Minerals from the dawn of mankind to the twenty-first century
Presidential Address

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SYNOPSIS

An account is given of the development of man's interest in the recovery and working of minerals from Palaeolithic times to the present. This is followed by a discussion of future production trends for the more important minerals, and of likely technological developments in the recovery of various minerals.

The crucial importance of energy minerals is stressed, as are several other factors of significance to a flourishing minerals industry: manpower, education, financial climate, industrial health and safety, and preservation of the environment.

SAMEVATTING

'n Weergawe van die mens se belangstelling deur die eeue in die herwinning en verwerking van minerale word gegee. Die toekomstige produksie neigings vir die meer belangrike minerale en die moontlike tegnologiese ontwikkelings in die herwinning van verskeie minerale word bespreek.

Die uiterse belangrikheid van minerale vir energie word beklemtoon. So ook ander faktore in 'n florende minerale industrie: mannekrag, opleiding, finansiële klimaat, industriële gesondheid en veiligheid en die behoud van die omgewing.

Introduction

Throughout history man has searched for metal supplies or ore deposits. This search has led to the widening of horizons, the discovery of new lands, and the expansion of trade, thought, art, and technology. At no time in history has it been more important for us to recognize our dependence on minerals and metals, and to acknowledge their influence on our progress and destiny. The future demands that we exercise the utmost ingenuity in solving problems of world-wide material shortages, expanding energy demands, and threats to global ecology as a result of uncontrolled pollution.

A mineral, according to its classical definition, does not include fossil fuels, petroleum, and natural gas. However, a review of the part played by minerals in man's evolution would be incomplete without the products of organic processes, and preference is given here to the miner's definition: a mineral is anything of economic value that can be extracted from the earth.

The Past — Leading to the Present

Very little is recorded, or has survived, of man's early quest for minerals. According to present knowledge, the Greek philosopher Theophrastus (*circa* 300 B.C.) was the first to write about minerals. Four hundred years later Pliny recorded the mineralogical thought of his time, and, during the 1300 years that followed, the few works that were published contained little information. It was not until the German physician Georgius Agricola published *De Re Metallica* in 1556 that a scientific account of mining and metallurgy in his and earlier times became available.

We have learnt more from observing the remains of mining activities, and the paintings and metals found in tombs and dwellings, than from writings. Modern archaeology, in which geologists, anthropologists, and engineers work as a co-ordinated team, has pushed back the historical horizon some 7000 years. Beyond that twilit zone, history becomes a sort of backward prophecy, based on relics and recently established dating methods.

Palaeolithic Age

It has been suggested that the story begins 250 000, perhaps 500 000, years ago when man emerged as a rare animal — a food gatherer and storer. For 98 per cent of his sojourn on this planet, man existed in the environment of this Palaeolithic or Old Stone Age gathering-economy.

From early Palaeolithic times, over a period that covered perhaps two glacial cycles, hand tools patiently shaped from stone followed a traditional form from the Cape of Good Hope to the Mediterranean, and from the Atlantic to India. It appears as though some contact was made between these widely scattered groups, and that ideas and technical expertise were shared.

Neolithic Age

The Neolithic or New Stone Age emerged 10 000 to 12 000 years ago as some societies, actively co-operating with nature, increased their supplies of food by cultivating plants and breeding domestic animals.

Flint was the first mineral to be used in art and industry, and the Neolithic miners were highly skilled specialists. In Egypt and most parts of Europe, Neolithic groups evolved elaborate shaft-sinking techniques and mined flints for the manufacture of hand tools and axes. These are found distributed over wide areas, and indicate the existence of a fairly elaborate trading system.

Bronze Age

Man emerged from the Stone Age when he mastered certain elementary metallurgical techniques. The ceonomic revolution that accompanied this event signified more inventions and discoveries than in any period of human history until the sixteenth century A.D. In

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the Bronze Age, man learnt how to work copper and bronze, how to harness animal motive power, how to use the wheel (both for vehicles and the making of pottery), and how to build in brick.

Copper metallurgy included four major discoveries: these concerned the malleability and fusibility of the metal, the reduction of copper from ores, and the alloying of copper with other metals. Although the malleability and fusibility advantages of native copper over stone did not take man very far, in order to make use of these qualities which included furnaces with draughts, crucibles, tongs, and moulds, were necessary.

The reduction of copper revealed the magical qualities of superior types of stone that had no resemblance to metallic copper nor its qualities. Yet, in the form of oxides, carbonates, silicates, and sulphides of copper, these stones yielded the metal when heated in the presence of charcoal. The discovery of this property unlocked adequate supplies of copper and at the same time provided a technology that could be applied to other ores.

The stage was set for the most important discovery. By adding antimony, arsenic, lead, or (best of all) tin to copper, the metallurgists found casting easier and the product more reliable.

These mining and metallurgical advances had far-reaching social and economic effects on man's progress. Metal workers practising their craft, which represented a new branch of applied science blended with magic and embodying the result of long experience, became the first specialists. For society to afford full-time workers withdrawn from food production, it became necessary for farmers to produce surplus supplies.

Furthermore, independent farming communities had to sacrifice economic self-sufficiency. As the fertile alluvial plains preferred by most Neolithic farmers did not possess ores of copper, it became necessary for the majority of farming communities to import copper or its ores in exchange for surplus foodstuffs.

Prospectors, miners, and smelters came to command a body of knowledge more abstruse than that commanded by the metal worker. Together with the metal worker, they formed a group of specialists relying on the foodstuffs produced by those who consumed their products.

The scientific implications of mining and extraction of metal from its ores were perhaps even more far-reaching than those of metal working. For production on a large-scale, complicated furnaces and other techniques had to be devised. Surface ores of copper could be directly reduced with charcoal, but the deeper ores, generally sulphides, had to be roasted in the open to oxidize them before they could be smelted. Other metals required different treatment. Lead, it was discovered, would volatilize and vanish with smoke when its ore was heated in the open furnace used for the smelting of copper.

The emergence of the crafts essential for satisfying man's new-found use of metals triggered an urban revolution and a completely new economic structure.

