The role of research and development in the South African gold-mining industry

Presidential Address

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Introduction

The decision of the gold-mining industry in 1974 to embark on a major ten-year research and development programme was widely publicized at the time. In choosing a subject for this address, I felt almost obliged to use this opportunity to give an account of the progress of this undertaking. On reflection, however, I felt that a simple progress report would not suffice. It seemed important that the programme should be shown in persepective, and that its aims should be outlined to the mining and metallurgical engineering community, many of whom are vitally concerned with the well-being of the gold-mining industry.

Of course, such a general discussion is fraught with dangers. No generalization applies to any one specific instance; no two mines are exactly the same, some being old and having a legacy of many years of operations, others being in their prime, and yet others being new or in the planning stage. Then, again, grade and geological conditions vary from place to place. It is therefore not surprising that the views of mining engineers differ about the route that should be followed to assure the future of the industry.

However, I feel that there are some fundamental concepts on which there ought to be concensus, I suspect that there is fairly general agreement in the profession that the gold-mining industry must attempt to modernize its basic operation, namely stoping. My arguments in this address are concerned essentially with stoping. I am convinced that there can be no significant improvement in the performance of our mines, unless there is also a substantial improvement in the efficiency of our stoping operations.

Traditionally, the President-elect is permitted to look into the future and speculate with a certain amount of impunity. I propose to join the ranks of my distinguished predecessors in this respect. I intend to put forward some ideas that, I hope, will provoke some debate with regard to the future of our mines and in this way make a positive contribution. I must admit, however, that I do not expect all my ideas to enjoy general acceptance.

Motivation for Research & Development

Socio–economic Background

I must state at the outset that I am not a sociologist or economist; nor do I wish to spend much time on political matters in this address. Nevertheless, the South Africa of 1976 calls for at least a brief look at some of the socio-economic factors that have a direct bearing on my subject.

South Africa is richly endowed with mineral and human resources. The theoretical balance in this regard is better than in most other highly mineralized parts of the world. To mention only two examples, Australia is rich in minerals but is short of people, while most parts of Asia are overpopulated in relation to their natural resources.

The non-uniform distribution of the Gross National Product (G.N.P.) over the population has been part of South African life ever since the start of industrialization in the last century. Unquestionably, the *per capita* contribution of the White section of the population to the G.N.P. has been significantly greater than that of the other sections. Correspondingly, the Whites have enjoyed a greater slice of the national cake.

Many in this country agree that efforts must be made to redress this situation if South Africa is to remain a part of the world where different races coexist in reasonable harmony. However, even an amateur economist like me will be permitted to argue that a satisfactory readjustment of the distribution of the cake can come about only if the contribution of the non-White section of the population grows in proportion to the growth of their share of the cake. In fact, the G.N.P. must grow at a rapid rate if an equitable readjustment is to take place within an acceptable period of time.

Most of us are familiar with the old argument that the solution for a country in which a large part of the population is unskilled is to involve as many people as possible in the production process, virtually regardless of their productivity. Up to a point this reasoning is valid. It is possible to achieve some growth in this way, and the involved workers will receive certain income, but this approach has a fundamental weakness. It results in a low human productivity and, consequently, it permits only a low level of *per capita* remuneration.

I am not alone in arguing that the only feasible solution in the long-term is to give a worker the opportunity of reaching reasonably high levels of output and, as a result, make it economically possible for him to earn commensurately more. There is little doubt in my mind that the timeous implementation of this simple principle represents one of the greatest challenges to modern South Africa.

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Mining Background

The South African mining industry, as the cornerstone of the country's economy, is no exception to this general principle. In fact, several sections of the industry have already embarked on a programme of modernization. Many of our base-metal mines use the most modern equipment, and the coal-mining industry is rapidly adopting the results of recent developments in the U.S.A. and Europe. Our new strip mines can be compared with the best overseas operations, and the performance achieved with the aid of recently installed longwalling equipment has been bettered by very few faces elsewhere.

Clearly, however, the overall mining picture is affected by the prospects of modernizing the giant gold-mining industry. To put the situation into perspective, it will be helpful to examine some broad measures of mining productivity. It is clear from the figures presented by Professor R. P. Plewman in his Presidential Address to this Institute two years ago, which are reproduced in Table I, that the output per employee is several times lower in deep-level, hard-rock, narrow-reef mining than in any other type of mining. Before discussing the prospects for modernization, we need to pinpoint the reasons for the great labour intensiveness of gold mining. Table II, which gives some of the important statistics that characterize gold mining, was compiled as an aid in the search for these reasons.

TABLE I

PRODUCTIVITY IN MINING

Type	Tons/employee/year
Narrow tabular underground	
Hard rock, deep-level	220
Coal (fully mechanized)	1 400
Massive underground	
Hard rock	800
Others	1 230
Trackless	1 700
Surface	
Open-pit, hard rock	2 250
Open-pit, others	5 200
Strip mining	10 000

Thus, a fairly typical gold mine may operate at a mean depth of some 1600 m, hoist 250 000 tons of rock per month, some 72 per cent of which is extracted from stopes of about 1,3 m in width, and employ some 8800 men underground and 2600 on surface, giving a total complement of 11 400 men. Every month ore is extracted over an area of some 50 000 m^2 where the width of the gold-bearing channel is likely to be less than 0,5 m. At any one time the mine will have available for production some 10 000 m length of face, which on average is expected to advance some 5 m per month. To provide the face length necessary to maintain production, the mine will have to develop some 30 km of tunnel every year. Currently, the mean virgin-rock temperature can be expected to be in the range of 38 °C, with wet-bulb temperatures in the stopes in the region of 29 °C. During the last 13 years, the weighted mean depth and virgin-rock temperature have increased in the industry on average by 29 m and 0,41 °C per year, respectively. Thus, heat conditions in our typical mine are likely to become more severe in the years to come.

