Deep level mining and the role of R&D

by R.G.B. Pickering*

Synopsis

The Faculty of Engineering at the University of the Witwatersrand and the Mining Technology Division of the CSIR have co-operated to define the problems associated with deep level mining and in this paper they will identify what they consider to be the critical areas requiring technological solutions. This perspective will then be applied to work currently being carried out by both the organizations and gaps for additional developments will be identified. Finally the Co-operative Research Centre methodology operating in Australia is described. The purpose of this CRC is to provide a vehicle for R&D co-operation to develop and implement technologies which will increase the competitiveness of the mining industry. A further objective is to develop an appropriately skilled human resource base.

Introduction

Mining, by definition, is a process which depletes a natural resource. It starts with the recovery of the easy resources and progresses to more and more difficult resources. As the difficulty of recovering the resource increases so the planning and the technology employed must be improved if the cost of recovery is to be contained. In the early days of the Witwatersrand the reef outcropped on surface, was extensively weathered, and of high grade. This made it possible to extract the gold with relatively simple tools. However, it soon became necessary to import capital equipment and introduce new technology as the depth increased. Without the introduction of the McArthur-Forrest Cyanide Process it is likely that the fledgling Witwatersrand mining industry may not have survived to see the start of the 20th Century let alone head into the 21st Century.

Gold production peaked in 1970 with some 1266 tons being produced. Over the last 25 years production has decreased with 517,2 tons being produced in 1994, 491,9 tons in 1995 and 119,1 tons in the first quarter of 1996 (some 3% down in 1995). Table 1 shows how the revenue from 1995 was distributed. The figures clearly show that the output of the gold mining industry and its contribution to the wealth of the country is decreasing but with gold contributing close to 50% of total mineral revenue it is clearly the most important player. The challenge is to develop technology which will enable the gold mining industry to increase its competitiveness.

Table I

Breakdown of revenue SA Gold Mines: 1995

	Rand (million)	Revenue %	Sub section %
Revenue	21 703		
Costs	18 301	84.3	
Labour costs	9 883	45.5	54.0
Consumables/ stores	8 418	38.8	46.0
Capital	2 641	12.2	
Profit	3 402	15.7	
Taxation	573	2.6	16.8
Dividend/retained earnings	2 829	13.0	83.2

Gold sources

The resources of the Witwatersrand basin are massive and it has been estimated that only 40% of the available gold has been recovered. Figure 1 attempts to predict where the future mining will take place and it is considered that the single most important parameter will be increased depth. Figure 1 shows that currently only approximately 10% of the SA gold production comes from depths greater than

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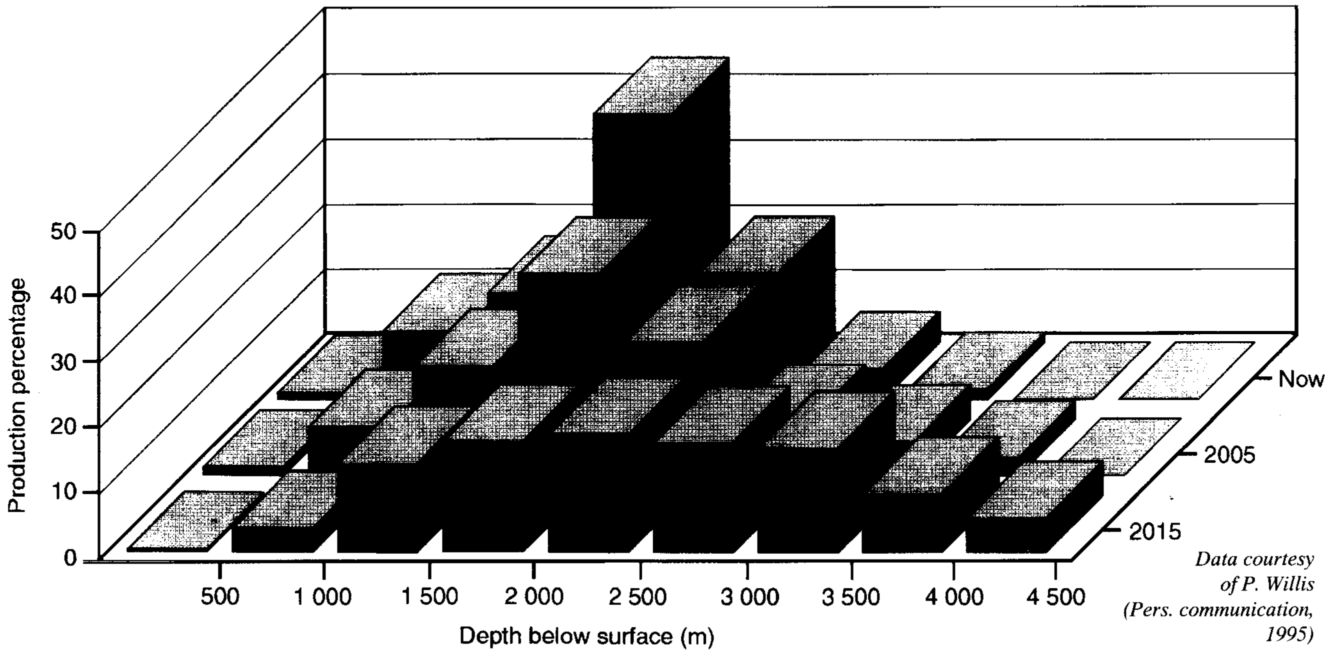

Figure 1—Percentage production versus time and depth below surface as determined and projected for the gold production from the Witwatersrand basin

2500 m, however, by the year 2015 close to 50 per cent of production will be at depths greater than 2500 m. This picture is based on the assumption that the gold price and potential technology changes are not going to change the economics of mining the shallower deposits and that we have the technology to mine the deeper deposits. The gold price is obviously a major player in mine economics and in the early 70s we saw a number of mines which were being closed suddenly getting a new lease of life. The technology of mining has seen little change in this century with pneumatic rockdrills in the early part of the century followed by the water hydraulic rockdrills more recently; the use of scrapers introduced in the late 1920s; hydraulic prop support in the 1960s; a considerable incremental improvement in our understanding of how to design mines to reduce the effects of seismic activity; and the development of chilled water and ice for cooling. The majority of the technology changes have been incremental and have been constantly stretched to meet the demands of the industry.

Nature of the problem

Much has been written about the reasons as to why the gold mining industry has become one of the highest cost producers of gold. The following sections are an attempt to categorize the problem and identify what technological developments are necessary.

Gain advance knowledge of geological structures and gold distribution

With the increasing costs associated with deeper mining and the low grades in shallow mining areas, it is essential that payable areas are identified ahead of mining to avoid unprofitable effort and to maximize grades into the mill. Reliable advance information, obtained cost-effectively, is therefore required on various aspects of the orebody and its surrounding geology in order to enhance mine planning and operational management decisions. The information required includes the location of the orebody, the location and orientation of geological structures such as faults and dykes, and the grade distribution both laterally and vertically within the orebody. This information would not only assist in mine planning for new areas but would also assist in more effective selective mining in mines already developed.

Provide rapid access to reef plane and stopes

There is a need to maximize capital utilization by providing more rapid access to the reef plane through faster shaft development and longer single shaft systems, as well as providing for more rapid horizontal development. There is also a need to transport men and materials to the stopes as quickly as possible. In addition to maximizing the efficiency of those operations, the interface between the transport and stoping systems needs to be optimized both for conventional and on-reef mining methods.

Develop new and improved mining methods

The actual mining process on gold and platinum mines influences some 50 per cent of total mining costs while footwall development accounts for a further 15 per cent. A large portion of these costs are associated with infrastructure requirements. There is thus a need to effectively minimize the infrastructure required by maximizing the utilization of working faces and by minimizing the amount of development work. This can be achieved through the development of new improved stoping systems, both continuous and with high rates of face advance, which form the basis for determining new and improved mining methods and layouts, such as on-reef mining, and hence minimizing the development capital required and operating costs. There is also a need to develop more effective selective mining methods to maximize potential in existing mining areas. As the potential for the development of continuous mining systems is largely restricted by blasting, the emphasis in developing such systems should be in the area of alternative rockbreaking methods.

Deep level mining and the role of R&D

Rock engineering as a tool to facilitate the reduction of rock related hazards

Rockfalls are responsible for a large proportion of all injuries, and more than 25 per cent of fatalities. Improved mine design and rock support methods are necessary to implement safer and more productive mining methods and layouts. The implementation of efficient and effective stope face and gully support systems, especially in high stressed areas, has the potential to dramatically reduce rockfall casualties in gold and platinum mines as well as the potential to reduce dilution. Also, an understanding and implementation of design rationale for the design of permanent and regional stope support (especially backfill and pillar design) has the potential to both reduce rock related casualties and reduce stoping and development costs. Increased implementation of existing technology and equipment is a critical factor within this area.

With mining continuing to go deeper, particularly in the longer term, the problems associated with rockbursts dominate the ability to mine safely. At present, rockbursts are responsible for a large proportion of all injuries, and for a further 25 per cent of fatalities, and they often cause serious production losses. Rockburst prediction and control techniques using seismic management and engineering techniques are necessary to help reduce the incidence and severity of the rockburst hazard. Strategies, methodologies and technologies for seismic monitoring, analysis and interpretation in rockburst prone mines should define where and indicate when sudden release of large amounts of energy can occur allowing action to avoid or minimize losses and save lives. The successful use of appropriate rockburst control techniques will allow inaccessible ground to be mined safely and improve the safety of existing mining layouts at deep levels. As much as 25 per cent of a mine's ore reserves may be locked up in pillars and the techniques will assist in releasing these reserves.

To facilitate an improvement in the basis for controlling rockbursts and rockfalls, fundamental research into the behaviour of the highly stressed fractured rockmass is essential. This may be achieved by using numerical techniques to simulate the mechanics of rockbursting and fault slip seismic events and to define fracture mechanisms and hence methods for controlling the failure of rock in a stable manner. The analyses of seismic events also has the potential for creating a more quantative understanding of rockmass behaviour. Improved understanding also has the potential to result in the introduction of innovative mining strategies; this includes items such as preconditioning, mining close to geological structures, the evaluation of different support methods and novel mining layouts.

Provide acceptable underground environmental conditions at minimum cost

With mining activities taking place at greater depths and the corresponding high virgin rock temperatures, the provision of cooling and ventilation is becoming ever more costly. Techniques for providing underground environments, which allow men to work safely and productively are thus required at minimum cost. Novel cooling systems and new approaches, such as selective cooling of mines and recirculation, may enable the cost-effective cooling and ventilation of deeper workings. Reducing heatflow at source through methods such as the insulation of tunnels and novel layouts could reduce cooling costs. Software as a design tool for ventilation and cooling systems needs to be continuously upgraded to expand the applications in the industry and thus ensure cost-effective systems. The control or reduction at source of noise, dust, diesel emissions and other harmful gases is also required. Improved lighting conditions should lead to improved safety and productivity.

Future mining systems

The main objective of all mining systems is *safe production* which is a term intended to include the philosophy that occupational health and safety, and production should not be separate issues. Whatever mining method is utilized, it must ensure an acceptable quality of life for those working in the industry and an acceptable return on investment for those who finance the venture. The concept of safe production unites the sub-objectives into a common goal.

Concentrated mining

Concentrated mining is the single most important feature of future mining systems as it makes it possible to maximize the benefits obtained from ventilation, cooling, transportation, and general services reticulation. The cost of supplying all these services increases as depth increases and for a given tonnage hoisted the extent of the services network is directly proportional to the rate of force advance. The average rate of force advance is about 6 m/month with a good mine achieving 18–20 m/month. It is considered that with incremental modifications to existing technology it would be possible to obtain a face advance of 25 m/month. The challenge is to ensure that the incremental improvements in all the elements of the mining operation can be combined into a practical mining system.

As any mining man will know, the problem with concentrated mining is perceived to be a concurrent lack of flexibility and the ability to 'make a plan' when things go wrong. Therefore the future mining system must ensure that there are no surprises related to *grade continuity, reef discontinuities, rock bursts* and *services reliability*.

There are techniques to evaluate grade continuity, determine reef discontinuities and to evaluate where seismic events are most likely to occur. There are methodologies and monitoring devices to ensure that services are reliable and performing effectively. However, it is questionable that the information is sufficient to ensure 'no surprises'. A major effort should go into implementing existing technology and creating a practical harmonious whole.

Waste rock

A mine is defined as an excavation in earth for extracting metal, coal, salt, etc. Thus the purpose of a gold mine is to mine gold, unfortunately current mining practices ensure that a large amount of waste rock is also mined. Some of the waste rock will be hoisted as waste as it was broken from tunnels which provide access to the reef; other waste rock will be broken from around the reef and because it is mixed with the reef it will be treated as reef. It is important to maximize the ratio of reef tons to development tons and to ensure that stope width is as close as possible to channel width.

Mine startup

The issues described in the previous two sections refer to operating mines, however, the costs involved in starting a mine are very large and it may take 10–14 years from start-up before the mine experiences a positive cash flow. The main start-up costs are those incurred in accessing the ore body and, for example, the time and costs associated with a vertical and sub-vertical shaft system are substantially more than a single shaft.

Once the shaft is in, then extensive development is required to access the ore, this may require 10–15 km of development before stoping can commence on any reasonable scale and each heading would only advance at ±110 m/month. Thus technologies permitting deeper single shafts and more rapid rates of development could play a major role in the economics of opening up new resources.

Proposed co-operative research methodology

Both the Faculty of Engineering at the University of the Witwatersrand and the Mining Technology Division of the CSIR have extensive experience in mining R&D. Miningtek is involved in nearly all the areas identified in this paper. Wits is conducting specific research to develop new vertical transport systems, non-explosive rockbreaking techniques and more efficient scraper motors. The two organizations are already working closely together in the field of rock engineering and in developing ways of counteracting the effects of the high heat loads generated in deep level mining. In the long term it is the objective of both organizations to develop technology to enhance the viability of the mining industry and to develop skilled human resources. The following is an example of how the mining industry, the researchers and the academics could co-ordinate their activities for the general good of the mining industry and the country.

The co-operative research centre for mining technology and equipment

The CMTE was established in 1991 as part of the Australian Government's Co-operative Research Program. It was considered that despite access to vast mineral reserves and strengths in research and development; the mining industry faced important technological problems. To remain competitive on the world scene it needed to lower production costs and invest in higher quality products and processes which were more environmentally friendly. The CMTE brought together, for the first time, Australia's leading mining and mineral research organizations in a co-operative effort to develop innovative mining and processing techniques and supporting equipment for the industry.

The CMTE is an unincorporated joint venture between the University of Queensland, the Commonwealth Scientific and Industrial Research Organization and the Mineral Industries Research Association.

The university is represented by:

- The Julius Krattschnitt Mineral Research Centre
- The Department of Mining and Metallurgical Engineering
- The Bryan Mining Geology Unit.

The CSIRO participants are the Divisions of Geomechanics, Mineral and Process Engineering and Manufacturing Technology.

AMIRA serves the common interests in research and development activities of its members, namely the minerals, coal and petroleum companies of Australia. The association works exclusively in the area of collaborative research where its members see benefit in sharing costs, risk and outcomes. AMIRA has no facilities and contracts out all projects to universities, public sector research organizations and private industry.

The CMTE defines its income as coming from industry, from a CRC grant and in-kind contributions from partners. In-kind contributions from CSIRO and the University of Queensland are effectively government money whereas AMIRA in-kind contributions are from the mining industry. The total contract income from industry was A$ 3 000 000 and the CRC grant from government was A$ 3 166 000 in 1995.

A further objective of the CMTE is to develop an appropriate human resource base and Table 2 shows how resources are divided across the CSIRO staff.

This is being achieved by involving postgraduate students in the leading edge research projects which are being undertaken by the Centre and by employing a significant number of postgraduate students in these projects. There are currently 14 PhD and 9 MSc students with three PhD and 1 MSc theses having been submitted.

Table II

Research projects — staffing

Research projects/ staff	CSIRO	University		Total
		Staff	Students	
Metalliferous mining	7	4	4	15
Metalliferous processing	3	5	10	18
Coal processing	10	6	2	18
Mining	5	–	4	9
Equipment	2	2	–	4

Conclusion

It is probably fair to say that work to address most of the issues identified is going on at either Wits or Miningtek. For example Wits is investigating a synchronous linear motor which could be applied to mine shafts much deeper than can be serviced by conventional hoisting. Miningtek is looking at ways to continuously develop the hamolages at rates of two to three times those currently achieved. Both institutions are actively involved in establishing a better understanding of the rock mechanics to ensure safer mining and in the development and application of a healthier environment. These activities tend to be isolated and there is no 'grand plan' which would ensure that the possible synergies between the various sub-sections of the two institutions are realized.

The model employed by the CMTE in Australia deserves consideration as a way to harness the potential of the research organizations, academics and the industry to ensure that we have a vibrant mining industry well into the next century, which in turn acts as a wealth engine for the creation of jobs. ◆

Identifying profitability and safety 'hot spots' on your mine

by R.G.B. Pickering* and S.G.E. Ashworth*

Introduction

Successful management of mining operations depend on the accurate and reliable measurement of performance as a monitoring instrument in a feedback and control loop. However, when changes are being considered, the probable effect of the change on bottom line results requires different measuring techniques incorporating an in depth understanding which can identify hot spots in the operation which exhibit strong sensitivity to change.

The CSIR's Division of Mining Technology has therefore been devoting a considerable effort to the establishment of techniques which enable changes to be analysed in terms of their impact on the two key parameters describing mine performance, i.e. profitability and safety. This paper describes these techniques, outlines their application to some example situations and discusses planned enhancements.

The first section of the paper addresses the profitability model, and this is followed by a section considering the mine safety model.

The mine profitability model

It is trite to state that profit is equal to revenue minus cost and yet, when profit is measured in Rands, revenue in Rands per gram and costs in Rands per ton, it is easy to see how the message can be diluted. In the 1980s, the common wisdom in the gold mining industry was that the hoisting of more tons was a solution to falling profits as, with higher tonnage, overhead costs would be distributed over a larger base and costs per ton hoisted would be reduced. The argument is correct but the flaw was that the grams of gold in each ton hoisted were also reduced, resulting in revenue decreasing at a faster rate than costs; the net result of lower working costs was thus lower profits. Currently, substantial effort is being spent convincing the authorities of the need to work a seven day week with the argument being similar: spread the overheads over a greater base. However, the more effective way to increase profits is through the introduction of new technology, and in this context new technology is any technology which is not being used by the mines. The new technology can be introduced as new tools, new mining methods, or new procedures.

Fundamental to determining the effect of new technology on profitability is an in-depth understanding of typical running cost distribution on the mines.

Working cost distribution

Mine working cost control procedures tend to be structured around management responsibility areas. Using this system, for example, direct mining costs associated with the mining production departments may be categorized broadly into stoping, development and transport costs. Services costs associated with these activities, such as ventilation and refrigeration costs, are not considered as environmental services costs, while charges relating to supervisory labour are regarded as general or management services costs.

Although appropriate for operational control purposes, responsibility-based approaches such as this, because of their generalized nature, are not suitable for determining the true cost of mining activities required for the financial evaluation of new technology. This, rather, requires a cost allocation system which acknowledges the actual mining activities taking place rather than how the operation is being managed.

The generalized nature of the 'responsibility-based' cost accounting system is illustrated in Figure 1; the values used in this figure are taken from a representative deep level West Witwatersrand gold mine for the period April 1990 to June 1990. A high percentage of these costs (46%) are allocated to services. To ascertain the true distribution of working costs between the primary mining activities of development, stoping, transport, reduction and genuine overheads, a series of linked LOTUS 1-2-3 spreadsheets has been created. This model adopts a total cost approach and accounts for all costs, direct and indirect. Results from using this model to redistribute the service costs are presented in Figure 2, which shows that stoping and development influence 64 per cent of total mining cost, compared with 39 per cent when using the 'responsibility-based' approach.

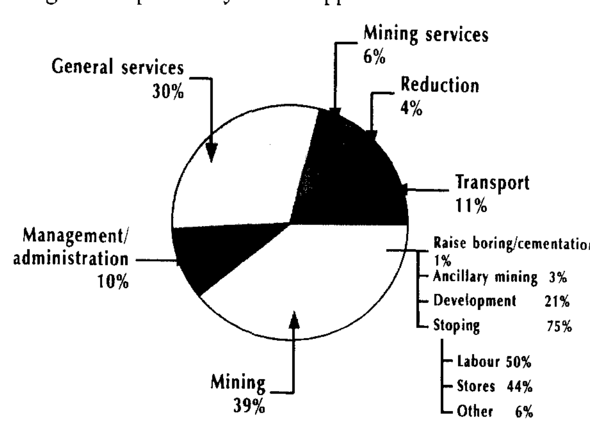

Figure 1—Responsibility costing

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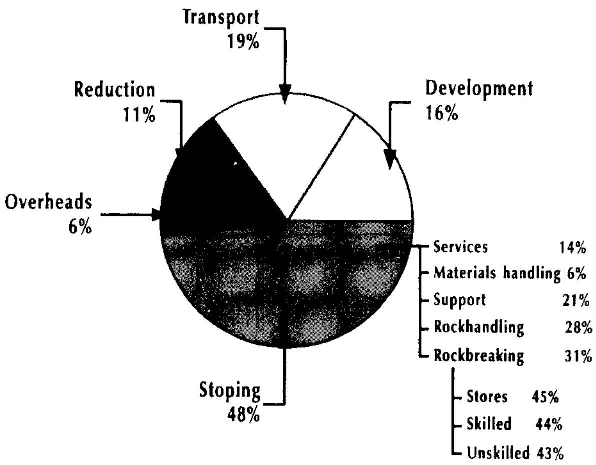

Figure 2—Activity costing

Economic modelling

Having developed a method of redistributing both the management cost and the statistics information from responsibility costing to activity-based costing, it was then possible to develop an incremental analysis type economic model which would provide a rapid means of estimating changes to working cost and revenue following changes to the mining system. The model is shown schematically in Figure 3 and is used to compare a proposed change to a system with an existing mining method. To facilitate comparison, the model is structured around a 'Minimum Production Unit' consisting of a single-sided raise connection. This unit of comparison can be varied to suit local requirements but must remain small enough to allow comparison of the component parts of the new mining system, layout or technique.

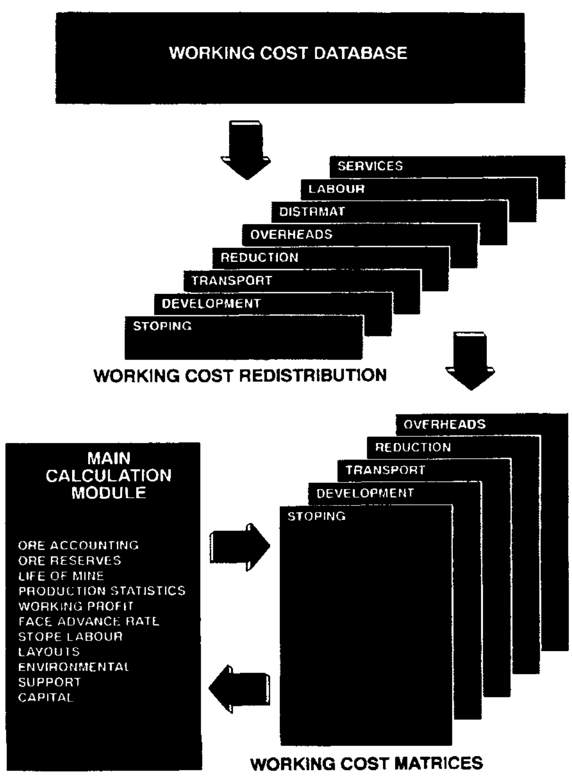

Figure 3—Schematic representation of model structure

It must be stressed that using this approach results in the evaluation of proposed changes relative to a performance 'snapshot', which is relevant only to the mine under consideration. However, it is anticipated that the trends which are established will be applicable to similar operations within the mining industry.

Using the model, the profit sensitivity to the parameters of dilution, face advance rate, and development ratios has been evaluated for a marginal West Rand gold mine using conventional stoping techniques.

Dilution

In narrow reef mining, the main causes of dilution are the mining of a stoping width in excess of the channel width and the digging of large gullies. Improved stope width control can be achieved through the use of controlled rockbreaking techniques, either explosive or non-explosive, and effective stope support systems which control fractured rock under both dynamic and static loading conditions. The size and extent of the gully system are almost entirely dependent on the rockhandling method used. Figure 4 shows the impact on profitability of variation in both stoping width and gully cross-section. Stoping width shows the highest sensitivity, a 10 per cent change resulting in a R10/ ton change in working profit. For this particular mine, gullies are small and their excavation has a limited effect on profitability.

Face advance rate

Increased rates of face advance are desirable as they lead to a concentration of mining activities and associated cost savings, which are achieved through minimizing the reticulation of services to the mining activity and through intensified utilization of equipment. Figure 5 shows the improvements in face advance rates, and their effect on profitability, following changes to mining cycles, lost blast rates and advance per blast. It is interesting to note that a change from a blast cycle of once every three days to twice every three days would increase profitability by R12/ton milled. By obtaining the maximum advance which could be achieved from 1,2 m long holes drilled at 70° to the face, a cycle of blasting every second day would increase profitability by R14/ton milled.

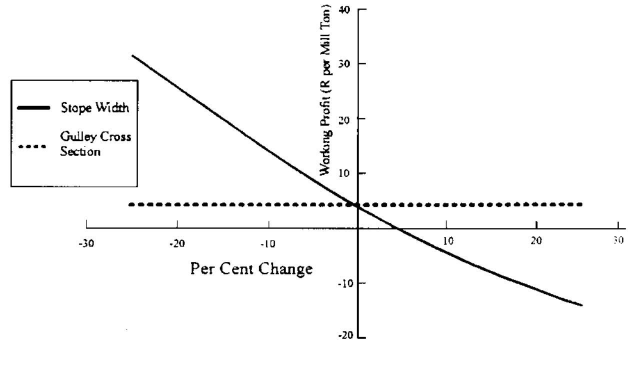

Figure 4—Effect of stope width and gully cross-section on profitability

Identifying profitability and safety 'hot spots'

Reduced off-reef development

A reduction in waste mining will result in reduced working costs through improved labour utilization and lower use of consumables, coupled with increased ore hoisting capacity. Development ratios, measured in m^2 (of stoping)/m (of development), can be increased by improving mining layouts through the utilization of new technologies that increase the distance, in both dip and strike, over which rock and material can be transported. Figure 6 shows the effect of changes in primary development (footwall and cross-cut excavations), secondary development (raising and boxholes) and in-stope development (dip and strike gullies).

In this example, the maximum benefit comes from primary development with a 20 per cent change in development ratio resulting in a profit increase of less than R3/ton milled. However, the major savings possible from reducing the number of levels were not included in the analysis.