Surplus home-grown produce would in future not only serve as exchange for metals, but would also support the merchants and transport workers engaged in obtaining them, and the body of specialized craftsmen required to work the precious imports to best advantage. Soldiers would be needed to protect convoys and to back up the merchants by force, scribes to keep records of transactions, and state officials to reconcile conflicting interests.

By 3000 B.C. the great alluvial valleys of the Nile, Tigris, Euphrates, and Indus supported societies that differed from one another in detail, yet exhibited a notable common feature: dependence on relatively uncommon and expensive metals and alloys for industrial equipment. The new economies, by securing adequate supplies of metal, guaranteed a livelihood to the specialists who could work them.

Gold in Ancient Times

The history of all the civilizations in the Eastern Hemisphere is interwoven with the story of gold. Nations rose and flourished because of the wealth that gold inevitably attracted to them, imposing fleets sailed the seas seeking gold, and men suffered untold torture in its quest. It must have been one of the earliest metals to attract the attention of primitive man since it occurs free as virgin gold in nature, and is found in the rocks and gravels of many rivers.

One of the richest gold-producing areas in the ancient world, Egypt, exploited alluvial deposits by shallow surface mining. A vivid description of the toil and suffering of those compelled to work in the Egyptian mines is given by the historian Diodorus, and representations of quartz-crushing and gold-refining processes are reported to have been found in tombs dating to 2500 B.C.

The quest for gold took the Egyptians as far afield as Ophir, which is said to have been the area between the Zambezi and Limpopo where the Zimbabwe ruins are found. Further evidence of the importance to them of gold was their association of that metal with immortality: they encased the remains of their pharaohs in gold and left golden treasures to accompany them to the Afterlife.

Other Ancient Metals

Silver was probably used as money as early as gold, and there are references to it in the Old Testament. Silver appears to have been purified by a process of cupellation, but there is little evidence that the ancients knew how to separate gold from silver.

Tin seems to have been fairly common in olden times, as shown by several discoveries of tin in Egyptian tombs. The resemblance between the Sanscrit word *castira* and the Greek *cassiteros* has been used to support the hypothesis that the tin used by the Phoenicians was of Eastern origin, although Pliny stated that cassiteron was obtained from the Cassiterides in the Atlantic Ocean. This may refer to tin obtained from Cornwall, for certain islands north of Spain were often referred to as the *insulae cassiterides*.

It is not surprising that mercury should have been known in ancient or even prehistoric times. The first man to have built a fire on an outcrop of its ore would probably have found globules of quicksilver in the cold ashes of his fire. The red sulphide ore was mined and used as pigment vermilion before the beginning of written history, while Theophrastus (*circa* 300 B.C.) credited the Athenian Callias with the invention of methods to beneficiate cinnibar in 415 B.C. The metal reduced from its ore was used for amalgamation, for gilding, and for medicinal purposes.

Used in Egypt before 3000 B.C., lead, because of its softness, may have been regarded by prehistoric man as not comparable in value with the other metals that he knew. Not only was lead unfit for edged tools, but it must have seemed inferior in colour and lustre to native gold and copper. While the Egyptians had little use for lead, the Romans seized upon it at an early date and made effective use of its peculiar properties.

Iron Age

It was inevitable that man's improved technology would finally lead him to iron, which occurs far more abundantly in the earth's crust than any of the other ancient metals. The Iron Age started in about 1200 B.C., and iron remains the key metal even today.

It has been suggested that the first iron produced was the result of chance, when lumps of iron ore, in place of stone, were placed to form a crude hearth for the preparation of some feast and the fire was maintained long enough to effect reduction. Several fables describe how meteoric iron was sent from heaven as a gift of God to man, and meteoric iron may well have been the first iron used by primitive peoples. The discovery of an iron implement in the pyramid at Gizeh, which is probably 5000 years old, lends weight to this theory.

It is evident that the ages identified in terms of stone, copper, bronze, and iron, occurred at different times in various parts of the world. Owing to an abundance of iron and a lack of copper in India, for example, the Iron Age preceded the Bronze Age. The Egyptians and other civilizations possessed metals many centuries before the Aztecs and the Incas, whereas certain peoples in Africa are today still living in the Neolithic Age.

Coal

One of the most amazing things about coal is that its use was ever discovered at all. Yet its discovery was certainly one of the most important developments for mankind in the whole of history.

Stone Age man may have known the value of coal as fuel, as seems to be indicated by a flint axe that was discovered in an English coal mine some years ago. The axe was stuck into a coal seam that had once been exposed on the surface. Perhaps these men extracted coal from the earth using the only tools that they knew. Stone hammers, flint wedges, and crude wooden wheels have also been found among coal workings in other places; so it seems that primitive man did use coal.

The early civilizations of the East, particularly China, may have been the first to exploit coal. More than 2000 years ago the Greeks used it to provide the intense heat needed by their metal-workers, and the Romans mined coal in Britain during their occupation. However, it was not until the sixeenth century, when many of Britain's forests had been cut down and timber for fuel was becoming scarce, that coal came into its own.

Ancient Metallurgists

Until fairly recent times, when chemistry and physics started replacing the dark secrets of alchemy, metallurgy remained closely linked to the occult influence of magic and priestly secrets. Wayward angels on their earthly carousals were believed to divulge supernatural knowledge to favoured mortals. Such beliefs persisted until fairly recent times, as indicated by Swedenborg's reference to a reagent from crab's eyes in his *De Cupro*, published in about 1750. The recovery of metal during this period, which was based on empirically developed processes, was mainly confined to the long-known elements gold, silver, copper, iron, lead, tin, and mercury.

The theories of Aristotle relating to metals persisted right through to the seventeenth century. His belief that an element could be changed into another gave rise to one of the major preoccupations of alchemists for centuries, and the transmutation of metals dominated much of the scientific effort throughout the Middle Ages. While the alchemists never succeeded in making gold from base metals, the discovery of arsenic, antimony, and phosphorus can be attributed to their experiments. Even miners believed bismuth to be a form of lead that was in the process of being transmuted into silver. When they struck a vein of bismuth, they said sadly, 'Alas, we have come too soon'.

