Minerals and the survival of mankind
Presidential address

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SYNOPSIS

Without minerals, man cannot possibly hope to maintain his present standard of living.

Professional mining men throughout the world, particularly in mineral-exporting countries like South Africa, are faced with the increasingly difficult task of ensuring adequate supplies of minerals. The problems of gradually diminishing mineral reserves and rapidly rising mining costs can to a certain extent be overcome by the use of more-sophisticated technological techniques and by the improvement of efficiency wherever possible. However, there is growing concern in some quarters, that, despite the ingenuity of engineers, geologists, metallurgists, and scientists, the earth's mineral reserves will eventually become insufficient to meet man's needs.

In order to ensure the continued well-being of the earth's population, it is therefore imperative that more attention should be paid to mineral research and the training of specialists in the field of mineral reclamation.

SAMEVATTING

Die mens kan onmoontlik die hoop koester om sonder minerale sy huidige lewenspeil te handhaaf.

Oor die hele wêreld, en veral in lande soos Suid-Afrika wat minerale uitvoer, is professionele mense in die mynbedryf belas met die steeds moeiliker taak om toereikende mineraalvoorrade te verseker. Die probleme van mineraalreserwes wat geleidelik verminder en mynboukostes wat vinnig styg, kan in sekere mate oorkom word deur meer gesofistikeerde tegnologiese tegnieke te gebruik en doeltreffendheid, waar ook al moontlik, te verhoog. Daar bestaan egter 'n toenemende besorgdheid in sekere dele dat, ten spyte van die vindingrykheid van ingenieurs, geoloë, metallurgiste en wetenskaplikes, die aarde se mineraalreserwes uiteindelik onvoldoende sal wees om in die mens se behoeftes te voorsien.

Om die voortgesette welsyn van die aarde se bevolking te verseker, is dit daarom gebiedend noodsaaklik dat meer aandag aan minerale-navorsing en die opleiding van spesialiste op die gebied van mineraalherwinning gewy word.

Introduction

Despite his technological ingenuity, man's material achievements still depend on two basic things — agriculture and minerals. Without these, society as we know it today would cease to exist.

Without minerals, we could not till our soil, build our machines, supply our energy, transport our goods, or maintain any form of civilization beyond the most primitive. It is true to say that our high living standards start with a hole in the ground. Consider, for example, how very different modern society would be without the motor vehicle, the television set, or the telephone. Few people realize that a motor vehicle contains some 15 different minerals, a colour TV set about 35, and a telephone nearly 40.

It has been estimated by the American Mining Congress that, at present levels of consumption, the average person born in the United States today will require, during his lifetime, over 476 kg of lead, 476 kg of zinc, 794 kg of copper, 2 t of aluminium, 41 t of iron and steel, 164 t of coal, and 606 kg of stone, sand, gravel, cement, and clay. These figures give some indication of the world demand for minerals.

We in South Africa are heirs to a sub-continent that is richly endowed with minerals. The rights of ownership have often been the cause of major disputes, and this is likely to continue. However, I am a mining engineer, and not a historian or politician. I am sure you would not wish either me, as your newly elected President, or your Institute itself, to become involved in matters that, although of vital importance, are better left to those in possession of the required expertise. However, we are bearers of an ensign that allows our fellowmen to identify our particular area of responsibility, namely the exploitation and beneficiation of South Africa's minerals and metals. A man's responsibility towards society is proportional to the importance of his specific skills and attributes to mankind, and the way in which he uses these to increase or maintain the standard of living of his fellows. The importance of minerals to mankind demonstrates how great our responsibilities are.

It is not my intention in this address to pass judgement on the endeavours of our predecessors to provide mankind with the optimum benefits from the resources available to them; nor do I intend to prove by statistics the role of minerals and metals in the furtherance or the maintenance of culture, civilization, or standards of living on our planet. I intend to deal with some of the aspects to which I have already vaguely referred, particularly with the South African situation, the mining industry and its related professions, and, as is appropriate to the occasion, the professions we represent.

Some of the aspects with which I will deal will no doubt be considered by my audience as self evident or even elementary, but it is the obvious that at times, particularly times bordering on the critical, needs to be pointed out.

South Africa's Minerals

Much has been written and said about the mineral potential of Southern Africa in relation to the rest of the world or, to be more specific, to the Western World. The importance of South Africa as a supplier of strategic minerals to the world cannot be overstressed. South Africa today produces about fifty minerals and exports about 80 per cent of its mineral production. We in the

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TABLE I

COMPARISON AND RANKING OF TWENTY MINERAL COMMODITIES PRODUCED IN SOUTH AFRICA AND THEIR STATUS IN THE WORLD'S MINERAL INDUSTRY

(Abbreviations: mt = millions of tons; kg = kilograms; mkg = millions of kilograms; c = metric carats; mc = millions of carats; Rm = millions of rands; (w) = world figures; n.a. = not available; n.s. = no significance; e = estimate)