Additional analysis

Using the economic model described in the previous section, a further eight mining operations have been analysed in the period June 1993 to March 1994. These mining operations included gold and platinum, the depths varied from 100 m to 2800 m and the mining methods evaluated included

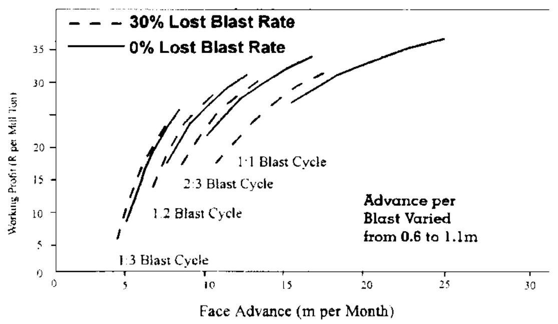

Figure 5—Effect of lost blast rate, blast cycle and advance per blast on profitability

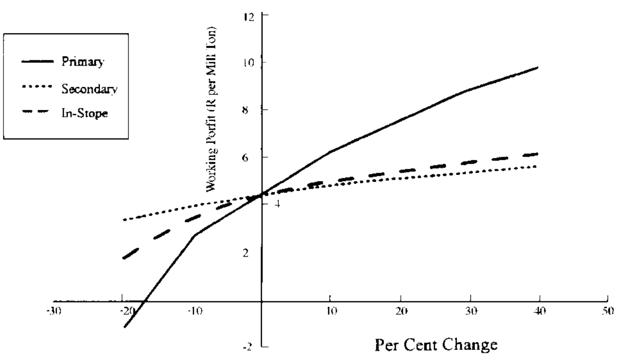

Figure 6—Effect of primary, secondary and in-stope development ratio on profitability

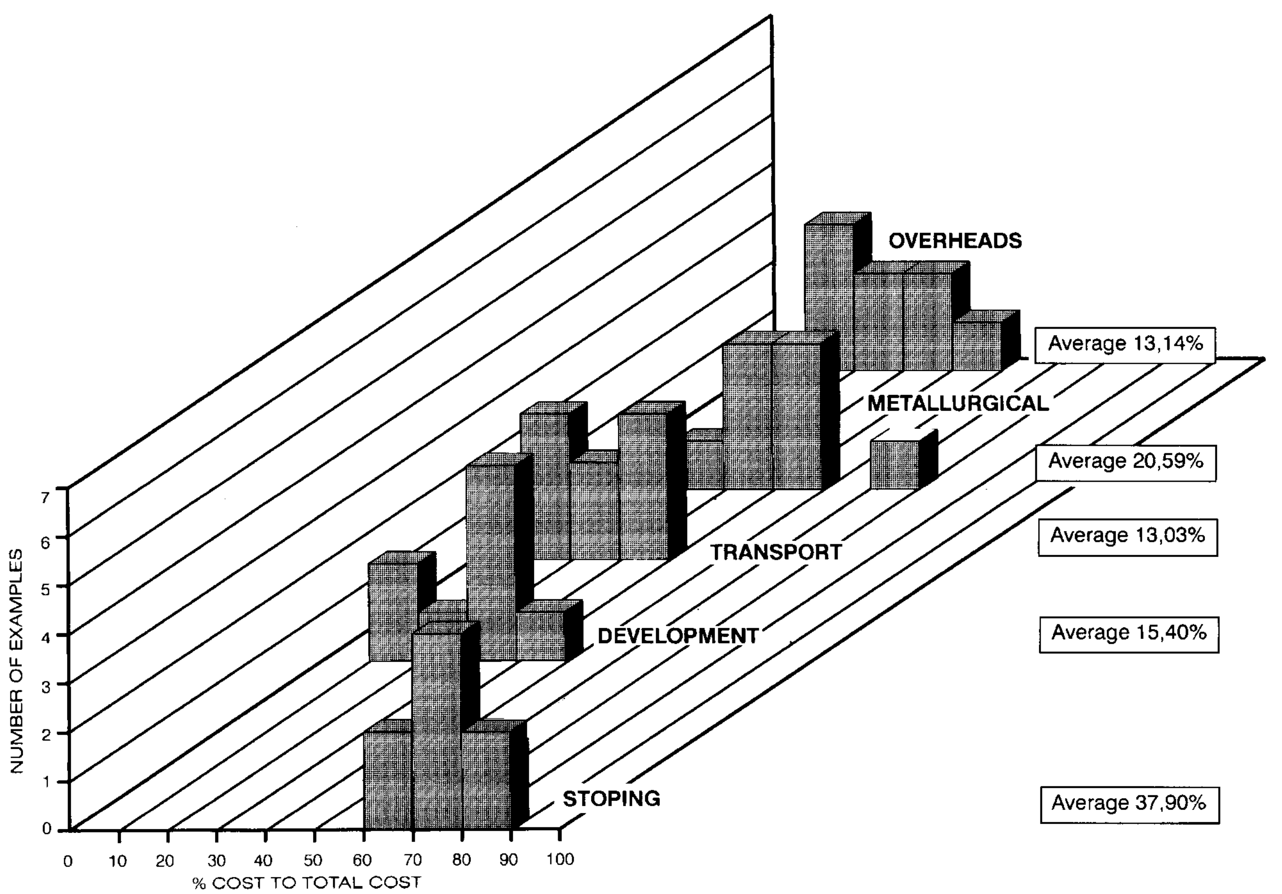

Figure 7—Percentage distribution of working costs - by activity

Table 1

Analysis of working results — gold mining members of the Chamber of Mines - October to December 1993

ANALYSIS OF WORKING RESULTS - GOLD MINING MEMBERS OF THE CHAMBER OF MINES - OCTOBER TO DECEMBER 1993

REF NO	QUARTERLY ANALYSIS OF WORKING RESULTS / MINE	DECLARED RESULTS OF OPERATIONS FOR THE GOLD: ORE MILLED metric tons 1000	PRODUCTION kilograms fine TOTAL	PRODUCTION GRADE grams per metric ton milled	WORKING REVENUE (a) Total R1000	WORKING REVENUE (a) Per metric ton milled R	WORKING COST (b) Total R1000	WORKING COST (b) Per metric ton milled R	WORKING COST (b) Per kilogram R	WORKING PROFIT Total R1000	WORKING PROFIT Per metric ton miled R
	A. GOLD PRODUCERS (Including producers of uranium as a by-product)	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
1	Barberton	32	295,0	9,22	11265	352,05	9732	304,14	32991	1533	47 91
2	Blyvooruitzicht	481	1559,0	3,24	57809	120,18	60599	125,98	38870	* 2790	5 60
3	Bracken		6,0	58,82	306	3000,00	985	9656,86	164167	* 679	6656 86
4	Buffelsfontein (Buffelsfontein Section)	547	3500,0	6,40	132043	241 39	109815	200,76	31376	22228	40 63
4A	Buffelsfontein (Beatrix Section	534	3401,0	6,37	128463	240,57	77632	145,38	22826	50831	95,19
5	Deelkraal	367	2202,6	6,00	87784	239,19	70552	192,24	32031	17232	46 95
	Doornfontein	328	949,4	2,89	38149	116,31	34850	106,25	36707	3299	10,06
	Driefontein Cons. (East Driefontein)	715	7506 0	10,50	296756	415,04	140676	196,75	18742	156080	218 29
7A	Driefontein Cons. (West Driefontein)	710	7628,8	10,74	303129	426,94	157209	221,42	20607	145920	205 52
7B	West Driefontein Reclamation		358,2		14377		7021			7356	
8	Durban Deep	523	1098,0	2,10	40192	76,85	47643	91,10	43390	* 7451	14 25
9	E.R.P.M.	748	1869,0	2,53	73152	97,8	77364	103,43	40955	* 4212	5 63
10	Elandsrand	548	4264,0	7,78	169171	308,71	108476	197,95	25440	60695	110 76
11	Free State Cons.	6066	28147,0	4,64	1130863	186,42	910293	150,06	32341	220570	36 36
11B	Free State Cons. Metallurgical Scheme		629,0								
12	Grootvlei	120	660,0	5,50	24859	207,16	21788	181,57	33012	3071	25,59
13	Harmony - Underground Operations	1514	5111,0	3,38	189371	125,08	187584	123,90	36702	1787	1 18
13A	Harmony - Surface Operation	97	215,0	2,22	7965	82,12	2364	24,38	11000	5601	57,74
14	Hartebeestfontein (High Grade)	798	7342,0	9,20	287947	360,84	202838	254,18	27627	85109	106 66
14A	Hartebeestfontein (Low Grade)	491	712,0	1,45	28489	58,02	11340	23,10	15927	17149	34,92
15	H.J. Joel	149	886,0	5,95	33736	226,42	33017	221,59	37265	719	4 83
16	Kinross	477	3195,0	6,70	122256	256,30	77534	162,55	24267	44722	93,75
17	Kloof (Kloof)	540	7527,8	13,94	300830	557,09	156354	289,54	20770	144476	267 55
17A	Kloof (Leeudoorn)	315	2213,6	7,03	88673	281,50	73859	234,47	33366	14814	47 03
17B	Kloof (Libanon)	465	2685,1	5,77	107155	230,44	97307	209,26	36239	9848	21 18
18	Leslie	104	689,0	6,66	26412	255,19	19280	186,28	27983	7132	68 91
19	Loraine	467	1535,0	3,29	63880	136,79	61808	132,35	40266	2072	4 44
20	Randfontein	2037	81187,0	4,02	320578	157,38	226784	111,33	27701	93794	46 05
21	St. Helena (St. Helena)	200	1349,0	6,75	52351	261,75	40156	200,78	29767	12195	60,97
	St. Helena (Oryx)	10	12,0	1,19							
–	Stilfontein	275	274,0	1,00	10445	37,98	8921	32,44	32558	1524	5 54
23	Unisel	150	944,0	6,29	36202	241,35	31188	207,92	33038	5014	33 43
24	Vaal Reefs	2951	19239,0	6,52	756907	256,43	519641	176,05	27010	237266	80 38
25	Western Areas	586	4300,0	7,34	168112	286,88	124338	212,18	28916	43774	74 70
26	Western Deep Levels	1688	11210,0	6,64	445349	263,83	308113	182,53	27486	137236	81 80
27	Winkelhaak	415	2730,0	6,58	104507	251,82	84235	202,97	30855	20272	48,85
	TOTAL & AVERAGES	**25448**	**144449,5**	**5,64**	**5659483**	**221,92**	**4101296**	**160,95**	**28541**	**1558187**	**60,96**
	Rand Mines Milling		1058,1								
	Other		2089,8								
	TOTAL		147597,4								

* working loss

In addition, gold production by non-chamber members has been ascertained to be 9892,2 kgs.
Free State Cons. North & South Regions merged on 1 April 1993 to form Free State Cons. Gold Mines
Free State Cons. Gold Mines Metallurgical Scheme's working profit is included in the sundry revenue of Free State Cons. However, the production is excluded from grade calculations for industry totals.
Driefontein Cons. (West Driefontein) - The gold production revenue, costs and profits from the reclamation plant are included in industry totals but are excluded from grade, costs per kilogram and per ton milled calculations for and industry totals.
St. Helena (Oryx Mine) - Ore milled and gold production included in totals but excluded from costs per kilogram and per ton milled calculations for industry totals.
Bracken and Marievale ceased Chamber membership as from 1 November 1991.

trackless, scattered and longwall mining methods. The purpose of this section is to summarize the results obtained from the analysis.

Working costs

Typical results for the gold mining members of the Chamber of Mines are shown in Table 1. From this table it can be seen that costs in Rand per ton milled vary from approximately R110/ton to approximately R290/ton. Costs lower than R110/ton usually imply that the mine is milling surface rock from its rock dumps. The mining operations sampled had working costs which varied between R95/ton and R228/ton. The lower costs were associated with particularly well run sections of the mine.

Percentage distribution of working cost by activity

The bar chart shown in Figure 7 shows how the working costs are distributed as a percentage of total working cost. Even though working costs varied by a factor of 2,4 the distribution of activity costs was remarkably consistent with stoping accounting for close to 40 per cent of costs and the other four elements accounting for approximately 15 per cent each.

Activity cost distribution — stoping

Stoping accounts for close to 40 per cent of total mining costs and Figure 8 compares the costs of the various stoping activities. The basic mining activities of rockbreaking and rockhandling make up nearly 60 per cent of stoping costs. Thus stope rockbreaking and rockhandling account for 25 per cent of total working cost and changes in either activity will not only change working costs but may dramatically change mining methods and overall mine profitability.

Activity cost distribution — development

Development accounts for 15 per cent of total mining costs and Figure 9 shows the cost of the various development activities. The total cost of driving a development end heading averages at R127/ton or, for a 3,5 × 3,5 m heading, R4200/m developed. The high cost of development end rockbreaking (47,31/ton) compared with stope rockbreaking (R17,50/ton) reflects the benefit of an additional free face in stoping. The high cost of development rockhandling (R31,66/ton) compared with stope rockhandling (R15,08/ton) shows the difficulty of loading rock in a confined area. Considering that the South African gold mining industry drives approximately 1000 km of development heading per year, the industry would benefit from improved development end rockbreaking.

Activity cost distribution — transport

Total cost of transportation of men, material and rock between surface and stope or development end accounts for

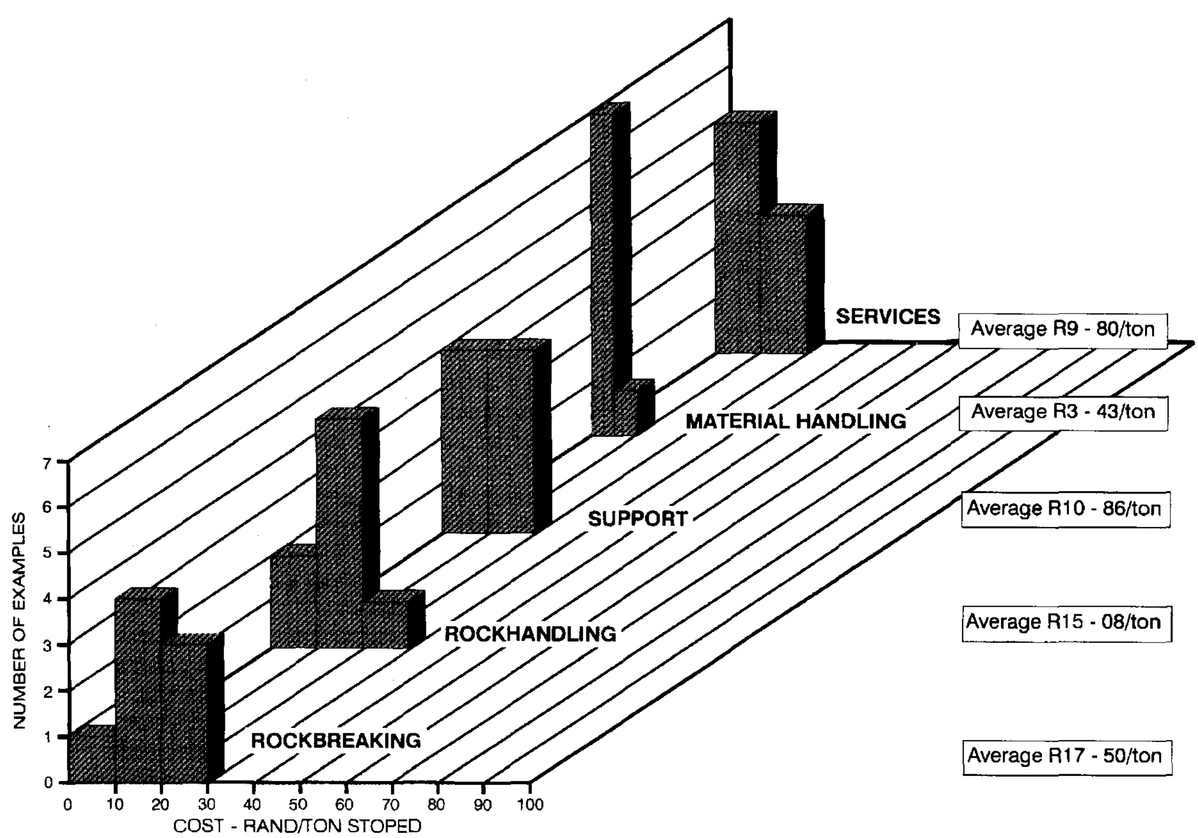

Figure 8—Activity cost distribution - stoping

13 per cent of total mine working costs. If all transport costs are converted to Rand/ton trammed then horizontal transport costs account for R7,92/ton and hoisting costs are R10,35/ton, as shown in Figure 10.

Activity cost distribution — metallurgical and overheads

Figure 10 shows the activity cost distribution for the metallurgical processing and those overheads that cannot be distributed. Metallurgical costs are typically 20 per cent of total cost and average R29,26/ton treated. Overheads are 13 per cent of total cost and average R18.60/ton milled.

Sensitivity to change

Direct changes in working costs will have an impact on profitability. However, it is also necessary to evaluate the benefits from change in layout and more efficient stoping operations. Figure 11 shows the impact of changes in development ratios, increase in face advance rate, and decrease in stoping width. ◆

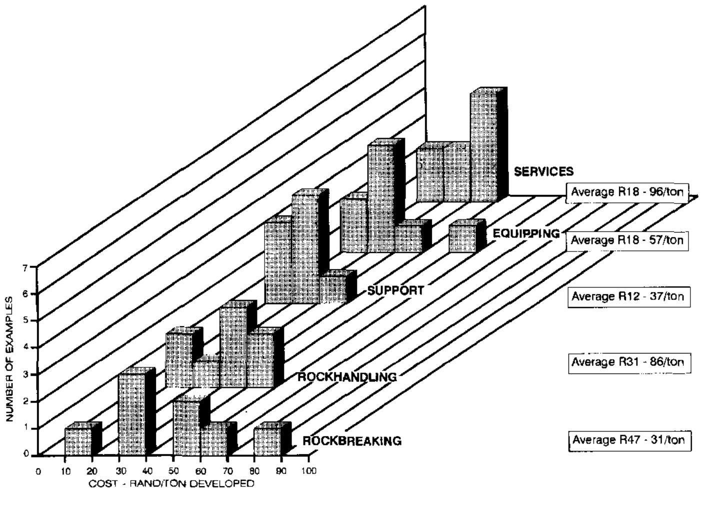

Figure 9—Activity cost distribution - development

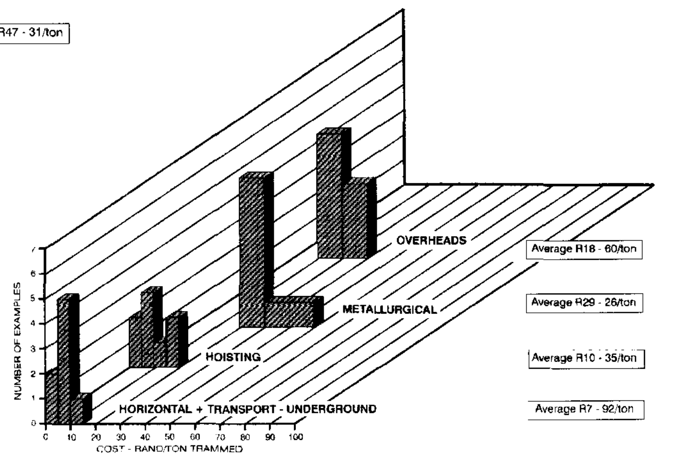

Figure 10—Activity cost distribution - transport, metallurgical, and overheads

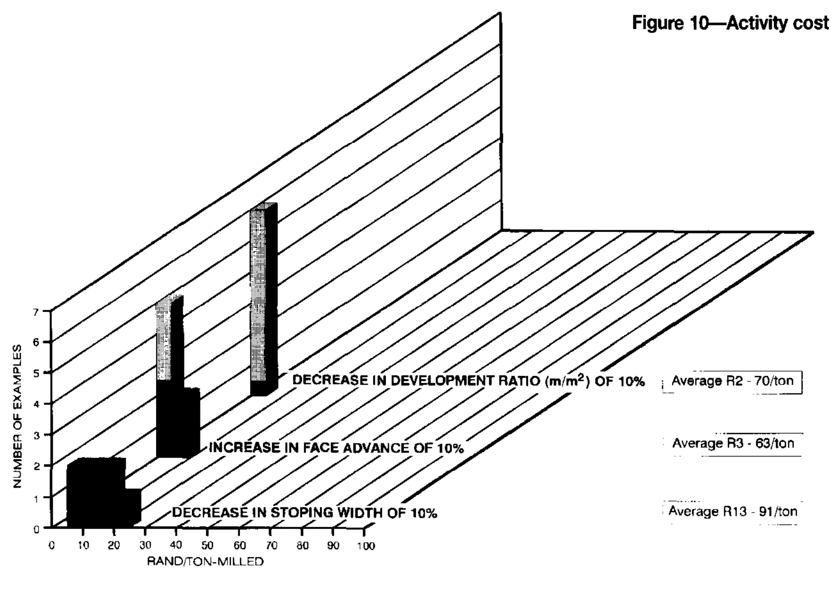

Figure 11—Sensitivity to change

Selective blast mining in gold mines

by I. Bock*

Summarized overview

This presentation describes a technique under development referred to as Selective Blast Mining. The technique involves millisecond sequential blasting. It applies to mines where the gold bearing conglomerate band is clearly demarcated, and separated from the waste rock in the foot and hanging wall. The width of the conglomerate band should be less than ± 0,7 metres.

A research program was initiated in August 1994 by Drs R.E. Robinson and I.E. Bock. The objectives were to develop new blasting methods that can reduce:

- the losses of gold in narrow reef stoping. Losses of gold can be as much as 10–15%
- and to introduce selective mining to reduce ore dilution with waste rock.

Solutions to these problems seemed possible with the advent of new blast initiation techniques.

The newly developed ability to detonate individual holes in a prescribed sequence at time intervals of the order of milliseconds provides for an interactive and reinforcing effect which throws the broken rock at right angles from the stope face at high velocity. These initiation systems also offer opportunities to improve safety at the stope face by introducing well distributed roof support immediately after the blast.

The techniques being developed represent a rejuvenation of the known Resue Mining practices. Resue Mining's limitations of intermittent face advance, and hanging wall problems until the ore is lifted can be overcome by Selective Blast Mining.

- In Selective Blast Mining the waste rock is cast blast into the back-fill region. The cast blast gives an immediate roof support, and might replace roof support, and/or back-fill. This can (potentially) dramatically reduce the occurrence of pressure burst at the face.

  A second stage of the same blast then fragments the gold bearing ore, with minimal explosive energy being applied in the ore body, and with minimal spatial displacement of the rock. The gold bearing conglomerate is thus only fractured. Robinson has been examining the problem of gold losses during blasting for many years. He points out that the gold is situated in fine particles in the fracture planes of the conglomerate. A significant portion of the gold is released as fine particles (often associated with light carbonaceous material) which can be carried away from the collection areas by the large volumes of gases released when the rock is blasted conventionally. The gold ends up dispersed throughout the stope and gully and is lost. This loss can be avoided in Selective Blast Mining.
- Only the gold bearing material need be sent to the surface so that up to 60% of the material blasted is left underground.
- In certain stope conditions, where the waste rock stope height can be increased, the face advance per blast can also be increased. This tends to maintain the mass of ore sent to the mill, while the grade of the ore is now approximately doubled.
- There are potential advantages for Selective Mining at all depths: These advantages become more significant when ultra deep mining has to be undertaken. Radically different approaches to material handling and metallurgical extraction can be contemplated. Crushing might be undertaken underground, say, in gullies close to the stope face so that crushed material can be conveyed to a central point in the mine by hydraulic or pneumatic conveying in pipes. Robinson estimates that as much as 70% of the gold in the crushed product can be recovered by simple gravity separation or even froth flotation in the form of high grade concentration, and this should be possible underground.

Selective Mining has a dramatic impact on the profitability. A model is given for stope costs and gold income.

For normal stoping with an ore grade of 5.2 g/ton, a cost of R303.53 per metre of stope face per blast is derived. This covers development, drilling, initiation, explosives, backfill, material transport, and milling. The value of the gold recovered per blast (with a call factor of 0.85) is R610.93 per metre of stope face per blast.

For Selective Blast Mining, (with increased stope height and face advance, with cast blast roof support and with a call factor of 0.95), the total cost per metre of stope face per blast is R444.93 and the value of the gold recovered is R1280.25 per metre of stope face per blast.

Thus for Selective Blast Mining, the cost/metre of stope face per blast increases by R141.40, the income increases by R669.32 per metre per blast, showing an overall gain of R527.92 per metre per blast.

Experiments on Selective Blast Mining commenced in June 1995 and showed that:

Presented at the FRD/SAIMM Symposium 'Innovative Concepts for Viable Technologies in Ultra Deep-level Gold Mining', FRD Auditorium, Pretoria on 11th June 1996.

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- cast blasting is possible.
- the fragmentation is finer than for normal blasting.
- the potential for roof support with the cast blasting seems good and is now being investigated further.

Fracturing of the exposed ore body is a well-known process. Further experiments are required to determine the optimum fragmentation for gold recovery and material transport.

To date the tests have been privately financed. The tests have been conducted using the ZEDET Electric Initiation system, developed by Johannesburg Construction Corporation (Pty) Ltd, who also supported the adaptations of the system that are required for this application. At the commencement of the study a detailed literature search was conducted in the library of AAC Research Laboratories. Mines have provided stopes and staff for tests. The suppliers of explosives have made engineers available to assist in and to give guidance during the tests. It is now necessary to undertake more intensive testing underground and this will require both practical and financial support from industry and/or government. The chances of success are good.

Selective blast mining concepts

Selective Blast Mining is an advance on the concepts of Resue Mining, as used in Sub-Nigel in the 1930 era, and further developed in the period 1955 to 1965 by R.S. Pearson[1] and D.V. Baum[5] at President Steyn and R.H. Bryson[2] at Loraine and others. In Resue mining, the waste rock is first blasted by creating a 'secondary footwall' above/below the ore body, and advancing the blast in the waste region by several metres. The ore body above the true footwall is then lifted and collected. The ore is shattered but not displaced.

Bryson[2] listed the disadvantages of Resue mining as:

- *intermittent face advance:* Faces are stopped at the end of every cycle of advance for reef lifting, etc.
- *hanging control:* Permanent support can only be installed after the reef lift cycle is completed. During the waste overcut and reef lift period temporary supports only can be used
- irregular supply of reef depending on the daily number of panels on reef lift and this fluctuates
- labour variations as the waste overcut is hand packed
- excessive waste must be trammed and in many cases this holds up work on other reef panels.

Selective Blast Mining is designed to overcome these disadvantages by,

- continuous face advance
- permanent hanging wall support after each blast (temporary support at the face will still be required)
- regular supply of reef
- the waste overcut is cast-blasted into the backfill region so that hand packing is not required.

Selective Blast Mining (to achieve these objectives) is now possible through the advent of millisecond blast initiation systems such as ZEDET and Shock-tubing. The ZEDET system has been used in all the Selective Blast Mining experiments. ZEDET was originally developed and tested for conventional millisecond stope blasting. The additional cost of this millisecond system acted against its general adoption (this experience is shared by all systems in this market). However, ZEDET proved to be a very flexible system and to be readily adaptable to different initiation schemes, such as Selective Blast Mining where 'value added' concepts bring economic reasons for its acceptance.

The ability to blast at millisecond intervals with ZEDET provides a means of cast blasting rock over considerable distances, while at the same time maintaining a controlled cut between the waste rock and the gold bearing rock. The initiation system also makes it possible to do compound blasts in one operation. The cast blast of waste and the subsequent fragmentation of ore are initiated in one sequence.

The selective blast stope conditions are shown in Figures 1 and 2. Figure 1 shows a side elevation of the stope. It is

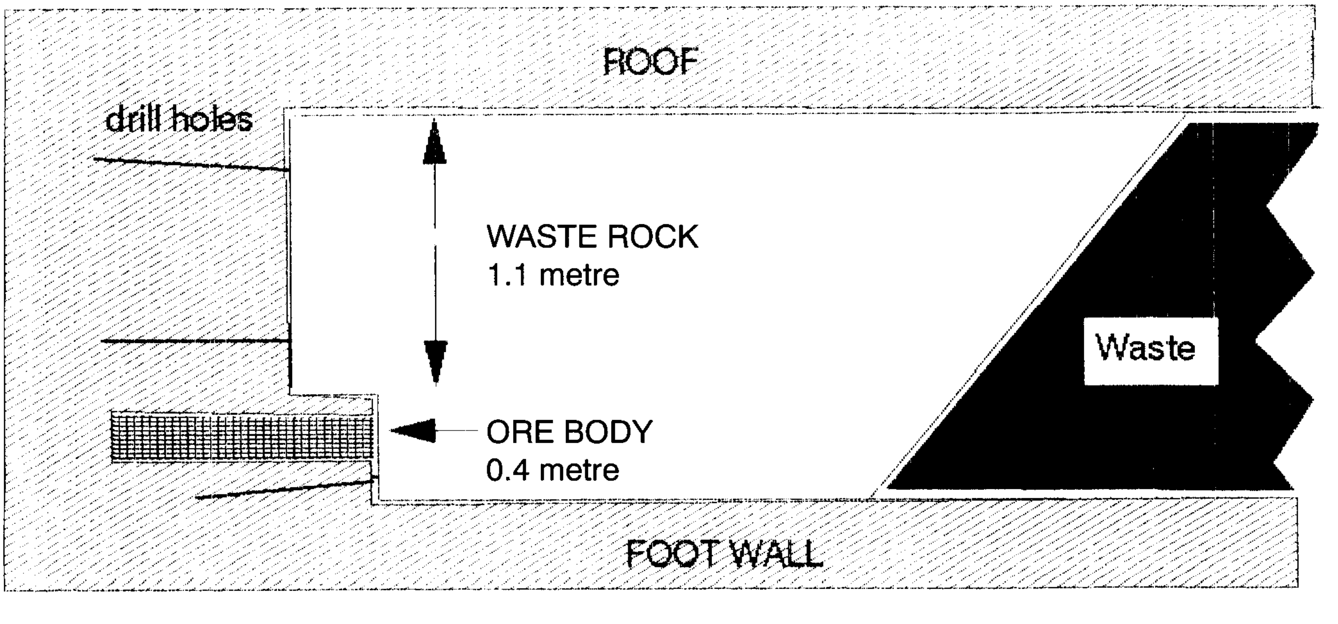

Figure 1—Side elevation of a selective mining stope

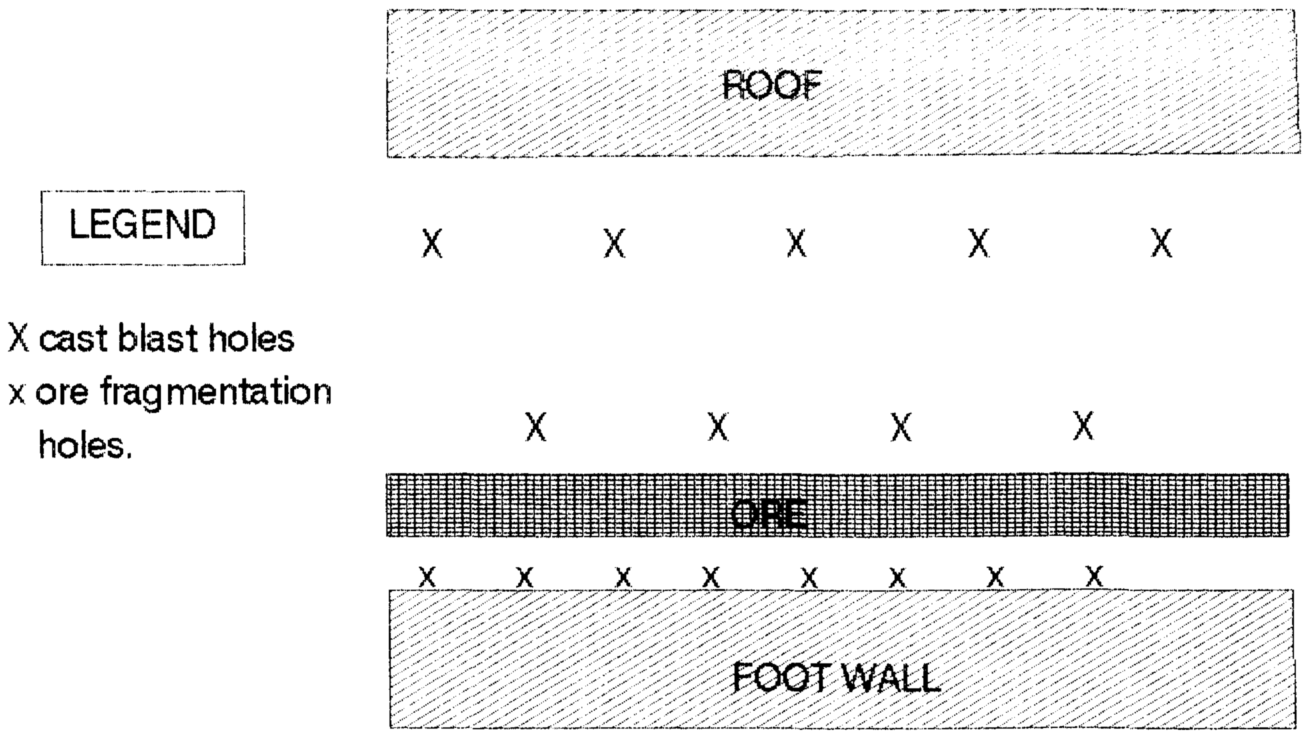

Figure 2—Front elevation of a selective blast mining stope indicating blast drill holes

assumed that the ore bearing rock is in the lower 0.4 metre of the stope. The waste rock is above the ore body. A step is introduced in the stope face to act as a secondary footwall to prevent excessive erosion of the ore body region by the blast in the waste rock. Figure 2 shows a possible drilling pattern.