Important metals isolated in the eighteenth century included zinc, cobalt, nickel, and manganese, while investigations at the time foreshadowed the discovery of chromium, tungsten, chlorine, titanium, and beryllium.

The Industrial Revolution

The rapid transformation of economic life in England during the eighteenth and nineteenth centuries was stimulated by wars in Europe and enhanced prices for agricultural products, which gave impetus to the adoption of new methods. These included developments in the mining of ores that revealed ore sources at locations and depths previously unkown and inaccessible to man. The improved steam engine of James Watt in 1870 made it possible to remove mine water. In fact, it was the work on the steam pump in 1704 and its use in the removal of water from mines that assisted Watt in perfecting his invention.

The Industrial Revolution saw the emergence of the factory system, which was also based on a number of important mechanical inventions. Powder became available for blasting, and there was power for hoisting — both exciting developments in mining. The iron industry, on which the revolution was based, became more efficient as the result of using pit coal for its smelters and steam for its furnace blast.

Petroleum Era

One of the significant events in the history of mankind took place near Titusville, Pennsylvania, in 1859, when an oil well belonging to Colonel E. L. Drake proved successful, and history began to move unsuspectingly towards the petroleum era. This well, when drilled to a depth of 20 metres, yielded 2 tons of oil a day, which sold for 50 U.S. cents a gallon. The product was used as a medical cure-all and as fuel for lamps. The oil industry was assisted by the American Civil War, which had preempted the nation's supply of whale oil. A dozen petroleum-based fuels and thousands of petrochemicals emerged in the decades that followed.

Scientific Advance

Rapid scientific advance accompanied these events.

The discovery of a number of chemical elements led in 1867 to Mendeleev's classification of the elements according to periodic law, which enabled him to predict the properties of various undiscovered elements with surprising accuracy. Gradually, during the seventy years that followed, the empty spaces in the periodic tables were filled. By 1939 no element was known beyond uranium, and the table was thought to be complete. But this was not the end. The first transuranium element, neptunium, was discovered in 1940, while the atomic-bomb project provided the stimulus for the isolation of elements 94 to 104.

The economic evolution of society that had started in the grey light of Neolithic prehistory, based then as it is today on minerals, led mankind into modern times. The 104 elements of the periodic table, which are recovered from widely spaced — often remote — mineral deposits by dedicated people using a variety of complex mining and metallurgical techniques, form the foundation of modern society. They provide its heat, its light, its buildings and bridges, its transportation, and its communication. The standards of living achieved by industrial nations — which developing nations are striving to attain — are based on minerals, and societies could not continue in their present state without them.

The Future

The demand for minerals will continue to expand to satisfy the needs of the industrial powers as well as those of emerging Third World nations who lay claim to their share of affluence. What then are our responsibilities in the future?

As in the past, a diversity of interwoven circumstances and conditions will present themselves and influence our decisions. These circumstances will not only be confined to the technical aspects of mining and metallurgy, but will embrace a variety of economic, social, political, environmental, and educational aspects, which together will form the spectrum of our challenge.

Adequacy of World Mineral Supplies

Our obligation as providers of minerals to future generations depends on the availability of these minerals. It is comforting to be reminded that there is not a single mineral resource that has been exhausted and that, after centuries of exploitation, the earth still weighs the same and can still be regarded as a vast, barely scratched source of minerals.

Predictions of mineral resources vary from the Club of Rome's first study, which suggests that we are running out of everything, to the contradictory premise, aptly labelled the cornucopian view, of Brooks and Andrews that we can never run out of minerals as proved by calculations that each cubic kilometre of average crustal rock contains 200 million tons of aluminium, 100 million tons of iron, 100 000 tons of zinc, 250 000 tons of copper, and so on. Their view is that technological advances are more important to the future availability of minerals than the discovery of new deposits. A new discovery adds a new mine, but a new technology can open up deposits around the world. Although neither of these views can be regarded as practical, as with most oversimplified views, both contain elements of truth.

After an examination of the available evidence, it becomes clear that the world's discovered and prospective reserves of non-energy minerals are more than adequate to meet world consumption in the foreseeable future. However, in the case of oil and gas, availability beyond the year 2000 is too uncertain to count on, and shortages will occur long before that time. It is anybody's guess as to how long the recoverable coal will last. Technology for large-scale economic conversion of this energy source into gaseous and liquid forms must be pursued with far more urgency.

Potential uranium supplies (that would become available at acceptably higher prices) may be enough to make up for any deficit in energy minerals. Even if shortages do develop, nuclear generators can be fuelled by thorium, recycled uranium, or plutonium.

It is therefore predicted that future generations will not find the availability of energy an economic restraint. Sufficient evidence exists to support the claim that, even if world population doubles every 35 years and there is a substantial increased demand from developing nations, mineral supplies will keep pace with demand for the next 50 to 75 years, notwithstanding the critical situation in the supply of fossil fuels.

Distribution of Minerals

Much more important than the question of the worldwide scarcity of resources is the regional distribution of reserves. Of special significance to the industrialized Western countries, which become increasingly dependent on imported sources of mineral raw materials, is the uniqueness of the resources in the U.S.S.R. and Southern Africa. The variety of commodities and the large proportion of strategic minerals found in the confined areas of these two countries are impressive by any standards.

The origin of this maldistribution is well understood, and relates to the nucleus around which these two land masses and the Canadian Shield formed. The earlier onset of stable conditions than in other continental nuclei of the world made possible the deposition and preservation of mineralized erosional debris at a time when associated sedimentary processes of mineral concentration had not yet come into operation elsewhere. Sedimentary basins already stable 3000 million years ago in these areas accumulated mineral wealth. Crustal development continued for perhaps 500 million years (and still does so) in other parts of the world.

These evolutionary geological events placed Southern Africa in a unique position.

South Africa has more than a third of the world reserves of seven minerals: chromium, gold, vanadium, manganese, fluorspar, aluminium silicate, and the platinum-group metals. Of the same seven minerals, Southern Africa accounts for more than 40 per cent of Western reserves and, for four of them (vanadium, platinum, chromium, and manganese), more than three-quarters.

