, Wheeler, A J, Howe, J H, Tucker, D, 1988. *Computer Assisted Evaluation and Planning of Quarries.* 21st APCOM proceedings pp 429-441.

Kuchta, M E, 1990. *A Microcomputer Program for Teaching Computerised Mine Planning.* 22nd APCOM proceedings pp 167-176.

Ptolemy, Claudius, 2nd Century AD, Greek astronomer that fixed the earth in the centre of the universe in his work *Almagest.*

Schubert, Cameron J and Crookes, Richard A, 1993. *Tick Hill Gold Mine, Open Pit to Underground,* AIG Bulletin 14, pp 87-94.

Gooding, Kenneth, *Big Bell Strikes a Minor Chord for Owners.* 'Financial Times' 21 February 1992.

David, Michel, 1988. *Dilution and Geostatistics.* CIM Bulletin June 1988.

Coles, Alan J, Hadlow, Haydn R, Levy, Ian W, 1993. *Reconciliations at the Kundana Gold Mine, Western Australia,* AIG Bulletin 14, pp 95-102.

Taylor, H K, 1985. *Cut-off Grades - Some Further Reflections.* Trans Instn Min Metall (Sect A Min industry), Vol 94, October 1985.

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