The stages in Selective Blast are:

1. Create a secondary footwall between the ore and waste regions by blasting the waste on a reduced stope height and then fragmenting the ore body with less face advance. Or, create a pre-split shear plane between ore and waste.
2. Cast blast the waste rock into backfill region to introduce immediate roof support.
3. Fragment the ore without displacement.

Productivity improvements are achieved by:

- ore of higher grade transported and milled
- reduced volume of backfill brought from surface
- increased safety for workers with the immediate and distributed roof support. R.G. Gürtunca[3] reported that when 60% backfill is introduced, the accident rate reaches a minimum of <1/3 the normal
- increased gold recovery because less explosive energy is released in the ore body. If this stage is done correctly the additional ore recovery is possible even without sweeping, thus presenting a huge labour saving mechanism.

The additional cost to achieve these improvements are:

- increased number of holes drilled
- in some cases rock conditions may permit sympathetic initiations in ANFO and this will introduce the need to use more expensive cartridge explosives
- more expensive initiation systems.

Increased stope heights and face advances

If Selective Blast Mining is introduced in a mine without making an adjustment to the overall stope height, the face advance per blast is reduced. This is because a geometric relationship exists between stope height and the face advance that can be achieved. Pickering and MacNulty[4] report that stope advance has a dramatic impact on mining economics. The present average advance per blast is 0.75 m which is of the same order as the stope height.

In conventional mining, if the stope height is decreased in an attempt to reduce ore dilution of narrow reefs, the number of holes drilled per metre of face must be increased. The explosive charge per hole remains the same, so that the specific explosive energy/m^3 is also increased. Thus, not only does the blasting cost go up but also the potential for gold losses.

In selective mining, without changing the stope height and for the same face advance, the amount of rock transported to the mills and processed is reduced by 50 to 60%. The mine would now have unused capacity for materials handling and milling.

However, because the waste rock is cast blast into the backfill region by the explosive and this is a very cheap chemically driven process, the total stope height can be increased, and the face advance per blast maintained, or even increased *provided the rock mechanics conditions permit this development.*

Consider a new overall stope height of 1.5 metres as shown in Figures 1 and 2. The blast in the waste rock has a height of 1.1 metres. The proportional 'ore height' is 0.4 m so that the gold content in the ore transported is now increased by 2.5 times. A face advance of 1.5 metres per blast should be possible.

Table I

Stope economic model

	Assumptions:	
Selling price of gold	395 $/ounce	
Gold content for 1m stope height	5.2 g/ton	
Material Handling	36 R/ton	97.2 R/m³
Milling costs	30 R/ton	81 R/m³
Development costs	45 R/ton	121 R/m³
Back-fill costs	16.3 R/ton	44 R/m³
Total Working Costs	**248 R/ton**	**669.6 R/m³**
	Stope conditions:	
	Normal Mining	Selective Blast Mining
Stope height (m)	1.0	1.5
Face advance (m)	0.8	1.5
Drilling holes/m	3	6
R/hole	6	8.25
Explosives R/kg	2	2
kg/holes	0.56	0.9
Blast Initiation R/hole	2.4	7.0 (a)
Back-fill, %	100	0
Material transported, %	100	40
Milling, %	100	40
Mine call factor, %	85	95
	Costs of various operations: R/blast/metre stope face	
	Normal Mining	Selective Blast Mining
Drilling	18	49.5
Initiation	7.2	42
Explosives	3.36	10.8
Back-fill	35.21 (b)	0
Development	97.2	182.2 (c)
Material	77.76	87.48
Milling	64.8	72.90
Total cost listed above	**R303.53**	**R444.93**
	Income from gold recovered/blast/metre stope face	
	Normal Mining	Selective Blast Mining
Value of gold recovered	**R610.93**	**R1280.25**

Notes: (a) this is typical for ZEDET and shock tubing
(b) hydraulic roof support costs R90/m²
(c) the development cost is dependent on the face advance.

The mass of gold bearing rock transported and milled is now 85% of that normally handled. The amount of gold recovered per blast can be increased by 100%. The impact of this development on mining profitability can be dramatic. (The calculations are given in Table I.) The increased stope height will make stoping far more comfortable for both man and machine. The need for accurate drilling is also relaxed when the stope height increases. The reduced fatigue experienced by personnel, now working under more comfortable working conditions, will also impact on productivity and the cost of cooling working areas at ultra deep levels. Mechanization of drilling operations also becomes possible.

Experiments have also shown that damage to hanging walls can be reduced by Selective Blast Mining.

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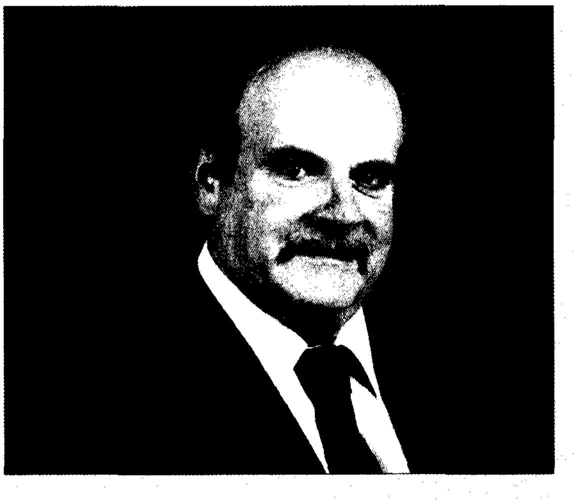
Mintek's Nic Barcza heads up SAIMM*

Mintek Vice President, Dr Nic Barcza, has been inaugurated as the 100th President of the South African Institute of Mining and Metallurgy (SAIMM). Dr Barcza will be President for the 1996/7 year, and he will be carrying on a family tradition, as his father, the late Mr Michael Barcza, was SAIMM President during 1958/9.

Other SAIMM Presidents from Mintek include Prof. Robbie Robinson (1975/6), Dr Peter Jochens (1980/1), and Mr Henry James (1985/6).



Dr N.A. Barcza

In his speech titled 'The role of pyrometallurgy in the development of South Africa (past, present and future)' Dr Barcza predicted that the total revenue from South African pyrometallurgical products could well grow from $10 billion in 1996 to double this figure around 2020. ◆

** Issued by Mintek, Private Bag X3015, Randburg, 2125.*

The Vaun self-climbing skip (SCS) system

by B. Kenealy*

Typical hoist system details

A typical deep shaft is President Steyn No. 2 in the Free State, where 9 tonnes of ore are hoisted at about 15 metres per second from 2378 metres below surface. The skips and attachments each weigh 7 tonnes and they are connected by 43 tonnes of rope, so that to hoist the 9 tonnes of payload, a total of 66 tonnes is accelerated from standstill to 55 km/h for each cycle, using an average of 3185 kilowatts of power in the process. The cycle time for the hoisting is 3.22 minutes. The peak power consumption is 6954 kilowatts, which determines the size of the motor used.

Is this the right approach? Are larger skips moving at higher speeds the answer? Is there another way?

A low speed alternative

In contrast to the high velocity approach is the Vaun self-climbing system. The same two compartments in a shaft are occupied, but instead of one skip plummeting down in the one compartment and the other rushing up in the second compartment, we have a number of Vaun skips quietly, slowly and steadily climbing up to surface, one behind the other in an orderly progression in one shaft compartment. In the other compartment the skips returning to the working levels move downward in the same orderly procession, but at higher speed, generating power as they go down.

Energy saving with the low speed system

It is interesting to compare the Vaun system power requirements with the rope hoist.

1) The average 3185 kW used at President Steyn to raise 9 tonnes could be used to raise 1217 tonnes at a steady 12 metres/minute, assuming 75% efficiency. This is the equivalent of 76 skips each of mass 16 tonnes with 9 tonnes payload. With the same power usage a slow hoisting system can lift 76 times the load!
2) At the 12 metre/minute speed a Vaun skip would move from the loading flask to the ore bin on surface in 3.3 hours, and to raise the same tonnage of ore per hour as the rope system (162 tonnes), we would need 18 skips arriving per hour, or a total of 60 skips climbing up in the shaft. Thus the power needed for a rope hoist will drive 76 Vaun skips, but only 60 are needed to do the same work! The Vaun skip has its on-board drive mechanism, so it is heavier than the conventional skip, but the increase is estimated to be only 3 tonnes, i.e. 19 vs 16 tonnes. The power to raise 60 Vaun skips of 19 tonnes, using 50 kW motors is 3000 kW, thus saving 5.8% on electrical energy on the journey to surface.
3) The skips descending into the mine from surface represent potential energy and the Vaun system recovers this as far as possible. The empty skips going down the shaft will return 662 kilowatts (after allowing very high transmission losses) to the system. This is a further 21.1% saving on the rope hoist, or a total saving of 26.9%. (The derivation of these figures is given in the Appendix.)

The energy savings available with the Vaun system are very large, but many other benefits are delivered by the system.

Mechanical features of Vaun self-climbing skips

It is now time to show you the basic mechanical features of the Vaun skip system, so that you may follow its features more easily when I discuss them (see Figures 1 and 2). The ore is carried in a conventional type of skip, which is carried on a cradle below the hoisting mechanism. The hoisting mechanism is in effect a mechanical copy of the ancient miner climbing up a shaft on a ladder, but it has three or more 'hands' instead of two, and it is tireless.

The drive is provided by a two-speed AC electric motor which drives a reduction gearbox, which in turn drives a set of three or more cams. These cams each control a 'hand' or ratchet, which starts a cycle holding onto a rung of the 'ladder' which is secured to the wall of the mineshaft. The cam moves the ratchet so that the skip as a whole is lifted upwards at a steady speed. When the ratchet has gone through most of its lift the second ratchet engages with the ladder and holds onto it, while the third ratchet, which had been holding onto the ladder now disengages and is raised rapidly by its cam to engage on another higher rung on the ladder. The first ratchet, still holding on and lifting, reaches the end of its travel and it disengages in turn. At all times at least two ratchets are engaged and holding onto the ladder, and so the skip is always securely suspended from the ladder. As the lifting motion of each ratchet is at the same speed and there are always two engaged, the upward motion of the skip is completely uniform, smooth and shockless.

The drive mechanism contains a second set of cams, these being designed for climbing down the shaft, and also for higher speed operation. The higher speed of descent is used to reduce the number of skips employed. In the

Presented at the FRD/SAIMM Symposium 'Innovative Concepts for Viable Technologies in Ultra Deep-level Gold Mining', FRD Auditorium, Pretoria on 11th June 1996.

* *Bergman-ingérop (Pty) Ltd, P.O. Box 3867, Rivonia 2128.*

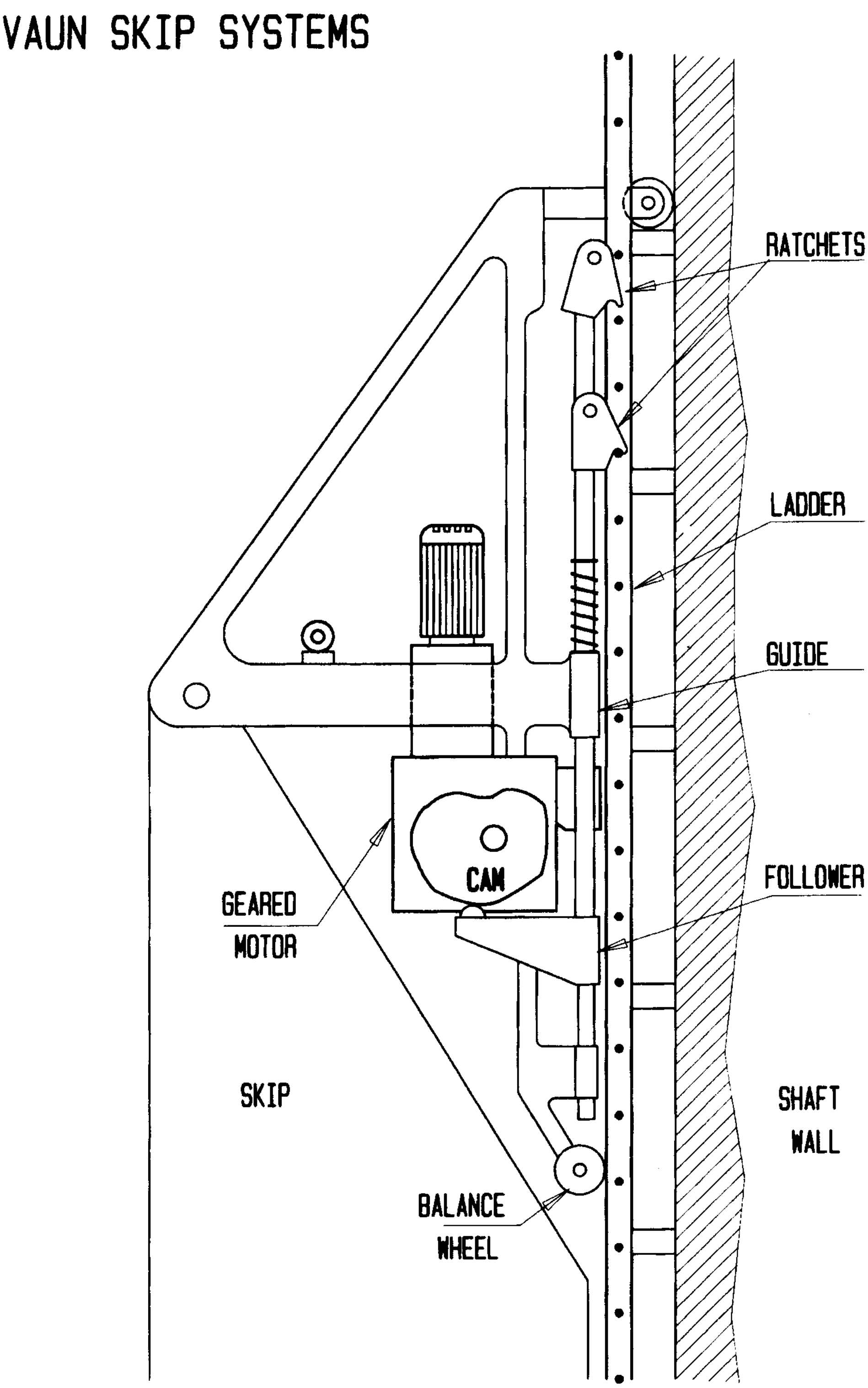
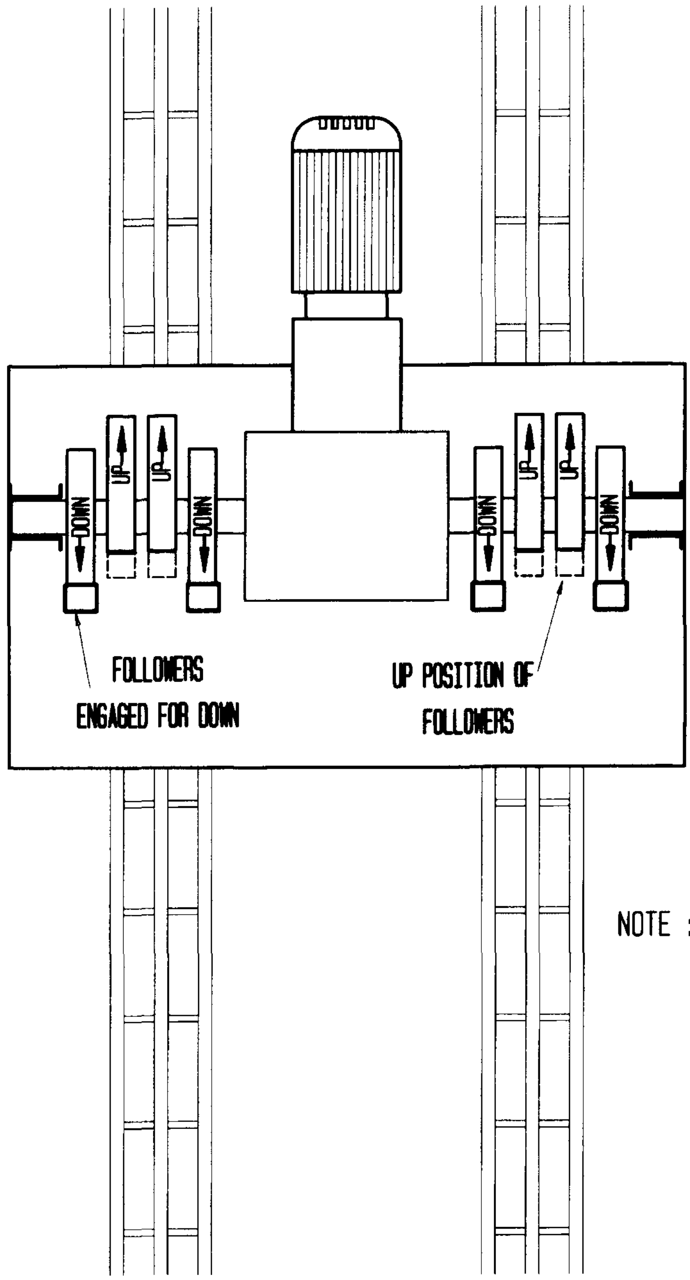


FIG. 1

GENERAL ARRANGEMENT OF VAUN SKIP

PATENT No 87/8511

VAUN SKIP SYSTEMS



NOTE :- RATCHET ARMS,
RATCHET RODS ETC.
NOT SHOWN FOR
CLARITY

PATENT No 87/9356
No 88/4630

FIG. 2

GENERAL ARRANGEMENT OF VAUN SKIP
CAMS AND FOLLOWERS

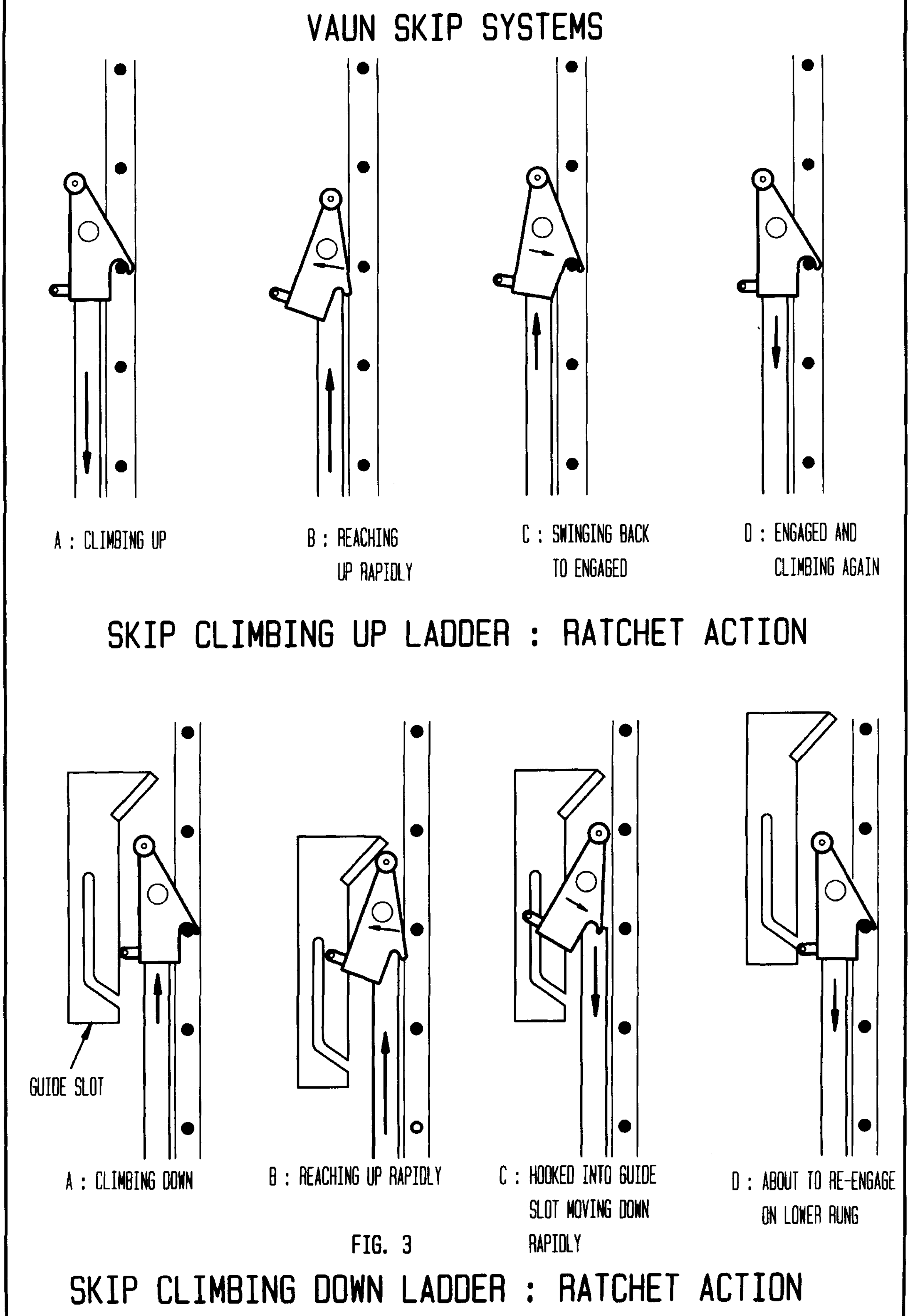


FIG. 3

SKIP CLIMBING DOWN LADDER : RATCHET ACTION

VAUN SKIP SYSTEMS

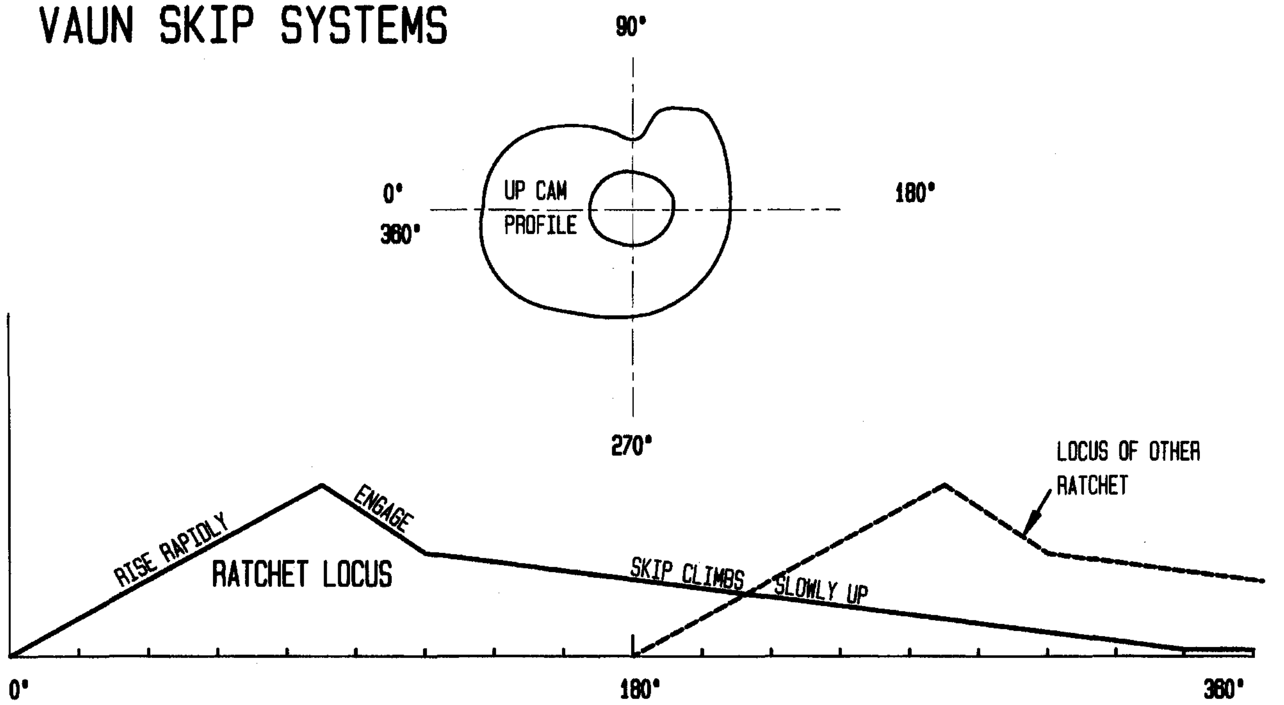


FIG. 4
CAM PROFILE FOR CLIMBING UP

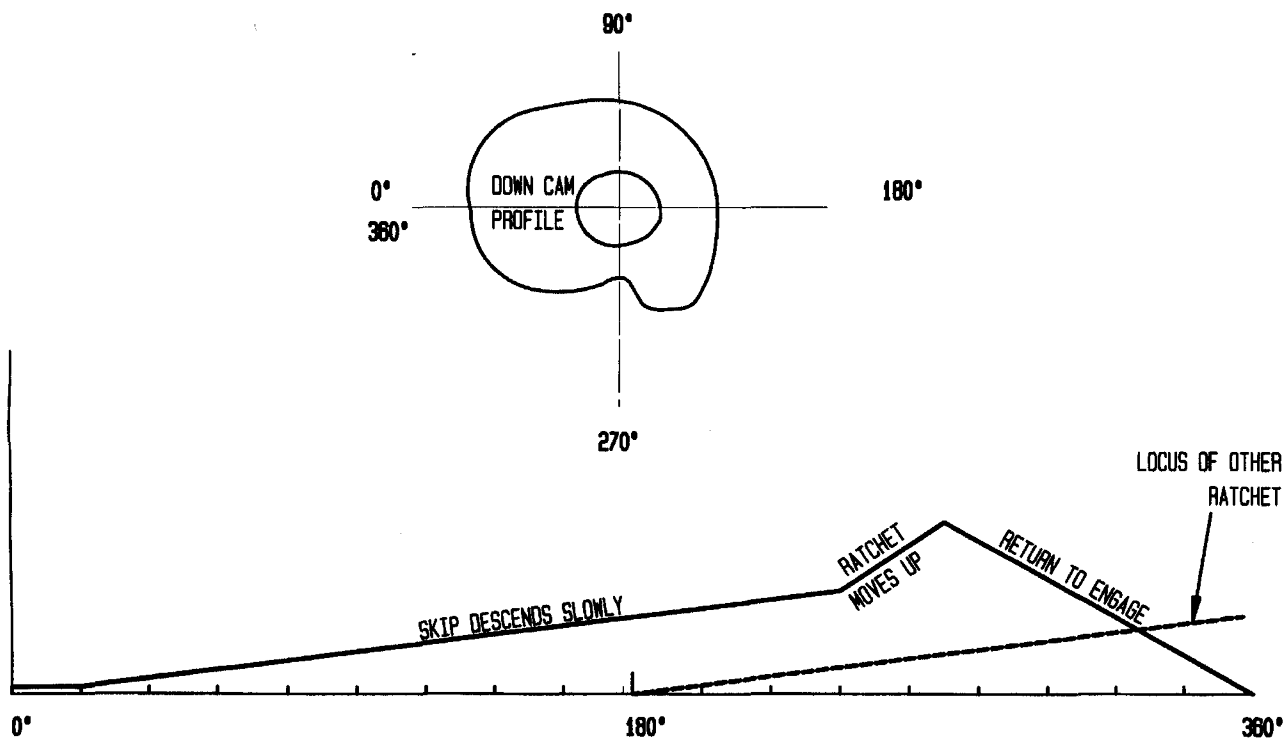


FIG. 5
CAM PROFILE FOR CLIMBING DOWN

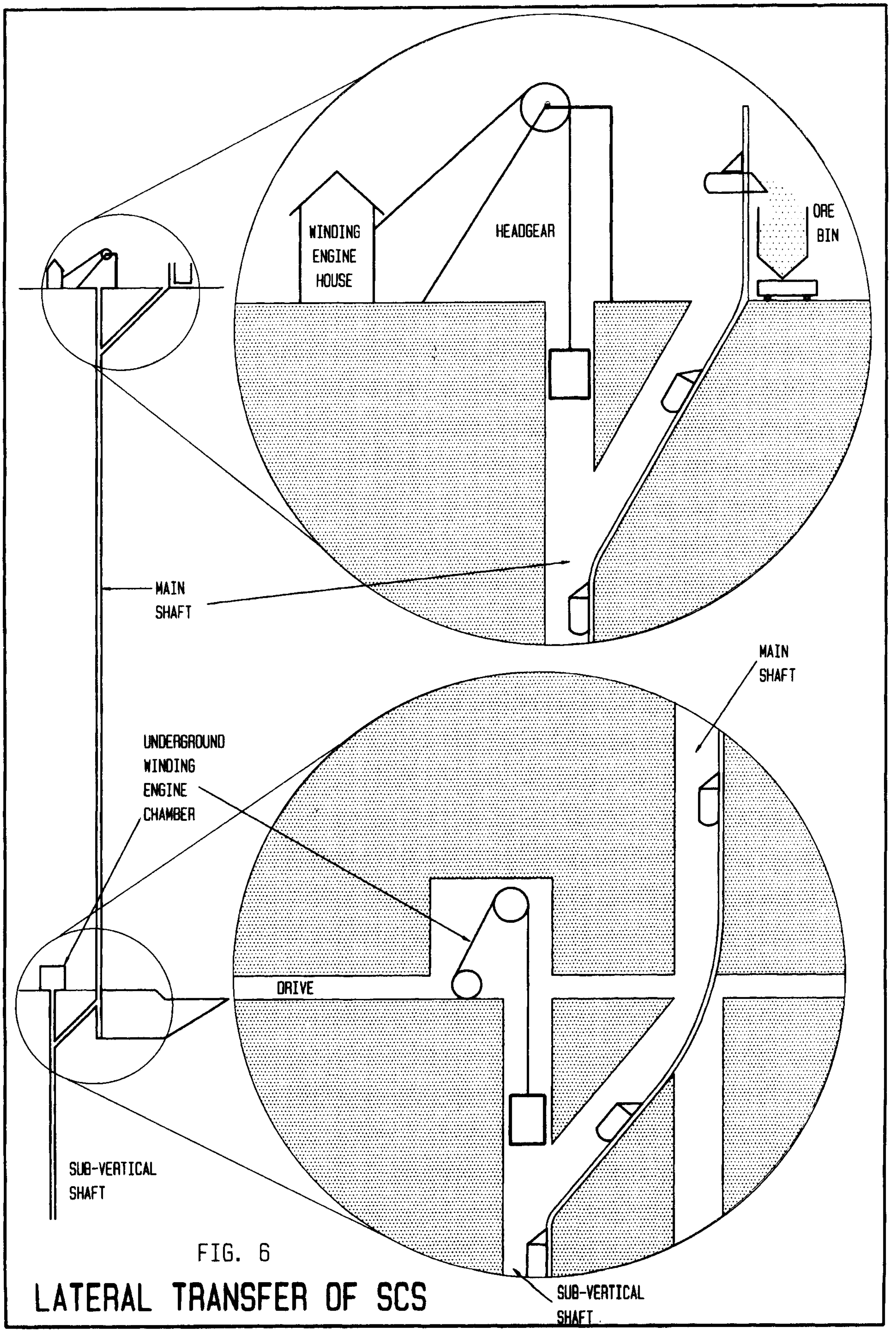


FIG. 6

LATERAL TRANSFER OF SCS

example only 20 skips are descending, at three times the ascending speed, i.e. 36 metres per minute. No power is used, in fact the motors are driven by the weight of the skip and actually generate power which is returned to the system to assist the skips climbing up.