In the light of this picture of our typical mine, or in view of the more detailed information in Table II, we do not have to look very far to identify the major physical factors that are responsible for the labour-intensive nature of gold-mining operations. There are essentially three factors, the first two of which are apparent from the data already presented. These are:

(i) the great depth of mining,
(ii) the narrowness of the gold-bearing channels, and
(iii) the hardness and abrasiveness of the reef.

The great mining depth is the source of two major problems: high air temperature and high rock stress. In 1974 some 58 per cent of all the rock was broken at depths at which the virgin-rock temperature exceeded 38 °C. At depths corresponding to these rock temperatures, it is difficult to provide an environment at the working places that is better than barely tolerable. Inevitably, human performance suffers under such conditions. As a result of the high virgin-rock stresses, virtually all the excavations in a gold mine are surrounded by fractured rock, which gives rise to very severe strata-control problems.

The narrow, tabular nature of the gold reefs results in a restricted space for mining and in the spread of working places over a very wide area, as typified by the face length of 10 km in our example. The narrow stoping widths, which, from sheer necessity, usually exceed the corresponding channel widths, impose an insurmountable limitation on the conventional rock-breaking process, which is blasting. It is not practicable to advance the face at each blast significantly more than the stoping width. This limitation, coupled with the relative inefficiency of the available rock-handling means in stopes, results in low tonnages broken per unit length of face during a given time. For example, in our hypothetical mine, an average of some 18 tons of rock is broken per month per metre of face. In order, therefore, to obtain the overall target tonnage of the mine, a very long face length must be kept in operation. The consequences of this low face utilization are many, including difficulties in supervision and in the provision of services such as compressed air and ventilation. Also, very large stress concentrations are induced near the edges of the extensive tabular excavations. This, and the high value of virgin stresses, are responsible for most of the severe strata-control problems of stoping.

Finally, the hardness and abrasiveness of the rock forming the reefs in gold mines have prevented the application of mechanized mining equipment, which was developed for the extraction of soft, tabular deposits such as coal or potash. As a result, the tremendous developments that have taken place in the last three decades in these fields have left our industry virtually untouched.

In summary, low human performance in the gold-mining industry is the consequence of the extremely difficult mining conditions that result from the great mining depth and from the geometry of the ore-body, and that are compounded by the unfavourable physical

TABLE II

SOME STATISTICS OF GOLD MINING DURING 1974/75*

Statistics for one mine	Mean	Range
Number of persons underground during the main working shift	5 500	1 200—14 500
Rock broken in stopes per month, t	130 000	13 000–350 000
Rock broken from all sources per month, t	180 000	21 000–500 000
Centares mined per month, m^2	35 000	6 000–125 000
Stoping width†, m	1,30	0,85–2,45
Channel width at various mines, m	0,50	0,13–1,98
Face length, m	6 800	600–22 300
Rate of face advance, m per month,	5,2	3,6–7,9
Length of development per 1000 m^2 stoped, m	51	20–150
Depth below surface of stoping at various mines†, m	1 620	470–2 650
Virgin-rock temperature, °C	37,8	22,3–46,3
Wet-bulb temperature in stopes, °C	29	25–33
Flow of downcast air, m^3/s	670	60–1 970
Mass of downcast air moved per mass of rock broken (all sources),	11	
Total rated capacity of installed refrigeration plants, MW	237	

*Compiled from various sources, including the Annual Report and the Annual Ventilation Report of the Chamber of Mines. The values in the table might be subject to some errors and may contain minor inconsistencies.
†Weighted according to tonnage broken.

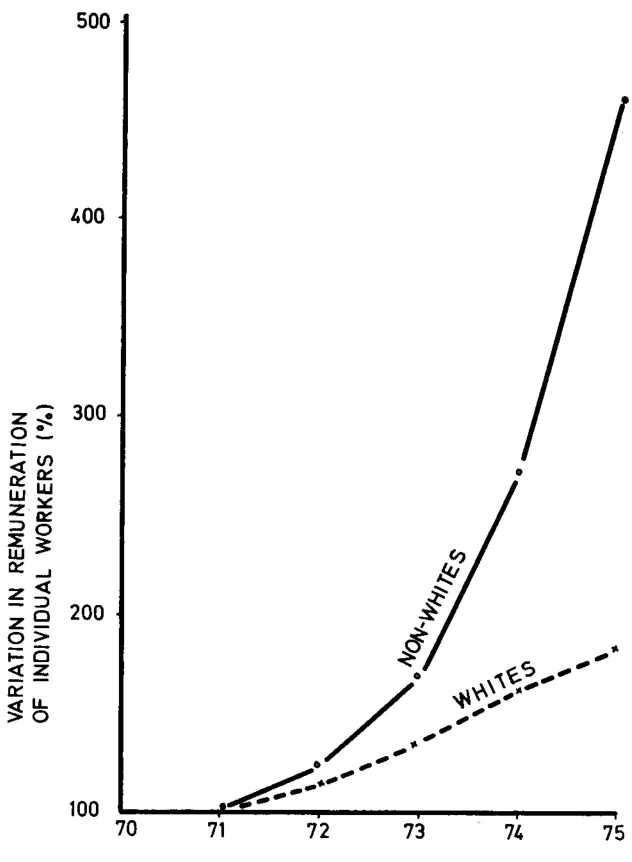

Fig. 1—Percentage increase in non-White and White remuneration in the mining industry in the 70s.

properties of the rock, which do not permit the use of equipment employed in other, much softer, deposits.

Inference

The rapid increase in the price of gold since 1972 has created the opportunity for the gold-mining industry to lift the level of remuneration of its non-White employees. Fig. 1 shows the percentage change in non-White wages relative to the wages paid in 1970 and also gives the change in White income in the industry. The rate of increase in the wages paid to non-White employees is, to my knowledge, unprecedented in a major industry. The ratio of the payments made to White and non-White employees was reduced from 23,8 in 1970 to 9,5 by 1975. This is a tremendous step forward, especially since White incomes also showed significant increases during the same period.