World reliance on South African mineral resources can be evaluated in the light of the following projections.

(1) South Africa's production of ferrochromium is expected to reach 40 per cent of present world needs when all its new capacity has been commissioned.

(2) By the turn of the century it is predicted that 20 million tons of the annual 80 million tons of manganese consumed in the world will be supplied by the Republic.
(3) The 1980s will see dramatic increases in ferromanganese exports.
(4) At full capacity, the Richards Bay venture will provide 46 per cent of the total world output of titania slag.
(5) In the year 2000, vanadium exports will represent 50 per cent of world requirements.
(6) The important role of gold exports (totalling about 700 tons per year sold on the free market) will continue to defuse the currency uncertainties that bedevil the economies of the West.

Escalation in international political strife has prompted nations to scrutinize the vulnerability of supply lines. The West is patently aware of its dependence on the highly mineralized region that stretches from the Transvaal to Shaba province in Zaire and into Angola, which geologists have named High Africa.

The future implication of this distribution is clear. Irresponsible decisions on the international political platform could lead to a situation in which major Western powers find themselves dependent on the eastern Siberian region of the U.S.S.R. for their supplies of strategic minerals.

New Discoveries

New mineral discoveries will be made, and new developments in mineral processing will bring ever lower-grade deposits into the category of ore. This does not mean, however, that we should regard exploration and extraction techniques as touchstones, capable of indefinitely supplying mankind's insatiable appetite for minerals. It is up to all of us to regard mineral resources as the common property of our species, to be used with care and discretion and not to be squandered.

With this in mind it is of interest to examine some of the techniques that will be used in future mineral exploration.

The first and most important 'technique' is the development of the correct me(n)tal attitude. The ideal mineral explorationist is a subtle blend of optimist and cynic. He knows his chances of success are minimal, for in no other field of technical endeavour is the success rate so low. It is well-known that only one prospect in several thousand turns out to be a viable mine by normal commercial standards. He must not allow such statistics to deter him, but must cultivate keen powers of observation and reasoning, coupled with a determination to succeed. Dichotomy of thought can be a valuable aid in the examination of a mineral occurrence: one side of the observer attempts to exaggerate the find, while the other plays the part of devil's advocate by searching for unfavourable features; this continues until a consensus of truth is reached. The human factor remains the most important, for mineral data must be interpreted and there is no substitute for keen eyes, well-shod feet, and enthusiasm. It was Pelletier who, when asked what in his opinion was the most useful geophysical instrument, remarked dryly, 'A pick'.

Observation is limited to exposures of mineral deposits or to visible signs, and remote-sensing techniques grow more important year by year. The most spectacular of these is satellite photography, in which regional features of the earth's surface show up as structural lineaments and gross tectonic trends. These are obscured on aerial photographs, and even more so on geological maps, which by their very nature concentrate on the trees and miss the wood.

Aerial photography has developed enormously in the last few years, and with colour and infrared film it is now possible to detect detail that was unthinkable a decade ago.

Geochemistry, using computer-processing of data, has advanced to the status of an exact science since its first serious application some twenty-five years ago. Concerned with the recognition of primary and secondary haloes surrounding buried mineral deposits, the techniques include the sampling and the meticulous (but cheap and rapid) analysis of soils, rock fragments, water, stream sediments, vegetation, and air. The last-named is a new and exciting development.

Geochemical anomalies are often investigated by geophysical techniques, which make use of the electrical, magnetic, reflective, or gravimetric differences between mineralized and non-mineralized material. Oil exploration depends almost entirely on co-operation between the disciplines of sedimentology and seismology. Airborne or motor-borne geophysical methods have now advanced to a high degree of perfection and sophistication, and provide a mass of data in the minimum of time and cost.

Remote sensing finally gives way to direct observation by drilling or excavation, which provides the basis for financial analysis.

Production Trends

The expansion necessary to develop ore deposits, metallurgical plant, and sources of cheap power is going to tax the ingenuity of engineers to the utmost.

Iron and Steel

To maintain the world-wide *per capita* consumption of iron, the present annual production rate of 700 million tons must double by the year 2010. This increase will have to occur without any relative increase in the price of iron and steel, which are cheap in comparison with other metals. Essential if the required expansion is to be met will be rapid technological advance. Recent innovations that have lowered costs and led to more efficient production include sintering, pelletizing, and direct reduction based on coal or gas (as well as the basic oxygen process, which is an adaptation of the old Bessemer process).

Steel alloys (which contain nickel, manganese, chromite, cobalt, and tungsten) have long been indispensable to industrial survival. In addition, the demands imposed by the rigid requirements of space exploration and atomic-energy research have given tremendous impetus to the development and understanding of ferro-alloys, and their application must expand.

More important perhaps for entrepreneurs is an understanding of political aspects. Diversification of ore supplies is essential to establish a measure of protection against political upheaval, labour stoppages, money-exchange difficulties, and unbusinesslike actions (particularly where mines are located in politically immature areas).

Other Important Mineral Commodities

Together aluminium, chromium, cobalt, copper, iron, lead, manganese, nickel, platinum, steel, tin, tungsten, and zinc account for between 80 and 90 per cent by value of the world's mineral production. Although having less than 30 per cent of the total world population, the rich industrialized countries of the world use more than 80 per cent of these materials. In general, the countries that possess the reserves or produce the materials are not the centres of consumption. It is evident that United Nations' organizations, with membership dominated by poor lands, foresee enhanced economic status for net exporters of industrial raw materials.

In advanced technical societies, as populations stabilize, so the *per capita* demand for minerals decreases. Predictions of future demand should balance this trend against the aspirations of the emergent Third World, which will demand a share of the good life and the minerals that support it.