Figure 3 shows the action of the ratchets in their two modes.

Minimum shock, smooth motion

The velocity of the skip is constant when out of the short acceleration period. Each cam is arranged to take over the load smoothly from the previous cam, both lifting together before the other releases its grip and rises rapidly to grasp another rung higher up. The cam profiles are shown in Figures 4 and 5.

Minimum wear

It is important to note that there is no relative motion between the bearing surface of the ratchet and the ladder rung, so there is no abrasive wear on either part. When the ratchet is moving up to grasp the next rung it makes contact on its sloping face with the lower side of the rung, but this occurs with no load on the parts and the forces are minimal, as will be the wear. When climbing down the spring-loaded hook which engages in the guide is a potential wear area, but this again works during an unloaded phase of the motion, so wear is minimised. These wearing surfaces would be hardened and replaceable. All other parts which have relative motion are lubricated and protected by seals or sleeves.

Safe, positive support on the ladder

At least two ratchets are always holding the skip at any time, and no forces acting horizontally or downwards can dislodge it. Only a force acting upwards can do this, and this is opposed by the mass of the skip. A seismic shock, should it act vertically, would have to be of very large amplitude to unhook all the ratchets from the ladder. The skip is thus secure against all normal forces which might act in the shaft, and if the power should fail, the climbing skips will slow to a halt, and then gently move back to a position where all the ratchets are holding onto their respective rungs. A skip climbing down would be rapidly brought to a halt by the built-in brake on the motor if any emergency developed.

Safety criteria are monitored

The status of all important equipment on the skip, such as the motor, gearbox, cams etc. will be monitored and the relevant information transferred to data transponders located every 12 metres in the shaft. The position and status of each skip is thus passed to the control room every minute, enabling appropriate action to be taken if a dangerous situation develops.

Manufacturing standardization and cost benefits

The Vaun skip is a mass-produced item, using standard items wherever possible, and is thus able to be made at a low specific cost, when compared with the rope hoisting equipment, which is purpose designed and made, and no two are alike. The cost-per-ton of such equipment will be much higher than a self-climbing skip.

Scheduled maintenance

The benefits of mass production and standardization are enormous, and the most important of these benefits is in maintenance. The skips will be maintained on a preventive basis in workshops on the surface, under clean and pleasant working conditions. Skips will be diverted on a regular schedule from the operating shaft to the workshop and thoroughly inspected and serviced. All wearing parts will be checked and replaced if at or near the condemning tolerance, all lubrication checked, topped up or replaced, as necessary, and any modifications required will be carried out. Each skip would thus be seen on a regular basis, say once per week. A history of each skip will enable the management to monitor trends and take action if a pattern which could lead to future operational difficulty is seen.

Breakdown procedures

In the event that a skip should stop while in the shaft, the supervisory system would halt all skip movements immediately. The disabled skip would then be reached using the hoist in an adjacent shaft compartment, and a "pony" skip moved onto the ladder above the disabled one and connected to it. The "pony" skip would then haul the disabled one to surface or to a point at which it could be removed from the ladder.

This emphasises the interdependance of the two systems of transport in the shaft. The traditional fast moving rope hoist will still be used, as the self-climbing skip is too slow for personnel transport and explosives etc. The two systems will be developed side by side in the shaft.

Major advances at the shaft collar

The self-climbing skip can negotiate curves, and this gives the possibility of improving safety and congestion at the shaft collar area. Vaun skips would be diverted out of the main shaft a short distance below surface, moving to an incline which would take them away from the headgear to an ore bin some distance away. This will improve safety at the headgear and give more space for safe and convenient loading of men and materials travelling on the rope hoist system.

The electrical collection system

The supply to and collection from skips of electrical power presented a problem. Power rail systems are available, but these give access from one side only for the power collector. This implied that there would have to be separate power rail systems for the up and down travel, which added a huge expense to the system. A special design of power collector system was thus necessary. This power rail system can have access from either side and will be located between the two ladder systems. Collectors for the up direction will work on the one side, drawing power, and the down direction collectors will feed power into the rails on the other side. The up and down collectors are arranged so as not to interfere and pass by each other easily.

Vaun self-climbing skip system

The conductors of the power rail system are protected from dust and moisture in the shaft with elastomeric shields which are opened by the passage of the collectors. The collectors are flexibly connected to the skip body, and follow it closely, yet can accommodate minor deviations of the track or the skip ladder from the ideal straight line. As the skip moves up or down the collector thus continues to conduct power to it without interruption.

The industry can save 25% or more on energy for raising ore, 50% on shaft equipping and a further large amount of interest chargeable on development costs, if the State can put up a modest development budget to make the Vaun self-climbing skip a reality. Employment for hundreds of new skilled workers will be created as well.

To summarize, the Vaun SCS offers the following:

* No limit on the depth of operation
* 25% or more saving on energy
* Reduction in capital expenditure
* Reduction in interest charges
* The system is self-stopping - no runaways
* Simple mechanical equipment
* Many standard production components used
* Compatible with existing shaft systems
* Simple, well-proven electrical equipment
* Adaptable to increased or decreased production
* Skips are transferrable to other shafts or mines
* Standardized designs
* Easy recovery if a skip stops *en route*
* Foolproof interlocking for safety
* Slow, steady speed = minimum wear
* Short delivery time = maximum flexibility
* Maintenance on surface
* Tipping can be away from the shaft collar
* Provides added employment.

The development programme for the Vaun Skip will be undertaken with the guidance of the Mining and Mechanical Engineering faculties of the University of the Witwatersrand.

TECHNICAL APPENDIX

The following is a comparison between the rope hoisting of ore at President Steyn No. 2 Shaft in the Free State with the equivalent Vaun self-climbing skip:

Pres. Steyn:	Mass of ore:	9 tonnes
	Velocity:	15 m/sec
	Maximum power:	6954 kw
	Average power:	3185 kw
	Mass of skip:	7 tonnes
	Mass of rope:	43 tonnes (Both skips)
	Shaft depth:	2378 meters
	Cycle time:	3.22 minutes
	Hoists per hour:	18.

1) Compare the average rope hoist power with Vaun skips raising ore at 0.2 metres/second:

Average power used in rope hoisting = 3185 kw
= 3185 × 101.974 kgf.m/sec
= 324,787 kgf.m/sec.

At 0.2 metres/sec and with efficiency of 75%, we will have:

$$\text{Tonnes lifted} = \frac{324.787 \times 0.75}{0.2 \times 1000} = 1217.95 \text{ tonnes.}$$

The existing skip has a mass of 16 tonnes (9 tonnes payload and 7 tonnes skip), and so at the slower speed we can raise, for the same power input:

$$\frac{1217.95}{16} = 76.12 \text{ conveyances of } 16 \text{ tonnes each.}$$

2) Calculate the number of Vaun skips needed to raise the same quantity of ore:

Ore raised per hour at Pres. Steyn:

18 × 9 tonnes = 162 tonnes.

Climbing time for Vaun skip at 0.2 metres/second:

$$\frac{2378}{0.2 \times 60 \times 60} = 3.30 \text{ hours.}$$

At 3.3 hours, to deliver 18 skips at the top of the shaft every hour, we require:

18 × 3.30 skips = 59.45 skips (say 60 skips).

The figure derived above refers to the number of skips climbing up the shaft only. The number of skips descending in the shaft has to be added to this, plus a number of skips under maintenance or repair to determine the full skip complement.

3) Power requirement for self-climbing skips:

If we assume a 75% mechanical efficiency, a mass of 19 tonnes (9 payload + 7 skip mass + 3 mechanical equipment) and a climbing speed of 0.2 metres/second, we have a power requirement of:

$$\frac{19.000 \times 0.2}{0.75 \times 101.974} = 49.69 \text{ kw.}$$

Rounding this to 50 kw, we have a total power requirement of:

60 skips × 50 kw = 3000 kw.

This is a power saving of 185 kw on the 3185 kw average power needed to hoist by rope from the same depth = 5.81 %.

4) The skips returning underground from surface have a mass of 10 tonnes, (7 tonnes skip + 3 tonnes mechanicals). The speed of descent should be faster than climbing, to reduce the number of skips and to use the full power rating of the motor to generate power from the potential energy in the mass of the skip. The motor is rated at 50 kw and the mechanical efficiency of the drive train is 75%. If we obtain the full 50 kw from the motor, the input from the skip must be:

$$\frac{50 \text{ kw}}{0.75} = 66.67 \text{ kw input from skip}$$

66.67 kw = 66.67 × 101.974 kgf.m/sec.

The speed of descent to give this power input will be:

$$\frac{66.67 \times 101.974}{10{,}000} = 0.679 \text{ metres / second.}$$

A speed of 0.679 metres per second is about 3.3 times the ascending speed of 0.2 metres per second.

If we use a two-speed motor with a 6 pole arrangement to climb (i.e. 970 rpm motor speed allowing 3% slip) and a 2 pole arrangement for descent (i.e. 3090 rpm speed allowing 3% slip), then we can expect a descending speed of:

Descending Speed

$$0.2 \text{ metres / second } \times \frac{3090}{1030} = 0.6 \text{ metres / second.}$$

The descending speed will thus be slightly less than the ideal to develop the full available power from the motor, and this power will be:

$$50 \times \frac{0.6}{0.679} = 44.18 \text{ kw.}$$

5) The number of skips descending will be one-third of those climbing up, i.e. 20, and the power they will push back into the system (at 75% efficiency, to cater for transmission losses) will be:

20 × 44.18 × 0.75 = 662.7 kw.

This is an energy saving, compared with the rope hoisting scenario, of:

$$\frac{662.7 \times 100}{3185} = 21.1\%.$$

The total energy saving due to the Vaun skip system is thus:

21.1 + 5.8 = 26.9%.

6) The headway, or distance between skips, in the scenario above will be:

Ascending skips: $\frac{2378}{60} = 39.6$ metres,

Descending skips: $\frac{2378}{20} = 118.9$ metres.

If there was a 1% difference in climbing speed, i.e. skip No.1 climbed at 12 metres/minute and skip No.2 climbed at 12.12 metres/minute, the 'catch-up' time to reduce the headway to zero would be:

$$\frac{39.6}{0.12} = 330 \text{ minutes} = 5.5 \text{ hours.}$$

As the climbing time is 3.3 hours, the headway would be reduced from about 40 metres to about 16 metres. The possibility of one skip colliding with another above it is thus not a significant factor, as motor speeds generally do not differ more than 1% for the same duty. ◆

Aid for small diamond diggers

As part of its commitment to assisting small, medium, and macro enterprises (SMMEs) in the minerals sector, Mintek is investigating ways of helping small diamond-mining operators.

In support of these operations, it will be offering small diamond miners the use of a portable diamond-panning pilot plant to optimize their recovery rates. A further form of assistance is the provision of (Mintek-manufactured) density beads, which are used to show the effectiveness of the miners' dense-medium separation activities, thereby enhancing the efficiency of their panning operations.

On a recent visit to a number of small operations along the Vaal River (near Barkly West), Mintek's Rob Guest and Jou Loo were impressed that many of the 'little guys' seemed more aware of the environment than some of their larger neighbours. 'The diggers separate out rocks and pebbles, which are used to build walls around the areas already excavated, and tailings are placed in these dams. Topsoil is then shovelled back on top, completing the operation in an environmentally friendly manner. This compares favourably with the many 'moonscape' dumps left behind both by diggers of yore and by some more modern medium-sized operations', says Rob Guest.

The African United Small Mining Association is also encouraging its members (who are often one-man operators working areas of 30 m × 30 m) to form larger groups of up to ten diggers, to enable them to enhance their buying power for earth-moving equipment and panning plants since, by moving more diamond-bearing gravels, they significantly increase their chances of recovery. ◆

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Stope support design methodology

The CSIR: Mining Technology has defined a methodology by which a stope support system may be designed, and then evaluated in order to determine how efficiently it would behave under either rockfall or rockburst conditions. The database used contains 12,000 fatalities and, because it is so big, for the first time reef specific criteria can be stated.

This technique will eventually lead to a computer program enabling mines to design stope support. As most people are in the stope(s), this will lead to increased safety in the stope(s), as well as cost savings for the mines through the design of the optimal support system for that particular stope.

In South African mines with tabular ore bodies, the design of stope support systems has in most cases been based on experience, past practices and cost considerations. Approximately 130 support systems have been identified in current use in industry. These include various support unit types with variations in spacing and support dimensions. Clearly, only a number of these systems are optimised with the rest being either over- or under-designed.

Variables were considered to evaluate a stope support system, i.e. force – deformation behaviour of the support units which constitute the stope support system, mining height, stope closure rate, stope closure during rockbursts and the associated velocity of closure (dynamic closure), spacing of stope support units, support resistance generated by the stope support system and the ability of the support system to absorb energy.

An analysis of the thickness of fall of ground and rockburst ejection was then undertaken for the Vaal Reef, the Ventersdorp Contact Reef and the Carbon Leader Reef. The intention is that any support system design or existing support system would need to be evaluated against these criteria. A similar process was undertaken to determine criteria for the support of stope gullies for these three reefs. This was done by measuring fallout thicknesses directly underground.

Further information: Mike Roberts (011) 358-0168, e-mail: mroberts@.csir.co.za ◆

Rockbreaking techniques key to survival

The number of advances in the development of rockbreaking processes and rockbreaking systems, has led the CSIR: Mining Technology to categorize these developments, thereby offering the mining industry an accurate evaluation of these systems, allowing them to select the best system(s) suited to their particular circumstances.

New rockbreaking processes and systems can form the basis of the new mining systems of the future which could significantly contribute to the South African gold and platinum mining industry, which urgently needs a technological breakthrough in stoping and development methods to remain competitive.

The innovative application of new and existing rockbreaking technologies would revolutionize mining methods, making them safer and more profitable, just as the worldwide trend to mechanize mining operations had as its major stimulus improved safety and mining operations in the face of rising labour costs.

While South Africa generally followed this trend in coal and base metal mining operations, in its unique precious metal industry mechanization has met with only limited success. Reasons for this are the very adverse conditions underground mitigating against mechanization — narrow, dipping reefs, hard, highly abrasive rock types; deep, extensive mines; highly stressed, seismically active ground conditions, a poor environment and a largely unskilled labour force. South Africa's gold and platinum mines' stoping operations have, therefore, remained the same for many decades, based on the drill-blast-clean-support cycle.

The design and operation of a face mining system is influenced by the rockbreaking method, the rock handling system, the support methodology, the materials handling system, the environmental control approach and the entire plethora of support systems. However, rockbreaking is the fundamental mining operation and can have a major effect on all the other parameters.

Further information: Rod Pickering (011) 358-0157 e-mail: rpicker@csir.co.za ◆

Quiet rockdrilling system

The pneumatically powered rockdrill used almost exclusively on South African gold mines emits approximately 111 dBA when running but not drilling, and 114 dBA when drilling. This latter equates to less than 30 seconds exposure to the noise per working day, without hearing protection, to ensure no long-term hearing loss.

The CSIR: Mining Technology took the opinion, as expressed by the US Bureau of Mines, that only by encasing the entire drill and steel in an air-tight bag would significant reductions in noise levels be possible. The concept involves a novel yet practical method of encasing the rock drill and drill steel (each of which currently contributes equally to the overall noise emission when drilling) in a sound deadening enclosure, controlling the exhaust air flow to reduce noise and adding sound deadening material as necessary, e.g. to the drill steel. To enable the system to drill in the stope, an integral stinger assembly will be included in future designs and an automatic drill retraction valve will be added, both of which will reduce the operator's involvement with his machine and thereby further improve his working conditions.

A laboratory version of the drilling system has been produced and evaluated; initial indications are that, without the addition of special sound deadening materials, the noise emission during over travel operation has been reduced from 111 to 87 dBA (256 fold reduction in noise power emission) and whilst drilling from 114 to 96 dBA (64 fold reduction in noise power emission).

Further information: George Harper: (011) 358-0084, e-mail: gharper@.csir.co.za ◆

Quantitative ground penetrating radar for rock mass characterization

by H. White*, P. Meyer* and A. Doorgapershad†

Introduction

The applicability of ground penetrating radar (GPR) in numerous qualitative applications has been demonstrated over the past five years in the South African mining industry. These applications include the delineation of faults and dykes, fracture mapping, delineation of shear zones, mapping of depth of weathering, and the delineation of contact between different rock types. The qualitative nature of the data collected using existing commercial GPR systems, often relying on expert interpretation, has however mitigated against the full-scale routine application of GPR in the mining industry. The recent development of the RockRadar system by ISS International has, to a large extent, overcome these problems. The result is that quantitative rock-mass studies can now be performed with the RockRadar system.

Ground penetrating radar (GPR) produces a two-dimensional pseudo-cross-section of the subsurface that is similar in nature to a reflection seismic-section. GPR operates on the principle of the reflection of electromagnetic waves to delineate subsurface structure. A transmitting antenna launches an electromagnetic impulse into the subsurface. The wave spreads out as it travels through the subsurface, until it reaches an object with different dielectric properties from the surrounding ground. Upon reaching the object, part of the energy is reflected back to the surface, while part of the energy continues to travel onward. A single trace records the reflected amplitudes as a function of time (depth). An increase in amplitude corresponds to a dielectric interface at a certain travel-time away from the transmit-receive antennas. In practice, measurements are made by towing the antennas across the ground. Data can be collected at fixed station spacing (usually < 1.0 m) or continuously as the antenna is dragged across the surface. The successive traces are plotted next to each other, so developing a pseudo-cross-section of the subsurface.

Theoretical background

Unlike a conventional radar system, which emits continuous waves, where the energy is confined about a particular frequency, impulse radar emits pulses containing a broad band of frequencies. This energy can also not be focused as accurately as that from a narrow band system. The broadband nature of the radiation has advantages: the higher frequencies give better resolution, while the lower frequencies have superior penetration capabilities. Depending on the antenna used, the centre of the frequency band ('centre frequency') may range between 10's of MHz and several GHz. The bandwidth can extend up to 100% of the centre frequency. Peak radiated power may be as high as several thousand Watts—nevertheless the very low duty cycle (time ratio of power-on to power-off) is so low that no significant health risk exists for personnel in close proximity to the system. The energy is radiated from an antenna into the subsurface, and energy is then reflected from interfaces where the **dielectric constant** changes. For simplicity, consider a two layer subsurface system, having dielectric constants ε_1 and ε_2. The reflection coefficient R_{12} of the interface (i.e. the amount of energy reflected back from the interface) is given by:

$$R_{12} = \left(\frac{\sqrt{\varepsilon_1} - \sqrt{\varepsilon_2}}{\sqrt{\varepsilon_1} + \sqrt{\varepsilon_2}} \right)^2 .$$

In general, the pulse propagates at a velocity v given by

$$v = \frac{c}{\sqrt{\varepsilon}}$$

where $c = 3 \times 10^8$ m/s is the speed of light in free space, and ε is the dielectric constant of the medium, typically varying between 5 and 25 for most geological environments. The depth of an object d can be calculated from the two-way travel-time t of a pulse according to:

$$d = \frac{ct}{2\sqrt{\varepsilon}} .$$

The resistivity of the ground determines the range of penetration: the higher the resistivity, the greater the penetration. Resistivity values greater than 10's of Ω.m are usually required for successful GPR work.

Ground penetrating radar systems

An impulse radar system comprises the following components:

- High-powered pulser
- Transmit antenna
- Receive antenna
- RF amplifier
- Sampler (with associated timing electronics)

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- A-D converter
- Associated digital electronics
- Control unit.

The transmit and receive **antennas** are generally some form of dipole, usually heavily loaded to prevent ringing in the vicinity of the ground. Some form of shielding (usually a grounded backplane) is often utilized to reduce the amount of above-ground signal. Alternative antenna designs are also available (including modified YAGI-type antennas and horn antennas) from different suppliers. The main requirement of the **pulser** is to produce an extremely short sharp pulse, up to 900 V with a rise-time of 1 nsec (0.001 μ sec). Alternative pulser designs produce low-power monocycle pulses, but the commercial use of these is limited to horn-antennas (1 GHz and 2.5 GHz). The **sampler** converts the received radio-frequency (RF) signal (in the frequency range 10 MHZ to 2.5 GHz) to an audio-frequency (AF) signal (50 kHz). Radio-frequency signals, by their very nature, are extremely sensitive to interference. Because of this, the RF–AF conversion should be done as close to the receive antenna as possible. The **analog-to-digital converter** (A-D) converts the analog signal into digital information. Again, this should be done as close to the receive antenna as possible, before signal degradation can take place. The associated digital electronics permit general control of the data-acquisition process. The **control unit** provides the user-interface with the system, as well as allowing some data pre-processing, as well as data storage. It is usually necessary to apply a suite of post-processing tools to the data after acquisition. This is usually done in the office after data is acquired. Most of the **post-processing** algorithms are standard digital filtering algorithms.

Performance and limitations

The three measures of performance of ground penetrating radar are:

- Maximum depth of penetration
- The ability to delineate a subsurface interface
- The resolving power, i.e. the minimum size of a buried object.

The resolution, detection and penetration capabilities of a GPR system for a given object depend on the electrical properties (dielectric constant and resistivity) of the subsurface, the centre frequency of the antenna, the power output of the antenna, and the dynamic range of the system. Dry resistive rocks and soils yield the highest penetrations. Moist clayey soils (low resistivity) yield the lowest penetrations. In general, GPR works worst in a subsurface which contains a combination of clay, water and salts. Nevertheless, fairly good penetrations can be obtained in dry clay. Lower frequency antennas usually yield greater penetrations for most soil and rock types. Higher centre frequency antennas provide better resolution, but with worse penetration ranges.

In field survey conditions, a number of other factors affect the ability of GPR to accurately delineate subsurface conditions. These include, but are not limited, to the following.

- Survey access: Often it is not geometrically possible to access a specific target from the best position. For example, if a cavity under a structure cannot be directly imaged below the structure, it may be necessary to place the receive and transmit antennas on opposite sides of the structure.
- Man-made interference: All antennas are susceptible to receiving reflections from above-ground (steel equipment etc.). These reflections appear within the data, and may be misinterpreted as originating from below-ground.
- Depth calibration: Although a Common Depth Point (see for example Steeples and Miller[1]) measurement provides reasonably accurate depth calibration in many situations, a drill-hole is still the best method of calibration.
- Cross-correlation with other techniques: As an example, when utilizing GPR to determine depth to bedrock, the results will often be cross-correlated with those obtained by trenching with a mechanical excavator. The definition of 'bedrock' for an excavator may be very different to that for radar (depending on weathering etc.) and may even be different from excavator to excavator (depending on the size of the excavator).

Recent advances

The qualitative nature of the data collected using existing commercial GPR systems, often relying on expert interpretation, has however mitigated against the full-scale routine application of GPR in the mining industry. The main reasons for this include the following: (i) data acquired with first generation digital GPR systems is often severely contaminated with incoherent and coherent noise, some of which cannot be reliably filtered from the data, and indeed cannot be distinguished from real data, (ii) repeatability of results could not be guaranteed due to complex instrumentation setup requirements, and (iii) the success or failure of the technique in an environment could not be predicted (without secondary measurements) prior to application.

The development of the RockRadar system by ISS International has, to a large extent, overcome these problems. Sources of incoherent and coherent system noise have been largely eliminated through advanced electromagnetic isolation of subsystems, and highly simplified operating requirements ensure repeatable system setup. An example of data collected with the RockRadar system at Vaal Reefs is shown in Figure 1, together with the interpretation in Figure 2. The RockRadar system has the following features:

- High true dynamic range
- Intelligent antennas allowing preprocessing of data
- All fibre-optic cabling between antennas and the control unit
- Ethernet communications between the antennas and the control unit
- A 32-bit multitasking operating system on the control unit allows data acquisition, processing and printing simultaneously
- Antenna centre frequencies between 50 and 300 MHZ
- Automatic data processing for shallow survey interpretation
- Sophisticated data and image processing capabilities for data interpretation in difficult survey environments.

