

## Deep Mining

# Technologies required for safe and profitable deep level gold mining, South Africa

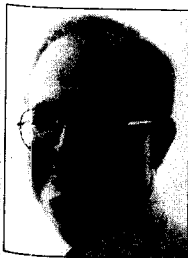
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**KEYWORDS:** Deep mining, Gold mining, South African mining.

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### Abstract

*Since the 14th CMMI conference, held in Edinburgh in 1990, at which a paper was presented by the author (Willis, 1990) reviewing the role of integrating new technology as a survival strategy for South African gold mines, considerable change has occurred in the South African mining industry. This paper reviews the current state of the industry and provides an update on the technologies discussed ten years ago. It reviews available technology and provides a broad economic assessment of these technologies if they were to be introduced in an integrated mining system with a focus on deep level mining below 3000 m. It also reviews possible future technologies currently being researched and developed by CSIR: Division of Mining Technology (Miningtek).*



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has had the portfolios of planning manager and marketing manager before taking up his current position.

### Introduction

The integration of new technology into the South African gold mining industry is required as a survival strategy (Willis, 1990). The challenge for South African gold mining lies in exploiting the rich reserves that now predominantly exist at great depth. The main technical hurdles to be overcome include heat, rockbursts, erratic grades and the need for maximum extraction. The single most important feature which contributes to overcoming these hurdles, and thereby reducing overall costs and maximizing the utilization of capital, is the potential for concentrated mining (limiting concurrent working areas by increased face advance rates). Using current technology, the maximum possible face advance is some 25 m/month using full calendar operations (FULCO), blasting every face once a day and allowing for some lost blasts due to unforeseen delays.

This paper focuses on ways of reducing the effect of the above-mentioned hurdles, and on various means of achieving increased face advance rates, to be combined into a practical mining strategy. The advantages of high face advance and concentrated mining are now well accepted (MacNulty, 1997). A consequence of concentrated mining is the reduced flexibility because of limited spare faces. The future mining system must, therefore, ensure that there are no unknowns related to grade distribution, reef discontinuities, and service reliability. Routine use of both surface and in-mine geophysical techniques would, thus, play an essential role, while planning and operational control must also be more precise.

The main technology thrust within the gold industry is now to go deeper, but it is important that technologies required for these depths are well proved and tested on existing operations before investors can commit to new technology implementation for great depths.

Although it may be possible for current technological developments to meet these challenges, future research and developments have the potential for providing quantum leap benefits.

### Current Trends

At present the gold price is below \$300/oz, while increasing depths and no significant improvements to productivity have caused costs to remain static. This has resulted in reduced profits and increased pay limits which reduce available ore reserve (Fig. 1).

The major South African mining houses are now being forced to consider possible alternative reserves. Although these are being considered and exploited outside South Africa, deeper level reserves (between 3000 m and 5000 m below surface) within South Africa remain the world's largest gold reserves. To date, some 43 000 t of gold have been extracted from the Witwatersrand Basin, with the predicated reserves comparable to that mined to date. A number of initiatives have occurred recently that may result in these reserves being exploited in the near future, including:

- a significant rationalization of mineral rights by means of restructuring of the industry, and mineral right swaps and purchases;
- the proposed formation of a collaborative research program (CRP) known as Deepmine designed to ensure that the appropriate technology is available when even more deep level mines materialize (Deiring, 1997a);
- a move away from longwall mining toward more selective mining methods, such as sequential grid mining and mini-longwalls; and
- increased productivity and improved utilization of equipment by moving to full calendar

dar operations (FULCO) which will allow seven-days-a-week operation. The FULCO details are presently under discussion with the various government agencies and labour organizations.

Although only some 5% of tonnage is currently produced below 3000 m, it is estimated (Willis, 1997) that some 40% of total South African production would be sourced from below these depths by 2015, considering a favourable economic environment (Fig. 2).