Clearly, however, such a high rate of increase in wages can be maintained only if there is a significant increase in the gold price or if there is a corresponding increase in productivity. The data in Table III clearly illustrate the first of these two requirements. This Table summarizes the percentages of working cost attributable to salaries and wages during the past six years, and gives the percentage of working profit for the same period.

The figures in Table III reveal that, while Black wages (excluding housing and feeding) accounted for some 14,4 per cent of the working cost in 1970, this percentage increased to 25,4 per cent by 1975. It is also important to observe that, during the last two years of this period, the percentage of working cost attributable to labour costs increased by a further 4,3 per cent and that the

TABLE III

SALARIES AND WAGES AS A PERCENTAGE OF WORKING COST AND OF WORKING PROFIT*

Year		1970	1971	1972	1973	1974	1975
$100 \dfrac{\text{Labour cost}}{\text{Working cost}}$	Whites	30,8	30,2	29,0	27,7	26,1	23,7
	Blacks	14,4	14,5	15,0	17,1	20,6	25,4
	TOTAL	45,2	44,7	44,0	44,8	46,7	49,1
$100 \dfrac{\text{Working profit}}{\text{Revenue}}$		33,8	35,5	45,2	55,5	61,5	51,5

*Source—Annual Reports of the Chamber of Mines of South Africa.

total has now reached almost 50 per cent. The percentage of working profit in the last row of the table is even more revealing. While there was a very healthy improvement in profit, especially during the period 1972 to 1974, a large relative decrease occurred during 1975. The writing is on the wall; the rate of improvement in Black wages cannot be maintained any longer, unless the gold price or labour productivity is increased. Unfortunately, the first alternative is out of our hands, but can we improve labour utilization?

There are many approaches to the improvement of productivity. These can be grouped into two basic categories: improvements arising from better organization, where the word *organization* is used in the broadest sense, and improvements arising from advances in technology.

Better organization or management can undoubtedly lead to better productivity. The avenues for improvement are numerous, and include, for example, rationalization of work practices, better training and motivation, and efficient planning. It is impossible to give an accurate estimate of the magnitude of productivity improvements that can be achieved by such methods, but the total effect is likely to be significant. Every effort must be made to explore all these avenues to the greatest possible extent. It must be admitted, however, that the potential of the 'organizational' steps is limited. I suspect that, after significant achievements during the first few years, these methods employed in isolation would result in ever-diminishing returns from ever-increasing efforts.

It seems clear that major and sustained improvement in productivity will be achieved only by an attack on the root of the problem; that is, by improving mining technology. Perhaps the most striking, though indirect, evidence for the need to develop new mining technology to achieve a major increase in labour utilization is provided by a recent unpublished study by D. G. Krige. He has found that some 88 per cent of the variation in productivity (P), measured by the centares duty (i.e. m^2/u.g. Black at work/year), between 25 major mines can be explained by a linear regression function of four variables:

$$P=67{,}5-9{,}97\frac{\Delta M}{M_o}-6{,}48\frac{\Delta C}{C_o}-17{,}32\frac{\Delta h}{h_o}-8{,}58\frac{\Delta D}{D_o}$$

where ΔM, ΔC, Δh, and ΔD are respectively the deviations from the mean development per unit area stoped (M_o=51,02 m per 1000 m^2), the mean channel width (C_o=49,8 cm), the mean hangingwall condition factor (subjective judgement: h=1=good, h=3=bad, h_o=1,74), and the mean depth below surface (D_o=1640 m).

The surprisingly good predictive power of this regression function implies that currently available stoping methods leave relatively little scope for engineering ingenuity to improve productivity. To make a significant step forward, we shall have to break out of our technological confinement.

It was such reasoning that led the leaders of the gold-mining industry to embark on a major programme of research and development.

Feasibility of Technological advances

In an examination of whether technology can be advanced in the particular circumstances of the gold-mining industry, three fundamental questions come to mind.

The first question that might well be asked is whether the resources of the industry are sufficient to undertake a major programme of technological development. In this respect, the example of the British coal industry, which is comparable in revenue* to our industry might be relevant. The National Coal Board almost completely changed the technology in its collieries during the period between 1947 (the date of its establishment) and the early 1970s.

Another obvious question that comes to mind involves the time required to bring a development programme to fruition. Here we can only speculate on the basis of historical data.

The overall productivity in British coal mines increased at a compound annual rate of 3,0 per cent during the 24 years between 1947 and 1971. During the same period, the overall productivity in South African gold mines increased by only 1,3 per cent per annum. According to these figures, productivity in the British collieries will double every 23 years, and in the gold mines every 52 years.

I suggest that a rate of improvement significantly greater than 3,0 per cent per annum should be aimed at by the gold industry. Does this aim appear to be feasible in the light of historical data? I submit that it is feasible since we shall start from a level of technology that is

*For example, in 1970/71 the total value of its sales amounted to £900 million.

obviously open to improvement. In this respect, we can take heart from the fact that the productivity of the South African coal-mining industry (excluding Natal) has improved by 47,1 per cent during the last nine years. This achievement represents an average increase of 4,4 per cent per annum, which was accomplished through the gradual adoption of modern technology.

The third question to be asked is whether our gold mines can afford to change from a labour-intensive mode to a capital-intensive mode of operation. I shall not attempt to answer this complex question in depth, but shall merely mention a few figures that I feel are relevant. On the basis of the average grade and revenue received (see Annual Report of the Chamber of Mines for 1975), and by use of the average stoping width given in Table II, the average revenue earned by our gold mines during 1975 can be estimated as about R120 per square metre. Based on statistics from the same source, the average revenue accruing to collieries mining a seam of 2,5 m width is some R12 per square metre in the Transvaal and Orange Free State. Thus, to earn revenue at the same rate in a given length of face, the rate of face advance in a colliery would have to be ten times greater than that in an average gold mine. In recent self-advancing longwall installations in coal mines, the capital investment has been in the region of R20 000 per metre of face. Managements responsible for these installations have set their targets at a face advance of some 150 to 200 m per month to achieve profitability.