Item	Antimony (metal)	Asbestos	Chromium	Coal	Copper	Diamond	Fluorspar	Gold (Free World)	Iron
Production									
RSA production, 1975	16 000t	0,3547mt	2,075mt	69,4396mt	0,175mt	7,2951mc	0,202583mt	713 447kg	12,2978mt
World production, 1975	73 028t	3,734mt	7,3500mt	2942,5mt	6,624mt	49,3827mc	4,732mt	940 000kg	875,00mt
% of world production	21,91%	0,09%	28,24%	2,36%	2,64%	14,77%	4,28%	75,30%	1,40%
Production proportion 1941–45	2,5%	2,6%	3,6%	7,8%	5,0%	1,7%	0,8%	9,4%	2,4%
,, ,, 1946–50	6,6%	4,1%	6,9%	9,1%	6,2%	4,9%	1,0%	8,2%	4,4%
,, ,, 1951–55	14,1%	9,2%	10,9%	10,6%	7,7%	9,5%	3,5%	9,0%	6,0%
,, ,, 1956–60	15,1%	13,5%	11,5%	13,5%	9,6%	10,7%	11,2%	13,0%	8,2%
,, ,, 1961–65	17,1%	17,6%	15,9%	16,2%	11,0%	16,7%	15,0%	19,1%	15,5%
,, ,, 1966–70	22,0%	23,0%	20,3%	19,2%	26,2%	28,0%	24,8%	22,1%	25,9%
,, ,, 1971–75	22,6%	30,0%	30,9%	23,6%	34,3%	28,5%	43,7%	19,2%	37,6%
Percentage annual growth 1941–45	+94,60%	+1,48%	—13,13%	+6,18%	+7,73%	+74,25%	—9,98%	—2,66%	+6,99%
,, ,, ,, 1946–50	+29,90%	+29,22%	+43,97%	+2,42%	+6,71%	+9,90%	+16,42%	—0,88%	+6,93%
,, ,, ,, 1951–55	+50,94%	+8,79%	+2,83%	+3,64%	+7,74%	+9,61%	+37,67%	+4,71%	+11,39%
,, ,, ,, 1956–60	—4,05%	+8,24%	+2,17%	+3,56%	+0,79%	+3,45%	+30,36%	+8,41%	+9,45%
,, ,, ,, 1961–65	+11,04%	+6,76%	+11,87%	+4,90%	—6,12%	+12,53%	—4,59%	+7,48%	+14,00%
,, ,, ,, 1966–70	+6,11%	+5,91%	+2,92%	+2,47%	+25,14%	+10,20%	+21,66%	+1,04%	+5,50%
,, ,, ,, 1971–75	—0,20%	+3,93%	+14,81%	+4,96%	+3,76%	—1,89%	+12,08%	—6,50%	+11,84%
Growth ranking, 1971–75	16	14	7	13	15	18	9	20	10
Average annual growth 1941–75	+26,90%	+9,19%	+9,35%	+4,02%	+8,28%	+16,87%	+14,80%	+1,66%	+9,44%
Growth ranking, 1941–75	2	12	11	16	13	5	6	17	10
World annual growth, 1961–75	+2,25%	+4,58%	+3,73%	+3,92%	+3,42%	+1,88%	+5,96%	—1,30%	+4,27%
Export price, 1975R/unit	R1486,04	R312,13	R22,95	R13,90	R817,69	R21,74	R53,17	R3588,77	n.a.
U.S. price, 1975R/unit	R2596,10	R135,00	R29,80	R13,91	R795,15	n.a.	R70,87	R3510,15	R12,33
U.S. price movement, 1971–75	+22,00%	+13,66%	+15,80%	+25,99%	+5,14%	+1,99%	+5,39%	+37,43%	+11,69%
,, ,, ,, 1961–75	+16,22%	+4,25%	+7,97%	+9,95%	+5,78%	+0,04%	+6,16%	+12,85%	+3,53%
Production value, lowest price, Rm.	R23,7766	R47,8858	R47,6304	R965,2104	R139,1512	R158,5955	R10,7713	R2560,395	R151,6319
Value ranking	14	12	13	2	8	5	16	1	7
Production/total sales value	0,57%	1,16%	1,15%	23,35%	3,36%	3,83%	0,26%	61,93%	3,67%
Projected production to 1980–85	3,5%(w)	n.a.	9,4%	3,2%	7,9%	n.a.	19,0%	n.a.	8,45%
Projected production to 2000	3,5%(w)	n.a.	5%	4,0%	6,0%	n.a.	19,0%	n.a.	7,4–8,3
Reserves, resources									
Reserves, indicated	125 000t	—	—	58 250mt	476 500t	—	—	—	—
Reserves inferred		7,1mt	2333mt	23 274mt	1,0mt	50mc		18,66mkg	6500mt
Resources, identified	175 000t	—	2083mt	—	13,3255mt	—	30mt	—	
hypothetical		6,9mt	3048mt	—	—	—	—	—	5100mt
World reserves	4,3mt	87,09mt	4344mt	n.a.	408,233mt	1050mc	105mt	—	263156mt
World resources	1,45mt	48,00mt	3639mt	11421156mt	1451mt	n.a.	762mt	41,99mkg	772195mt
RSA % of world	2,64%	8,15%	71,5%	0,4%	3,74%	4,76%	27,6%	59,2%	1,12–2,47%
RSA inferred life, years*	8–22	20–30	1124	1000	75	13	148	21–26	163
World inferred life, years*	60	25	604	3880	68	21	22	34	300

*Based on 1975 production.

mining industry are therefore playing a major part in maintaining the standard of living of the people of the developed nations. We are also playing a growing part in improving the lifestyle of the people of the developing nations — something that is perhaps being overlooked by South Africa's critics both on this continent and overseas.

The well-being of South Africa itself is greatly influenced by the contribution of its minerals as the following statistics show. In 1976 mining contributed 12,5 per cent of the gross domestic product, while minerals comprised about two-thirds of the country's total exports. In 1976 the quoted value of mineral sales amounted to 4469 million rands, an increase of 8,1 per cent over the previous year. The value of mineral sales for the first quarter of 1977 amounted to 1255 million rands, which, if this rate is maintained, indicates that the total sales for 1977 will exceed 5000 million rands for the first time. While gold is still by far the most important mineral produced, constituting 53 per cent of the mineral revenue during 1976, the value of other minerals is rising sharply.

Free enterprise and private ownership of mines are officially encouraged in South Africa. Consequently, our mining industry is one of the most progressive and viable in the world. The State does, however, participate in the industry through lease arrangements and royalties, and through the Industrial Development Corporation of South Africa. In addition, it has entered into the large-scale exploitation and processing of ferrous metals, coal, and phosphate rock. The Department of Mines administers the legislation governing mineral exploration, development, and exploitation, special regulations being applicable to radioactive and prescribed minerals, precious stones, and natural oil and gas. The State also operates, and is in the process of expanding, synthetic oil-from-coal plants. All utilities, including the expanding rail transportation and harbour facilities and the country-wide electrical generating capacity, are owned and operated by public authorities. Mineral commodities are transported mainly by rail to domestic consumers or are exported through the major ore-handling ports of Port Elizabeth and Durban. However, a portion of our mineral production is still exported through Maputo. The new ports of Richards Bay on the east coast and Saldanha Bay on the west coast have been constructed principally for the export of iron, manganese, chromium, and coal. It is expected that these ports will in time enable South Africa to treble the volume of her total mineral exports.