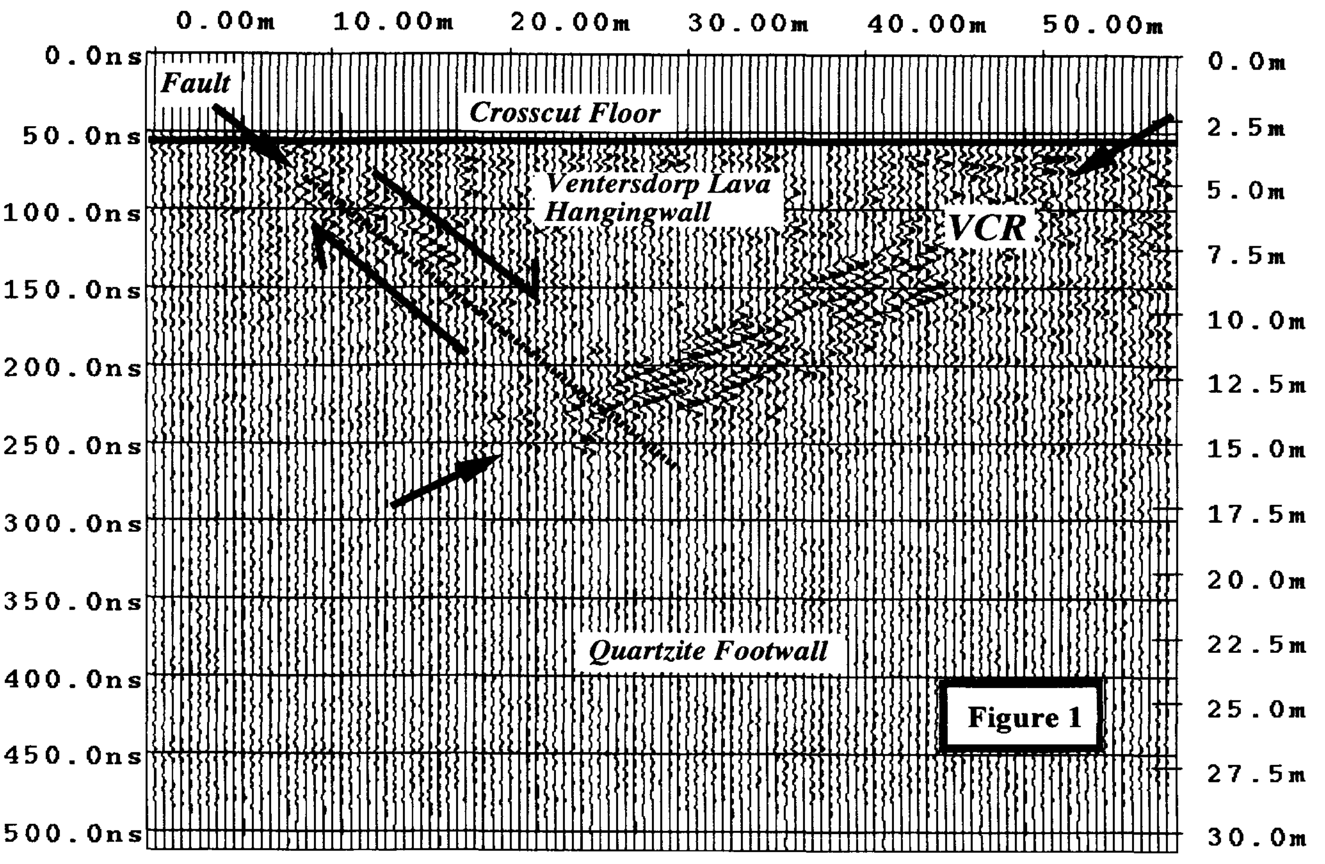

Figure 1—An example of data collected with the RockRadar system at Vaal Reefs

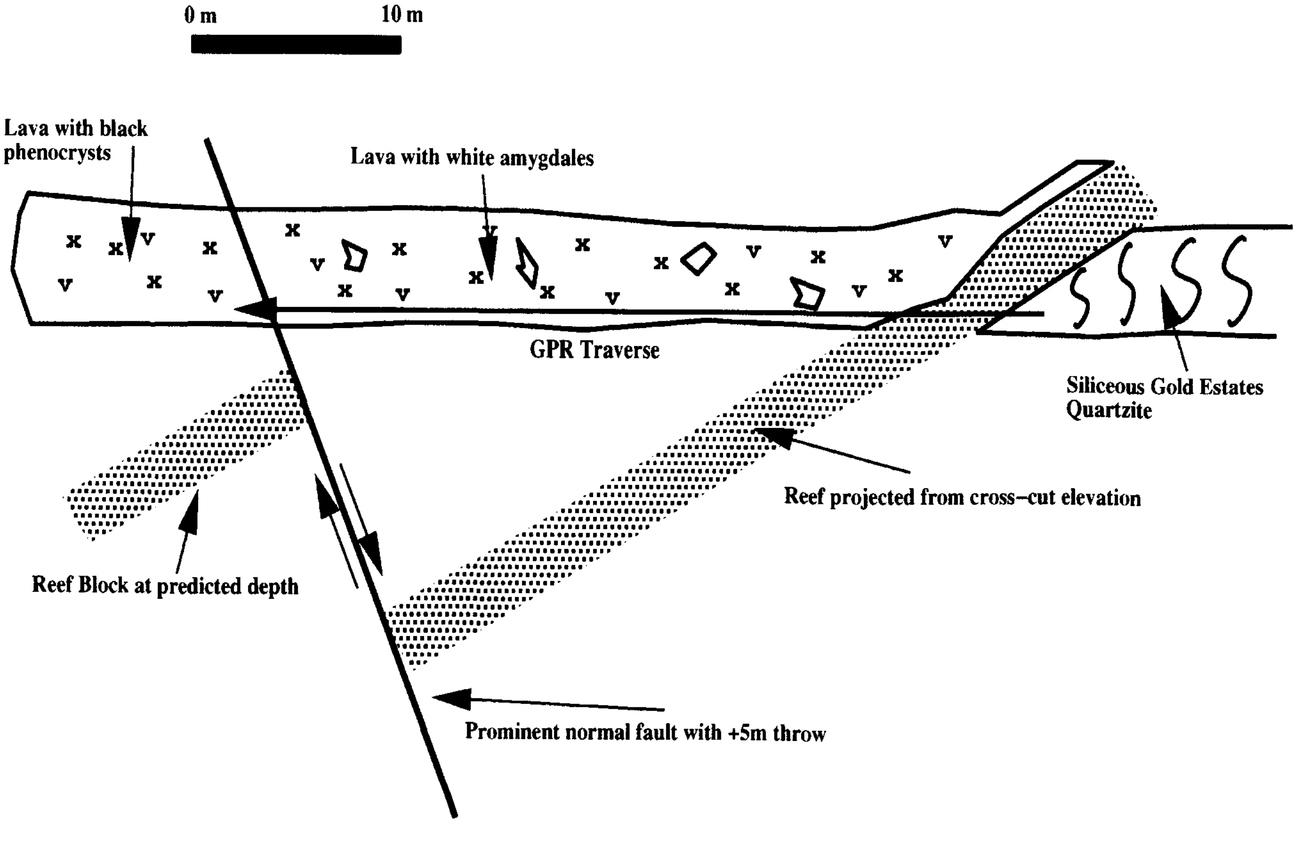

Figure 2—Interpretation of data collected with the RockRadar system at Vaal Reefs

Quantitative ground penetrating radar for rock mass characterization

Current and future developments

The recent advances discussed above ensure highly improved data quality to the extent that system performance is highly predictable in any environment, based on simple operational guidelines. The result is that quantitative rock-mass studies can be performed with the RockRadar system. Studies aimed at extending the quantitative application of GPR in subsurface characterization have, or are being, initiated. These include the following.

(i) Quantitative determination of the dielectric properties of the subsurface, including permittivity, conductivity and dispersion relations, and correlation with physical characteristics of the rock-mass. This allows the following to be achieved, for example:

- The depth to a fault-zone can be accurately determined directly from GPR measurements.
- The fracture zone surrounding an excavation can be dielectrically characterized, and the dielectric properties correlated with physical (mining) properties.
- Correlation between mineralization and dielectric properties.

(ii) Fully flexible data acquisition geometries, including fixed-offset, common mid-point, tomographic and large-offset setups are now supported. Examples of new applications arising from this include the following:

- The ground beneath a structure can be imaged by placing the transmit and receive antennas on either side of the structure.
- Tomographic 'time-of-flight' investigations of pillars can be performed.
- In cases where standard reflection studies are not successful (in conductive environments, for example), transmission studies can assist in dielectric characterization of the subsurface. Recent work on a clay-core dam-wall conducted by ISS International illustrates this point: The conductivity of the dam-wall was too high for standard reflection studies to be of much use, and so an acquisition geometry was used whereby the transmitter was placed on top of the wall and the receiver at the foot of the wall. Time-of-flight measurements through the dam wall (from top to bottom) allowed the complete dielectric characterization of the wall, including determination of the clay-core geometry.

(iii) In certain situations, GPR refraction (the analog of seismic refraction, see for example Lankston[2]) can now be performed. An example of this is the following:

- Determination of the thickness of a horizontal mineralized ore-body, underlain by barren sedimentary layers.

Conclusion

In conclusion, with the advent of the RockRadar system, quantitative ground penetrating radar studies of the subsurface can now be done. The technique of GPR has thus matured to a similar level to that of seismic reflection and refraction evaluations. ◆

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New appointment at Mintek*

Mr C.J. (Hans) van Vuuren has been appointed Senior Director: Metals Technology at Mintek.

Mr Van Vuuren, who has spent most of his professional life in various technical and managerial positions at Iscor, is also Professor Extraordinary: Material Science and Metallurgical Engineering at the University of Pretoria. ◆

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Lecturer Award

Professor Michael J. Nicol of the University of the Witwatersrand has been awarded the 1998 Extraction and Processing Distinguished Lecturer Award from The Minerals, Metals and Materials Society (TMS) of the United States. This award recognises an outstanding scientific leader in the field of extraction and processing metallurgy by inviting him/her to present a comprehensive lecture at the Society's Annual Meeting. ◆

Centennial reflections of the Department of Mining Engineering at the University of the Witwatersrand

by S. Budavari* and H.R. Phillips†

Synopsis

On the one-hundredth anniversary of the founding of the South African School of Mines, this paper presents a historical review of the tertiary mining education carried out by the School of Mines in Kimberley and the subsequent institutions in Johannesburg. In addition to recording and evaluating a century of mining education, it describes the current activities of the Department of Mining Engineering at the University of the Witwatersrand, which is believed to be the natural successor to the School of Mines.

The comparison of earlier and contemporary academic mining activities reflects a gradual transition from the educational philosophy and objectives of a school of mines to those of a modern university department. In the conclusions, some aspects of the educational effort expended during the past hundred years are briefly highlighted.

Introduction

According to Orr[1], the first recorded tertiary education in mining in South Africa started on 10th August, 1896, at Kimberley in the newly established South African School of Mines. Students who enrolled for the course had to be in possession of a university pass in the pure sciences, and instruction in these sciences was provided, over a period of two years, by the South African College, Cape Town. After one year's study of mining and allied subjects in the School of Mines, students were required to spend a further year on the Witwatersrand goldfields, where they were expected to receive additional mining tuition. Those who successfully completed the four-year programme were awarded a diploma in mining engineering by the University of the Cape of Good Hope.

The creation of the School of Mines initiated a chain of events that eventually resulted in the establishment of the University of the Witwatersrand (Wits). After the South African School of Mines had been transferred to Johannesburg, it underwent a number of name-changes, and its character was modified from a school of mines to that of a technical institution covering a broader field of engineering studies and, finally, to that of a fully fledged university.

During these changes, the provision of mining education at a tertiary level was always the primary objective of the appropriate institution, under whatever name it was operating. However, as the number of disciplines catered for increased within the successive institutions, an academic unit was established to facilitate the teaching of mining and metallurgy, and later on the mining courses only, thus giving a full and independent identity to the Department of Mining Engineering.

Because of its origin, its history, and the nature of the education provided, it is believed that the Department of Mining Engineering at the University of the Witwatersrand is the natural successor to the original South African School of Mines. This direct line of succession charges the Department, its academic staff, and present student body with the responsibility of preserving the academic objectives, and fostering the traditions and legacies of the South African School of Mines. For these reasons, the Department celebrates the anniversary of the establishment of the South African School of Mines one hundred years ago.

As part of the centennial celebrations, it is appropriate to explore and record some aspects of the history of the relevant academic institutions, to evaluate the activities of the Department, and to review its current responsibilities for the present and not-too-distant future. It is the purpose of this paper to meet these objectives and to record the status of the present undertaking.

Although the authors have attempted to combine a description of relevant past events with an interpretation as they see them, this study is not intended to be a comprehensive history of the institutions involved. There are two reasons for this. The first one is that the authors' main interest lies in the historical events associated with the academic activities directed to the education of mining students only. The second reason is that an excellent and detailed historical account of the pre- and early-university periods of Wits by Murray[2] is already available. Consequently, the present study

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is based mainly on published sources, rather than on original documents. In dealing with relatively recent events, appropriate university or departmental records were utilized.

The Kimberley Years

The history of southern Africa in the second half of the 19th century is characterized by the conflicting political and economic interests of the peoples inhabiting the sub-continent. One of the prominent components of these conflicting interests was brought about by the extension of European influence and the conclusion of British political supremacy over southern Africa. An equally significant factor was the birth and growth of the Afrikaner people, with their own national consciousness. The interests of the various indigenous peoples and their political and economic influence on the events shaping the history of the region represents the third important factor.

The various conflicting pressures were compounded by the opening up of the diamond fields at Kimberley in 1870 and, later on, in 1886, the discovery of gold on the Witwatersrand. From the perspective of this study, the rapid development of mining and the service industries in the last three decades of the century is of particular importance.

By 1890 the recovery of diamonds at Kimberley was becoming more difficult, and the increasing depth of mining brought about technical problems, including floodings and rockfalls. The haphazard system of mining by small prospectors was drawing to a close, and mining became more sophisticated owing to the mining methods used and the consolidation of claims. At the same time, gold mining on the Witwatersrand was well and truly established. As a result of the opening up of a great number of mines along a considerable length of the outcrop and the drilling of boreholes south of this outcrop, the vastness of the gold deposits was clearly demonstrated. The increasing depth of mining and, associated with it, the change in the nature of the orebody, brought about an urgent need for the introduction of complex mining and metallurgical technology.

Although a great deal of valuable mining experience, gained in California and Australia, was utilized in the early days of South African mining, the absence of locally educated mining engineers was very obvious by the last decade of the century. Therefore, conditions were ripe for the establishment of an institution of higher learning that would prepare young South Africans to become leaders of the rapidly developing mining industry.

The establishment of the South African School of Mines was influenced and supported by many eminent individuals, the government of the Cape Colony, De Beers Consolidated, and the two existing institutions of higher education in Cape Town. Among the outstanding individuals were the Prime Minister of the Cape, C. J. Rhodes, and P. D. Hahn, Professor of Chemistry at the South African College, who were keenly aware of the opportunities offered by the mining industry to young South Africans. The two existing institutions of tertiary education were the University of the Cape of Good Hope, the approved examining university for the Cape Colony, and the South African College, a teaching institution preparing students for both matriculation and university examinations.

Although the Council of the South African College proposed, in 1890, the establishment of a school of mines in Cape Town, the proposal was accepted by the Cape government only in 1894, with the significant modification that the school would be located in Kimberley. The prevailing political atmosphere in southern Africa and Rhodes's long-term plans, driven by his colonial ambitions, were responsible for the change in the location of the school.

After long discussions, the compromise scheme of study accepted was as follows. During the first two years, a course on basic sciences was provided in Cape Town by the South African College. At the end of the two-year study, students were required to pass the examination set by the University of the Cape of Good Hope. The third-year instruction in technical subjects and some practical training were given in the School of Mines at Kimberley. The fourth-year students were directed to spend a year in Johannesburg, where they received further technical instruction and practical training in gold mining. On successfully completing the fourth year of study, students were awarded a diploma in mining engineering by the University of the Cape of Good Hope.

For a number of reasons, the proposed scheme was modified in some respects. One of the major changes was the reduction of time the students spent on the Rand. Only the first group of fourth-year students spent a full year in Johannesburg. Despite the valuable assistance of the Chamber of Mines of the South African Republic in organizing the supervision of students and providing some lecturing facilities in Johannesburg, the practical training and further technical instruction could not be carried out as had been intended. Consequently, the time spent by students in Kimberley was increased to one-and-a-half years, and the duration of practical training on the Rand was reduced to six months.

The initial conditions at Kimberley were primitive, and the School was short of facilities, money, and staff. Some of these shortages were prevalent right through the Kimberley years. There were only two full-time members of staff, who carried out the theoretical and some of the practical instruction during the whole period of the School's existence. They were Professors J. G. Lawn and J. Orr. It should be recorded, however, that the School made extensive use of the technical and managerial staff of De Beers Consolidated in its practical training scheme.

In the first half of 1899, with the financial assistance of De Beers Consolidated and the Cape Colony, some new buildings and laboratories were added to the converted workshop and restaurant buildings used by the School. These purpose-built premises are shown in Figure 1. Thus, by the middle of that year, the teaching facilities and student accommodation improved to an acceptable level, and the organization of courses attained a certain degree of maturity. Unfortunately, the outbreak of the Anglo-Boer War, and the subsequent siege of Kimberley by the forces of the South African Republic and the Orange Free State in October 1899, disrupted the normal activities of the School and arrested the further development of this pioneer institution.

The number of students enrolled in the third and fourth years of the course at Kimberley are given in Table I. This table was drawn up on the basis of Orr's publication.

Because of the Anglo-Boer War, the number of new

Figure 1—The School of Mines, Hull Street, Kimberley

entrants from 1899 to 1902 and the number of students progressing from the third to the fourth year of study are not clear from the source, and therefore may not be accurate. Nevertheless, one can see from the table that, despite the need and expectations, student enrolment was at a relatively low level right through the life of the School.

With the defeat of the Boer Republics and the extension of British rule over the whole of South Africa, the political incentive to maintain the School of Mines at Kimberley vanished. Owing to the difficulties under which the School was operating, and the fervent wish of Johannesburg to establish a system of technical education of its own, the decision was taken, after several meetings of appropriate representative bodies in 1902 and 1903, to transfer the School to Johannesburg. Although this decision was not free from political influence, the School was to be located, at last, in the centre of a thriving mining area, where its future existence was ensured. Thus, at the end of 1903, 12 third-year and 24 fourth-year students, 1 staff member, and all the equipment were transferred to the newly formed Transvaal Technical Institute in Johannesburg.

Table I

Students enrolled in the third and fourth years of study at the School of Mines, Kimberley

Year of study	Aug 1896	Aug 1897	Aug 1898	Aug 1899	Jul 1900	Jul 1901	Feb 1902	Feb 1903
3	5	13	13	12	24		8	22
4		5	13	14	14	24		8

Despite its short existence, the School of Mines at Kimberley played an important role in the development of South African higher education. With the establishment of the School, the education and training of mining engineers began and, in the wider sense, the development of technical education was stimulated on the sub-continent. It created an acceptable framework for study and education, elements of which can be recognized even in the present-day curriculum. The School produced some fifty engineers, who later became well-respected leaders of the South African mining industry.

On the negative side, the School was affected by a shortage of funds, students, and teaching facilities. The division of the teaching and training effort among the South African College in Cape Town, the School of Mines in Kimberley, and the mines on the Rand was believed to be part of the School's shortcomings. By present-day standards, a further negative aspect of the School's activities was the placing of too much emphasis on practical training, especially during the third year of study.

The Pre-Wits Years

The transfer of the School of Mines from Kimberley to Johannesburg triggered off a long and fierce struggle to elevate the standard of the School and to expand its activities to the level of a teaching university. The period of struggle ended with the inauguration of the University of the Witwatersrand in 1922. As the birth and demise of the School of Mines at Kimberley were influenced to a significant extent by the prevailing political and economic forces, the establishment of the University of the Witwatersrand was also affected by similar, but more diverse and intense, forces.

The period under review began with the conclusion of the Anglo-Boer War and ended with the Rand revolt. Having signed the Treaty of Vereeniging in 1902, both the British and the Afrikaner leaders formulated their own political objectives. While British politics were motivated by imperial ambitions, the aims of Afrikaner politics were to win the peace and to re-establish self-governments for the Transvaal and Orange River Colonies. With the Liberal government coming into power in Britain in 1905, the zest for meeting Afrikaner political objectives gained momentum, and resulted in the award of responsible governments to the two new Colonies and, eventually, in the formation of the Union of South Africa in 1910. The First World War, the emergence of organized labour, and the sowing of the seeds of apartheid were the factors that characterized the politics for the rest of this period.

The increase in gold production and the rapid expansion of the economy had a positive influence on the recovery of the devastated country shortly after the Anglo-Boer War. Similar improvements in the economy were brought about by the recovery after the 1906–09 depression and the brief economic expansion after the conclusion of the First World War. In addition to these economic events, the importation of Chinese workers, various strikes, and the exclusion of Blacks from most skilled categories of work were features of the turbulent economic history of the period under discussion.

The names of the successive institutions operating in this transitional period reflect the fluctuating levels of success achieved in reaching the ultimate aim of establishing a university in Johannesburg. The Transvaal Technical Institute, which was in existence from 1904 to 1906, provided mainly technical instruction. In order to facilitate the transfer to university status, courses were begun in arts and sciences, and the name of the Institute was changed, in 1906, to Transvaal University College. When, in 1910, Jan Smuts ignored the desire of Johannesburg to promote the Transvaal University College to university status and was instrumental in transferring the teaching of the arts and pure sciences and the Transvaal University College itself to Pretoria, the part of the College that was left in Johannesburg was given the name South African School of Mines and Technology. Because of the perseverance of Johannesburg, the Union Parliament granted powers to the School of Mines, in 1916, to organize courses in arts and pure sciences again and, in recognition of the rapid expansion which took place in the following years, the new title, University College, Johannesburg, was approved in 1920. It was not long after, in 1921, when the establishment of the University of the Witwatersrand was ratified by Parliament.

As can be seen, while the teaching of the arts and pure sciences by the various institutes in this period vacillated, the provision of mining and engineering instruction was continuous and undergoing steady consolidation. One of the reasons for this favourable state of affairs was that both the Engineering and the Mining Departments were set up very early in the life of the Transvaal Technical Institute. Consequently, with the existence of the organizational framework and programme of study, the conditions for the development of higher mining education were established.

Soon after its formation, the Transvaal Technical Institute wanted to be as independent as was possible from both the South African College and the University of the Cape of Good Hope. To this end, the initial plan was to offer a three-year programme in general engineering, to be followed by an additional year of study in which students could specialize in mining and metallurgy or mechanical, electrical, or civil engineering. Furthermore, the Institute decided to examine all its courses and award its own diplomas. Nevertheless, any student who wished to obtain a degree was allowed to sit the examinations set by the University of the Cape of Good Hope.

Despite the suggestion outlined above, the programme of study in mining remained substantially the same during this period as that formulated in Kimberley: two years of science and basic engineering studies, and two years of specialization in mining and metallurgy. As intended, all the courses were provided by the appropriate institutes. The duration of practical training on the mines was reduced considerably, being restricted to the summer vacations. In addition to the full-time study programme, evening classes were also offered and, in 1908, the Senate of the Transvaal University College approved the establishment of a sandwich system of study, which consisted of alternating periods of six months' work in industry and six months' study at the College. This latter system was introduced mainly to overcome the shortage of full-time students brought about by the 1906–09 economic depression.

Initially, accommodation for the Transvaal Technical Institute was primitive, consisting of temporary premises in an old cigar factory and in the Lost Properties building, where the Engineering and Mining Departments were located. To improve the situation, a group of temporary wood-and-iron buildings, known as the Tin Temple, were erected in Plein Square and were occupied early in 1905. Accommodation improved considerably when, in 1909, the first of the Transvaal University College buildings, as shown in Figure 2, was completed on the Eloff Street end of Plein Square. This building housed most of the academic activities of the various institutes, including the University of the Witwatersrand, until 1926, when it was taken over by the Witwatersrand Technical College. The rest of the buildings planned for the Transvaal University College were never completed.

The availability of financial resources, or the lack of them, influenced both the student numbers and the quality of mining instruction provided by the various institutes. In the early days, almost all the finances were directed towards the acquisition of buildings, teaching facilities, and employment of academic and administrative staff. No finances were made available to assist students in the form of bursaries, scholarships, and student amenities. The general funding by the Transvaal Government, the Council of Education, and the mining houses was at a low level, especially during the 1906–09 economic recession. Because of this lack of finance and the recession in general, there was a dramatic reduction of student enrolment in this period. The situation changed favourably during the ensuing economic recovery.

As far as the mining students were concerned, the improvements emanated partly from the establishment of a

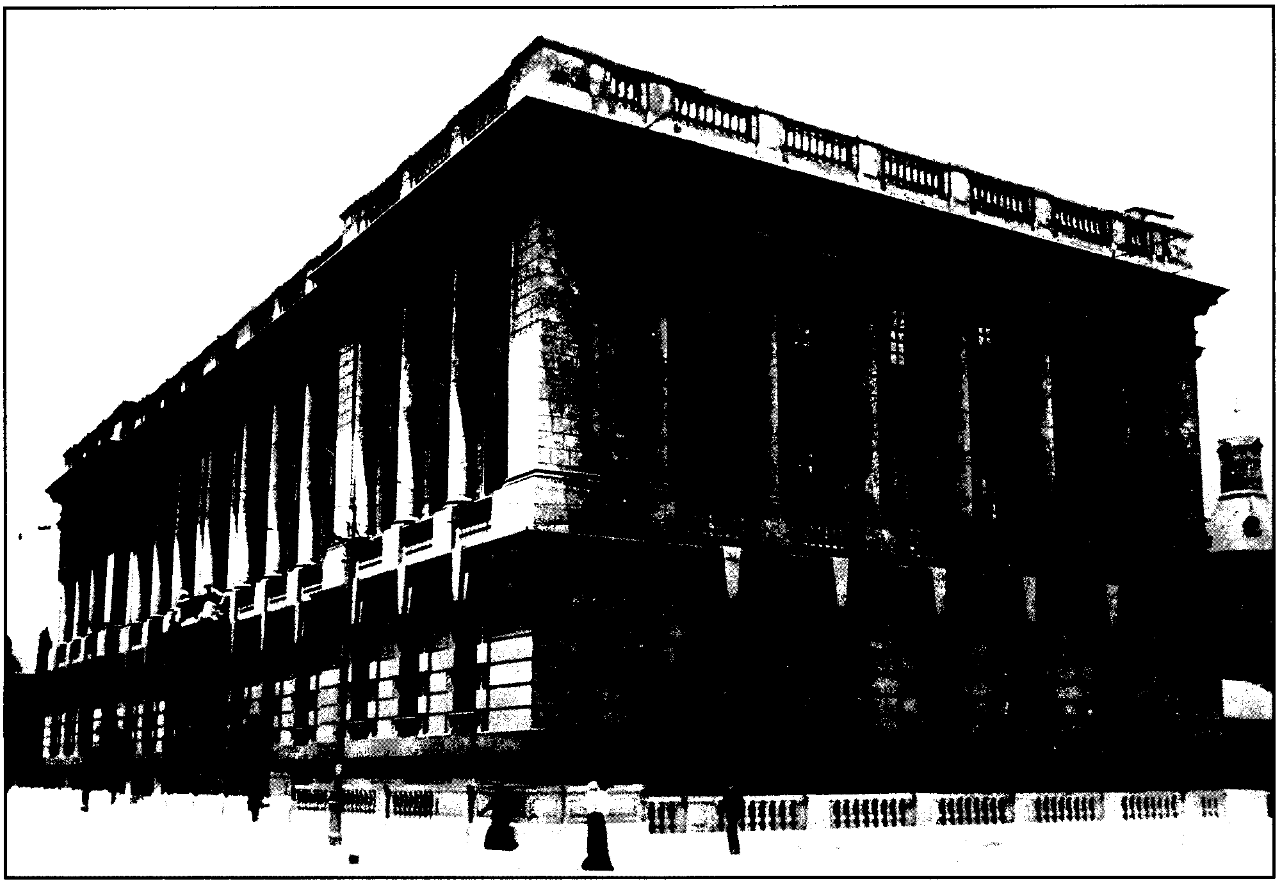

Figure 2—The Transvaal University College, 1909

number of major scholarships. The Hennen Jennings, Barnato, and Neumann scholarships were intended to assist full-time students and were awarded on the results of first-year examinations, while the Rand Mines, Consolidated Goldfields, and E.R.P.M. scholarships were available to selected students taking evening classes to enable them to transfer to day courses. Another particularly important scholarship established in this period was that of the Chamber of Mines for post-diploma research work. Unfortunately the recovery in student numbers was halted by the First World War until the resurgence of economic activities after the War. However, the level of enrolment in mining remained low for the remainder of this period.

As indicated, student numbers were also affected by the participation of students in the War. The level of this participation can be gauged from the following statement by Orr[1]. 'The Great War seriously interfered with the educational work at this time; so many of the engineering students joined the forces that for nearly two years there were practically no third- or fourth-year students in attendance and no mechanical and electrical students for over a year in the fourth-year course'.

Although, in the early part of this period, a number of individuals had been appointed as professors of mining, only a few were directly involved in mining education. The reason for this incongruity was that, until 1912, the professor of mining was also the principal of the appropriate institution. Consequently, several persons were appointed to the position for their administrative abilities, and not necessarily for their mining expertise. Those who participated in mining instruction were Professors T.E. Robertson, J. Yates, G.R. Thompson, and J.S. Cellier. Professor Cellier was a product of the School of Mines in Kimberley, and was the first South African mining graduate to hold the Chair of Mining.

From the points of view of mining education, the period under review had some positive features. The provision of an organizational framework of a department of higher learning and the establishment of a complete programme of mining instruction led to the consolidation and further development of tertiary mining education in this period. The establishment of major scholarships for pre- and post-diploma studies and the foundation of many facets of student life on campus were all part of the continuous development of mining education. The main negative aspects of the activities of the Department of Mining were the low student enrolment and, initially, poor resources. In many respects, the period can be characterized as transitional, but it was an essential period in the evolution of tertiary mining education in South Africa.

The First Three Decades under Wits Administration

In historical terms, the birth of the University of the Witwatersrand, Johannesburg, in 1922 coincided with the White miners' strike, culminating in the Rand revolt and its subsequent suppression by government forces. The period under review began with this act and ended with the National Party winning complete political power in 1948 and, in the early 1950s, introducing laws that served to underpin its policies of total racial segregation. In the intervening years, both the cause of Afrikaner nationalism and the National Party grew in strength, despite occasional setbacks. The Second World War in this period was also a cataclysmic event that affected the lives of many South Africans, among them some of the students in the Department.

The most important factors that influenced the economy of South Africa in this period were the Great Depression and the subsequent suspension of the Gold Standard in 1932. On the positive side, the gold-mining industry, in particular, benefited from the sharp rise in the gold price. This resulted in one of the greatest expansions of the industry in this century. This consisted of the developent of 15 new mines on the East Rand and the location of a new mine on the Far West Rand, hence opening up one of the richest goldfields in South Africa. After the war, large-scale exploration resulted in the completion of the development of the Far West Rand and the opening up of the Orange Free State goldfield, thus establishing a secure future for the gold-mining industry well into the 21st century.

The inauguration of the University was in some respects not a positive step for the Mining Department. The transition from the Kimberley School of Mines to the University of the Witwatersrand represented a gradual loss of autonomy and importance to the Department. From a major role-player in the affairs of the various institutions, it became virtually the smallest department of the Faculty of Engineering, which was established soon after the University was inaugurated. The very low numbers of students and staff in the Department, and the contraction of the gold-mining industry during the early years of this period, contributed to the despondency and lent uncertainty to the future of mining education in South Africa. It took many years of hard work, the intervention of the mining industry, and changing historical circumstances to propel the Department eventually onto a positive development path.

Figure 3 depicts the number of graduates produced by the Department since 1922. The first portion of this illustration reflects the fluctuating fortunes of the Department associated with student numbers during the period under discussion. It can be seen that, until 1927, the Mining Department at Wits graduated only a small number of mining engineers. It was believed that there were many reasons for the low figure.