I hesitate to draw firm conclusions from these figures. Nevertheless, the comparison appears to suggest that capitalization in 'average' gold-mining stopes is not out of the question, provided equipment can be developed that permits the establishment of a correct balance between the rate at which cost, including capital charges, is incurred and the rate at which revenue is earned. It is tempting, although of course premature, to deduce from the above example that a stope-face advance of some 15 to 20 m per month would be required to achieve profitability.

Let us speculate here on the assumption that we shall succeed in developing a system of mechanization that will result in some improvement in stope labour productivity. The introduction of this system in a face would therefore result in some saving in stope labour costs. How much money can we afford to spend on equipment to obtain the improvement in productivity?

The answer to this question is complex, but, as a rough guide, let us assume that we are prepared to trade off all labour cost saving for the purchase of new mechanical equipment. If the expected life of this equipment is four years and it is therefore amortized during this period allowing 15 per cent per annum for capital charges, then the maximum permissible investment per metre of face length is as shown in Fig. 2. It was assumed in the compilation of this diagram that current stope labour costs are R12 per square metre. As expected, this illustration reveals that there is a strong relationship between the rate of capitalization and the achieved productivities, as measured by labour productivity and the rate of face advance. It is apparent, also, that significant capital investment can be made in gold-mining

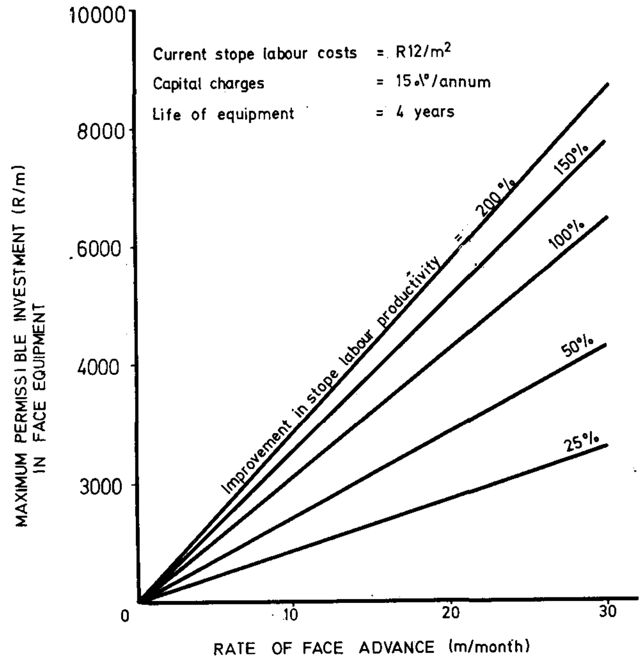

Fig. 2—Rough guide to the maximum permissible investment in face equipment as a function of the rate of face advance and improvement in productivity.

stopes even at relatively modest face advances, say 15 to 20 m per month, provided the current productivity of face labour can be increased significantly.

This brief discussion of the fundamental factors that affect the feasibility of technological advances in gold mines indicates that a *prima facie* case exists for research and development. It seems that the technological success or otherwise of a programme will determine whether major improvements can, in fact, be implemented timeously.

Targets for Research and Development

Key Operation: Stoping

I have already expressed the view that the key to significant improvement in the productivity of our mines lies in the improvement of stoping efficiency. I would add hastily that the converse of this statement does not necessarily hold. Significant overall improvement will be achieved only if the opportunity presented by a major advance in stoping technology culminates in better efficiency in all the other underground operations. Obviously, therefore, if technological advances are to be introduced in our mines, these will have to affect virtually all aspects of underground operations.

Nonetheless, I shall restrict most of my comments to stoping. I do this because I feel that the non-stoping operations (development, transport, etc.,) are by and large problems that are not unique to gold mining and, when the time comes, we shall be in a position to adopt advances already achieved elsewhere. The same cannot be said, however, about stoping. No significant interest in the mining of narrow reefs in deep, hard rock can be expected to be shown elsewhere in the world. To achieve progress in this area is up to us.

Traditionally, we have endeavoured to optimize the use of our manpower by providing a stoping crew with sufficient face length to allow it to make up for any day-to-day setbacks. It is well-known that the 'crowding' of contractors results in a drop in productivity when this is measured in centares per month. For example, in the typical mine referred to earlier, the average face advance was assumed to be 5 m per month, suggesting that each panel in this mine is blasted on average five times per month. This is an amazingly low face utilization, which is tolerable only because the cost of maintaining a panel operational is currently very low. There are clear disadvantages in this situation. I shall give two examples to illustrate this. There are many faces in our mines where significant improvement could be achieved in strata control by the use of rapid-yielding props, but the adoption of this improvement is often made impossible by the low rate at which revenue is earned by a unit length of face. Similarly, greater investment in refrigeration equipment could result in improved environmental conditions. In many instances, however, mines are prevented from taking advantage of this by the great cost of improving stope cooling over excessively long faces.

Experience has shown that the modernization of a labour-intensive industry has almost always involved the increasing employment of mechanical or electrical power; that is, machines are introduced to supplement the effort of men. I believe that gold mining is no exception to this general rule. If we accept this argument, the conclusion that major improvements in stoping efficiency will involve significant investment in face equipment is inescapable.

It is almost a truism to say that the secret of success for most modern mining ventures lies in the concentration of mining operations. The desirability of the concentration of operations in our gold mines was a very hotly debated topic during the early 1960s. In a memorable paper in 1964, W. J. de Villiers presented his arguments for concentrated mining to this Institute. Virtually everyone agreed that, in the pre-production stage of a mine, the concentration of stoping effort is profitable. However, strong reasons were put forward at the time against concentration in the steady-production stage of the life of a mine. I shall mention only a few of those arguments. It was suggested that, if concentration was pursued, loss of production would result from the crowding of stoping crews, and large fluctuations in gold production would follow due to the unpredictable variability of grade that is encountered across most mines. Also, it was predicted that 'bottlenecks' would arise in the transport system, and that it would be necessary to purchase expensive stoping and other equipment which would require high-level training of at least a part of the migratory labour force.