TABLE I

WORLD DEMAND FOR RAW MATERIALS: EXPANSION 1971-2000

	1971 to 1975	2000	Ratio
Crude steel ($t \times 10^6$)	642	1 301	2,0
Iron ore ($t \times 10^6$)	432	919	2,1
Nickel ($t \times 10^3$)	618	1 314	2,1
Manganese ore ($t \times 10^3$)	20 030	46 728	2,3
Chromium ore ($t \times 10^3$)	6 941	15 751	2,3
Cobalt (t)	23 434	56 720	2,4
Lead ($t \times 10^3$)	3 650	8 760	2,4
Tungsten (t)	40 182	92 637	2,3
Refined copper ($t \times 10^3$)	7 923	16 839	2,1
Primary aluminium ($t \times 10^3$)	12 249	36 516	3,0
Platinum (oz tr. $\times 10^3$)	5 387	14 030	2,6
Zinc ($t \times 10^3$)	5 506	12 022	2,2
Tin ($t \times 10^3$)	232	393	1,7

TABLE II

	Probable annual growth rates %	Estimated cost of additional capacity per annual ton $	Cost of capacity expansion 1977 to 1990 *$\$ \times 10^9$
Iron ore	4,0	168†	75,8
Copper	4,2	6 500	48,5
Bauxite		84	3,5
Alumina		672	12,5
Aluminium	6,0	2 690	38,8
Zinc	3,0	1 800	4,1
Nickel	4,2	20 200	6,5
Lead	2,8	1 400	2,4
			$192,1

*1977 dollars

†Per ton of Fe content based on an estimate of $100 per ton of 66 per cent Fe ore.

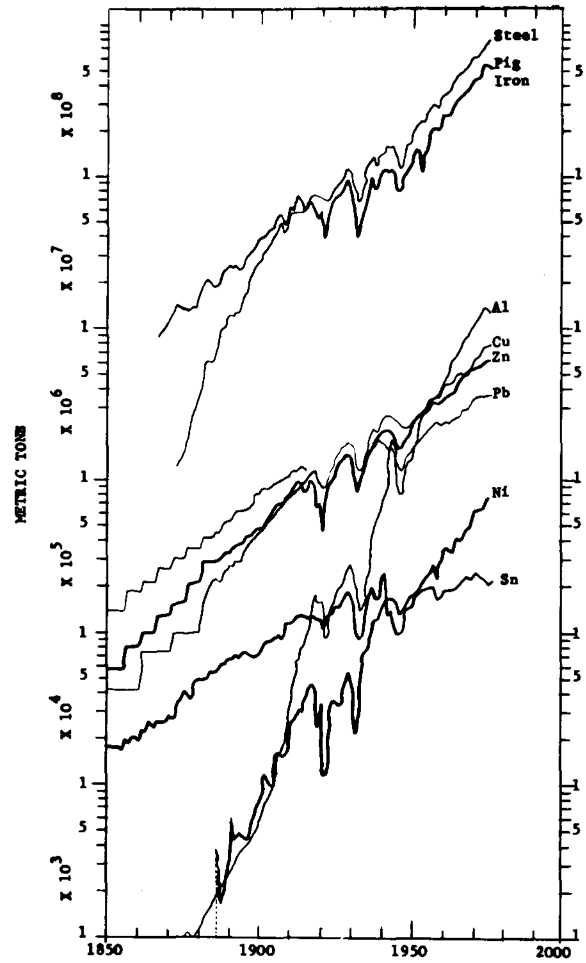

Fig. 1—The production of major metals in the world (with acknowledgement to *Mining Engineering, January, 1979*)

While the demand for minerals will continue to increase (Fig. 1), it is anticipated that global annual growth will show a slow but perceptible decline. Saturation of markets, increased recycling, substitution, and more efficient use of materials are some of the reasons for such a trend. In spite of this trend, considerable expansion of existing mine and smelter capacity will be necessary to meet future demands.

Future demand as seen by Wilfred Malenbaum is set out in Table I.

Extracted from a United Nations study, the data in Table II give an indication of the cost of the additional production capacity required by the Free World for a few important metals from the late 1970s to around 1990.

If a further 25 per cent is included for infrastructure, the potential annual investment for the period amounts to about $18 billion. The study indicates that roughly $6 billion will be spent in developing countries annually, of which $4,7 billion must be derived from external sources. By comparison, a rough estimate of the external financing of mining projects in developing countries shows injections of less than $1 billion per year over the past five years.

The sums appear formidable, but international mining companies are unlikely to have serious difficulty in mobilizing the required capital. The major problem lies in the availability of high-risk capital for the exploration and expansion of mine and smelter capacity in developing countries. There is little doubt that the Free World demand for minerals is going to be met, but the allocation of future additions to capacity will favour developed countries to a greater degree than indicated by the United Nations' survey.

The political availability of certain minerals is of great concern to the three major industrial nations of the Free World: the U.S.A., Western Europe, and Japan, who import 15, 75, and 90 per cent respectively of their industrial raw materials. They must obtain guaranteed supplies of manganese, tin, platinum, gold, chromite, bauxite, and cobalt. The development of chromium cartels, requiring collusion between South Africa and the U.S.S.R., is regarded by some observers as a not unlikely event.

It can be concluded that

(a) a true scarcity of almost any mineral is too remote for accurate prediction, as is indicated in Table III for certain selected minerals;
(b) sufficient capital will be motivated for the required expansions; and
(c) it is unlikely that developing countries will achieve the predicted growth rates for mines and smelters.

Gold

After sixty centuries of relentless searching, tunnelling, panning, dredging, and blasting, man has relatively little gold to show for his efforts: a cube comprising all the gold recovered by mankind would measure 16,5 metres on each side. Even today the importance of gold to the world is out of all proportion to the amount produced. The supply of new gold to the market is about 1800 tons a year, and there are no signs that the present output will increase significantly. However, the fixed price for the metal between 1934 and 1972 inevitably inhibited the exploration and exploitation of known deposits, which might now be brought to account and slightly increase the supply.

The 13 micrograms of gold per ton of seawater, which represents an enormous reserve, is for technological and financial reasons unlikely to be tapped in the near future. Also absurd to contemplate is the gold, which according to scientists exists on Mars, Mercury, and Venus.

When faced with inevitable currency uncertainties and strife on national and international levels, gold, referred to by Lord Keynes as 'this barbarous relic', will continue to serve as a monetary metal — at least for some time to come. The U.S. gold-sales programme, which was prompted by pressure on the dollar and by a general desire to demonetize gold, had the traditional effect of stockpile sale on commodity price: after an initial reduction, the price rose as the inventory became gradually depleted until the price reached a higher level than before.