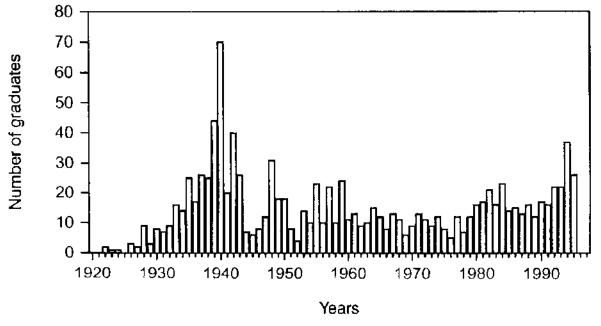

Figure 3—The number of mining graduates from 1922

Murray[2] recorded some of the most important ones. These included a lack of job and promotion prospects in the contracting gold-mining industry, the far-too-theoretical course content, and the unnecessarily high standard that was required from students in the examinations, especially in the mathematical subjects. In order to correct the situation, both the Department and the mining industry contributed to the solution of the problem.

Representatives of the mining industry took part in the work of a joint committee, set up by the University, to scrutinize the standard and programme of study. For its part, the Department had already, in 1924, changed the structure of its mining programme. The change involved sending the final-year students out to work in the mines from Monday to Thursday, and arranging academic instruction to take place on Friday and Saturday. One of the major recommendations of the joint committee was that this system of instruction brought the theoretical and practical work into closer contact and should therefore be continued.

Owing partly to the recommendations of the joint committee, and partly to the abandonment of the Gold Standard in 1932 and the subsequent expansion of the mining industry, the number of graduates in mining increased, as Figure 3 reflects, and remained at a relatively high level until 1943. The largest number of graduates ever produced in a year was 70 in 1940, when many third-year students were permitted to write their third- and fourth-year examinations simultaneously before joining the armed forces. In the last year of the war and in the immediate post-war years, there was a substantial drop in the number of graduates, except in 1948 as returned servicemen completed a shortened degree. Although the number of graduates improved periodically, it remained at a relatively low average figure for many years.

The system in the final year of study of combining practical work on the mines with academic instruction at the University was retained, in various forms, until the early 1940s. Since then, mining students have obtained their compulsory practical training during the summer vacations after the first, second, and third years of study. Until 1942, the degree that was awarded to the graduands of the Department was for a combination of mining and metallurgy. Before that year, students in their final year could specialize either in mining or metallurgy. From 1942, the programme of study offered by the Department led to the award of a degree in mining engineering only. It should be noted that the figures plotted in Figure 3, until 1942 represent the number of graduates in the combined disciplines specified above.

Another change took place in the mining curriculum in 1958 with the introduction of the two specialist options. According to this specialization, students in the final year could choose either the coal- or the gold-mining option of study, giving rise to the award of the Collieries or the Metalliferous sub-divisions of the Mining Engineering Degree, respectively. Initially a number of students took the coal option, but this number soon dropped to a level that made the running of the Colliery option unacceptable, and consequently it was abandoned in the mid 1960s.

The physical location of the Department also changed during this period since the engineering departments had remained in the Plein Square premises until the Engineering Block at Milner Park was ready for occupation in 1926. The Mining Department was housed in that building until 1941, when it was transferred to the new Hillman Building. No space was acquired by the Department to set up a laboratory to facilitate laboratory practicals in mining subjects either in the Engineering Block or in the Hillman Building.

As indicated earlier, the number of staff involved in the teaching of mining subjects was small during this period. For more than a decade, the staff consisted of a professor and a senior lecturer. In 1939, despite the substantial increase in student numbers up to that year, the staff numbered only three. The Professor of Mining and Surveying, who headed the Department during the early years of Wits, was appointed in 1921. He was G. A. Watermeyer and served the University as Professor of Mining until 1934. His successor was C. Biccard Jeppe, who held the chair until his retirement in 1954. The most notable contributions to mining education of these incumbents of the Chair of Mining were their respective textbooks[3,4].

Before the war years, the leadership of the South African mining industry was largely in the hands of mining graduates from overseas universities. By the early 1940s, there were sufficient Wits graduates working in the industry to take over its technical command. Many mining graduates from this period had distinguished careers, and rose to the highest positions in the mining industry. It would be difficult to list all of them in this paper, but two who achieved great eminence, both as mining men and as citizens of South Africa, should be mentioned.

The first was F. G. (Pinkie) Hill, who graduated in 1927. After completing his studies at Oxford as a Rhodes Scholar, he joined Rand Mines and served the Corner House Group in a variety of technical positions until 1969. His industrious life has been described by Lang[5]. F.G. Hill's interests and activities extended well beyond his technical duties and, with his humanitarian approach to management, he set new standards in labour relations. His achievements were acknowledged by many professional bodies and two universities by the award of various prestigious medals and two honorary doctorates. In his retirement, F. G. Hill also served the University, first as a member then later on as the Chairman of its Council.

The second outstanding individual is D. G. Krige. After graduating in 1938, he worked for Rand Leases Gold Mine, the Department of Mines, and Anglovaal Ltd. During the early years of his retirement, he also held the chair of Mineral Economics in the Department. Most of his professional activities have been associated with ore-reserve calculations, geostatistical research, and mine economics, and his research investigations in geostatistics led to the method of kriging, which is accepted and used world-wide. In recognition of his contributions to the development of geostatistics, he was awarded a D.Sc. by Wits and honorary doctorates by the Universities of Pretoria and South Africa. In addition, he has received numerous gold medals and special awards from professional bodies in South Africa and overseas.

The Department is proud to list both Pinkie Hill and Danie Krige among its most eminent graduates.

As in the First World War, students of the University, including a number of mining students, joined the armed forces in the Second World War. Records show that a total of 1140 Wits students interrupted their studies to take part in the War. In 1970, the University established a Roll of Honour recording the names of members of staff, graduates, and students who gave their lives in the two World Wars and the Korean War. Unfortunately, the records do not indicate the home department of the students who served or lost their lives in the Second World War.

In some respects, this period of the Department's history was positive, in others it lacked historical significance. In one decade of this period, 1933 to 1943, the number of students who successfully completed their studies was much higher than any other decade between 1896 and 1996. The quality of some of the graduates was also outstandingly high. However, perhaps owing to a lack of leadership, these and other positive factors were not utilized to build up the Department by increasing the staff and establishing a mining laboratory. It was also unfortunate that the genuine transition from the old School of Mines to a true university department was not given sufficient impetus in this period.

Decades of Steady Progress

The period from the mid 1950s to the early 1980s was characterized by the two opposing political objectives and actions of the major role-players in South Africa. On one hand, the ruling National Party pursued its separate-development policies with new determination. As a result, hundreds of thousands of non-Whites were relocated, and the homelands were turned into national states. On the other hand, the killing of 69 people protesting against the pass laws at Sharpeville provoked the liberation movements to abandon non-violent protest and opt for armed insurgency. The liberation of Zimbabwe and the Portuguese colonies of Mozambique and Angola changed the balance of political power in the region in favour of the emerging Black nations and the liberation movements in South Africa. The Soweto rebellion on 16th June, 1976, which, within a short time, took on countrywide proportions, had far-reaching repercussions and represented a turning point in the most recent history of South Africa.

By the mid 1950s, most of the gold mines that had opened up during the large-scale expansion in the pre- and post-war periods were in operation. This was also the time when the problems associated with the large extent of worked-out areas and the increased depth of the workings began to take on serious proportions. The increasing number of rockbursts and the deteriorating environmental conditions in the workplace were the most noticeable problems experienced by the gold-mining industry. The coal-mining industry also had its share of difficulties, of which uncertainty about the safe level of extraction of a coal seam was the most serious. Unfortunately, this lack of expertise eventually resulted in a serious accident at Coalbrook in 1960, which claimed the lives of 437 men.

To overcome the technical problems in the mining industry, increasingly greater amounts of effort were expended on research into a variety of mining-related fields. Consequently, from the beginning of the period and with the passage of time, more and more research results became available that had to be incorporated in the teaching material. It was also a period when the Department had the opportunity to participate in the accelerating research programme. Both the availability of advanced knowledge and the departmental research work gave rise to the establishment of post-graduate courses and corresponding academic qualifications.

The progressive outlook in the teaching of mining-engineering subjects and the initiation of research activities justified the Department's claim for more appropriate housing. Thus, in 1961, part of the new Geology Building was made available to the Department, where the standard of both the staff accommodation and the lecturing facilities was much improved, and the establishment of a mining laboratory and workshop could begin. By the end of the period, the Department had a first-rate workshop and several well-equipped laboratories. Unfortunately, the lack of space in the Geology building restricted the further development and, later on, the modernization of these laboratories.

The accumulation of contemporary knowledge in mining engineering was mainly associated with developments in rock mechanics, mine valuation, environmental engineering, and the use of explosives. In addition, the application of electronic computers in engineering and education was also gathering momentum. To take cognizance of these advances, the undergraduate programme was modified several times during this period. In the early 1960s, the first two years of the mining-engineering programme was the same as those of the other engineering students in the faculty, and the teaching of professional subjects was restricted to the last two years of study[6]. The mining programme two decades later reflects that several courses in the second year were replaced by mining and related subjects, retaining only the first year as common with the other engineering departments.

The publication by Plewman and King[7] shows that both the subjects taught and their contents in the senior undergraduate years also underwent considerable changes. By the early 1970s, rock mechanics was well and truly entrenched in the mining programme, covering both the essential theoretical and practical aspects of the discipline. The importance of this aspect of the mining degree was recognized in 1974, when the University created a Chair of Rock Mechanics. The new material on the study and control of the working environment was incorporated in the old mine-ventilation subject and given a new name: environmental engineering. The teaching of mining economics was increased in scope, eventually resulting in four courses. The relatively new study of geostatistics, which gave a scientific basis to mine valuation, was one of the four courses. The introduction of a subject covering surface-mining methods and a new approach to the use of explosives completed the re-structuring of the mining programme at Wits to the extent that it was possible at the end of this period.

Despite the accelerated expansion of the mining industry, mentioned earlier, and the corresponding improvements in job and career prospects, the enrolment in mining engineering, and consequently the number of graduating students, remained relatively low. There were years in which the enrolment was high, but the failure rate in the first two years of study was so high that only 40 per cent reached the final, graduating year. It is believed that the major reasons for these phenomena were the general drift of prospective students to the more fashionable branches of engineering, and the establishment of a new mining department at Pretoria University in the early 1960s. Furthermore, at the beginning of this period, it was general practice that students sponsored by the mining groups spent one or more years on underground training as learner officials before being sent to university to study for their degrees. Unfortunately for some students, this break was too protracted and adversely affected both their attitude to study and their performance in the academic subjects. The system was therefore discontinued, and the bursary scheme was modified. Despite the availability of generous bursaries, school-leavers did not favour mining engineering as a career, and the number of graduates produced by the Department remained relatively low until the early 1980s.

Although the more recent graduates from this period have still to make their mark in the mining industry, some earlier graduates have already achieved prominence in leading the industry in a variety of senior positions. One can record with pride that, from this group, 10 have risen to the pinnacle of success in mining houses, 4 have served as president of the Chamber of Mines and 3 have elected to serve the industry as professors of mining engineering. It should also be recorded that 2 graduates were selected to complete their studies as Rhodes Scholars.

Although 13 M.Sc. degrees were awarded by the University for research work in mining engineering in the period 1922 to 1955, the option of obtaining an M.Sc. by a combination of course work and a limited research project was introduced only in 1961. In that year, the Department offered three technical postgraduate courses and five courses in the fields of mine management and economics. The latter courses were intended for men with some years of practical experience. By 1982, the number of courses on offer grew to 25 but, owing to limitations imposed by staff numbers, no more than 6 could be run in any one year. Postgraduate students could also obtain the qualification of Graduate Diploma in Engineering by successfully completing the required number of courses without the research project. Towards the end of the period, some 15 to 20 students attended these courses annually. University statistics show that, between 1955 and 1982, 10 Ph.D. degrees, 40 M.Sc. degrees, and 31 Graduate Diplomas were awarded for mining-related postgraduate studies and research.

Research became a part of the Department's activity not only to satisfy the requirements for the award of higher degrees, but also to utilize its resources. To give a framework to the various research activities, a Research Unit was established in 1961 and remained in operation until 1982. Most of the finances to maintain the Research Unit came from the Chamber of Mines. The fields in which the Department contributed to the ongoing research effort were: rock mechanics, rock fragmentation by explosives, and environmental engineering.

The number and composition of the academic staff also reflected the steady growth of the Department. In 1961 the staff consisted of 1 Professor, 3 Senior Lecturers and, in the Research Unit, 2 Senior and 2 Junior Research Fellows. The corresponding numbers in 1982 were: 3 Professors, 4 Senior

Lecturers and 1 Senior Research Fellow. The two specialized professorships were established in the fields of rock mechanics and mineral economics respectively, with the chair of Rock Mechanics being held from 1974 to 1991 by Professor S. Budavari and the personal chair of Mineral Economics by Professor D.G. Krige from 1981 to 1991. During this period the Department was headed by Professors R. A. L. Black, from 1955 to 1962, and R. P. Plewman, from 1963 to 1982.

The preceding paragraphs in this section reveal that the Department's activities underwent fundamental changes in this period. From a purely teaching institution, it became a progressive university department, which incorporated relevant, modern technical knowledge into its curricula and extended its activities into postgraduate studies and research. It established and equipped several laboratories and introduced laboratory practicals to complement the classroom instruction. The increase of academic staff and the establishment of research positions and the two specialized chairs also reflect the steady growth of the Department. It is believed that the shortcoming of this period was that the high failure rate in the junior years was not addressed with sufficient vigour.

The Period of Transition to Multiracial Education

The Soweto unrest and its aftermath caused deep economic depression, industrial strife, flight of foreign capital, broadening international isolation, and a rising tide of Black opposition. All these factors contributed to the accelerated decline of White rule, thus bringing about the conditions for inevitable political changes. Eventually, the De Klerk government accepted the failure of apartheid and the need for transformation. The political changes and the accompanying restructuring of South African society characterized this last period under review.

The liberal spirit that dominated the policies of Wits since the beginning of the apartheid era inevitably influenced the Department of Mining Engineering in carrying out its duties. For decades, the Department had advocated the extension of its educational activities to all students irrespective of colour[6,7]. Despite these efforts, the gradual recruitment of non-White students to the mining-engineering programme began only in the 1980s, when political conditions permitted it. This change was made possible by the weakening of the apartheid system of government and the consequent repeal of the relevant legislation in 1983.

As a result of the fundamental transformation of South African society, the Wits student population in mining engineering has gradually become multiracial, as shown in Figure 4. While this was to be expected and was indeed welcomed by the Department, the problems associated with the teaching of classes containing a considerable number of under-prepared junior students, especially those from disadvantaged educational backgrounds, have caused increasing concern. This prompted the Department to review its responsibilities and the objectives and methods of the education it provided. This critical review, with the aim of providing a modern and more effective mining education, has dominated the activities of the Department in recent times. The main aspects of the review are briefly described in the following paragraphs.

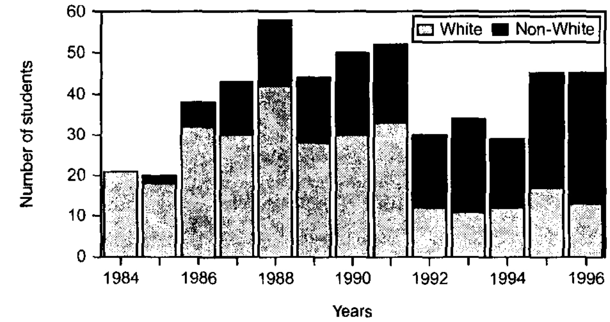

Figure 4—New enrolments in first year, 1984–96

As generally accepted, the activities of university engineering departments are governed by their responsibilities as determined by society, various industries, and the appropriate professional bodies. Among their main responsibilities is that of promoting engineering sciences through education and research.

At undergraduate level, the objectives of engineering education are the acquisition of knowledge and the development of certain abilities and attitudes. Knowledge, in this context, includes basic engineering science and its application, current practice in the relevant engineering branch, economic considerations, safety requirements, and the principles of management. The various engineering courses are required to assist students in the development of abilities to obtain and manage information efficiently, to think clearly, to make decisions, to be creative, and to communicate effectively. University education should also provide the engineering student with a certain degree of professionalism, and a responsible attitude towards his work and society. In order to keep up with the rapid advances in technology and in discipline-related knowledge, students of engineering should be taught to accept progress and to develop a habit of learning.

For postgraduates, the objectives of university engineering departments are to enable students to acquire knowledge, in some selected field, to a greater depth, and to gain experience in scientific research. Postgraduate courses should present the most up-to-date practice and give examples of its application in an appropriate industrial environment. Research carried out in a university department is an essential activity, and is a combined effort by postgraduate students and staff. One of the distinguishing factors between the old mining schools and a university department is that the latter, in addition to fulfilling its educational obligations, promotes postgraduate studies and research, thus taking part in advancing the frontiers of knowledge.

The Department of Mining Engineering is committed to the philosophy set out above, which is in agreement with the aims and objectives of professional bodies both here (SACPE document No. 15/1/4) and overseas. The curriculum, the material taught, the method of teaching, the industrial training, and the close liaison with industry are all designed to facilitate the education of students to the highest international standard.

The present undergraduate programme at Wits, which is of four years' duration and leads to the degree of Bachelor of

Science in Engineering, educates the student to enter any sector of the mining industry. The first year of study is devoted to the basic sciences in order to supplement the broadly based matriculation obtained at the end of 12 years of schooling. Thereafter, the successive years of study involve engineering sciences, mining sciences, and professional mining subjects. The curriculum for the mining degree is shown in Figure 5.

In a review of the Department's activities, the curricula at 32 university mining departments in 23 countries were studied and compared with the mining programme at Wits. It was concluded that, with minor variations, the Wits curriculum was similar to those of the overseas institutions and that, apart from the fact that the Wits curriculum contained more rock mechanics, more reserve valuation or geostatistics, more financial management, and less liberal and environmental studies than some of the courses overseas, it was well balanced and directed to serve the South African mining industry.

The Department also investigated the educational achievements of its intake, the efficiency of its teaching, and the receptiveness of the students involved in the educational process. This was particularly relevant in view of the diverse backgrounds of the current student population. In this respect, the cumulative experience of the Division of Engineering Support Programmes in the Faculty of Engineering was utilized to provide an appreciation of the problems.

In the survey of the educational standard reached by scholars entering university, the main requirements to become successful engineering students were identified as follows: a degree of innate intelligence, a level of knowledge in mathematics and physical sciences, an acceptable level of communication capability in the medium of instruction, the essential abilities and skills for learning, and a high degree of motivation. It is generally accepted that, apart from innate intelligence, most of these attributes can be improved and brought up to the required standard by remedial education and the use of bridging programmes.

An analysis of the performance of first-year mining students indicated that many of them were poorly prepared to undertake engineering studies. Their shortcomings were attributed to a low level of knowledge in mathematics and physical sciences, communication deficiencies, and lack of essential abilities and skills for learning. Further problems experienced were the difficult transition from high-school to university studies, difficulties in absorbing the study material at the rate it is presented, and lack of personal development to meet the needs of modern society. The analysis also yielded a number of conclusions that called for a series of actions to be taken by the Department if it wanted to ensure that the standard of its graduates was not impaired irrespective of the educational achievements of the intake.

In order to deal with the poor preparedness of students and to assist in their studies in the first and second years, the Department accepted the need for bridging courses, remedial teaching, and the small-group tutorial system. During the past decade, several bridging programmes have been established to offer Black matriculants who have the potential to succeed either a one-year programme of academic and engineering studies before enrolment in first year, or a two-year programme to enable successful students to obtain credit for the first year of study. These bridging

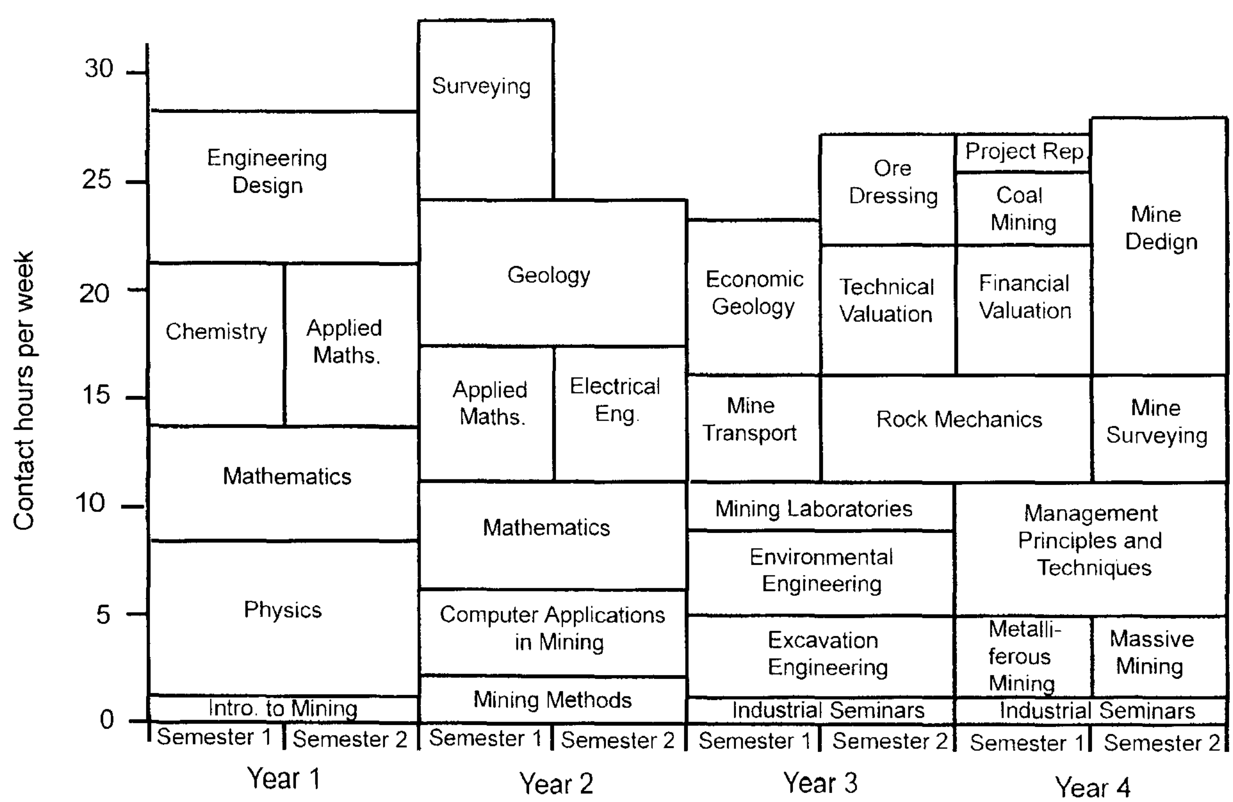

Figure 5—Mining-engineering curriculum

Figure 3 - Mining engineering curriculum

programmes are run by the Division of Engineering Support Programmes and the College of Science. The small-group tutorials and supplemental instruction schemes were introduced to assist selected students in their first and second years by providing them with increased contact with tutors and group-learning sessions in some subjects.

As far as the third- and fourth-year students were concerned, the Department recognized that more conscious effort had to be expended to improve the development of abilities and attitudes, especially problem-solving capabilities. To this end, students are more actively involved in the educational process, and the teaching and learning aspects of student–staff contact time have been made more effective. The staff also suggested and implemented ways and means by which the theory and practice could be balanced in the various courses, and both the confidence and the motivation of the students have increased by measurable degrees.

The structure of the postgraduate studies leading to the award of the Graduate Diploma in Engineering (G.D.E.), M.Sc. and Ph.D. remained substantially the same as was established in the 1950–80 period. The one modification that has been made allows students after successfully completing 12 G.D.E. courses, to obtain an M.Sc. degree by coursework alone in the specialized fields of mineral economics and rock mechanics. To cater for the high demand in general, and to allow students to complete the 12 courses within a reasonable period, the Department increased the number of G.D.E. courses on offer to 16 or 17 each year. Departmental records indicate that there has been a significant expansion in postgraduate activities over the past decade. Figure 6 depicts the postgraduate registration since 1984. The plotted data reflect an equal growth in demand for continuing education through coursework and for research-based degrees.

The late 1980s was a period of considerable change for the Department, involving a growth not only in student and staff numbers, but also in its physical location. In 1985, the University acquired the agricultural showgrounds adjacent to the existing campus, and started the development of the West Campus. On completion of the new Chamber of Mines Engineering Building on the West Campus in 1989, the Department moved into new premises, and the current home of the Department is shown in Figure 7. Staff accommodation and lecturing facilities were provided in this building, while the laboratories and the workshop were transferred to the adjacent Genmin Laboratories Building. The overall laboratory space was adequate to increase the sizes of the

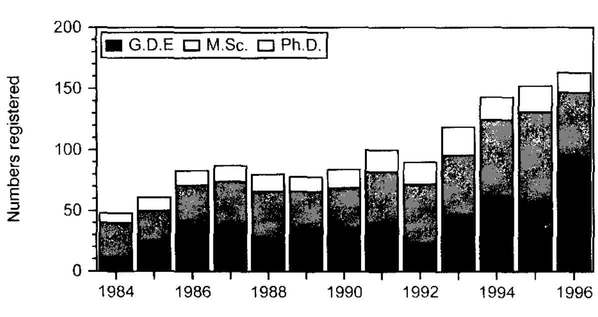

Figure 6—Post-graduate registrations since 1984

old laboratories and to create accommodation for postgraduate students and for several new laboratories. The move to the West Campus provided the Department with the stimulus to re-equip in certain areas, and there are now up-to-date laboratories to serve both teaching and research in the following areas: rock mechanics, excavation engineering, mine ventilation and climate control, computing, mine design, and digital photogrammetry.

In the 1980s, the number of students studying for a degree in surveying dropped considerably throughout South Africa. Consequently, an agreement was reached with other universities that, in the foreseeable future, only two universities would provide courses and award degrees in the field of surveying. Having lost the need for providing mainstream courses, the Department of Surveying at Wits merged with the Department of Mining Engineering in 1990. The four staff positions that were transferred to the Department allowed for service teaching in surveying throughout the University, and these staff are also involved in giving specialized courses in mining and surveying at both undergraduate and postgraduate level.

Even before Surveying merged with the Department, the number of academic staff increased gradually. However, with the merger and the appointment of several specialists in certain key areas, the size of the staff doubled in the first years of the 1990s. The new appointments led to the development of additional postgraduate courses and an upturn in departmental involvement in research and postgraduate supervision. The present academic staff consists of 2 professors, 1 associate professor, 7 senior lecturers, 3 lecturers, and 1 junior lecturer; 4 of the positions listed are fully financed by the Chamber of Mines of South Africa, and all the staff salaries are also supplemented by the mining industry. From 1982 to 1985, the Department was headed by Professor Budavari. The Chamber of Mines Chair of Mining Engineering, which fell vacant with the retirement in 1982 of Professor Plewman, was filled in 1985 by the appointment of Professor H.R. Phillips, who has also been head of the Department since 1986.

During this period, a great deal of effort has been expended in the modernization of the undergraduate syllabus, in improving the performance of students, and in the development of additional postgraduate courses and research. Some of the efforts have already borne fruit, but a number of educational objectives are of long-term duration, and their outcome cannot yet be evaluated. In addition, the period under review is a short one in comparison with the earlier periods. For these reasons, it would not be appropriate to discuss the Department's performance in this period in historical terms. Nevertheless, as the previous paragraphs indicate, in recent years, the Department, utilizing the accomplishments of preceding periods, has considerably improved its educational facilities and capabilities, and increased its number of both undergraduate and postgraduate students.

Concluding Remarks

This short review of past and present educational activities of the various institutions, from the South African School of Mines to the Department of Mining Engineering at

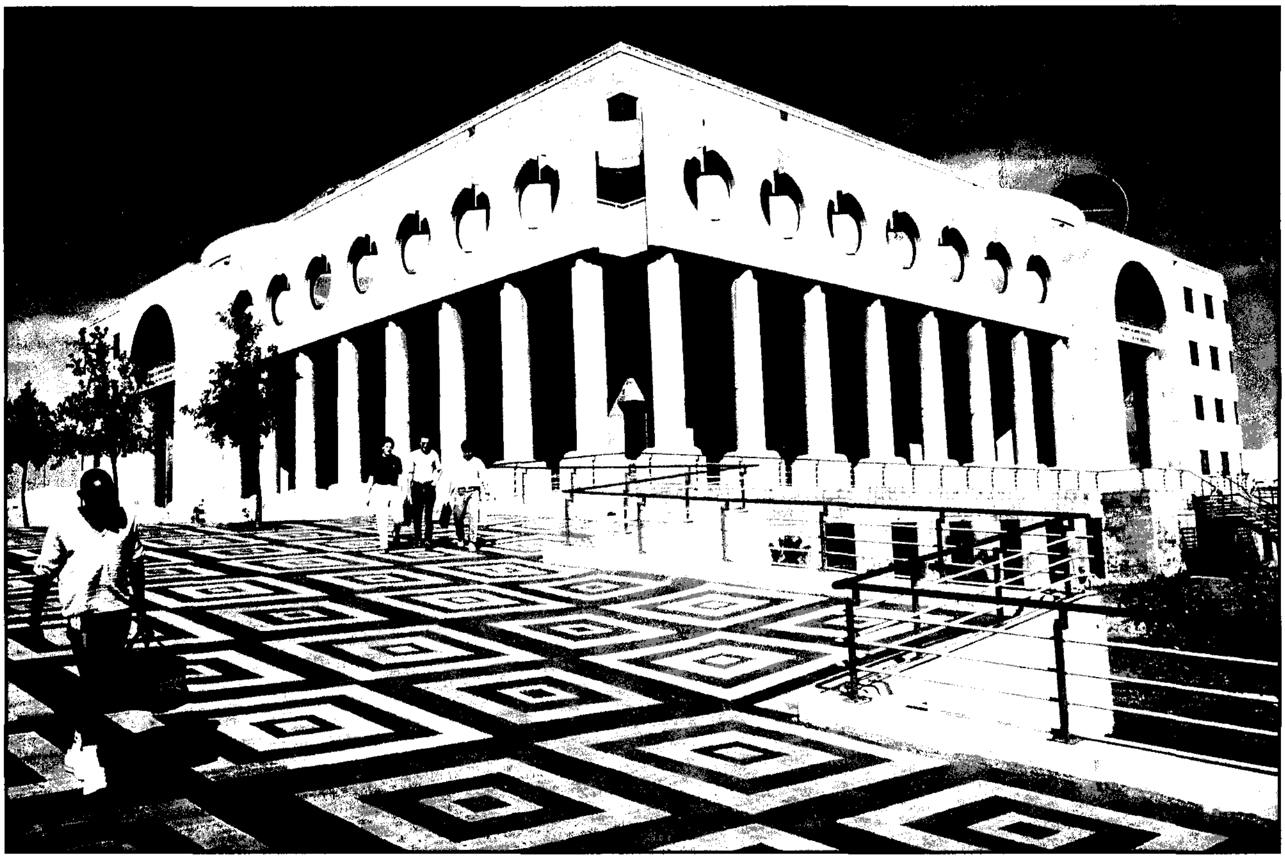

Figure 7—The Chamber of Mines Engineering Building, 1989

the University of the Witwatersrand, brings to light a number of important points that need to be recorded. It is appreciated that the formulation of these points and the critical evaluation of the academic activities in the various periods are subjective, and are based on a present-day perspective. The authors also accept that, during the past hundred years, a number of educational practices and objectives directed the work of the mining schools and the Department, and that these practices and objectives were fully sanctioned in the respective periods.