Strategic Minerals

The universal realization of the finite nature of economically exploitable mineral reserves and resources was emphasized by the 1973 energy crisis, as was the powerful weapon that the mineral-endowed countries could wield. The consequence has been a revaluation of existing reserve and resource inventories, especially in

TABLE I (continued)

Lead	Manganese	Nickel	Phosphate	P.G. metals	Silver	Tin	Uranium (Free World)	Vanadium (contained)	Vermiculite	Zinc
3605t	5,863mt	20 754t	11,6261mt	83 979kg	0,95923mkg	4 534t	2,8095mkg	14 968t	207 529t	68 917t
3,351mt	22,498mt	745 252t	105,8685mt	180 431kg	8,80mkg	217 434t	22,362mkg	20 411t	509 838t	5,7152mt
0,11%	18,10%	2,78%	10,98%	46,50%	1,09%	1,60%	12,56%	41,20%	37,4%	1,20%
4,7%	2,6%	n.a.	—	n.a.	9,4%	4,7%	—	—	—	n.a.
8,8%	4,5%	n.a.	0,6%	n.a.	8,1%	4,8%	—	—	—	n.a.
18,8%	7,6%	n.a.	1,4%	n.a.	8,7%	11,6%	5,9%	—	5,5%	n.a.
17,5%	9,0%	n.a.	2,8%	n.a.	12,9%	15,7%	31,2%	2,2%	12,1%	n.a.
1,2%	14,0%	n.a.	6,2%	n.a.	18,9%	16,3%	23,9%	11,7%	20,1%	n.a.
0,1%	20,2%	n.a.	20,1%	n.a.	19,6%	18,5%	19,7%	18,8%	25,3%	n.a.
48,9%	42,1%	n.a.	68,9%	n.a.	22,4%	28,4%	19,3%	67,3%	37,0%	n.a.
n.a.	—18,37%	+0,66%	—	+3,09%	—0,38%	—3,84%	—	—	—	n.a.
n.a.	+56,50%	+12,84%	+10,02%	+12,66%	—2,05%	+7,49%	—	—	—	n.a.
n.a.	—5,08%	+23,15%	+25,72%	+28,06%	+5,88%	+19,09%	—	—	—	n.a.
n.a.	+15,34%	n.a.	+13,54%	n.a.	+9,01%	+1,37%	+14,98%	—	+4,75%	n.a.
n.a.	+5,81%	n.a.	+9,01%	+26,82%	+7,16%	+2,35%	—13,66%	+24,99%	+13,10%	n.a.
n.a.	+11,01%	n.a.	+26,31%	+16,40%	+57,27%	+3,93%	+7,26%	+13,78%	+1,62%	n.a.
+383,64%	+17,79%	+15,18%	+69,83%	+14,72%	—1,53%	+10,13%	—5,36%	+52,12%	+11,30%	527,47%
2	5	6	3	8	17	12	19	4	11	1
(+97,70%)							(1956–75)	(1961–75)	(1956–75)	
n.a.	+11,86%	+12,96%	25,74%	+16,96%	+10,76%	+5,79%	+0,80%	+30,30%	+7,69%	n.a.
—	8	7	3	4	9	14	18	1	15	—
+2,50%	+4,00%	+5,55%	+8,20%	+14,52%	+1,59%	+0,92%	—3,10%	+6,49%	+4,95%	+4,05%
R28,84	n.a.	n.a.	R19,34	R2028,23e	R104,38	R3662,05	n.a.	n.a.	R30,43	R139,18
R320,43	R42,95	R3122,74	R13,35	R2863,14e	R95,59	R5132,87	R32,64	R4094,43	R31,15	R580,00
+7,87%	+20,89%	+10,21%	+33,14%	+10,50%	+25,25%	+18,36%	+35,85%	+7,76%	+5,48%	+22,87%
+5,08%	+4,50%	+7,36%	+11,86%	+6,88%	+13,63%	+10,34%	+15,50%	+8,21%	+7,25%	+8,96%
R0,1040	R251,8373	R64,8093	R155,2084	R237,5119	R10,0125	R16,6037	R91,7021	R61,2854	R6,3151	R9,5919
20	3	10	6	4	17	15	9	11	19	18
0,002%	6,09%	1,57%	3,75%	5,74%	0,24%	0,40%	2,22%	1,48%	0,15%	0,23%
20,0%	5,1%	2,8%	10,0%	2,8%	n.a.	1,8%	15,5%	14,9%	n.a.	5,2%
20,0%	5,1%	2,8%	10,0%	2,8%	n.a.	1,0%	6,9%	4,0%	n.a.	5,3%
			(P_2O_5)				(U_3O_8)			
—	—	—		—	1,5mkg	n.a.	238 600t	3,249mt	80mt	
5,61mt	3000mt	20,8mt	1050mt	62,89mkg	6,633mkg	n.a.	—	10,304mt	—	10,933mt
0,724mt	3000mt	—			1,000mkg	n.a.	351 553t		Large(?)	1,700mt
—	2000mt	Large	Large(?)	Large	—	n.a.	—	Very large	—	—
145,149mt	5380mt	53,977mt	16066mt	17,47mkg	189,731mkg	10,3638mt	1,1793mt	34,623mt	172,365mt	136mt
Large	17700mt	63,503mt	Large	55,99mkg	Large	27,48mt	—	Large	—	5085mt
3,86%	37,1%	42,24%	6,5%	71,2%	4,28%	—	20,23%	9,38%	39,5%	8,03%
1757(?)	512	1000	90	714	95	—	85	713	385	183
43	239	72	152	97	22	38	53	1696	338	24

countries such as South Africa whose economies are highly dependent on the performance of their mineral industries. Without this inventory appraisal, the forward planning of all aspects of mineral economy, including geological, metallurgical, and mining research programmes, would not be possible.

The recent revival of interest in the Malthusian theory by many organizations, such as the Club of Rome, reflects a growing awareness of the importance of natural resources in supporting the continued well-being of the world's population. According to some opinions, the basic economic problem is not merely the growth rate of world population (1,9 per cent from 1969 to 1975, exceeding four thousand million in 1975) but also the rapid increase in the proportion of people comprising the affluent middle class (12,5 per cent in 1970, increasing by 4,7 per cent per annum). These people utilize up to five times the quantity of materials and environment as the poorer population. The real issue thus becomes not how many people can live, but how many people can live well. Opinion is strongly divided about the future of the world's mineral resources: some authorities paint a gloomy picture of non-renewable and finite resources, but others, realizing that mineral reserves are dynamic, place a high reliance on technology to find the means of converting resources of ever-decreasing grade into economically exploitable reserves.

It may be appropriate at this stage to refer to the statistics indicating the estimated resources of minerals that are currently considered to be of strategic importance. For this purpose, twenty-one metal and mineral commodities that are important to the South African and world economies have been chosen, the details being given in Table I.