**Technology Requirements**

**Technology Update**

Not all the technologies discussed ten years ago (Willis, 1990) have been adopted universally. The current status of each of the primary technologies is as follows:

- **Shaft Technology** — Shafts have now been sunk and operate to 2500 m below surface and shafts as deep as 4000 m are being contemplated. However, considerable advances on rope and winder design are required to achieve these depths.
- **Backfill** — Despite some implementation problems, backfill is now a well accepted, well proven and essential technology for deep level mining.
- **Hydro-power** — The disadvantage of hydro-power is the expense and effort required to install the infrastructure. For this reason, only new mines find it economical to introduce this essential technology.
- **Mechanized Mining** — In 1990, mechanized mining referred to continuous scrapers and trackless equipment (Willis, 1990). Neither of these technologies has been widely adopted. Although the adoption of trackless equipment did experience a growth phase, in practice the disadvantages seemed to outweigh the advantages. Disadvantages included a high potential for reef dilution, high maintenance costs and the contribution of diesel engines to the hot and polluted environment. Although continuous scrapers have been adopted successfully for various specialized applications, they have not enjoyed widespread appeal, due in part to the difficult installation process. Manufacturers are continuing with further developments of this type of equipment and their introduction into deep level mining potentially offers considerable benefits in terms of savings in access development requirements.
- **Recirculation** — Although the cost benefits of recirculation are well established, it has not been implemented because the current refrigeration and ventilation requirements

Fig. 1. South African gold mine revenue and working cost.

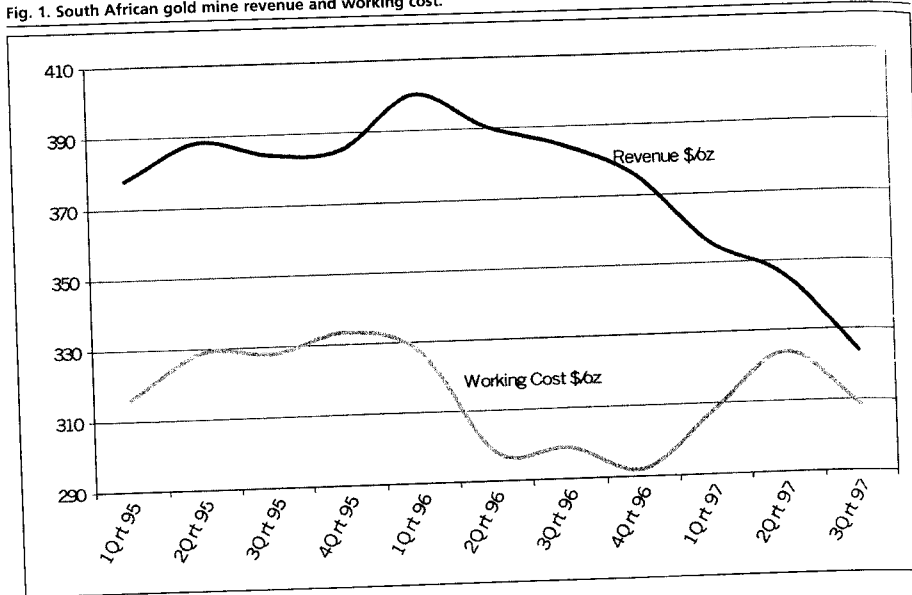
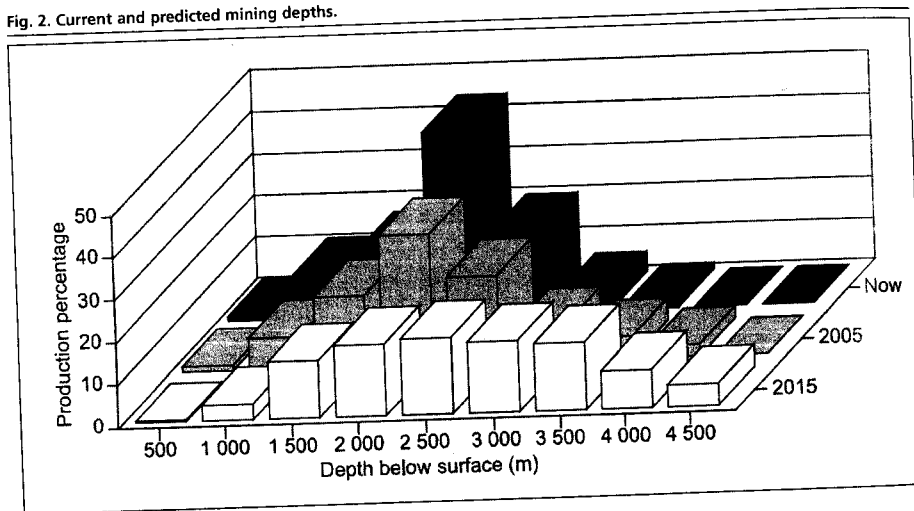


Fig. 2. Current and predicted mining depths.



are adequate. However, costs associated with refrigeration and ventilation increase exponentially with depth. This technology is therefore not excluded from deep level mining as it has a potentially significant impact on costs.