From a historical point of view, the various academic mining institutions played their part in the development of South Africa. Tertiary mining education set the pace of technical education in the country during many decades in this century. Through their activities, the institutions contributed to the development of the mining industry and to the industrialization of the country. The evolution of Wits was also influenced, to some extent, by the existence of a mature Mining Department.

It is obvious from the preceding discussions, that mining education was influenced, from its inauguration to the present day, by both political and economic factors. However, the fortunes of the mining industry had an overriding effect on the provision of this education. Student enrolments and the numbers of graduates produced fluctuated in harmony with the varying degrees of prosperity in the industry. Since the number of students enrolled in mining was generally low, these fluctuations made it even more difficult for the Department to satisfy the needs of the South African mining industry, despite the consistent and generous support, financial and other, it received from the industry.

Following the development of tertiary mining education, one can conclude that the early institutions, and for a number of decades also the Mining Department at Wits, were almost exclusively concerned with technical instruction. Engineering education with wider objectives, as is accepted and practised today, was consciously included in mining academic pursuits only in the 1950s. Since then, the Department's activities have advanced to the level of a modern university engineering department.

Right from the beginning, the primary aim of tertiary mining education has been the transformation of intelligent matriculants into young engineers, ready to be trained as professional mining engineers. This has been carried out through a programme of study that was updated periodically by the incorporation of new developments both in South Africa and in overseas countries. More intense postgraduate teaching and research were included in the academic activities only from the mid 1950s and, owing to their accelerated development, the extent of the Department's involvement has become nearly equal to that of its undergraduate teaching duties. The Department has also met its obligations to the South African mining industry and professional bodies by extending its activities beyond the confines of the University.

The final conclusions one should derive from this paper are associated with the academic accomplishments and the quality of educational activities in which the mining schools and the Department have been involved. As far as the numbers of graduates are concerned, in some periods the relevant institutions did not fare well, but the technical leadership of the South African mining industry, past and present, bears testimony to the quality of the graduates. If one considers the full spectrum of activities, there is no doubt about the high degree of accomplishments, and there is every cause for satisfaction. The achievements are due primarily to the dedicated staff of the various institutions, the energetic student bodies, the caring alumni associations, and the many individuals who, directly or indirectly, contributed to this remarkable educational effort over the past hundred years.

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New appointment

Denis Twigg has been appointed as Professor of the Port Elizabeth Technikon.

With his wife Margaret, two sons, Christopher and Philip, and daughter Jennifer, he emigrated from England to South Africa in 1975. His first position in this country was Lecturer in Materials Science at the University of Port Elizabeth. He then moved on to the Metallurgy Division of the South African Bureau of Standards, Pretoria, where he eventually became the Head of Division. From 1983 to 1990, he was the Executive Director of the Galvanizers Association of Southern Africa. He has held his present position as Head of Department of Materials and Metallurgical Engineering at the Port Elizabeth Technikon for the past six years.

The Port Elizabeth Technikon follows the qualified *ad hominem* approach to professorships. Accordingly, his title was awarded on specific criteria, which included his achievements in his present and previous positions, research, contributions to journals, papers delivered, supervision of postgraduate students, and recognition by industry.

Professor Twigg assists industry in the disciplines of corrosion protection and metal-failure analysis. ◆

SA technology for Chile*

A Mintek team returned recently from Chile, where it scored a double first at the gold-milling plant of El Indio's Tambo mine in the Andes. It was the first time that Mintek's particle-size estimator (PSE) was used outside South Africa, and the first time that this piece of equipment was installed on a cyclone cluster, having been used only on single cyclones in the past.

The PSE is a microprocessor-based instrument that is used in conjunction with a hydrocyclone underflow meter (HUM) to monitor, control, and optimize hydrocycloning and milling circuits. The HUM gives an accurate reading of a hydrocyclone discharge spray by means of a mechanical arm that floats on the discharge stream, the angle of the arm being measured by an electromechanical transducer: the PSE derives a continuous estimate of the particle size in a hydrocyclone-overflow product stream from a heuristic model based on the output of the HUM, as well as on the flowrate of the cyclone feed and density measurements.

The advantages of this technique is that it is simple and robust, and it eliminates the need for the sampling of the product stream. The particle size is displayed numerically, as well as by electrical signal.

The equipment is currently in operation in a number of milling circuits on South African gold mines.

Issued by Mintek, Private Bag X3015, Randburg 2125. ◆

Chemical Engineering graduate is cream of the Wits Crop*

The top 1995 graduate at the University of the Witwatersrand is Andrew McCarthy, pictured receiving the Eskom Merit Award from Eskom's student development manager, Ann Lamprecht, at the Engineering Faculty's recent prize-giving. Andrew graduated in chemical engineering last year with top marks, not only in the Engineering Faculty but also in the University. Eskom makes Merit Awards to the best engineering graduates at all South African universities, and will announce the name of the country's top engineering graduate later in the year.

Other prizes awarded to Andrew at the prize-giving were the Benjamin Tannenbaum Memorial Medal, the J. Arthur Reavell Medal and Prize, the Pretoria Portland Cement Company Limited Prize and Certificate, and Sasol prizes for chemical-reactor analysis and design, and process control. At the end of last year, he won the prestigious Chamber of Mines Gold Medal for the best graduate in the Engineer-ing Faculty at Wits. Andrew leaves shortly for Oxford University as a Rhodes scholar to study philosophy, politics, and economics. ◆

Issued by Lynne Hancock Communications, P.O. Box 180, Witkoppen 2068.

In memory of a great coal man*

Amelia Kleijn congratulates Robert Machowski on winning the Professor David Wright Horsfall Memorial Award

Guests at the annual Engineering Faculty prizegiving at the University of the Witwatersrand remembered David Horsfall, when a prize was awarded in his memory. Colourful and multi-talented, David Horsfall was a professor in the School of Process and Materials Engineering, and died on 5th September last year.

Professor Horsfall's daughter, Amelia Kleijn, came forward to hand the Professor David Wright Horsfall Memorial Award to final-year student Robert Machowski. Robert was selected as 'the student who demonstrated perseverance and displayed an original and innovative approach in a final-year laboratory project and/or design course in the field of mineral processing/ metallurgy'.

This award, which takes the form of a cash prize and a book, is awarded to a student who is not necessarily at the top of the class academically but who shows perseverance, an inquiring mind, and an ability to think laterally. Robert Machowski won the award for a mineral-processing laboratory project.

David Horsfall held the position of Shell Professor of Coal Studies in the School of Process and Materials Engineering at Wits at the time of his death, and was internationally respected in the field of coal processing. He had a gift for languages, including French, German, Russian, and Japanese, and was acknowledged as possibly the country's leading expert on Gilbert and Sullivan. ◆

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The clean-up of the plant at Bracken Gold Mine

by M.A. de Ruijter*

Synopsis

Bracken Gold Mine ceased mining operations during February 1993. The clean-up of the gold plant, which had already commenced in September 1992, was completed in January 1994. The mine had been in production since early in 1962 but, because of a decreasing ore reserve, increasing working costs, and a relatively low gold price, closure had become inevitable.

The closure had been under consideration since August 1983, when the first estimate was made regarding the amount of gold that could be recovered from the clean-up operations. Until that stage, it had been accepted that Bracken would conform to the commonly accepted idea that 0.25% of the total gold produced by the plant would be recovered during the clean-up operation. This idea was dispelled when the initial estimates indicated that the gold recovery would vary between 0.049 and 0.095%. The actual figure realized was 0.036%, showing that there is no general formula for the calculation of the amount of gold to be recovered from such clean-up operations.

During the clean-up operation, Bracken became an unexpected contributor to the State's Reconstruction and Development Programme by having all the mine and plant buildings purchased and converted into a community development centre. This shortened the time available for the clean-up, and several of the buildings remained intact. However, the foundations and sub-soils had been sampled extensively, and it is considered that no recoverable gold was left behind.

Introduction

Bracken Gold Mine is situated near Evander, in the southeastern Transvaal. Bracken was the second gold mine to be brought into production in the Evander basin after Winkelhaak Gold Mine, and officially started production in February 1962. By the time production had ended in January 1994, 238.1 kg of gold had been produced from the 31.8 Mt of ore mined. These figures relate to Bracken Gold Mine only[1]. However, for a consideration of the total gold produced by the Bracken plant, the toll-milling of Winkelhaak low-grade ore and Kinross ore also needs to be taken into account. This information is given in Table I.

Bracken Gold Mine was planned as a relatively short-life, high-grade mine from the start. The plant was designed as a run-of-mine milling plant, which was a new and unproven concept at that stage. This design rejected the traditional crushing, screening, and multi-stage milling approach in favour of single-stage milling and classification. This change resulted in a plant of very compact design.

Table I

Total throughput and gold produced by the Bracken plant[2–4]

Mine	Material milled, t	Gold produced, kg
Bracken	31 832 569	238 134
Winkelhaak	66 348	44
Kinross	259 500	1 575
Total	32 158 417	239 753

By the early 1980s, it became apparent that the ore reserves were running out, and that closure was inevitable. Preliminary closure plans were initiated at that stage, involving the early calculations and investigations that are given in this paper, together with details of the eventual closure of the Bracken gold plant.

Records from the previous clean-up of gold-plants had given the gold-recovery figures reproduced in Table II. As shown, a significant amount of gold had been recovered from these pre-1985 clean-up operations, and the expectation of a high recovery from the clean-up in the case of the Bracken plant also prevailed. In fact, a gold-recovery figure of 0,25% of the total gold produced was assumed. Included in Table XIII is an estimate of the gold recovery based on the Harmony formula as given in a recent publication[8]. Calculations based on this formula indicated that the plant lock-up would be 0.30% of the total gold produced by the plant. Although the origin of this formula is not clear, the estimate is included to emphasize the high expectations that are generally held regarding the clean-up of a gold plant.

* *GENCOR, P.O. Box 2357, Springs 1560.*

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Table II

Gold produced from plant clean-up operations[5–7]

Mine	Total gold produced kg	Clean-up gold produced kg	Clean-up gold %
Modderfontein Deep	187 000	528	0.282
East Geduld	524 434	1 857	0.354
St. Helena	615 689	2 719	0.442
Grootvlei (partial clean-up)	565 603	2 166	0.383
Marievale	272 400	394	0.145
WRCM—West Plant (estimate)	64 000	180	0.281

Clean-up administration

The administration relating to the clean-up of the Bracken plant was scheduled in such a way that a comprehensive record would be kept of all the data related to the following: the tonnages and grades of the material treated, the origin of the material, the treatment route, the scheduling of the treatment of materials from different sources, the final amount of gold recovered, the costs of treating the clean-up material, and the related excavation and restoration costs. This information was collected in order to provide data for the future clean-up of other gold plants in the GENCOR group, and specifically run-of-mine milling plants.

The Bracken closure

Early calculations and investigations

During August 1983, the management of the Bracken plant was asked to provide an estimate of the amount of gold that would be recovered from clean-up operations at the plant. This request referred to the fact that gold plants that had been cleaned up after mine closures in the past had produced at least 0.25% of their total gold production[9], as detailed in Table II. It was tacitly assumed that the Bracken plant would follow this trend and, on the basis of the gold produced by Bracken up until that time, it was expected that the clean-up would result in the recovery of at least 520 kg of gold[10]. However, detailed sampling of the identified clean-up areas at Bracken resulted in an estimate of only 110 kg of gold being recoverable[11].

In July 1988, the management was asked to submit a further estimate of the recoverable gold from the clean-up of the gold plant[12]. It was acknowledged that a run-of-mine milling plant generally produced less spillage than a conventional washing, screening, crushing, and multi-stage milling plant, thereby reducing the amount of gold available for clean-up. Since there was no precedent for the clean-up of a run-of-mine milling plant, it was regarded as reasonable that 0.10% of the total gold produced at a recovery of 95% be taken as the estimated gold production. Based on the gold produced by Bracken up to that date, this amounted to 217 kg of recoverable gold.

A survey to identify potential high-grade clean-up areas in the plant was subsequently requested[13]. The assay results for 25 samples taken from various sections of the plant varied from 0.7 to 3807 g/t of gold. Because of the limited value of this exercise, no further work was done[14].

Following on from the previous sampling exercise, an extensive sampling programme was undertaken during December 1989 and January 1990. Laboratory dissolution tests were also performed on selected samples[15]. The exercise started with the establishment of a sampling grid for the plant area, consisting of 107 sample points spaced at 20 m intervals. Figure 1 shows the plant area, while Table III indicates the location of the sample for each sampling point on the grid and gives the assay values for a surface sample, a sample taken at a depth of 0.5 m, and one taken at 1.0 m. The results of the dissolution tests are given in Table IV.

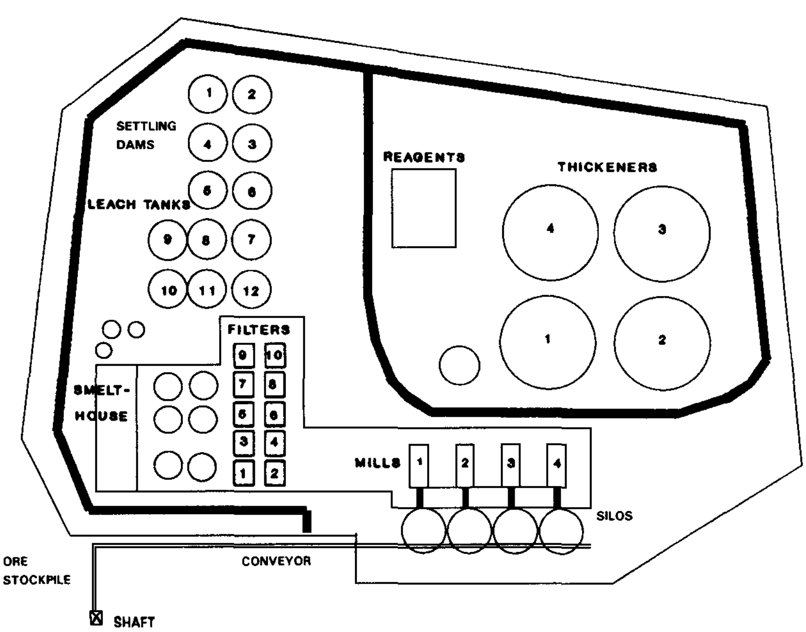

Figure 1—Layout of the Bracken metallurgical plant

Table III

Assay value for the grid samples

Plant area	Sample number	A Surface Au g/t	B Au at 0.5 m g/t	C Au at 1.0 m g/t	Average Au value g/t
Thickeners	4	4.79	0.72	2.27	2.59
	6	0.56	0.32	0.51	0.46
	8	0.11	<0.01	<0.01	0.04
	11	6.09	1.57	0.65	2.77
Mills	13	1.71	0.29	1.37	1.12
	14	3.49	0.13	0.22	1.28
	15	0.85	0.43	0.18	0.49
	18	17.43	2.57	1.13	7.04
Thickeners	20	1.37	0.21	<0.01	0.53
	23	0.65	<0.01	<0.01	0.22
	25	0.43	1.83	0.22	0.83
Mills	33	63.90	3.53	3.24	23.56
	34	143.30	0.89	0.76	48.32
	36	17.38	0.17	0.44	6.00
	37	1.57	0.28	0.34	0.73
	38	164.00	0.21	0.13	54.78
	42	0.30	0.62	<0.01	0.31
	44	3.02	0.41	0.07	1.17
	46	11.42	1.69	0.37	4.49
	48	1.22	0.36	0.20	0.59
	49	2.62	2.87	6.71	4.07
	50	4.72	0.55	0.62	1.96
	55	0.50	0.81	0.55	0.62
	56	221.80	1.75	1.83	75.13
	61	1.44	0.18	0.05	0.56
	62	30.00	0.93	3.99	11.64
Reagents	65	0.25	<0.01	<0.01	0.08
	67	2.45	<0.01	<0.01	0.82
	69	0.02	<0.01	<0.01	0.01
	72	0.47	2.08	1.64	1.40
	73	0.46	1.18	1.21	0.95
	74	0.94	1.18	1.21	1.11
	75	0.94	1.18	0.73	0.95
Leach	77	0.92	0.72	0.53	0.72
	78	3.15	0.41	1.13	1.56
	79	0.98	0.49	0.19	0.55
	80	0.82	2.85	0.27	1.31
	81	11.42	1.31	2.85	5.19
	82	24.12	1.45	1.32	8.96
Filter	88	0.97	0.17	0.39	0.51
Smelthouse	91	2.10	2.02	5.91	3.35
	92	9.83	0.53	0.62	3.66
	93	4.52	0.33	0.32	1.72
	94	5.47	4.49	2.95	4.30
	95	55.53	3.07	0.95	19.85
	96	1.81	4.01	0.73	2.18
	97	0.93	1.16	0.57	0.89
	98	1.51	0.69	1.07	1.09
	99	1.73	1.53	0.55	1.27
	100	2.51	1.41	0.33	1.42
	101	1.13	2.23	0.18	1.18
	103	2.45	0.33	0.23	1.00
Conveyor section	106	1.53	4.40	1.39	2.44
	107	0.35	0.49	<0.01	0.28
Waste-rock dump	108				1.79
Toe dam	109				6.01

It should be noted that certain samples could not be taken for reasons of inaccessibility. The assay results given in Table III show that the mill and filter buildings, the smelthouse, and the surrounding areas constituted the higher-grade areas of the plant. Furthermore, the grades decreased with depth. The dissolution tests indicated that generally more than 86% of the gold could be recovered by cyanidation. Based on these results, 229.8 kg of gold was calculated to be locked-up within the plant area contained in 84 kt of total material available for treatment. At a recovery of 86%, this equates to 197.6 kg of clean-up gold being recoverable, or 0.087% of the total gold produced by the plant over its operating lifetime.

During 1991, a financial exercise based on the costs of excavating and treating the clean-up material established that the payable gold grade[16] was 1.69 g/t. The lower-grade areas were therefore excluded from the cleaning-up exercise. Based on an excavation depth of 1 m, the higher-grade areas amounted to 33.36 kt of material at an average gold grade of 4.0 g/t. At a recovery of 86%, 114.8 kg of gold would be recovered, representing 0.049% of the total gold production up to that time. The main area targeted for the clean-up included the mill buildings, the filter building, the smelthouse, and their surrounding areas.

Table IV

Results of laboratory dissolution tests

Sample	Type of material	Head value Au g/t	Solution value Au g/t	Washed residue Au g/t	Dissolution %
20–A	Rock	1.37	0.83	0.11	91.97
23–A	Soil	0.65	0.01	0.33	49.23
42–A	Rock & concrete	0.30	0.89	0.13	56.67
42–B	Rock & soil	0.62	0.51	0.08	87.10
46–A/B/C	Soil	4.49	2.98	0.28	93.76
50–A/B/C	Soil	1.96	1.71	0.24	87.76
56–A	Concrete	221.80	115,20	10.16	95.42
56–B/C	Soil	1.79	1.62	0.37	79.33
91–A/B	Rock & concrete	2.06	1.01	0.39	81.07
91–C	Rock & concrete	5.91	3.98	2.14	63.79
106–A/B/C	Rock & concrete	2.44	2.11	0.19	92.21
108	Rock & concrete	1.79	3.23	0.17	90.50
109	Rock	6.01	2.11	0.32	94.68

Notes

(1) **Head Value**
The head value given for all the leaching tests is that obtained during the sampling exercise (Table III). It is the average value for samples A, B, and C unless otherwise stated.

(2) **Conditions for the Leaching Tests**
- (a) Grading 83% – 75 μm
- (b) Water-to-solids ratio 1
- (c) Lime addition (as 100% CaO): minimum 1875 ppm CaO, or conditioning to pH 11,5
- (d) Cyanide addition (as 100% NaCN), ppm
  - Rock samples 200
  - Soil samples 400
  - Concrete samples 1000
- (e) Bottle-rolling period 24 h
- (f) All tests in duplicate

Actual plant clean-up

The clean-up of the Bracken gold plant started during September 1992. At that stage, underground ore was still being treated, albeit at ever-reducing tonnages. The last underground ore was treated at Bracken on 15th February, 1993, and the Bracken plant was stopped on 28th April, 1993. The clean-up material remaining at that time and about 7 kt of underground ore was then transported to the Leslie plant. The treatment of Bracken clean-up material ceased during January 1994, and the rehabilitation of the Bracken plant and its environs was completed during October 1994.

A complete record was kept of all the sampling procedures and sample values in the various sections of the plant[17]. Tables V to XI give the assay values of the special clean-up samples taken in the different sections. The range of values obtained shows the highly variable nature of the clean-up material. This information was used by the plant staff in deciding whether the material would be treated or dumped.

Table XII gives a summary of the gold recovered during the various months that the clean-up was in operation based on the assay values obtained for each section as given in Tables V to XI. Representative samples of all the materials treated were leached in the laboratory to provide the respective recovery values.

Shaft bins, conveyors, and ore stockpile

The waste-rock conveyor section was cleaned first and the equipment removed. The shaft bins and ramp area were subsequently sampled and treated, followed by the dismantling of the ore conveyors to the mill silos. The ore stockpile was sampled, and excavated to a depth of 0.5 to 1 m to ensure that no gold-bearing material was left behind. All this material was treated at the Bracken plant. The assay ranges of the special samples taken in specific areas are given in Table V.

Mill section and silos

The dead loads in the silos were removed, and each silo was washed out. All the mill liners were removed, and the concentrate was tabled. The insides of the mill shells were de-scaled with needle de-scalers to remove all traces of concentrate, and were then scoured with concrete. The mill feed and discharge hoppers, and the cyclone underflow and overflow boxes, were cleaned, while the feed belts, gantries, and cyclones were removed and cleaned. All this material, except that from the last mill, was treated at Bracken, while the material from the last mill was treated at Leslie. The particularly high values from the scale material should be noted. Great care was taken to remove all this material from the mill buildings and trenches, but the tonnages were very low. Table VI gives the range of assay values for all the special samples taken in the mill silo section and mill buildings.

Table V

Special clean-up samples: shaft bins, conveyor area, and ore stockpile

Sample	Range of assay values, Au g/t	No. of samples
Ramp	0.48 to 0.97	6
Reef box	5.17 to 50.93	4
Shaft-bin area	0.57 to 4.16	6
Ore stockpile	0.51 to 3.89	6

Table VI

Special clean-up samples: mill section and silos

Sample	Range of assay values, Au g/t	No. of samples
Pedestal and foundation concrete	0.31 to 2.14	3
Mill silo dead load	5.03	1
Mill silo liner scaling	4.18 to 41.18	3
Mill floor scaling:		
General	0.65 to 125.14	7
Top 2 mm only	541 to 13 360	4
Mill Floor:		
0 to 0.1 m depth	3.60	1
0.1 to 0.3 m depth	1.40	1
0.3 to 0.7 m depth	1.04	1
0.7 to 1.0 m depth	0.15	1
Trench spillage	234 to 5 317	12
Trench scaling	610	1
Mill feed hopper	140 to 15 960	3
Mill load	380 to 1 004	2
Mill shell scaling	117 to 2 920	5
Cyclone boxes load	15 to 1 930	5
Cyclone overflow launder scaling	13 to 743	7
Mill return dam scaling	0.31 to 19.0	4

Thickener Section

A hydraulic breaker was used to break the concrete thickeners after the solids had been washed out. The separation of the steel reinforcing from the concrete was very time-consuming and, because of the low gold assays reported for the concrete, this material was dumped and only the scale was treated at Bracken. The area around the thickeners was also extensively sampled to a depth of 2 m, but the assay values were low. The ranges of assay values for the special samples taken in the thickener section are given in Table VII.

Leaching section and settling dams

The number of leaching tanks used was reduced progressively in accordance with the tonnage treated, and the tanks were washed out and de-commissioned. Previous sampling had shown that the area was of relatively low grade. The additional samples taken from this section gave the range of assay values shown in Table VIII, which confirmed the low values obtained on all but the scale material. This material was treated at Bracken during the clean-up operation as it became available. Spillage from the leaching section had accumulated in settling dams adjoining the section over the years. These dams were also cleaned, and the material was treated at Bracken.

Table VII

Special clean-up samples: thickener section

Sample	Range of assay values, Au g/t	No. of samples
Thickener foundation	0.01 to 1.00	4
Thickener:		
Wall	0.29 to 0.87	8
Floor	0.11 to 1.83	16
Bed	14 to 426	3
Thickener area soil:		
Surface	0.10 to 2.19	9
0 to 1 m depth	0.13 to 0.5	8
1 to 2 m depth	0.09 to 0.95	6
Thickener feed pipe scaling	33.48 to 133.13	4
Thickener scaling	1.60 to 6.07	11
Thickener rake scaling	15.78 to 450.76	4
Dorrco launder scaling	16.93 to 17.53	3

Table VIII

Special clean-up samples: leaching section and settling dams

Sample	Range of assay values, Au g/t	No. of samples
Leach tanks scaling	3.11 to 72.33	11
Leach tanks spillage	8.96	1
Pipes scaling	1.79 to 66.69	3
Leach tanks grit	2.83 to 5.15	3
Settling dams	1.37 to 4.79	8

Filter section

The filter area was originally considered to be a high-grade area but, apart from scale and some slime found below the drainage floor, the material in the area was of low grade. All the scale was removed with hammers and treated. The spillage was removed and treated at Bracken. The ashed timber material of the filter drum was treated at Leslie. Table IX gives the range of assay values for the special samples taken from this section.

Precipitation section and smelthouse

The smelthouse, in particular, was thoroughly cleaned since, in addition to gold smelting, mill gold had been treated in this area for the recovery of osmiridium since 1967. The building structures were thoroughly hosed down, and all the material collected was treated at Bracken, except for the concrete below the arc furnace, which was treated at Leslie. Table X gives the range of assays for the special samples taken in this area. Again, the tonnages were low.

Waste-rock dump

The remnants of the waste-rock dump were also sampled to ensure that any profitably recoverable material would be treated before the closure of the Bracken plant and the rehabilitation of the area. This material contained significant amounts of boiler ash and general rubbish, and its grade was too low for economic recovery. The rehabilitation of the dump area was therefore given the go-ahead, and the remaining waste rock was used as land-fill. Table XI gives the results for the special samples taken.

Summary of clean-up operations

A summary of the material treated during the months that the clean- up was under way is given in Table XII. A total of 85.959 kg of gold was recovered from the clean-up operations at the Bracken gold plant over a period of 17 months. A record was kept of all the costs incurred during the clean-up period from September 1992 to January 1994, including salaries, treatment costs, transportation costs, excavation costs, and other related costs. It was shown that a profit was made from the clean-up operations during this time, and this was used for further rehabilitation of the Bracken property (Table XII).

In accordance with the legal requirements of plant closure, a radiometric survey was conducted during the clean-up operations. The only areas that showed relatively high levels of radiation were the foundations of the shaking tables in the smelthouse. However, after this material had been excavated and treated for gold recovery, the radiation levels dropped to within the legal limits. This was not unexpected since the Kimberley Reef mined in the Evander area contains very low concentrations of radioactive minerals.

Table IX

Special clean-up samples: filter section

Sample	Range of assay values, Au g/t	No. of samples
Filter plant feed pipe scaling	108 to 784	3
Foundation concrete	0.91	1
Filter floor spillage	1.37 to 2.07	3
Filter pan scaling	1.65 to 7.62	4
Filter drum scaling	8.18 to 26.51	7
Filter plant pipe scaling	0.18 to 6.68	6
Filter drum timber	16.58	1
Ashed filter drum timber	29.23 to 391.33	3
Slime under drainage floor	2.29 to 2.42	4

Table X

Special clean-up samples: precipitation section and smelthouse

Sample	Range of assay values, Au g/t	No. of samples
Gold sump scaling	6.07 to 9.21	6
Zinc sulphate tank scaling	4 080 to 6 153	3
Barren solution tank scaling	0.27	1
Shaking table concrete	85 to 1 140	4
Shaking table floor concrete	29 to 332	6
Shaking table sump	37 796	1
Shaking table scaling	20 to 1 100	5
Arc furnace:		
Scrubber sump	85.32	1
Scrubber sump scaling	112 to 744	4
Arc furnace fan dust	920	1
Smelthouse trenches	243 to 1 918	7
Slag mill floor concrete	16 to 316	4

Table XI

Special clean-up samples: waste-rock dump

Sample	Range of assay values, Au g/t	No. of samples
Waste rock dump	0.46 to 0.64	3

Concluding remarks

The clean-up of the Bracken gold plant led to a recovery of 85.959 kg of gold, which equates to 0.036% of the gold produced by the plant over its total lifetime. This figure is significantly lower than that obtained from the clean-up operations in other gold plants. It is also lower than expected when compared with the calculations made during the various investigations prior to the clean-up. Table XIII summarizes the results of the various estimates.