These and many similar criticisms are valid if an excessive degree of concentration is to be introduced, and if the question is viewed in the light of present technology. In fact, it must be conceded that significant concentration cannot be introduced without incurring some problems of this kind. However, if we are resolved to improve the productivity of our labour force, and if we are consequently to embark on a modernization programme of our stoping, we shall have to accept that some degree of concentration of stoping is inevitable. As we install more and more equipment per panel at a greater and greater cost, it will become less and less tenable to provide spare panels to contractors. We shall have to expect greater output from each of fewer panels, and these panels will have to be consolidated into fewer regions of the mine.

Thus, successful mechanization of stoping would result in a reduction in the face length required to mine a given area, and, hence, would facilitate the introduction of improvements elsewhere in the mine. Concentration of production would result not only in increased human productivity and in enhanced utilization of face equipment, transport facilities, and services (ventilation, refrigeration, compressed air, and water reticulation), but at the same time would make the employment of better face support and the drastic improvement of environment economic realities. In turn, these changes would result in safer, more comfortable and, therefore, more productive mining conditions.

Selective Mining

No serious analysis of the potential for the introduction of new technology in the mining industry would be complete without devoting attention to the fact that the mass of gold produced by each mine is very small — only a few tons or, at most, a few tens of tons per annum. In theory, therefore, staggering benefits could arise if it became possible to mine only the gold, leaving all the associated rock behind. While clearly this ultimate is not attainable, there might be ways and means of approaching the ideal. Two possible approaches come to mind.

First, we might be able to mine and selectively tram the ore in the gold-bearing channel, and pack the excess waste rock in the mined-out area. In principle, this solution is feasible wherever the channel width is considerably smaller than the convenient mining width and may result in halving the effective tramming width. Unfortunately, blasting causes ore to be mixed intimately with waste. Conventional mining, therefore,does not lend itself to the wide-scale application of selective mining in this sense. However, it is possible to visualize non-explosive methods of rock breaking that would permit the attainment of the required selectivity.

The second approach involves the 'sorting' of the mined ore underground at some points, but not in the face. The aim would be to produce a concentrate representing some 40 to 50 per cent of the ore but containing virtually all the mined gold. The concentrate would be hoisted to the surface for recovery of the gold, and the remaining waste would be returned to the mined-out region for use as fill. This approach is applicable regardless of the width of the gold-bearing channel or of the method of mining, so that it could be employed in conjunction with conventional blasting.

The common feature of both these approaches is that, for a given area of mining, the mass of rock hoisted would be approximately halved, with a corresponding near-doubling of grade. At the same time, the mined-out regions would be filled with waste.

The implementation of either of these methods would result in many advantages that would become manifest in different ways in different situations. In the design of a new mine, it would be possible to reduce significantly for a given rate of gold production, the investment necessary to provide shafts and surface plants. The potential profitability of a new mine could therefore be increased markedly. In an existing mine, the possibility would be created for increasing the rate at which revenue is earned. This could be achieved by increasing the centares duty of the mine, but without the need to invest in new capital to provide additional shaft and surface-plant capacities. An alternative advantage of selective mining in an existing mine could arise in conjunction with attempts to achieve concentration of mining operations. Either method of selectivity would result in an effective doubling of shaft capacity relative to a given area mined. This might mean that, even if a large degree of concentration of mining is achieved in an area associated with a shaft, the resulting ore could still be handled by the same shaft. In this manner, considerable flexibility would be provided for the relatively unhampered. implementation of the concentration of mining activities.

In addition to these main advantages, a host of secondary benefits would arise from selective mining. These include a large reduction in the quantity of material needed for permanent stope support, much improved efficiency of ventilation and refrigeration, and significant amelioration of strata-control problems and fire hazards. Any one of these improvements in itself is very important in our deep mines.

Research and Development Programme

Up to this point my discussion has been general. In the remainder of this address, I shall focus my attention on the co-operative research and development of the industry, through the Research Organization of the Chamber of Mines of South Africa. However, it should be emphasized that, in addition to the cooperative effort, several mining houses are engaged in development work of their own.

The overall aim of the Research and Development Programme of the Chamber of Mines Research Organization is to husband our labour resources. The Concise Oxford Dictionary defines *to husband* as 'to manage thriftily'. This is exactly the sense in which the Executive Committee of the Chamber of Mines used the word in defining the overriding objective of its Programme. In greater detail, the Programme requires the development of (a) new systems of stoping and (b) engineering methods to improve underground environment and safety, with a view to facilitating significant and sustained improvements in labour productivity; moreover, to do all this, while ensuring that all preparations are made to overcome the human problems associated with the implementation of such major technological changes when employing an unsophisticated labour force.

The final decision to embark on this Programme was made some two and a half years ago. Since that time, the Research Advisory Committee and the Research Organization of the Chamber of Mines have proceeded to implement the decision of the Executive Committee with determination. The scale of the Programme is impressive, even by international standards, and certainly greater than anything undertaken by industry in South Africa. It is envisaged that some R100 to R150 million will be spent over ten years in order to reach the goals set.

Progress since 1974

Planning and Reorganization

The visionary and courageous decision of the industry to embark on such a large programme has presented an unprecedented challenge to its research and development staff. It required the rapid build-up of activities to a scale approximately three times greater than that in 1974. To enable the Research Organization to do this, many fundamental problems had to be tackled. While I do not intend to discuss in detail all the problems associated with our period of growth, there are four aspects that ought to be mentioned.

(i) *Restructuring of the Research Organization.* It was obvious from the outset that the new objectives of the Programme would require the restructuring of the Research Organization so as to equip it for its widened responsibilities. The principle employed in the reorganization was to create reasonably self-contained units that would provide bases for growth, each of which was designed to tackle well-defined tasks. The aim was to provide opportunities for personal leadership but, at the same time, to ensure that the activities of the various arms of the Research Organization could be coordinated.

The reorganization was completed before the end of 1974, resulting in the establishment of seven units or laboratories, the heads of which were all new appointees.