From Table I, it will be noted that the inferred periods

TABLE II

INFERRED PERIODS OF AVAILABILITY BASED ON 1975 PRODUCTION

Metal	Estimated world inferred life Years	Annual growth in world production 1961–1975 %
Antimony	60	—2,25
Asbestos	25	+4,58
Chromium	604	+3,73
Coal	3880	+3,92
Copper	68	+3,42
Diamonds	21	+1,88
Fluorspar	22	+5,90
Gold	34	—1,30
Iron	300	+4,27
Lead	43	+2,50
Manganese	239	+4,00
Nickel	72	+5,55
Phosphate	152	+8,20
Platinum-group metals	97	+14,52
Silver	22	+1,59
Tin	38	+0,92
Uranium	53	—3,10
Vanadium	1696	+6,49
Vermiculite	338	+4,95
Zinc	24	+4,05
Petroleum	37	

of availability based on 1975 production rates are as shown in Table II.

It is appreciated that the variables present in a forecast of this nature are such that the results obtained may be misleading. Variables that are considered to be of significance in the determination of future exploitable mineral reserves can be classified into two principal categories: those in which the human element has no influence, and those in which the human element can and does have some effect.

By using our skills and ingenuity, we, the members of the engineering profession, can materially assist in extending the actual life of the estimated reserves of many of the world's strategic minerals.

Motivation

The average individual requires strong motivation to be persuaded to deviate from a set pattern or routine. The message conveyed by the statistics in Table I is that the given reserves of strategic minerals are subject to a finite period of availability. I believe that this fact in itself is a motivating force strong enough to encourage all concerned with the exploration, exploitation, and utilization of minerals to act positively. But to provide direction to a course of action, it is generally necessary to find a body of people sufficiently dedicated to assume a role of leadership. Because of the extreme importance of the problem of continued mineral supply, those individuals, organizations, or statutory bodies capable of some or other form of positive action must be motivated to start working now.

Whilst admitting that no list of those who should share the responsibility can ever be complete, I shall attempt to list a number of potential contributors. In so doing, I must point out that many of the individuals or organizations mentioned have already made significant contributions and have extensive plans for the future to ensure continuity in the supply of strategic minerals.

For our immediate purpose, research facilities controlled by universities, statutory bodies, and private enterprise can be listed together as follows:

Council for Scientific and Industrial Research
Department of Agricultural Technical Services
Department of Commerce and Industries
Department of Mines
Department of Planning and the Environment
Department of Transport
Department of Water Affairs
Exploration research facilities of industry
Fuel Research Institute of South Africa
Geological Survey
Metallurgical process research facilities of industries
Mining research facilities of industry
National Institute for Metallurgy
Research and development departments of geology faculties at all the universities
Research and development departments of metallurgical faculties at all the universities
Research and development departments of chemical engineering faculties at all the universities
Research and development departments of mining engineering faculties at all the universities
Research and development departments of general engineering faculties at all the universities.

In many fields a high degree of co-operation is possible and, indeed, perceptible. Understandably, however, some fields of operation cannot be undertaken co-operatively because of the need to maintain competition in a capitalist system. There are, nevertheless, ways and means of overcoming problems of this nature; for example, the investigation by a State-appointed commission into the coal reserves of the country. From this has emerged the now well-respected *Report of the Petrick Commission*.

A further and final thought on motivation is whether sufficient fundamental research is being undertaken both in South Africa and in the rest of the world to ensure continuity of mineral supplies. Are we not, in some instances, relying too heavily on private enterprise, which is, of necessity, largely motivated by the economics of a project?

Exploration

If we are to maintain the continued availability of strategic minerals, research into mineral exploration becomes a primary need. For this, we are dependent on the skills of geologists, geophysicists, mineralogists, and metallurgists.

The exploration geologist has, until fairly recently, been able to discover mineral deposits by using simple methods and equipment. But the geological mapping of the mineral-rich countries is almost complete, and the possible occurrence of outcropping ore-bodies has been largely explored. This has led to the development of the sophisticated facilities, skills, and technology currently utilized in present-day exploration. The skills of both exploration and mine geologists are constantly being augmented by a powerful research geological team, who aim at refining conceptual models of ore localization applicable to unknown areas or extensions of ore-bodies. These teams also control research into cheaper and more efficient exploration aids to define the existence of an ore-body. Further, research geologists are also constantly concerned with the re-appraisal of mineralized areas, ore resources, and reserves with a view to future mineral needs.

The geological map remains the basis of all exploration, whether the exploration is used in solving the controls of mineralization in a regional sense or in solving the problem of the behaviour of extensions to known ore-bodies on a localized scale. Aerial photography is a fundamental aid to regional mapping. The recent introduction of photograph-based remote-sensing techniques such as false-colour satellite imagery, which provides a magnificent global geological and structural overview of large areas, is aiding the mapping of areas still not covered on the ground. Constant improvement of the resolution and the range of multispectral bands is achieved with successive satellites. But all geochemical, geophysical, or remote-sensing results should either benefit geological mapping or should be interpreted in terms of a good geological map, which must be regarded as the foundation of all further studies.

Airborne magnetic, electrical, and radiometric geophysical surveys have long constituted important aids to the geologists involved in regional mineral searches, and continue to be the basis of many global programmes. New airborne methods that have proved useful are side-looking radar imagery (SLAR), used where there is persistent tropical cloud cover and thick vegetation, and infrared line-scanner imagery, used as a discriminatory locater of outcrop and structure under thin overburden cover. Infant remote-sensing methods under research and development involve the use of ultraviolet light and laser beams, or dust and gas sampling as an airborne geochemical technique.

The principal aim of all indirect regional multidisciplinary prospecting techniques is to assist and augment geological and structural understanding, resulting in the delimitation of favourable mineralized terrains for closer local exploration.

Local prospecting methods, although still capable of covering large areas, are principally aimed at localizing and selecting mineralized targets. Again, detailed geological mapping is fundamental to an understanding and interpretation of the aids. There are a host of geophysical techniques, such as gravity, magnetic, electrical, seismic, radiometric, and mercury 'sniffer', that are applicable to Southern Africa, although these are more widely used in colder latitudes — Canada, for example, where extensive glacial debris covers fresh rock and ore material to shallow depths. More applicable to our tropical or arid climates are geochemical methods that test metal or mineral concentrations in stream sediments in regional searches, or in soils and rocks mostly in local surveys. Indispensible to geochemistry in any territory is the establishment of a centrally situated laboratory capable of handling and analysing vast volumes of samples rapidly and accurately. Owing to the environmental complexity and variability of the many data produced by geophysical and geochemical methods, computer simplification and interpretation of their geological meaning becomes imperative.