The clean-up procedure followed at Bracken gold plant was carried out in accordance with a comprehensive recovery plan, which aimed at the recording and documentation of all the information from the clean-up. The data accumulated and the experience gained will be of great benefit in the future clean-up operations of run-of-mine gold plants.

It is clear that there is no universal formula for the prediction of the amount of gold that will be recovered from a gold plant at the end of its useful life. The gold recovered depends entirely on the design of the plant and the type of spillage management exercised during its production life. It is apparent that the compact nature of the Bracken plant was the main reason for the small amount of clean-up gold recovered.

Clean-up of the plant at Bracken

Table XII

Summary of clean-up material treated[18]

Month	Origin of material	Estimated mass t	Gold recovered kg	Total cost of demolition R
September 1992	Mill: silos, launders, conveyors, cyclone boxes, settling dams	415.4	3.930	74 568
	Settling dams	715.0	1.869	
October 1992	Stockpile	1 860.0	6.512	52 614
November 1992	Filters: drainage floor slime, scaling	200.0	0.409	93 587
December 1992	—	—	—	61 213
January 1993	Thickeners	150.0	0.510	55 019
February 1993	Mills: foundations, concrete	243.0	1.100	36 094
March 1993	Mills: scaling, foundations	215.9	2.048	37 438
April 1993	Mills: scaling, mill load, cyclone boxes	16.0	15.472	49.739
May 1993	—	—	—	60 329
June 1993	Mills: launders, pipes, spillage, floor	1 603.0	17.040	118 343
	Filters: scaling	746.0	11.444	
July 1993	Mills: launders, floor scaling	157.0	3.704	72 385
August 1993	Mills: launders, scaling, concrete	120.00	6.355	173 706
September 1993	—	—	—	65 471
October 1993	Mills: launders, scaling, concrete	102.0	5.750	205 703
November 1993	—	—	—	246 055
December 1993	Smelthouse: shaking table, floor, concrete, scaling	3.0	4.900	232 155
January 1994	Smelthouse: floor, sumps, scrubber, furnace	40.0	4.916	64 763
Total		6 586.3	85.959	1 699 182
Income: average gold price received R36 000 per kg				3 094 524

Table XIII

Gold estimates for the Bracken clean-up

Number	Date	Clean-up gold recovered kg	Clean-up gold %
1	Historical formula	520.0	0.250
2	Harmony formula	719.3	0.300
3	August 1983	110.0	0.053
4	July 1988	217.0	0.095
5	December 1989	197.6	0.087
6	1991	114.8	0.049
7	January 1994	85.959 - Actual	0.036

It is to be noted that the complete clean-up of the Bracken plant as originally planned was not realized. Although the equipment, floors, sumps, and trenches were thoroughly cleaned and de-scaled, and the expansion joints in the buildings were checked and sampled for gold spillage, the clean-up of the plant was conducted in a much shorter period of time than had been planned. This was because the buildings were purchased early in 1994 by SASOL Limited for use, in accordance with the State's Reconstruction and Development Programme, as a community development centre. It is possible that complete demolition of all the buildings and foundations may have resulted in the recovery of additional gold. However, it is considered unlikely that this would have significantly affected the overall outcome of the clean-up.

Acknowledgements

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Green Topics

Hippo-crisy?*

Today's conservation thinking is becoming increasingly polarised—a widening gap that could eventually be to the overall detriment of mankind, one way or the other. In one corner, stand the disciples of the untainted wilderness, moral protectors of the natural world who subscribe to the doctrine that the fragile balance of nature is threatened by man's very existence.

On the opposite side of the ring, stands the relentless developer, with the megalomaniac notion that nature is purely there to serve humanity and civilisation, under the auspices of 'progress'.

Of course, it is impossible to support either stance in the real world, and in the modern South Africa in particular, where the environment is coming under increasing pressure from the needs of an ever-increasing population, neither of these options is viable. It is perhaps in this country more than any other at present, that mining companies must ensure that the clamour for economic development is not at the expense of the environment. After all, whilst mining fulfils a short term requirement, it is our surroundings that have the most lasting effect on our lives. We all like to live in a 'nice' area, don't we?

When mining takes place in any district, it should be viewed as a phase of adolescence in its development. For whilst the operations may cause an unsightly blemish during their active life, this phase soon passes and with care and attention no visible sign need remain. Indeed, as is the case with most adolescent problems, the perception of their severity is generally far greater than the reality.

Taking this into consideration, this month's news that Richards Bay Minerals has had its permission denied to extend its mineral sand mining leases on the eastern shore of the hippopotami inhabited St Lucia estuary in Kwazulu-Natal, South Africa, is all the more disappointing

It has been a well chronicled, high profile case with six years of claim and counter claim, debate and deliberation eventually culminating in the governmental decision to decline the proposal and immediately request that the area be registered as a World Heritage Site. For the green activists, the result comes as a major victory although it may be that in this particular case, 'green' does not simply apply to their political leaning.

In the world of industrial minerals, a mine or quarry is only as good as its market place. In short, no applications, no use! This is not the cut-throat world of metal trading, where a garage full of gold can make a millionaire overnight, industrial minerals operations exist through necessity, and nothing else. For example, if everyone stopped painting their houses, driving cars with welded parts and ceased to eat from ceramic cups and plates, then the mineral sand industry would collapse overnight.

Of course, this is not going to happen. Mankind has evolved to the stage where such considerations are viewed as essentials if we are to maintain our desired standard of living. Only the staunchest hypocrite could argue the case otherwise. And if all that gives the campaigning environmentalist a headache, then they should think twice before resorting to any form of coated pharmaceutical, lest they prostitute their morals still further.

In the vast majority of cases, mining environments can be restored to as good, if not better, a condition as they were prior to work commencing. The ongoing rehabilitation work at RBM's current operations bears more than adequate testimony to that. In addition, the fact that 50 local and overseas experts contributed their findings to an intensive report on the proposed mine extension demonstrates the kind of commitment that a company can make to ensure that its actions do not lead to irreparable damage of an area. Additionally, RBM's proposed mining area would not have affected a pristine environment and would have had little or no impact on the lake or wetlands that are the crux of this case.

For real, irreversible devastation, look hard at the decimation of hardwood rainforests, where the destruction is purely so that someone, somewhere a long way away can lay their afternoon tea out on a mahogany table. Suddenly, a temporary blight on the landscape does not seem such a bad option after all.

It must be hoped that in future cases, common sense will prevail and companies will continue to have the chance to demonstrate how mining can not only provide obvious economic benefits during its production phase, but can also preserve the environment for the long term benefit of everyone.

* *Industrial Minerals No. 343, April 1996.* ◆

Basel Convention: An Update*

In September 1995, Parties to the Basel Convention agreed by consensus to amend the Convention to include a ban on the movement of hazardous waste recyclables from developed, effectively OECD countries, to developing countries. To date, few if any countries have ratified the amendment, which is supposed to come into effect 1 January 1998. Not surprisingly, many countries are waiting for guidance from the Convention's Technical Working Group (TWG) on what recyclables are covered or excluded by the ban so that its impact on each country's national economy can be determined. This uncertainty is compounded by the now-questioned status of the sovereign right of countries to trade in recyclables under bilateral and multilateral agreements (Article 11 agreements). Also at issue is whether a developing country will forfeit its right to trade with its non-OECD neighbours if, under the amendment, it seeks to join, and is accepted into, the group of developed countries which can trade among themselves.

The full scope of the recyclables ban will not be known until the fourth Conference of the Parties, scheduled for September/October 1997. In the interim, the TWG has been charged with the urgent task of characterizing hazardous waste recyclables and making recommendations on what recyclables should be covered by, or excluded from, the ban.

In December 1995, the TWG recommended that metal and metal alloy 'wastes' (recyclables) in metallic, non-dispersible form should **not** be covered by the Basel Convention provided they are scrap prepared to specifications and do not contain Basel waste constituents or contaminants making them hazardous. Such materials would include: precious metals; iron and steel; and, scraps of copper, nickel, aluminium, zinc, tin, tungsten, molybdenum and manganese. However, there remain many steps before the status of these recyclables, as well as metal-bearing slags, drosses, ashes and alloys containing lead and other Basel-listed metals and their compounds, will be known.

Significantly, the TWG is working on the so-called *de minimis* concept aimed at providing developing countries with a practical measure for determining the hazardousness of recyclables. This would specify values, such as concentration levels and particle size, for hazardous constituents or contaminants of recyclables. The TWG has asked industry sectors to come up with suggested *de minimis* levels or ranges for recyclables traded. The metals sector has stated that *de minimis* makes little sense as a meaningful and simple proxy for hazardousness, given the complexity of composition and form of recyclables and their many uses. While the metals sector is promoting a risk-based approach to the implementation of the Convention, it has, however, agreed to cooperate fully with the TWG in providing: timely information on priority trade streams of recyclables from developed to developing countries; commercial specifications for traded recyclables; known composition data for these materials; and, available data relating to toxicity. Additionally, the metals industry sector will undertake a program to determine the normal constituents of traded recyclables.

Within the TWG, the focus is very much on hazard characterization at the expense of risk assessment and risk management. Consequently, important risk-related factors are not being considered in the *de minimis* exercise, such as whether or not recyclables are going to a facility which can process these materials in an environmentally sound manner. Nevertheless, the TWG does seem willing to consider factors contributing to hazard characterization such as the physical form of materials, speciation and bioavailability. The TWG will also take into account national hazardous waste definitions, including lists.

Within the TWG a special sub-group on metals, established to advise on metal listings, will convene at the next TWG meeting to be hosted by the Malaysian Government in Kuala Lumpur, 22–26 April, 1996. This meeting is being funded by the European Commission. All of the industry sectors participating will report on progress in information and data gathering and will bring along experts to make representations on selected recyclables.

In March 1996, ICME published a booklet entitled *Non-Ferrous Metals Recycling: A Complement to Primary Metals Production* to provide a brief overview on the scope, characteristics and issues related to recycling. The recycling of metals has a long history and is a major commercial activity throughout the world. The recycling of non-ferrous and precious metals offers society the potential to extend the use of valuable materials, to conserve resources and energy and to minimize waste disposal.

* *International Council on Metals and the Environment. Newsletter vol. 4, no. 1, 1996. p. 5.* ◆

Environmental Case Studies *

In February 1996, ICME and the United Nations Environment Programme (UNEP) jointly published *Case Studies Illustrating Environmental Practices in Mining and Metallurgy.* The publication draws from 29 case studies to illustrate how good environmental performance is achieved through a combination of sound procedures, technology and good management, operating in a clear regulatory framework. Case studies were chosen by members of the UNEP/ICME Working Group on Environmental Protection in Mining and Metallurgy which comprises members from government, academia and industry.

The case studies include examples of environmental management systems, project approval procedures, regulatory development, good operations and techniques, training and education. They cover the main elements of the mining cycle including exploration, project approval, mining, primary metals processing, recycling, rehabilitation and closure. Examples are all of innovative approaches that can be used in countries other than in the ones illustrated. Each explains what was done, and the results achieved.

The publication provides useful information for a range of interests from government and industry. It is especially intended to motivate decision-makers by demonstrating what has been achieved elsewhere. However, it is not a technical manual, and for more detailed information, the reader is advised to follow up directly with the case study authors identified in the document. The publication is available from UNEP Industry and Environment Programme, Tour Mirabeau, 39–43, quai André Citroën, 756739 Paris CEDEX 15, France; fax: (33-1) 44 37 14 74. The cost is US$20. Concessional rates are available to UNEP network members and to ICME members.

The management of the Hog Ranch Gold Mine in Nevada encountered an early challenge when the operation was faced with exploring for ore in an area which was home to a rare plant called *Crosby's Buckwheat.* In order to save the population of this rare species, Western Mining Corporation, under the guidance of the US Bureau of Land Management, embarked on a project to transplant the plants to a nearby area where they are now thriving.

* *International Council on Metals and the Environment. Newsletter vol. 4, no. 1, 1996. p. 7.* ◆

Metals in the Environment: How much did we start with?* by Arthur G. Darnley†

To many people this might seem an obvious question; a question to be answered before making any assumptions about the quantities being added as a result of human activities. Yet acceptable safe levels of metals in the environment are being recommended with little or no consideration of the fact that metals have been in the environment since the beginning.

The millions of tons of ash pumped into the atmosphere by volcanic eruptions such as Mount Pinatubo and Mount St. Helens, and spread over thousands of square kilometres, probably contain all of the 92 elements in the Periodic Table. In addition to the elements known to be essential to life, such as carbon, nitrogen, oxygen, sodium, potassium, calcium, magnesium, iron, copper, zinc, phosphorus, sulphur and iodine, volcanoes also redistribute those elements which under certain conditions are regarded as harmful, such as arsenic, beryllium, cadmium, mercury, lead, radon and uranium plus the remaining 72 elements, many of which have still undetermined biological effects. Similar volcanic events have occurred every few years throughout geological history. *Indeed, all known elements are present at some level of concentration throughout the natural environment. They are present in animal, vegetable and mineral materials, and their beneficial and harmful effects have been present since evolution began.*

The question of natural background levels has important economic implications. Before governments commit scarce resources to clean up or protect the environment from man-made contamination, it would seem prudent to determine how much 'contamination' merely reflects the pre-existing natural background. Likewise, it would seem appropriate to assess how much the natural background varies from place to place as a consequence of differences in geology, soil, climate and topography, and to determine the extremes of natural variation in the chemistry of the environment and the tolerance of natural ecosystems for variations in geochemical background.

To determine natural background levels, it is necessary to undertake geochemical mapping of the land surface. This began 50 years ago to aid mineral prospecting. Only over the last 25 years, as a result of developments in analytical and computer technology, has it evolved into a specialization capable of revealing the complexities of the natural chemical environment. Unfortunately, geochemical mapping and the resulting database have evolved in different countries and under different organizations in a very *ad hoc* manner. As a result, it is virtually impossible to make a quantitative comparison of data from different sources.

In 1988, the International Union of Geological Sciences (IUGS) and United Nations Educational, Scientific and Cultural Organization (UNESCO) jointly authorized a project to review the situation. The outcome is a report published by UNESCO[1] in 1995. The report reviews, on a country-by-country basis, existing data and methods and has detailed recommendations both for the conduct of new work and for the establishment of a global geochemical reference network which is regarded as essential for standardizing future work. As this report illustrates, there are at present virtually no published geochemical data for 80 percent of the global land surface. Where data are available, they are inconsistent between countries and often within countries. There has been no standardization of methods or data sets, and no independent quality control.

This deficiency of knowledge should be of serious concern both to the mineral industry and to the public at large. A systematic geochemical database that is both standardized and comprehensive is essential for the establishment of sensible environmental policy decisions. The UNESCO report has identified the need for the establishment of an international network of reference samples, analogous to a topographic grid in geodetic surveys.

Environmental phenomena are complex, and it is necessary to ensure that all the variables have been identified and documented before too many conclusions are drawn and regulations written. On the particular topic of metals in the environment, before quantitative limits are established, a global geochemical reference network is essential to establish global background values and to ensure measurements can be correlated and compared, irrespective of jurisdiction.

Reference

1. Darnley, A.G., *et al.* 1995. A global geochemical database for environmental and resource management: recommendations for international geochemical mapping. *Earth Science Report* 19. UNESCO Publishing, Paris, 33 figures, 8 colour plates, 122 pp. Price 100 FF. (ISBN 92-3-103085-X).

* *Previously published in* International Council on Metals and Environment, *Newsletter vol. 4, no. 1. 1996. p. 4.*

† *Co-Chairman, International Union of Geological Sciences (IUGS) Working Group on Continental Geochemical Baselines.* ◆

Environmental guidelines for mining projects: The African Development Bank

South Africa is now a member of this body, tailored on the World Bank, and headquartered in Abidjan—Côte d'Ivoire.

As a funding agency for capital projects within 59 member countries of the ADB it is to be expected that there are guidelines to the requirements for funding application and for project management and control.

One of the many advisory committees set up within the bank's headquarters is that of Environment. It is one of the bank's long-term strategic policies to integrate environmental concerns into its overall lending policy and to strengthen mining environmental management within Africa.

All projects fall into three category classes, the lowest (Category 3) which includes projects such as health programmes or education programmes, do not require formal environmental examination. If, however, such projects involve physical intervention in the environment then they immediately move to Category 2 and join the small-scale projects for Agriculture, Rural Development, Industry and Infrastructure. This category requires an impact assessment but if any of its projects is located in or close to an environmentally sensitive area, (listed by type) then it moves to Category 1. This is the most stringently controlled and contains such areas as large-scale agriculture, commercial logging, hydropower, roads and rail, ports and harbours, manufacture of hazardous materials, large-scale tourist development and, of course, mining.

Each of these has its own set of guide lines and under review here we examine those for mining projects.

This guideline document was funded by the Danish Government and drawn up by the Danish Environmental Technology Transfer (DETT), a Danish consulting company and Rock View International and published in June 1995. Among the literature consulted, reference is made to several papers produced by our own Department of Mineral and Energy Affairs during 1992 and 1993.

The first overriding impression from reading this 83-page document is one of clarity and simplicity of language. This is a document which meets its own objective of being easily understood by Bank staff, Government officials and the general public.

It is divided into nine clearly defined chapters and a detailed appendix. Perhaps the best summary of this guideline can be achieved by following its example and merely listing its chapters and sub-chapters.

1. Introduction.
2. Environmental impact monitoring and management during the project cycle.
3. Environmental assessment of small, medium and large-scale mining projects.
4. Outline for the Environmental Protection Aspect of the Project Feasibility Report. Sub chapters discuss the various phases of the project through to post-mining.

5/6. Special issues concerning small, medium, and large-scale mining projects are discussed.

7. Socio-economic and cultural issues.
   This chapter is very superficial and perhaps reflects on the lack of experience of the authors.
8. Recommendations for legislation in mining.
   A large proportion of this chapter is devoted to liability and compensation with the accent on the principle of 'the polluter pays'. To this end the idea of various bonds are discussed to ensure that the mining company keeps to its 'contract'. These include rehabilitation funds and bonds. The liability for disasters, it is suggested, should be covered by a 'liability insurance'.
9. Environmental checklist.
   Set out in the form of *aide memoir* tables, this chapter also includes sensitivity index score sheets.

Copies can be obtained from: African Development Bank, P.O. Box 01, Abidjan, Côte d'Ivoire, attention: E.H. Shannon Ph.D. Fax: 225 21 73 63. ◆

THE SOUTH AFRICAN INSTITUTE
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JOURNAL SUPPLEMENT

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NOTE: ALL PRICES INCLUDE VAT Contact: SAIMM, P.O. Box 61127, Marshalltown 2107 Tel: (011) 834-1273/7 Fax: (011) 838-5923

Spotlight

Minerals and Mining Policy Workshops

March 1996

The Steering Committee for Minerals and Mining Policy convened two workshops during March 1996 to address the following topics:

Business Environment: National and Provincial Powers, Administration and Regulation, Mineral Marketing, Beneficiation, Research and Development, Environmental Issues, Mining Impact on Surface Usage, Southern Africa Regional Issues.

Human Resources: Elementary Residual Racism, Housing, Downscaling, Migrant Labour and Human Resource Development.

Mineral Tenure: Mineral Rights, System of Access to Mineral Rights, Access to Exploration Information, Optimal Exploration, Trust Lands.

Small-scale Mining: Development of Small-scale Mining, Artisanal Mining.

The objective of these workshops was to arrive at a common vision for a Minerals and Mining Policy. A discussion document on a Minerals and Mining Policy for South Africa issued in November 1995 formed the basis for the workshop. This document was prepared by the Department of Mineral and Energy Affairs and the Mineral and Energy Policy Centre on behalf of the Mineral Policy Process Steering Committee, and contains a variety of stakeholder views on the policy issues. This document is available from The Director, Minerals Bureau, Private Bag X4, Braamfontein, 2017.

A green paper is being prepared for issuing at the end of July 1996, and the white paper is planned for October 1996, followed by a national conference in November 1996.

The aspects of the workshop most related to the interests of members were Human Resource Development, Research and Development, Environmental, Beneficiation, and Mineral Rights. Health and Safety is covered by a separate New Mines Health and Safety Act and is not addressed in the Mineral and Mining Policy. Human Resource Development is specifically addressed in the New Mines Health and Safety Act.

The following is a summary of the main areas of interest in regard to the proposed policy.

Research and Development

To support and co-ordinate surveys, investigations, and research, which are essential to stimulate the optimal development of the country's mineral resources but which cannot be conducted within the normal business-risk limits of private industry. Research and development efforts should be directed to areas of high need in the present mainstream industry, particularly health and safety, as well as to priority areas identified by the Reconstruction and Development Programme, particularly small-scale mining and mineral beneficiation.

A mining and mineral-processing research and development commission should be established for the purposes of making best use of the existing facilities, to promote collaborative research efforts, to promote technology transfer, and to ensure that minerals-related research and development is conducted in accordance with the country's science and technology policy and national objectives for the mineral industry.

Beneficiation

The aim of the policy shall be to develop South Africa's mineral wealth to its full potential and to the maximum benefit of the entire population. The Government shall promote the establishment of secondary and tertiary mineral-based industries aimed at creating job opportunities and adding maximum value to mineral raw materials, where economically justifiable.

Environmental Management

The policy shall provide for the maintenance of balanced and responsible standards with regard to the interface between mining and the environment that are based on local needs and requirements, but also take due cognisance of international practices.

Mineral Rights and Security of Tenure

The policy shall recognise State, as well as private, ownership of mineral rights, and shall encourage utilisation of such rights within prevailing economic conditions. It shall also provide for indisputable security of tenure with regard to mineral rights and prospecting, and mining authorisations.

Mineral Marketing

A number of Vision Statements were tabled by various stakeholders at the workshop. These were discussed, and a proposed overall vision was proposed as follows: 'To develop, optimise and sustain the mining industry, especially to earn foreign exchange, create jobs, and provide a base for growth and development'.

The policy shall endorse free-market principles, and shall allow Government intervention only to the extent of meeting the aims of the policy. The opportunities to increase the global consumption of certain minerals and metals produced in South Africa by joint marketing and promotion efforts, for example the World Gold Council, and research and development should be encouraged. A small levy on sales should be considered to fund such market-development efforts. ◆

Enquiries regarding the workshop can be made to:
The Secretariat (Attention Mr R. Goode)
Mineral and Mining Policy Workshops
P.O. Box 395, WITS, 2050
Telephone: (011) 403-8013; Fax: (011) 403-8023/4.

Budding metallurgists learn how to process coal*

The School of Process and Materials Engineering entertained visitors at the University of the Witwatersrand's recent open day with its 'Rock Horror Process and Materials Engineering Picture Show', including demonstrations of computer-controlled processes, metals with memory, and other actions and reactions designed to fascinate tomorrow's students. This coal-processing jig was one of many displays set up by staff and students. Herman Kok (right), post-graduate student in extractive metallurgy, explains the process to scholars (from left) Octavia Sibiya, Prudence Setlhaku, Giles Watermeyer, and Marjorie Ngwenya. The Wits open day attracted some 15 000 visitors, with the engineering faculty reporting good attendances at its various displays throughout the day. ◆

A mine of information*

The Department of Mining Engineering at the University of the Witwatersrand celebrates its centenary this year, and staff and students shared their special expertise with visitors at Wits's highly successful open day recently. Here, lecturer Daniel Limpitlaw (right) explains a cross-section of a copper mine to matric student George Phosa. Other drawcards in the Department included demonstrations of explosives and explosions, mine safety, rock testing, and the modern equipment that makes South Africa's mining industry one of the most advanced in the world. The open day was a great success, with an estimated 15 000 visitors passing through the gates of Wits. ◆

Chemical reactions keep scholars in suspense*

Words like *distillation, oscillating reactions, milling,* and *separating* reverberated around the laboratories of the School of Process and Materials Engineering at the University of the Witwatersrand's recent open day. Students and staff demonstrated chemical- and metallurgical-engineering processes, which ranged from mixing by hand to the use of complex computer controls. Sporting laboratory coats, post-graduate chemical-engineering students Eckhard Kroll (left) and Arno Steinmüller demonstrated the separation technique of flotation to a group of fascinated scholars. The open day was a great success, with an estimated 15 000 visitors passing through the gates of Wits. ◆

** Issued by Lynne Hancock Communications, P.O. Box 180, Witkoppen 2068.*

MEMBER'S OPINION

Re: Journal comment *Journal* of SAIMM vol. 96 no. 4 July 1996

In response to your comment on graduate engineers as opposed to diplomated technicians I would like to give the following comments.

(a) In order to design a furnace, for instance properly one would not only require *CAD,* but also a fundamental understanding of the process thermodynamics and kinetics. All of these are ultimately just *tools,* and the better the understanding the better the end result. University trained engineers are well equipped to provide this interface. They are trained in particular to relentlessly seek novel and ingenious approaches to solve problems and to improve productivity in doing this. They are trained to query, break out of paradigms of thought and to improve. They are also encouraged to be entrepreneurs.

(b) Good quality graduate engineers are lost to the international community continuously, to South Africa's detriment. The full impact of this is still to be appreciated in the medium term.

(c) No prospective engineering student will venture to engage in a minimum, demanding, four-year course, which few pass in the designated four years and a limited number ever pass, just to torture himself. Naturally such a student would demand a better salary.

(d) There are obvious financial advantages to engage in a practice where engineers and technicians are deemed to be equal in training, for the parent company.

(e) There is great concern amongst some of the larger South African employers that they are losing their graduate engineers at an unprecedented rate. There must be some reason for their concern.

(f) At the university that I attended it was reported that the engineers of that particular group, which apparently was not uncommon, had the highest average IQ and also the most distinctions in matric of all other disciplines studied. If the profession were to attract top-calibre people on an ongoing basis there must be some incentive for them, if not one would have to face the consequences, something that South Africa can ill afford.

(g) In my opinion it is time to recognise engineers for what they are. If the graduate engineers were treated in a dignified manner, one might be able to reverse the economic trend of this country with its vast resources and possibilities.

(h) I believe that the incorrect perceptions that you refer to, with regard to engineers as opposed to technicians are indeed that engineers are retrained to perform entrepreneurial and ingenious approaches to solve problems. They are frequently retained to perform a technician's duties.

An engineer, per definition derived from the word ingenious, will solve a problem in an ingenious way. He is consequently trained at university with 'mind-bending' problems such as non-linear partial differential equations, only to have the tools to come up with simple solutions. A technician will then be able to use these solutions in order to run a facility more efficiently, and so will a plant foreman with adequate experience and an enquiring mind.

(i) An engineer is not somebody with a degree, but with an ability to solve problems and improve processes in an ingenious way. Likewise should a medical doctor have the ability to heal, rather than to have a fancy degree certificate? The training that professionals get are there to enhance these probabilities, and as they sacrifice to get them, there is a premium to be paid by the community for these necessary luxuries. I, for one, would feel much better to drive over a bridge past a nearby furnace, *'designed'* by a well-trained professional engineer with or without *CAD,* than one designed by a technician.

I guess it is a question of opportunity:

'There is a tide in the affairs of men,
Which, taken at the flood, leads on to fortune;
Omitted, all the voyage of their life
Is bound in shallows and in miseries.'

Yours faithfully,
De Wet Combrink

Reply:

It has taken a great deal of provocation to promote reaction and comments in the *Journal.* Thank you Mr De Wet Combrink for your response.

Are there any other comments?.

R.E. Robinson

Funding for Wits*

Chairman of Boart Longyear, Dr Hilton Davies, has announced that the mining, drilling, and industrial supply arm of Anglo American Industrial Corporation (Amic) is committed to funding one of the chairs of mechanical engineering at the University of the Witwatersrand for the next five years. Professor Robert Charlton, vice chancellor of Wits, and Professor John Sheer, head of the School of Mechanical Engineering, were presented with the first annual cheque at a recent function.

Professor Sheer is the first incumbent in the Boart Longyear Chair, which was previously known as the John Orr Chair and is one of the oldest in the university, dating back to 1898.

'The School of Mechanical Engineering is very excited about this sponsorship', said Professor Sheer after the presentation. 'This kind of industry support is vital if we are to continue to function as an internationally recognized centre of engineering education and research. We look forward to interacting closely with the Boart Longyear companies for mutual benefit.'

Speaking on the reasons for funding the Boart Longyear Chair of Mechanical Engineering, Dr Davies commented: 'Just as universities depend on industry to support their educational initiatives, we depend on them to provide us with high-calibre graduates who can contribute in the workplace'. He added: 'There is a clear synergy between industry and education and, if industry is to continue attracting top graduates to maintain world competitiveness and universities are to ensure their training is relevant, our ties need to be strengthened'. ◆

Pictured at the handing-over of the first cheque to fund the Boart Longyear Chair of Mechanical Engineering at Wits were (from left) John Carr, Boart Longyear regional director, Sub-Saharan Africa; Professor John Sheer, head of the University's School of Mechanical Engineering; Professor Robert Charlton, vice chancellor of Wits; Dr Hilton Davies, chairman of Boart Longyear; Colin Wood, managing director; and Dr Brian Young, group director of technology.

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Professional Directory