(ii) *Definition of the details of the Programme.* The clearly defined overall aim of the industry's new research and development policy provided a firm basis on which the working objectives of the Research Organization could be built. These fall essentially into four fields.

(a) mining (stoping) technology,
(b) underground environment and safety,
(c) mining operations, and
(d) human resources.

Once the working objectives had been defined, the existing Research Programme was analysed in detail, and projects that did not appear to be strictly relevant in the light of the new policy were discarded. Simultaneously, new projects were initiated in line with the new goal.

The work on the new Research and Development Programme was completed well before the end of 1974. It must be emphasized here that we regard this Programme as a dynamic entity requiring continuous review and modification in the light of developments.

(iii) *Recruitment of staff.* To tackle the much enlarged task, the Research Organization had to be reinforced by bold, imaginative, and practical engineers and scientists. We attach great importance to the recruitment of practical men because most of our activities are in the realms of engineering and, emphatically, applied sciences.

Vigorous recruitment both in South Africa and overseas has yielded good results, but I must admit that this is the area with which I feel least satisfied. The key to our success lies in people, and I am not happy that we have all the talent we need.

(iv) *Collaboration of manufacturers.* Several basic considerations guided us in deciding to build up a system of collaborative agreements with commercial concerns, mainly manufacturers of mining equipment. Firstly, it was considered unpractical, and even wrong, to create a research organization that would be large enough to undertake the whole programme 'in house'. Secondly, it was recognized that the manufacturers, as a result of their practical experience and resources, could make significant contributions to the development effort. The third consideration in drawing up the development agreements was to ensure that the collaborators could expect to benefit financially from the eventual marketing of a successful product, and not from the development phase. This approach provides us with commercial safeguards. It is unlikely that a particular development will be pursued without a positive assessment of its viability by at least one experienced supplier of mining equipment. Fourthly, it seemed logical to expect that there would be considerable savings in time and effort when the time for large scale manufacturing arrives, if the potential producer of some machine would be thoroughly familiar with the product through his participation in its development. Finally, but perhaps most important, through the participation of manufacturers in the development it was hoped to encourage the timeous evolution in this country of a viable industry manufacturing mining equipment to supply the eventual requirements of the mines.

Perhaps the most notable achievement during the past two years has been the large-scale mobilization of the resources of such manufacturers. More than twenty of the principal manufacturers of mining equipment, both locally and overseas, are now actively involved in the programme.

Advances in Research and Development

It would be impossible for me to describe all the projects currently being pursued by the Research Organization. Instead, I shall attempt to indicate relationships between the various fields of activities.

(i) *Mining technology.* The Research Organization has been engaged in the development of mining machines since about 1967. In the last two years, we came to realize that we should devote our attention to the development of entire stoping systems, and not of individual machines. Unless this is done, a particular development might be carried out in a vacuum, with little or no chance of eventual success.

Another basic principle of our activities in this field is to ensure that the first viable systems should mature in a relatively short time. The realization of this need led us to pursue relatively short- and long-term objectives simultaneously.

The selection of the line of attack for *short-term developments* has been guided by the observation that there appears to be considerable scope for increasing the current low-face utilization in conventional mining. The most obvious way to do this is to retain blasting and to evolve a system ensuring that a full cycle of mining in a given panel can be accomplished with reasonable reliability during each shift. This concept holds out the possibility of increasing the rate of face advance, operating on a single shift, from the current 5 m per month to between 15 and 20 m per month at a face-labour productivity of some 30 to 45 m^2 per month. At present, face-labour productivity in the industry averages about 15 m^2 per month.

The ultimate form of this system of mining would involve the use of a face conveyor, blasting barricade, and carriage-mounted hydraulic drill riding on the conveyor. The face would be supported by self-advancing, rapid-yielding support, which would also act as an anchor to facilitate the forward pushing of the conveyor. The conveyor would be loaded initially by the blast and subsequently by being pushed into the rock pile.

All the components of this system are being developed in such a manner that most attention is being devoted to the key components, that is, to the conveyor and the barricade. This is to ensure that the system can be put into use even before all of its elements are fully developed. I am pleased to be able to report that the most promising version of the face conveyors, the

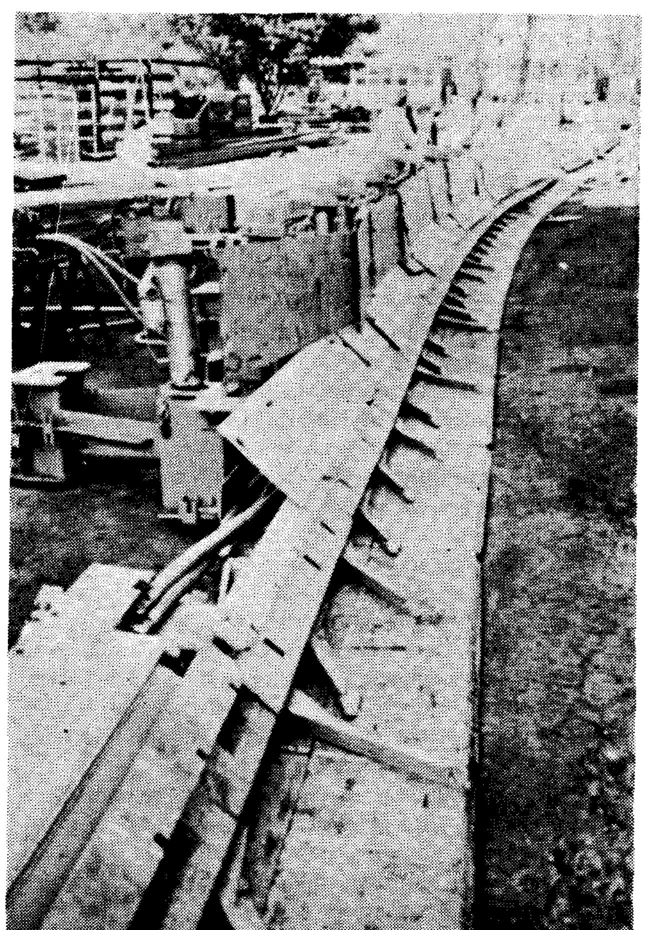

Fig. 3—Reciprocating flight conveyor with support and blasting barricade.

reciprocating flight conveyor (Fig. 3), is rapidly approaching the stage at which it can be regarded as a proven mining machine.