**Deepmine**

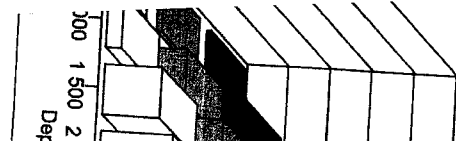
The collaborative research program (Deiring, 1997b) was conceived by the University of the Witwatersrand, CSIR: Division of Mining Technology (Miningtek) and the Foundation for Research and Development (FRD).

In order to identify research needs and subsequent projects, a technology wheel, originally adopted by AngloGold's Project 5000 initiative, was used (Fig. 3). The wheel consists of 15 elements, split into three tiers, which are considered crucial to mining below 3000 m. The first tier deals with mining, the second with accessing the orebody and the third with general technology issues not necessarily unique to deep level mining.

At this stage some of the more important needs for deep level mining have been identified:

- dealing with barotrauma caused by moving people in long shafts;
- 3D visualization of geological structures ahead of mining by integrating geophysical and geological data sets. Additional geophysical tools also need to be developed, improved and integrated;
- establishing the effect of face advance rates on seismicity;
- establishing and quantifying the critical rock engineering criteria;
- reef pillar replacement by high quality backfill (concrete);
- rockburst control and management;
- innovative alternatives to current ventilation and cooling techniques;
- effective tunnel support and alternatives to shotcrete;
- horizontal hydraulic transport of rock;
- concurrent support lining for bored orepasses;

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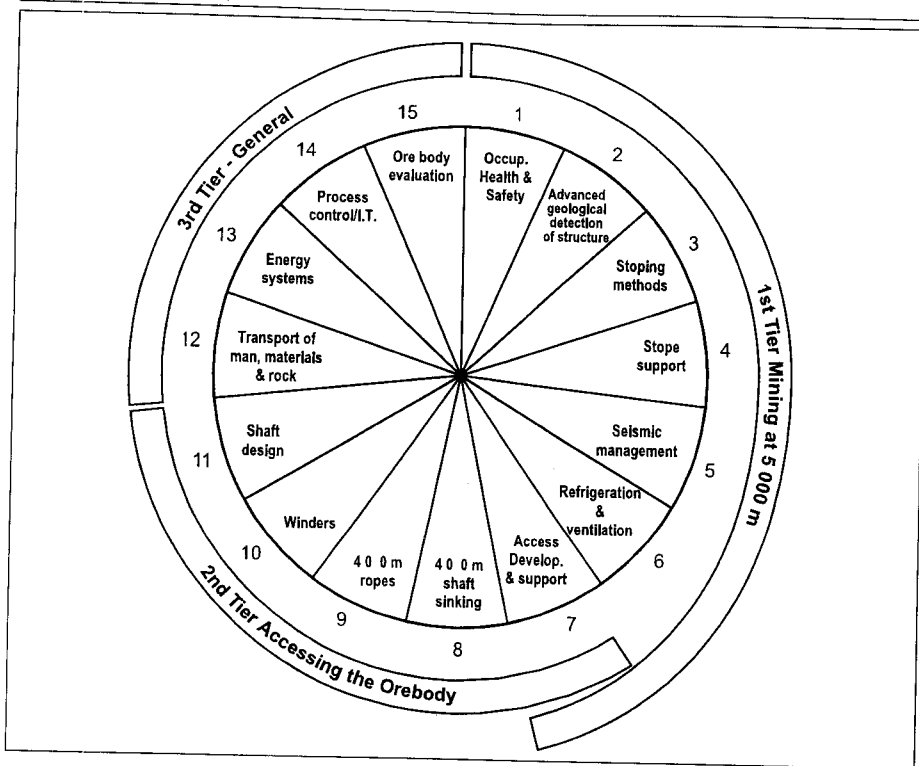
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- optimizing hydro-power systems for maximum energy efficiency;
- integrated information technology and systems for deep level mining; and
- better understanding of grades by the sharing of information across mine boundaries.

Two scenarios are potentially considered on completion of the Deepmine program. Scenario 1 projects would be extensions of present technology or new technology which can be developed and brought on-stream within a short time period. Most of the initial work

would be focused on these types of projects. Scenario 2 projects are future technologies. The overall objective of Deepmine is to ensure that proven technologies are available that allow mining down to 5 000 m levels at safer levels and lower cost than current mining.