In addition, gold's transactional role has been effectively re-established by the recently introduced gold-backed European Currency Units, which have become an important part of currency-stabilization policies. As the gold price continues to advance, E.C.U.'s will shore up any future major retreats in the gold price.

Gold's role as an industrial metal in the space age is growing, the fabrication demand being 1400 tons in 1978. New applications for the metal are epitomized by the gold-plated umbilical cord designed to reflect thermal radiation that tethered Edward White, the first American to walk in space, to his Gemini spacecraft.

TABLE III

ADEQUACY OF RECOVERABLE RESOURCE POTENTIAL FOR SELECTED NON-ENERGY MINERALS

	Recoverable resource potential c. 1970*	World consumption 1970 to 2000†	Recoverable resource balance at 2000
Copper (sh. ton $\times 10^6$)	2 337	381	1 956
Lead (sh. ton $\times 10^6$)	606	152	454
Zinc (sh. ton $\times 10^6$)	3 748	264	3 484
Nickel (sh. ton $\times 10^6$)	2 855	32	2 823
Cobalt (lb $\times 10^9$)	1 682	2,8	1 679
Molybdenum (lb $\times 10^9$)	103	10,2	93
Tungsten (lb $\times 10^9$)	112	3,6	108
Phosphate rock‡ (sh. ton $\times 10^9$)	401	7,2	394

* Source: U.S. Geological Survey, United States mineral resources *Prof. Paper* 820, 1973. c. 23 (Source gives data in metric tons).

†U.S. Bureau of Mines world production data for 1970-73 (Minerals Year Book, 1971-74, (Statistical Summary) have been added to the 1974 to 2000 consumption projections given in Table III as a reasonable approximation.

‡Source gives potential reserves in terms of phosphorus. These have been converted to phosphate rock on the assumption that average marketable rock contains 14 per cent phosphorus.

Technology for Tomorrow

The most decisive and expensive factor in the exploitation of minerals is specialized technology. More than a chemical formula, it is engineering know-how that holds the key to the future.

Perhaps the most ambitious mining operations being planned for the future are those aiming to recover manganese nodules from the ocean floor. Several international consortiums have directed considerable research effort in this direction, and have made substantial advances in solving the complex harvesting and metallurgical problems involved. Huge nodule deposits containing individually up to 550 million tons have been discovered and delineated, and will be worked in the future.

Solution mining will be used more extensively to improve the recovery of gold, copper, and uranium from low-grade deposits or from previously dumped tailings. Because time is less important in this type of mining, iron-oxidizing *thiobacilli* remarkable for the range of inorganic compounds that they act upon will be used in the treatment of ultra-low-grade ores.

Fundamental changes in pyrometallurgical processes involving plasma technology and continuous smelting systems will gain ground. Energy-intensive processes will be phased out, together with those unable to meet strict environmental standards.

Direct iron-ore reduction processes, permitting the use of coke oven gas, blast-furnace off-gas, coal or other refinery off-gases, will become more generally accepted.

The emphasis in mining and mineral processing will continue to be on the use of the largest efficient equipment.

Mounting pressure to increase efficiency and yield and to conserve energy, or to squeeze more productivity out of existing equipment, will cause technical personnel to take a harder look at instrumentation in certain instances. Digital control, which includes calculated variables such as assays, mass flows, recoveries, and other key information for economic optimization of metallurgical processes, will find wider use.

The recovery of valuable minerals from municipal solid waste presents a challenge that will have to be met. The dumping of solid waste becomes ever more unacceptable because of cost and value. Containing on the average 60 per cent combustibles, about 7 to 8 per cent ferrous metals, some 8 per cent glass, and 0,5 per cent aluminium, garbage represents an unusual 'ore' containing several useful components for recovery and recycling.

Benefits derived from rock-mechanics studies are going to make substantial contributions to safer working places. Non-linear and elastic-theory analyses will become routine, and indexes of rock quality will be used increasingly to characterize rock masses for preliminary design purposes. The use of structural fill can be expected to increase. Monitoring devices will become generally accepted for the remote measurement of seismic events, thereby identifying zones where high stresses can be relieved by timely adjustment in mine planning with the aid of sophisticated computer programs.

The employment of large underground work forces will gradually be phased out. Remote control of complex mining operations will become more prevalent, calling for highly reliable equipment combined with sophisticated instrument-sensing monitoring and reporting systems.

Energy will not be cheap nor abundant, and the recovery system — both mining and processing — will require careful evaluation in terms of expenditure on energy related to return on investment.

Energy

Sharp increases in the oil price, coupled with the political crisis in Iran and predictions by most authorities that oil production is expected to reach a peak in 1990, has again thrown into focus the crucial importance of energy supply to the industrial nations and also to less-developed economies.

The impact of steeply rising fuel costs on national finance is well-known. Less well publicized, and certainly less well understood, are the slowly unfolding consequences of radical changes in the cost of energy to basic industries and technological practice. Mining, minerals processing, and the use of metals and minerals are dominated by energy costs in all stages of the conversion of *in situ* natural material to fully fabricated end-products, and account for more than half the world's output of energy.

In 1975 the world's consumption of primary energy was about 75 000 terawatt-hours (1 terawatt-hour=10^9 kilowatt-hours=83 000 tons of oil=135 000 tons of coal). Demand has been growing at 5 per cent per annum for the past twenty years, and this growth, if projected exponentially to the year 2000, indicates an enormous gap between supply and demand. To fill only half the gap with nuclear power, the 3500-gigawatt capacity required (the present capacity is about 70 gigawatts) would consume proven world uranium resources in about twelve years, and would call for the commissioning of three 1000-megawatt stations each week between now and the end of the century.

Historically, the rapid growth in energy demand has been met by the expansion of fossil-fuel supplies. Oil and gas have taken over from coal during the past two decades as the major suppliers of energy, and now provide over 65 per cent of the total. Greater dependence on coal, combined with coal-conversion technology, is likely to result in the doubling of global demand by 1990.