The *longer-term developments* involve a total departure from the present cyclic system of mining, being based on some form of non-explosive rock breaking. Essentially, the rock-breaking methods under development are all mechanical and based on various applications of the indentation principle. In all instances, a fully mechanized mining system is being developed, including means for rock breaking, loading, transport, and support.

The most widely publicized system is based on drag-bit rockcutting. A total area of more than 40 000 m^2 has now been mined with this system. During the last two years, work has been directed towards developing a complete rockcutting system to give better labour productivity and a faster mining rate. It is expected that two versions of such complete systems will be tested underground during the next few months.

The second most advanced method is the swing-hammer miner. Underground trials of two complete units mounted on reciprocating flight conveyors are now in progress (Fig. 4).

In the third system of mining, the aim is to use hydraulic impact rippers or breakers (Fig. 5). Experiments underground have showed that the impact rippers have considerable potential as the rock-breaking element in a non-explosive mining system.

All the rock-breaking methods I have mentioned so far depend heavily on the fractures induced by the stresses in the rock. Investigations have started into stope rock-breaking methods that are effective in unfractured rock. An experiment for boring out the reef using raise-boring technology was started by Gold Fields of South Africa Limited and is now being conducted by the Research Organization. This experiment has highlighted some of the main problems, but it is too early to comment on the potential of the concept.

These are only the main features of our efforts in developing mechanized stoping systems. A host of other developments are in progress in the background. These are of fundamental importance but possibly less appreciated; they include work on the nature of reefs, on sophisticated sampling methods, on 95/5 water-emulsion hydraulic systems, on radio communication in working places, and so on.

In pursuing the development of mechanized stoping systems, we have not lost sight of the very material benefits that would accrue from the hoisting of ore enriched in gold. As I mentioned earlier, the enrichment could be achieved in one of two ways: either by tramming the highly mineralized rock selectively from the stope, or by employing some type of underground sorting.

Drag-bit rockcutting, reef boring, and, perhaps to a lesser degree, the use of impact rippers offer the possibility of applying the selectivity concept in stopes.

The wide applicability of the alternative sorting scheme renders it especially attractive, and significant effort is therefore being devoted to its implementation. The decision has been made to pursue a metallurgical method of sorting. The idea is to crush and mill the ore, and to float off a concentrate that will then be transported to the surface while the waste is filled back into the stopes. All aspects of this scheme are receiving intensive attention. Especially heartening progress has been made in underground milling with the aid of compact centrifugal mills and in flotation. A study of the properties of the slime as a potential fill material is also well advanced.

(ii) *Environment and safety.* As mentioned earlier, high wet-bulb temperatures in working places and difficult strata-control conditions in our stopes are important factors contributing to the labour-intensiveness of current mining practices. I believe that no new system of mining will be fully successful unless we alleviate these problems.

The wet-bulb temperature is the primary factor, and local air speed the secondary factor, that determine the suitability or otherwise of the thermal environment in mines. When air speeds are low and wet-bulb temperatures are between 28 and 33 °C (that is, within a range of only 5 °C) there is a marked change in the capacity of the air to remove the metabolic heat that is generated by working men. At wet-bulb temperatures below 28 °C, the environment can be considered to be adequately cool and to impose small thermal stresses on workmen. Prolonged hard work for extended periods at wet-bulb temperatures of more than 33 °C is not possible without severe risk of heat stroke. Ideally, therefore, our aim should be to maintain wet-bulb temperatures in working places at levels below 28 °C. Major strides have been made during the last two years to attain this condition.

Although air and water can both be used to remove heat from underground, only air has been traditionally regarded as a cooling medium. It has now been recognized that this is not the ideal approach to mine cooling.

It has been established that the primary cause of high air temperatures in deep mines is autocompression. The wet-bulb temperature rises, regardless of the virgin-rock temperature, by about 4 °C per 1000 m, reaching 28 °C during the summer months at depths of about 2200 m. Clearly, unrefrigerated air is not an efficient cooling medium in deep mines. Experiments in stopes have confirmed that it is not possible to reduce stope wet-bulb temperatures to less than the temperature of the free water on the footwall. Thus, if stope temperatures are to be brought below this value, service water will have to be cooled.

The quantity of water that is used underground for drilling and for suppressing dust is typically between 0,5 and 2,0 tons per ton of rock mined. Recent investigations have confirmed that pre-cooling of this water by refrigeration is of immense benefit in reducing temperatures in working places. Major underground trials are now in progress on the engineering aspects of this new approach to mine cooling. I expect to see rapid progress in this particular field of our endeavours.

Fundamentally, two factors are responsible for most of our strata-control problems. These are the depth of mining, and the geometry of our tabular stoping excavations. Given these constraints, research during the last decade has provided the industry with means for the