Biochemistry and geobotany are lesser-used methods, and, along with all the other aids, these are in the process of constant development. The final test of the vast multidisciplinary effort that makes up the modern exploration team remains primary exploratory drilling — and ultimately delineatory drilling, which finally establishes grade and continuity, converting the mineralization to ore and the resources to reserves. Drilling of any type is costly, so that the challenge facing the exploration or project geologist and his backup facilities is the formulation of a conceptual model of such sophistication as to guide drilling to maximum effect whilst keeping footage to a minimum.

Throughout any exploration programme, the constant availability of the sophisticated mineralogical and chemical facilities of a central laboratory is an absolute necessity. Here, again, there have been tremendous advances in the sophistication and accuracy of techniques and instrumentation. In the mineralogical field these include the X-ray diffractometer, the microvideomat, and the electron microprobe; and, in the chemical field, the X-ray fluorescence and emission spectrographs. At the stage when ore is actually located, mineralogical studies guiding extensive metallurgical bench-testing are undertaken to formulate the most economical and viable ore-dressing technique for application once a mine has been established.

Evaluation

Economics dictate the behaviour of individuals as well as of governments. The entrepreneur must therefore constantly assess the effect of economic considerations on the project with which he is associated.

The importance of a realistic economic assessment to indicate the viability of a mineral deposit cannot be over-emphasized. Methods hitherto used in the evaluation of complex ore-bodies are no longer sufficiently reliable for an investment of the magnitude now required for the establishment of a large-scale mining operation. It became necessary, therefore, to develop new and more sophisticated techniques of ore evaluation. I propose dealing only briefly with the new techniques developed over the past decade or so.

Ore valuation depends upon the data obtained from samples for its accuracy. Generally, the object of an ore-reserve evaluation is to make an objective estimate—on the basis of sample statistics—as to what to expect from an ore-body. The standard of efficiency of physical sampling, and the intelligent correlation and calculation of the resulting statistics, are therefore of paramount importance.

Unfortunately, sampling techniques have not advanced to the same extent as have other branches of the mining industry. The evaluation of ore-bodies cannot thus be computed with the accuracy that one would expect. Nevertheless, it is encouraging to note that, during the last decade, an awareness of the necessity for improved methods of valuation has become evident, and positive action is at last being taken. For example, photogrammetry has been used in conjunction with a computer with satisfactory results. The detection of gold in rock faces by means of chromatographic paint is another method that has possibilities, but more research is necessary before the required degree of accuracy can be obtained.

Broken-ore sampling has been used for approximately ten years on some mines with good results. There is no doubt that this method of valuation has certain advantages over conventional methods, but perhaps its greatest defect is its inability to indicate the value of ore *in situ*. With the advent of mechanization on the gold mines, it is contended that a prior knowledge of the exact value of a face, as well as the distribution pattern of the gold particles within that face, is essential.

The chipping of samples from stope and development faces is so vulnerable to bias and inaccuracies that it is remarkable that a better method of evaluating an ore deposit has not yet been perfected. However, the Chamber of Mines Research Organisation is actively engaged on a number of projects. These have already produced encouraging results and promise to revolutionize the whole concept of mine valuation and ore-reserve calculations.

Computers have been used for the storage and calculation of data on ore valuation for some years now, and mathematical and statistical theories have been employed in an attempt to arrive at a 'better estimate of parameters'. Nevertheless, no amount of mathematical manipulation of statistics can be expected to improve the inaccurate data being obtained from our present sampling techniques. The advances that are being made in the metallurgical and mining fields demand an accurate assessment of the mineral content of ore *in situ*. It is hoped that the gamma-ray fluorescence detector, which is currently undergoing extensive tests, will produce this higher degree of accuracy.

Coupled with research into the development of the gamma-ray detector are two other projects that, it is felt, will have a far-reaching effect on the computation and evaluation of gold ore reserves. Studies of the distribution and size of gold and generically related minerals, as well as of carbonaceous materials, in the Witwatersrand reefs are projects indicating that there is a wealth of information waiting to be gleaned from these sources. Correct interpretation of this information will provide an accurate prediction of the behaviour patterns of pay-shoots and trends.

Exploitation

The advances made by the mining engineer over the past decade or two in the exploitation of ore-bodies have been phenomenal. The degree of mechanization in certain sectors of the mining industry, even in South Africa, has been such that the emphasis has moved from a labour-intensive to a capital-intensive industry. Notable examples are the coal-mining industry, the base-metals divisions (where massive ore-bodies are exploited), and the diamond-mining industry (where similarly large ore-bodies are exploited).

Progress towards a less labour-intensive industry in the gold and platinum mines, although less spectacular, has not been insignificant. Over the past three years, the mines involved have been able to maintain production despite a reduction of approximately 10 per cent in the labour force.

The efforts of the mining industry, through the Chamber of Mines of South Africa and augmented by the industrial engineering divisions of the respective mining houses, are continuing unabated to evolve acceptable methods to mechanize the deep-seated, narrow, tabular ore-bodies that occur in most of our mines. Engineering professions such as those involving mechanical, electrical, civil, ventilation, and rock mechanics engineering have contributed substantially towards our ability to mine at depths under physical conditions that would have been intolerable a few decades ago.

I referred earlier to the phenomenal advances recorded, but let me now sound a warning. There is no justification for complacency. The challenge facing us is greater than ever before. The demand for minerals is increasing, replacement mineral fields are being discovered in ever more-remote parts of the country, inflationary trends are causing working costs to escalate, and there is an ever-diminishing return on investment. The apparently unstable economic atmosphere in our main consumer countries militates against meaningful forecasting. This is an extremely important aspect of the skills required to formulate strategies. Although generalities ought to be avoided, it needs stressing that a minimum of two years is required for the commissioning of a new project if it occurs on or near surface. This could rise to seven years in the case of a deep-seated deposit. Who in this volatile atmosphere can predict the market situation seven years in advance?

What then, you may ask, is expected of the mining engineer? Obviously, he should at least be able to maintain present efficiencies. This, you may say, is not good enough; a budget for continuing improvements is needed. I agree with you. Unless both we and our successors can continue to show improvement on our performances, the maintenance of a reasonable standard of living for all mankind will eventually be impossible.