Fig. 3. Deepmine technology wheel.



Analysis

An economic analysis was carried out using MinEcon, a computer spreadsheet based cost benefit model. The model allows the impact of changes, in terms of profit or working cost, mining method, mining layout or new technology, to be determined by comparing a current mining operation (base case) with a hypothetical mine based on the layout and application of Scenario 1 technologies (Table 1).

A typical deep level mine was chosen as the base case. This base case mine mills 180 000 tons per month using conventional longwall mining methods. The monthly face advance rate of 10 m is achieved in a 24-working-day month with two shifts per day. The planned mining cycle is a two-in-three cycle, i.e. a panel is planned to be blasted twice in every three days, and the advance per blast is 0.7 m.

A mining block is defined by the stope back and the crosscut spacing, 150 m by 60 m, respectively. This results in a stope of five panels, each 30 m long. The broken rock is cleaned via strike gullies feeding a dip gully to boxholes using conventional scrapers. The average stopping width is 1.5 m.

The Scenario 1 mine considers FULCO, using a 30-working-day month and a one-in-one mining cycle with an advance per blast of 0.9 m. This has increased the monthly face advance from 10 m to 24 m. The increase in advance per blast can be achieved by improved drilling accuracy and sequential firing with the use of electronic detonator systems. The labour complement per panel was increased by a factor of 30/24 to account for the additional working days. The improved drilling, sequential firing and support systems allow a reduction in stopping width from 1.5 m to 1.4 m. The mining layout was changed to a 240 m stope giving a stope of six, 40-m panels. The stope layout includes two strike gullies, one for rock and the other for men and material. The rock is cleaned using conventional face scrapers and continuous scrapers in the strike gullies that feed the centre dip gully. A conventional scraper is used to clean the rock down dip while a continuous scraper cleans up dip to a single boxhole positioned at the mid-point of the dip gully.

Comparing the 'Base Case' with Scenario 1, it is revealed that the total working profit

TABLE 1. Mine parameters used in the two cases for the economic analysis

Parameter	Conventional base case	% change	Scenario 1 case
Stopping width (cm)	150	-6.7%	140
Face broken	73%	3.8%	75.78%
Blast cycle	2 in 3	51.5%	1 in 1
Advance per blast (m)	0.7	28.6%	0.9
Working days per month	24	25.0%	30
Advance per month (m)	10.36	141.2%	24.98
Tons milled	180 000		180 000
Mined area (m <sup>2</sup> )	31 855	11.2%	35 429
Face length required (m)	3076	-53.9%	1419
Level spacing (m)	48	87.5%	90
Reef dip (°)	20		20
Back length (m)	150		240
Panel length (m)	30	33.3%	40
Panel number	5	20.0%	6
X/Cut spacing (m)	60		125

TABLE 2. The main financial results

Parameter	Conventional base case	% change	Scenario 1 case
Yield (g/t)	7.64 g/t	7.1%	8.19 g/t
Working cost per mill ton	349.75	-7.5%	323.47
Working cost per kg	45 770.39	-13.7%	39 519.82
Revenue (R/mill ton)	366.79	7.1%	392.89
Revenue (R/kg)	48 000.00	0.0%	48 000.00
Working profit (R/mill ton)	17.04	307.4%	69.41
Working profit (R/kg)	2229.61	280.3%	8480.18
<b>Total working profit</b>	<b>3 066 769</b>	<b>307.4%</b>	<b>12 494 040</b>
Profit margin	4.65%	280.3%	17.67%
Mining labour (R/mill ton)	48.53	-29.4%	34.28
Other labour costs (R/mill ton)	48.72	-20.1%	38.91
Ventilation	13.59	-22.8%	10.49

increased from R3.1 million to nearly R12.5 million per month (Table 2). The profit margin increased from 4.7% to 17.7%. This was a result of the combined effect of a decrease in the working costs, R349.75 to R323.47 per milled ton, and an increase in the yield from 7.6 g/t to 8.2 g/t. The decrease in the working cost is mainly attributed to the reduced labour and ventilation/refrigeration costs.

The reduced stope width and 1 blast/day resulted in an increase in area mined from 31 855 m<sup>2</sup> to 35 429 m<sup>2</sup> (Table 1). This effectively increases the working costs but this increase is more than offset by the gain in the yield. The reduction in the in-stope waste mined and increase in the face tons mined also contributed to the overall increase in the yield.