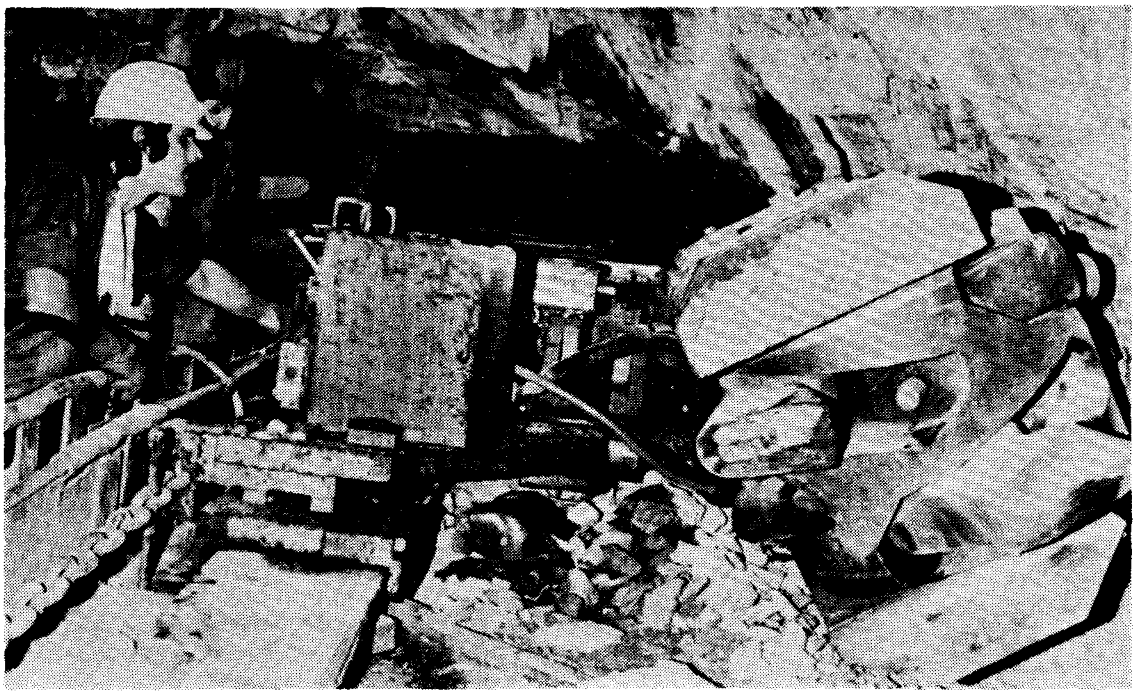

Fig. 4—Prototype swing hammer miner in a stope.

Fig. 5—Prototype impact reaper underground.

rational planning of mine layouts. While there is still room for improvement in the consistent application of these planning tools (electric analogue, MINSIM, etc.), work is already in progress on the next phase of development. This embraces the need for greatly improved stope support. There are two aspects to this problem: face support (including gullies) and regional support.

Rapid-yielding props represent the first step towards the introduction of modern face-support systems. It should be noted that these props are an integral part of all the mechanized-mining schemes that are at present under development. The next step is likely to involve the use of barrier props and self-advancing supports. The idea behind these developments is to provide an an effective and active face support that is advanced as the face moves forward. The most attractive regional support is the fill, which would be a by-product of the already discussed scheme for the hoisting of enriched ore.

(iii) *Human resources*. Economic, political, and social changes have combined to place an unprecedented strain on the labour resources of the mining industry. The contemplated technological changes could add to this strain, and their implementation might be hindered by personnel-related problems. These considerations have given a major impetus to the industry's research into human problems.

The research has three principal objectives: first, to monitor the demand for people, and their supply and utilization, so as to provide a better basis for action by the industry; second, to assist with the solution of particular human problems; and, third, to assist with the implementation of the results of research and development, particularly in training for new systems of mining.

The monitoring activity was initiated in early 1975 and has resulted in a continuous stream of information with regard to such matters as communication between management and mineworkers, topics of current importance to the men, and their attitudes to these matters. Considerable emphasis has been placed on the examination of the likely future availability to the mining industry of unskilled and semi-skilled labour. Information in this regard has contributed during the recent past towards the recruitment by the Mine Labour Organizations of South African mine workers in greater numbers than previously.

A specialist team has been intimately involved with the mechanization activities, dealing particularly with the personnel-related matters associated with the trials and, in the longer-term, with the introduction of mechanized mining methods. Aspects such as job design, job organization, training, and pay structures have been dealt with by this team.

(iv) *General comments*. I hope I have managed to convey in this somewhat lengthy, but nonetheless still superficial, account something about the special spirit of the people involved in our work. I suggest that the Chamber's Research Organization today is much more akin to a task force than to a traditional research institution.

Visitors to our sites find almost embarrassingly little of the usual laboratory-bound activity. We have to emphasize to them that the mines are our laboratories, which is perfectly true. Perhaps few people realize that right now some 700 persons are involved in field trials and underground experiments at fifteen of our gold mines.

Conclusion

My remarks would not be complete without some comments on the developments of recent months.

Lately, in the eyes of many, the horizon of the gold-mining industry has been darkened by the clouds of the sagging gold price. The question might well be asked whether, in the changed circumstances, it is justified to pursue the ambitious plans of more euphoric times.

Together with those who believe that the fall in the gold price is temporary, I feel that the fundamental factors leading to the decision in 1974 have not changed. The underlying need to allow our non-White workers to earn higher wages has, in the meantime, been crystallized even more by recent events around us. Also, a lower gold price dictates even more emphatically that higher wages can be paid only if the increase is associated with improved productivity. Thus, I suggest that we must not — in fact, we cannot — waver in the decision to aim for new technology.

Nonetheless, our development plans must be examined in the light of harsh realities. Managements of mines introduce new technology only under the pressure of abnormal forces or if there are economic advantages in doing so. An obvious example of abnormal reasons is on acute labour shortage, or a lack of sufficient face to permit working a mine to capacity. Although the possibility of encountering either or both of these conditions is not unlikely, no realistic development plan can gamble on the effects of abnormal factors for its viability. The proposed product or system must be economically viable in the projected economic climate. We are fully aware of this basic principle, and endeavour to make every effort to subject our plans to the cold scrutiny of economics.

I have few illusions with regard to the problems involved in introducing the fruits of our efforts into the mines. We shall have to face the inevitable reaction of the traditionalists, the indifference of some overstretched overloaded managements, and sometimes unfavourable economic factors. I feel, however, that none of these factors or others should deter us from persevering.

Acknowledgements

Clearly, this address could not have been made without the contributions of two bodies of men.

Without the courageous decision of the leaders of the gold-mining industry there would have been no new Research and Development Programme upon which to report. I compliment them on their foresight in making, this decision.

Equally important is the role played by my colleagues on the Research Advisory Committee and in the Research Organization, who are responsible for guiding and implementing the Programme. I cannot adequately