The question now arises whether the ideal of ever-increasing efficiency is attainable. The answer to this must be *yes* if the universities, colleges, research and development institutes — in fact, if most of the bodies or organizations quoted earlier — continue to co-operate. It needs to be emphasized that research and development are required, not only to improve accepted techniques, but also to develop techniques that will enable us to deal with hitherto unknown problems. We therefore depend and rely on our universities and colleges of advanced technical education to provide the industry with men and women able to improve on present achievements. Industry, on the other hand, should be prepared to increase its contribution towards research and development.

The shortage of suitably educated engineers of all types was adequately stressed by my predecessors during their induction addresses. It is gratifying to note that the intake of the relevant faculties at the universities concerned has improved since Professor Plewman's address from this rostrum. If this continues, the required numbers will be available in due course. However, the industry has been so critically short of academically trained mining engineers that the brain power that should have been available for research projects was fully utilized in the solving of current production problems.

The contribution made by the colleges of advanced technical education in providing diplomate engineers to augment and, in many cases, to substitute for graduate engineers is to be commended. Recognition is also due to the training institutions of the Chamber of Mines, as well as to the individual mining houses or mines for providing the students and rendering the motivation necessary for such part-time studies. I believe this to be an important source of future engineers, be they graduate or diplomate. The exemptions allowed to degree or diploma holders sitting for the various government certificates of competency are also an important incentive.

Extractive Metallurgy

I have dealt with the production of ore at some length, emphasizing the need to produce the cheapest possible ore with the highest possible metal content. The metallurgist is faced with a task that is becoming more difficult, for many of the ore-bodies available for exploitation have complex metallurgical characteristics. Clearly, it is his task to produce valuable constituents as efficiently as possible. In other words, the proportion of the mineral content that finds its way into tailings dams should be the absolute minimum.

Tribute is due to the metallurgical engineer for the advances recorded in recent times. The viability of base-mineral deposits in particular is largely dependent on the metallurgist's successfully separating, not only the minerals from the gangue, but also the individual minerals from one another in the enriched concentrate that remains after the removal of the gangue materials.

Much research has gone into the improvement of various processes, but the field for further applied, as well as fundamental, research is still vast. Consider, for example, the traditional metallurgical processes for the extraction of gold. Up to now an extraction percentage of approximately 98 per cent was accepted, but the revival of the gold price in recent years has provided the necessary incentive to improve this extraction percentage.

At a gold price of 140 U.S. dollars per ounce, an improvement of half a per cent in extraction efficiency could result in an additional revenue of 14 million rands to the gold-mining industry. An even greater potential exists in the platinum industry, where the gap between the actual and theoretical extraction percentages is much more significant. This, too, is receiving the attention of extractive metallurgists.

South Africa, with its unique variety of mineral wealth, is believed to have still further hidden potential, and even this would be considerably enhanced if the metallurgist could successfully separate the minerals from certain highly complex ores. I am confident that this will be achieved in due course.

One of the significant developments relating to mineral processing is the adoption of run-of-mine milling. The elimination of crushing plants and the consequent simplification of the overall process have lowered operating and capital costs appreciably.

The chemistry of the gold-extraction process possibly precludes major innovations, and yet the effort devoted to the refinement of unit operations and process control should not go unnoticed. Particular attention is drawn to the application of stellar filters to precipitation, continuous calciners in smelt-houses, the Kegold electrode for cyanide control, flat-bottomed leaching vessels to replace Browns tanks, and the horizontal-belt filter. This lastnamed filter is most notable for capital savings and a remarkable improvement in efficiency. Solution recoveries of more than 99,7 per cent are currently being obtained, and the filter can be applied to uranium extraction even more advantageously than to gold extraction in that two-stage filtration can be accomplished in one step.

A further outstanding development in uranium processing is the process involving continuous ion-exchange, known as the CIX process. This process permits the recovery of uranium from unclarified solutions, a much lower resin inventory, and the return of barren acid solution to the dissolution stage thereby effecting reagent economy. The principle advantage of CIX, however, lies in the possibility of treating ores of lower and lower grades. The development of instrumentation for the control of reagents, such as the controller for oxidation potential in the uranium-leaching step, is also worthy of note.

In the platinum field, some success has been obtained in the use of computer-based direct digital control, particularly on two-stage milling and flotation circuits.

The *piece de resistance* in the development of platinum technology is the application of Davcra-type unit flotation cells in the mill circuit, allowing the recovery of the platinum-group metals in the form of finely divided mineral particles. The first recorded description of gold recovery by the placing of sheep-skins in streams led to the legend of Jason and the golden fleece. Yet this process, modified only by the use of corduroy blankets and controlled flow, was still used for the recovery of the platinum-group minerals until very recently. Every previous attempt to replace corduroy recovery by more-modern equipment proved unsuccessful. The Davcra flotation process has, however, proved to be 10 per cent more efficient than corduroy recovery, and has at last brought this orphan operation into the modern automated era.

Productivity

The Club of Rome, to which I referred earlier, advocates an immediate reduction of 75 per cent in the rate of usage of natural resources and a 20 per cent decrease in the production of food, coupled with a 30 per cent reduction in the birth rate and a 40 per cent reduction in the rate of generation of capital investment. The Club has pointed out that efforts made now to feed, clothe, and accommodate a larger population may only ensure even greater disaster later. The appalling choice with which we are faced is whether it is better to let tens of millions starve to death now or hundreds of millions later on.

It seems improbable that any of these recommendations will be carried out. Being a believer in survival and driven by the instinct of self-preservation, I would not like to be among those who starve to death now, nor do I advocate an immediate reduction of 75 per cent in the rate of usage of natural resources or a significant reduction in capital investment. On the contrary, the expected rise in world population and the striving for a higher standard of living will continue unabated, and for this reason I believe it is the task of the mining engineer to at least maintain the current level of mineral production. Preferably, he should be able to increase this production to satisfy the increasing world demand. This task can be achieved by continuing to produce from existing mines, by exploring and opening up new mines, and, last but not least, by substituting alternative minerals or materials for those minerals that are becoming scarce.