The increase in the advance per blast, mining cycle and working days per month resulted in an increase in the monthly face advance from 10 m to 24 m per month. This reduced the amount of working face from 3076 m to 1419 m and, consequently, is the main source of the reduced working costs.

Although there was an increase in the panel labour complement, the reduced face length required has resulted in an overall reduction in labour and a corresponding increase in labour productivity. Labour productivity considering Scenario 1 increased from 25 m<sup>2</sup> to 41 m<sup>2</sup> per man month.

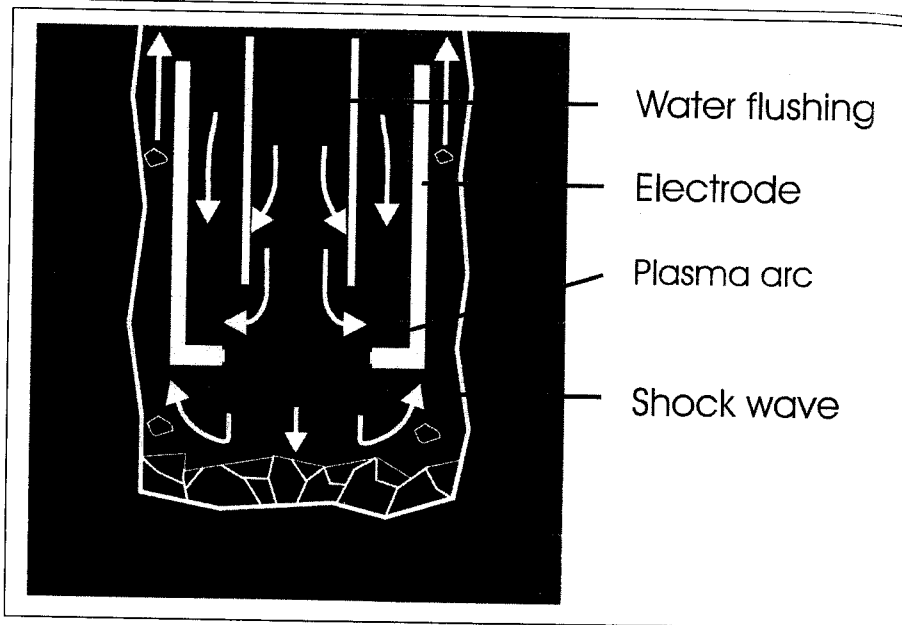
### Future Directions

Although the base case mine considers a typical deep level mining operation, there is sufficient potential to improve profits by implementing and integrating current technology, good management practices, planning and control to suggest that ultra deep level mining would still be profitable using currently available technology. However, this technology will be stretched to the limit, and, therefore, there is a need to consider future developments so that quantum leap benefits can be reaped. As mines go deeper it is anticipated that safety statistics can at least be maintained at current levels. However, major consistent improvements are only possible by extensive mechanization, and remote control and automation which remove the workers from hazardous areas.

### Non-explosive Rock Breaking

Non-explosive rock breaking is attractive because it holds out the promise of real mechanization while at the same time avoiding many of the disadvantages arising from blasting. Face advance rates of up to 100 m per month and better utilization of all resources become possible through continuous mining.

Fig. 4. Principle of plasma hole maker.



The fact that different geotechnical areas have a significant effect on the success of various non-explosive mining methods is, with hindsight, obvious. However, it is only recently that attempts have been made to map and quantify the effects of the various geotechnical areas.

Four impact mining systems are currently undergoing pre-production field trials. This technology makes use of face fracturing inherent in deep level and highly stressed mining. Research is continuing in developing more powerful hammers and in modifying the machine to mine wider stope widths. The machine, although expected to be more effective for deeper mining, is very unproductive in areas with no stress fracturing, generally at depths of less than 1 km.

A test rig of the water pulse gun, which utilizes a high pressure downhole slug of water to break rock, has just completed successful underground trials. It has proved capable of breaking up to 0.5 m of burden in both fractured and unfractured conditions. The main thrust of the work is now to design a practical mining machine. This technology is ideal for conditions where drilling is still required but explosives are unacceptable.

Activation, where vibration is superimposed on cutters (Haase, 1996), has been demonstrated to reduce cutting and penetration forces to a third. In deep level hard rock mining, this technology could be applied to roller cutters for both development and stoping, and to sawing while stoping. Initial laboratory tests are currently being conducted to understand how the variables can be optimized. This technology has the potential to revolutionize deep-level mining.