On the uranium front, political problems — and not technical problems — are the most important ones to be faced. One way or another, it is essential that the industry should come to terms with politicians, environmentalists, and action groups. The remarkable and orderly penetration of the electrical-power market by nuclear power in the past, as shown in Figs. 2 and 3, must continue. Adequate and rational public discussion and education, which should include an appreciation of science and technology, should prevail.

However, there are certain constraints that invalidate the long-term planning of uranium-based and coal-based power. The supplies of both minerals are finite. There is concern in some quarters that proven uranium energy

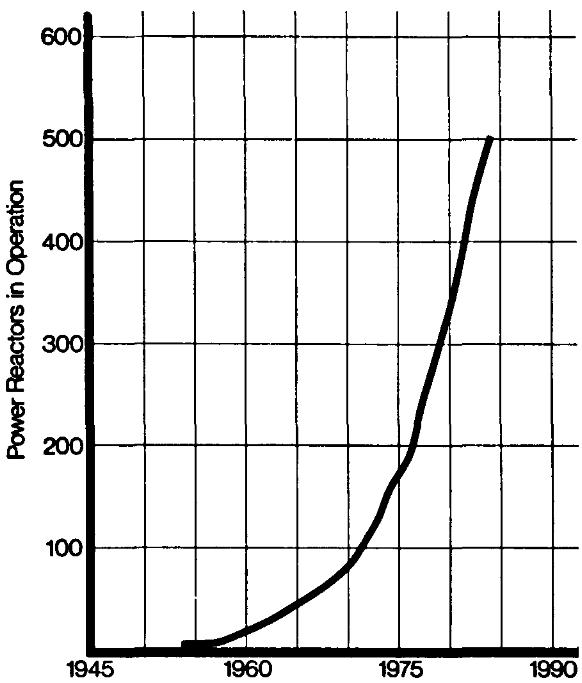

Fig. 2—Increase in the number of nuclear-power reactors with time (with acknowledgement to I.A.E.A. ***Power reactors in member states, 1977*****)**

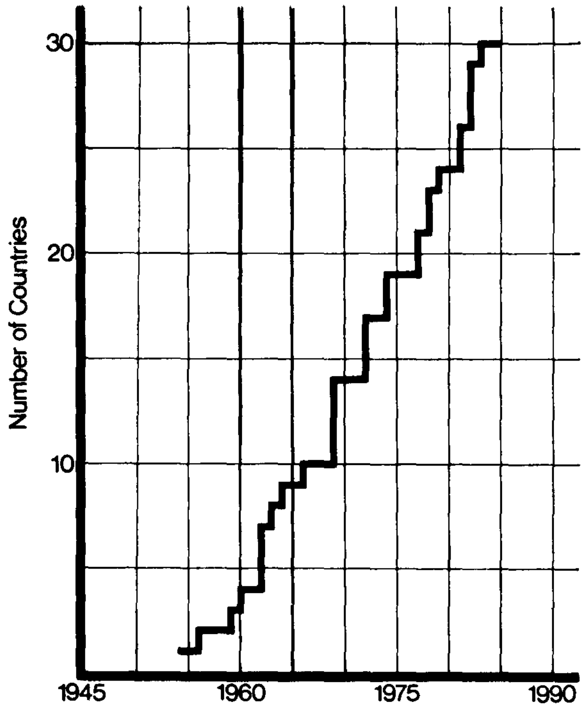

Fig. 3—Number of countries having nuclear-power reactors (with acknowledgement to I.A.E.A. *Power reactors in member states, 1977***)**

resources are not much greater than those of oil. Though the coal reserves could provide the world's power requirements for many centuries to come, the consumption of fossil fuel during the next century will be limited by atmospheric tolerance for carbon dioxide long before the resource is exhausted.

A variety of new energy options are emerging on the horizon of the twenty-first century, but their implementation will require considerable technological evolution. The lead times for the development of alternative energy sources are measured in decades, and vigorous programmes of research will be required if we are to have a viable energy economy by the year 2000.

Nuclear power or nuclear-fuel reprocessing, despite pressure from the environmentalists, is one of these options. Fast-breeder reactors that convert thorium to fissile fuel will effectively produce more fuel than is consumed, and in that way we may be able to secure our uranium resources for thousands of years.

The enormity of the technical problems associated with nuclear fusion can be gauged by the fact that the hydrogen–boron reaction requires temperatures of three billion degrees centigrade, whereas the deuterium–tritium reaction takes place at 100 million degrees. However, the latter reaction, on which much current research is focused and which scientists claim will be a commercial reality in thirty-five years, does not have a limitless supply of fuel, for tritium is derived from lithium, an element that is no more abundant than uranium.

Substantial advantages, none of them economic, favour the use of renewable energy sources — direct sunlight, wind, and water. Their impact is likely to be minimal in the short to medium term; for solar power, the most optimistic targets of the U.S. Energy Research and Development Agency indicate that, by the year 2000, the cost would be ten times the present cost of energy; calculations indicate that 2,7 million windmills would be needed to generate the power required by the state of Pennsylvania if the largest types of windmills were used; wave energy is beset by apparently prohibitive economic and technological problems in the development of suitable converters, the early designs proving expensive (R7000 to R8000 per kilowatt installed as compared with R850 to R2000 for fossil or nuclear-power stations).

The concept of fission power occurred in the late 1930's. Now, 40 years later, some four per cent of total U.S. energy needs are nuclear fueled. This gives some indication of the timing and impact of exotic undeveloped energy technologies, such as, solar, wind and tide, especially as these technologies lack the large-scale U.S. national security funding, that helped develop nuclear power.

There is no question that the transition from oil-based economies will have to be made. The real question is whether the change will be a smooth one (the result of careful planning) or chaotic (the result of a succession of worsening economic and political crises).

Manpower

It is generally accepted in the minerals industry that manpower is its single largest investment. The right man for the right job is not born to it, but is created by meticulous selection, training, and job orientation. It is doubtful whether enough is being done throughout the world to attract sufficient mining personnel, and whether enough time is being spent in motivating this most important asset.