All these alternatives are feasible, but a considerable amount of capital is required to finance new technologies, new mines, and research into substitutes. Hence, the

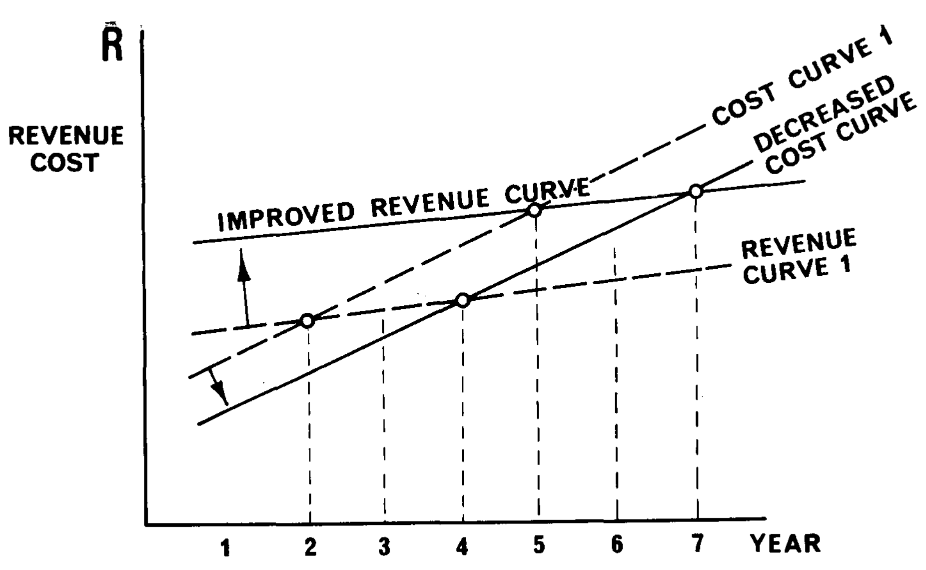

Fig. 1 — Total productivity model.

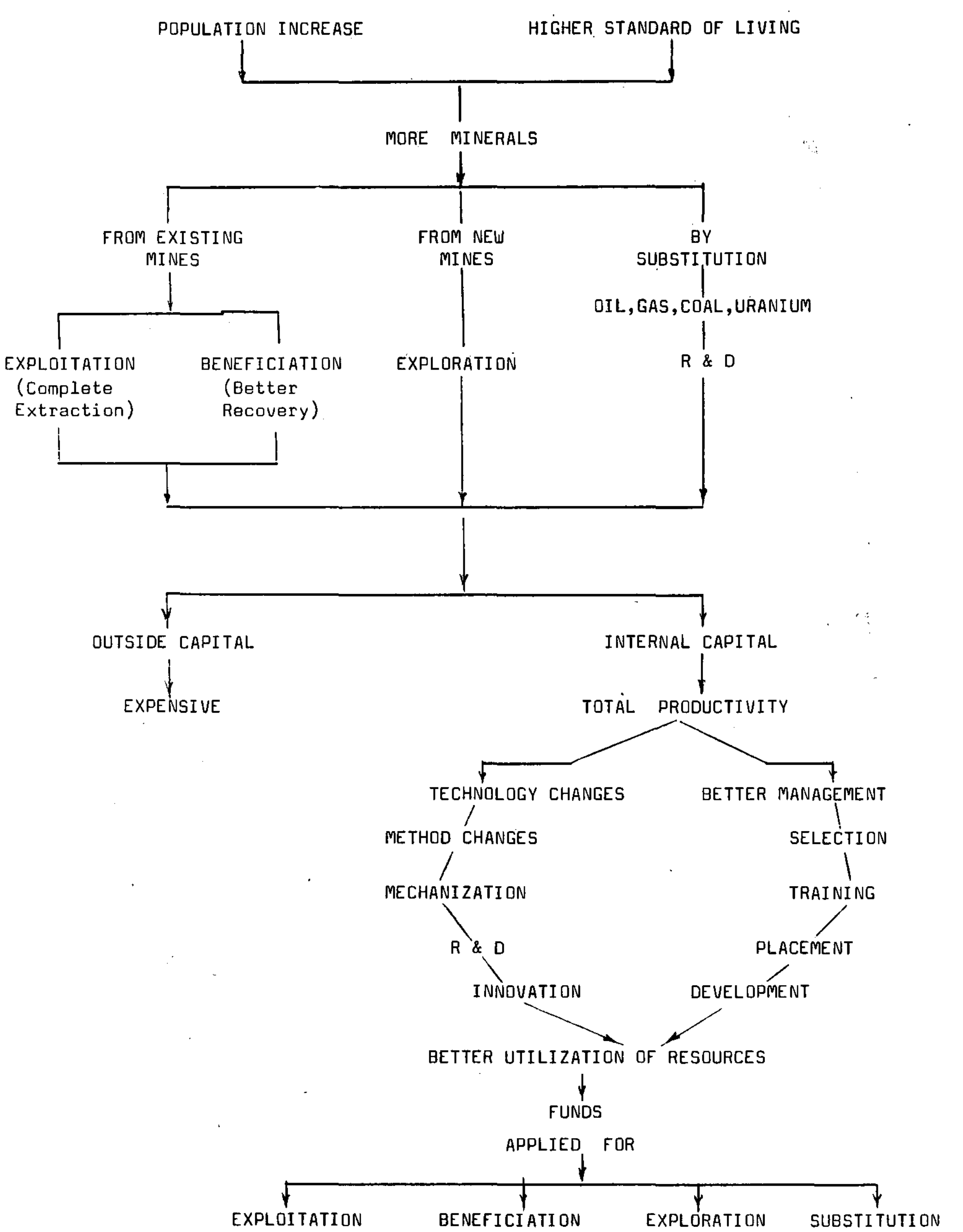

Fig. 2 — Minerals for survival.

TABLE III

STATISTICS FOR COAL MINES IN THE TRANSVAAL AND ORANGE FREE STATE

Year	Annual amount sold t × 10³	Total output t	Output per employee t	Output per employee Index
1960	31 652	38 606	820	100
1961	32 277	40 103	805	98
1962	33 568	40 265	834	102
1963	35 287	40 661	868	106
1964	37 068	41 481	894	109
1965	39 487	42 827	922	112
1966	38 157	43 267	882	108
1967	39 266	40 254	975	119
1968	41 439	40 140	1038	126
1969	41 926	39 264	1068	130
1970	39 822	38 816	1026	125
1971	43 278	40 055	1080	132
1972	43 941	40 224	1092	133
1973	47 878	38 973	1228	150
1974	50 811	39 477	1287	157
1975	54 378	41 779	1302	159
1976	58 726	43 901	1338	163

critical question has always been and remains: From where are the funds to be derived?