The use of electricity to directly break the rock has been tried with dubious results in the

past, but recent developments around the world in capacitor and switching design suggest that this method of mining might move from its current 'blue sky' status to a technology that can be applied. Some basic small-scale laboratory tests are underway to establish breaking rates and power requirements. A project is also underway to develop a prototype plasma hole maker. This device makes use of pulsed power and resultant shock waves to make a small diameter hole (Fig. 4).

### Hydraulic Transport

Mechanized mining methods require a high volume continuous transport system fully integrated into the mining system. Hydraulic transport (Ilgner, 1997) can provide such a system and also eliminate many of the problems associated with current rock handling systems. The elimination of ore passes alone makes this an attractive technology. Work is currently focused on identifying and evaluating various innovative compact comminution devices and pumping technologies.

### Conclusions

Although it is likely that current technology with some minor improvements is viable for greater depths, it is anticipated that significant benefits can be achieved, also concerning safety, from the introduction of new technologies at depths greater than 3000 m. The adoption of selective mining at the depths being considered should also improve yields. An important issue is the application of JIT & RIS (just-in-time & right-in-space)

concepts to ensure maximum efficiency (quality). Improved capture, management and transfer of relevant data using electronic media, and the adoption of more sophisticated computer planning software, are essential to ensure these concepts are achieved, both in terms of mine planning and operational control. Having advanced knowledge of the structure and grade of the orebody, by the extensive use of surface and in-mine geophysical and other predictive techniques, will also play an important role in ensuring these concepts are achieved.

Labour requirements can be reduced significantly when using existing technology in an integrated system. This is seen as an essential part in keeping accidents to a minimum and in allowing for increased wages. The labour will, however, have to be much more highly motivated and skilled to achieve the productivity levels envisaged. Higher monetary rewards, participation in relevant decision making and more focused management structures and teams will result in improved motivation.

One area of concern is the cost of providing acceptable environmental conditions, although acceptable conditions can be achieved at an acceptable cost in this scenario. However, to achieve this in all mining areas, it appears essential that new innovative technologies be researched and developed and that current technologies be adapted.

### Acknowledgments

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### NEWS IN BRIEF

## 86TH ANNUAL MEETING AND EXFOR 2000

The 86th Annual Meeting of the Pulp and Paper Technical Association of Canada will take place January 31-February 4, 2000, at Palais des Congrès in Montreal, as part of PaperWeek International 2000.

The annual meeting will offer a myriad of professional development opportunities targeted specifically at those who are involved in the technical operations of pulp, paper and board mills. Mill production and maintenance personnel, engineers, scientists, and technologists will be provided with special opportunities to learn from experts in a broad range of technical disciplines. The program will feature more than thirty technical sessions, the 42nd edition of the products display, EXFOR®, and a mill managers' forum focusing on health and safety issues.

Technical sessions and EXFOR 2000 will commence on Tuesday morning, February 1 and will continue until Thursday afternoon, February 3.

A full program of technical papers has been designed to deliver current information on the technology of the industry.

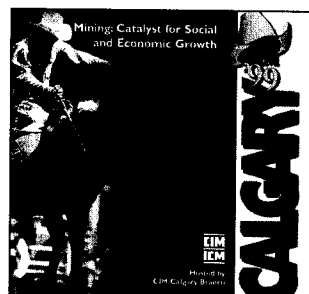
Sessions at the Annual Meeting sponsored by the Association's 23 standing

committees will present a comprehensive technical program including mill operating experiences, case studies and the results of industry research. The technical program for 2000 will consist of 200 presentations on all aspects of pulping and papermaking in 30 different half-day sessions.

Sessions will include: New technology; Posters — Mechanical wood-pulp network research results; Process control; Multivariate modeling and control; Fibre quality and value; Electrical/instrumentation engineering; Printing and graphic arts, and Mechanical pulping. There will be many additional sessions on engineering, converting, paper and board making, pulping, research and standards, and professional development.

The 42nd anniversary of the products exposition, EXFOR, the world's largest annual exhibition of pulp and paper technology, will be held in conjunction with the annual meeting. In 2000, some 450 exhibitors will be on site to show you how the latest research and technology can help you to produce higher-quality, value-added pulp and paper products, or serve the mills that do.

For complete program details, contact Glen D. Black, 740 Notre-Dame St. West, Suite 810, Montreal, Quebec, H3C 3X6, Canada. Tel.: (514) 392-6967; Fax: (514) 392-0369; e-mail: gblack@paptac.ca.



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