Today, externally generated capital is expensive and difficult to obtain. A possible solution to the problem would be the generation of capital from within a company through improved productivity. By productivity, I mean total productivity, which I define as a steady increase in the gap between revenue and cost. The total productivity concept is directed not only towards the reduction of costs but also incorporates the aspect of increasing revenue, as shown in Fig. 1. As can be seen on the arbitrary graphs, without an improvement in productivity, the mining company would make a loss after Year 2, while a lowering of costs would lead to a break-even point in Year 4; but a combined effort in lowering costs and increasing revenue, i.e. a total productivity effort, would ensure profits until Year 7.

Economic models such as that shown in Fig. 1 are an excellent means of showing the best solution to our problem. Unfortunately, they omit the substance of the small print on the back page of the contract, i.e., they omit to show how to solve the problem or how to improve productivity. People much wiser than myself have pondered over this question, and solutions have been recommended by men like Adam Smith, Keynes, Marshall, Galbraith, and Drucker, to mention but a few. These famous men disagree in many ways, but they all concur in principle that increased productivity is brought about by improved technology and better management.

Here, mechanization will probably contribute most in the foreseeable future, though no major break-through has as yet been made. Technology in milling has been advanced by run-of-mine milling, by sophisticated instrumentation, by computerization and automation of circuits, and by the introduction of pressure leaching, better and larger plants, etc. In mining, our shafts and haulages have been mechanized and partly automated, while our stopes have been partially mechanized with scrapers, L.H.D. machines, and self-advancing hydraulic supports. Much has been achieved, but much more has still to be done. Here I should mention the research and development effort of many mining groups in raise boring, tunnel boring, reef and boxhole boring. This effort has led to viable methods of ore pass and flat development, utilizing drill jumbos, diesel and electrical loaders, bunker trains, and roof bolting machines. The research work undertaken by the Chamber of Mines on behalf of the industry pushes vigorously in the direction of stope mechanization with extensive experimentation in drilling, blasting, cleaning, and supporting stope faces.

The second requirement for increased productivity is better management, and much has been done by the mining industry to select, train, place, and develop managers. I refer to in-house courses held by the various mining groups and the extensive use being made of both local and international management courses.

Improved technology and management will ultimately lead to better utilization of all resources (see Fig. 2), which in turn will provide the capital to maintain or increase the production of strategic minerals necessary for the survival of mankind. Some statistics relating to the production from coal mines that are members of the Chamber of Mines of South Africa are given in Table III.

Agricultural and Ecological Considerations

It can reasonably be assumed that arable land is fully utilized in developed countries and possibly under-utilized in underdeveloped countries. The population growth is such that better utilization of all the world's food-producing facilities has become imperative. The contribution of the mining and metallurgical engineer in achieving this is not insignificant. It is our responsibility to produce minerals as a base ingredient for fertilizers, without which the agronomist faces the formidable if not impossible task of improving yields from the ever-diminishing land available for food production.

In South Africa, agriculture currently has access to 75 per cent of the country's water resources. This could be reduced to 40 per cent in twenty years. Will we be able to feed a population of perhaps 45 million in twenty years' time?

To be realistic, I must point out that the mining engineer in his efforts to provide the world's users with essential minerals is becoming more and more destructive. Pollution caused by mining activities requires more attention. Disruption of ecological balances by open-cast mining methods and tailings dumps, although of a temporary nature, is causing concern the world over, and legislation to combat this is becoming more stringent and consequently less conducive to the efforts of the mining engineer to control his unit costs.

It is, however, wise to remember that nature itself is a notorious polluter through earthquakes, forest fires, tornadoes, tidal waves, dust storms, droughts, floods, volcanoes, and numerous other phenomena. Mining operations, including smelting and refining, are fortunately still possible without environmental damage on this awesome scale. Human presence inevitably involves some environmental disturbance, and mining forms only a minor part of that disturbance. Roads, cities, factories, and communications take up far more land from nature than mining ever does.

Economics

Survival can also mean economic independence. The extent to which South Africa is economically independent is largely attributable to the strength of its mining industry. The contribution made by this industry is illustrated by the following statistics.

	$R \times 10^{12}$
Value of mineral sales in 1966	1 263
Value of mineral sales in 1976	4 469
Value of mineral exports in 1966	1 106
Value of mineral exports in 1976	3 655

During the fiscal year 1975–1976, gold-mining taxation amounted to 664 million rands, and the mining taxation amounted to 779 million rands, which represents 18,0 per cent of the total inland revenue. During 1975, the stores consumed by the mines amounted to 1381,7 million rands, and the mines used 30,1 per cent of the electricity generated by Escom. At the end of 1976 the mining industry provided employment for 657 592 people.

Conclusion

I shall conclude by summarizing the message that I have endeavoured to convey.

Minerals are necessary to the survival of mankind. The known reserves are finite, and the continued supply of some strategic minerals could, within the foreseeable future, become critical. We must rely on the ingenuity of mankind to find the necessary substitutes or replacements for potentially exhaustible ore reserves.

It is the duty of all of us associated with the mining industry to use our expertise not only to ensure our own future and that of our children but also to improve, or at least maintain, the standard of living of mankind as a whole. I am appealing to all of you not directly associated with the mining industry to use your influence to assist us in our endeavours to attract to the industry the brain power necessary for the achievement of our objectives.

Reliance is being placed on the universities, colleges of advanced technical education, high schools, mine training courses, and outside recruiting to provide us with the engineers and technicians who will be employed in the exploration, exploitation, beneficiation, and marketing of our mineral products.

South Africa joined the array of mineral-producing countries about a hundred years ago, and has since developed its resources to the point where it can justifiably claim the respect of friend and foe alike. Mining has long been the mainstay of the economy of this country. It has provided employment, either directly or indirectly, to a large percentage of the population and will, I believe, continue to do so for many years to come.

It has been said that the good Lord gave South Africa the most complex racial situation in the world, but He compensated by also giving it some of the world's richest mineral resources. It is our duty to develop these for mankind.

Environmental engineering

The National Committee on Environmental Engineering of The Institution of Engineers, Australia, is continuing its regular series of conferences on important environmental topics. The next conference will be held in Sydney in July 1978.

The theme of the conference is 'Environmental Enquiry'. It aims at an overall examination and evaluation of such enquiries and will seek to look at their objectives; the way in which they have been or might be conducted; their requirements for background data and investigation; their cost and consequences; and their role in planning and decision making. It is hoped that a wide range of contributions will be received from the engineering, scientific, economic, legal, political, industrial, and conservation fields.

All correspondence relating to the Conference should be addressed to

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