A steady degradation of the image of the mineral profession is evidenced by the decline in enrolments in the field. To attract young people, strategies should be devised that expose them to the adventures of the miner prospector, the skill of the metallurgist, and the never-ending reward that the earth's mineral wealth confers on man. Schemes, such as Phoenix, in which teachers and groups of school boys are introduced to mining and metallurgical activities during their vacations, and to metallurgical experimentation in their schools with apparatus provided by mining companies and others, already show positive results, and must be pursued vigorously.

The basic interests that are likely to lead a person into the industry must be identified and used to advantage. Recently, a large cross-section of engineering-student enrolments listed an engineering-based hobby as the student's main reason for selecting engineering as a career. Perhaps an annual Olympiad for mining- and metallurgical-based hobbies should be sponsored. The alternatives are many and varied, and societies such as the South African Institute of Mining and Metallurgy should co-sponsor and initiate dynamic imaginative programmes to secure adequate manpower skills for the future.

Education

Rapid technological advance emphasizes the need for communication between industry and the universities. Engineering education, in which basic scientific and engineering studies lead to specialized courses, should be moulded to the needs of industry. The lack of university-level teaching in various aspects of coal technology is a glaring instance of how local needs can be met only by some type of inhouse training.

Coal mining accounts for approximately half the total mining in the world, a proportion that is approximately also true for South Africa. Coal, with its hundreds-of-years of reserves, is emerging as an important proven long-term source of energy, and it would be difficult to single out a major worldwide industry with a more certain future. The introduction at undergraduate and post-graduate levels of courses that embrace coal mining and the beneficiation of coal must be called for with a degree of urgency.

The competence of future engineers depends largely on the quality of their teachers. In many countries, as in South Africa, inequalities between academic and industrial salaries has led to staff shortages, and in some instances has resulted in the selection of unsuitable candidates for teaching posts. The subvention of salaries by industry is not the answer. State departments of education responsible for this unsatisfactory state of affairs should be prevailed upon to rectify this matter.

The training of new graduates who join the industry, and their assimilation into the corporate structure of the organization, vary from company to company. but their common goal should be to channel graduates into senior engineering and executive positions, where they can contribute to corporate strategies. In the past, new engineers have levelled much criticism at the proffered training courses. If the minerals profession is to retain a share of future engineers, it is important to have well-planned and managed training programmes. These should instil a greater sense of responsibility, and should make people more enthusiastic and more interested in the job; more important, they should make the new engineer realize that his engineering degree does not incorporate all the knowledge he will ever need.

Scientists form another group of people essential to the industry. The dearth of scientists, science teachers, and science students is disturbing. This situation has not arisen from a youthful disillusionment with science because of its alleged involvement in war and pollution. Questionnaires have revealed an image of poor salaries, low job status, fewer job opportunities, and less chance of becoming independent. While many theories have been put forward to explain the swing away from science, serious research on the priorities that influence a pupil's choice of career is required as a matter of urgency.

Financial Climate

The mining industry's ability to maintain its traditional contribution to the national and international economy is largely dependent upon the future financial climate. In recent years, return on investment has been depressed as capital and operating costs continued to inflate. Market rates of interest have risen well above their historical long-term average, while the political risk component of mineral investments is increasingly difficult to predict.

Inflation continues as the nemesis of project financing, and capital overruns have characterized most major mine projects started in the 1970s. Enormous cost inflation was one of the major factors behind the decision to halt development of the Tenke Fungurume project, and the financial requirement of the southern Peru Caujone project exceeded $700 million, although the initial estimate was $350 million. Financing in mineral resources seems to have lost much of its appeal, and many international mineral projects are being deferred or reduced in size.

It has also become clear that the minerals industry will not in future generate sufficient cash to finance its own expansion programme. This will require massive injections of capital as enormous increases in the capital costs of mineral production accompany the decrease in ore grades, the development of mines in remote areas, the rise of material and energy costs, and the increased cost of borrowing money. Considerable ingenuity to improve project economics and reduce investment risk is required.

Although more-expensive project financing, in which debt funding is made available to a mining-company subsidiary without the parent being directly liable for repayment of the debt, must take on added importance. This trend has been initiated by the high cost of new mine development involving multinational participation by joint-venture partners, together with the deteriorating financial condition of major international mining companies. The debt involved in the financing of joint ventures may have a minimal effect on each partner s balance sheet, thus maintaining his ability to raise funds for other needs. Lenders are, however, going to look critically at the credit-worthiness and technical proficiency of potential customers.

More attention to careful mine planning is therefore required in the future to assure optimization of profitability. Investment decisions will become more reliant upon competent predictions of ore grade, the timing and magnitude of capital expenditure, production costs, and mineral prices.

Construction schedules must be shortened by better planning and modern management-control techniques. Sufficient time and money for process development, operator training, and plant-component selection and design should minimize the risk associated with start-up problems.

Exploration and Investment Decisions

The shrinking world for exploration is a much-debated topic and has important bearing on future investment decisions.

Large base-metal areas of the world are being eliminated as target areas for exploration programmes by international mining companies because of political instability or socialist trends in the host country. Investor disillusionment could slow down new mineral development in the Third World. A shift to investment in mineral projects in countries with far lower-grade deposits but with common philosophies will continue.

This unsatisfactory state of affairs is unlikely to improve while the World Bank and International Monetary Fund continue to provide developing countries with whatever finance they require to cover losses. There is little incentive for states to learn to conduct their business properly while this situation exists. Security of investment, sanctity of contract, predictability of outcome, and return for the risks of investment are assurances that must be forthcoming to attract capital and the associated management know-how.

International mining companies have come to the conclusion that the U.S.A. and South Africa, because of their economic and enlightened mining-legislation environments, represent favourable exploration target areas. This stems from endorsement of common-interest and orderly development policies, dividend repatriation, and the assurance that ownership will not be diluted or lost.

The South African position could be improved further if Treasury would heed protests that discriminatory taxes on mining (and on gold mining in particular) are inhibiting growth in the industry. The fiscal system, which confiscates a large proportion of the earnings, is giving very little encouragement to further investment in minerals.

Though it is extremely unlikely that lack of finance will inhibit the supply of minerals in the future, there is a need for an invigorated investment climate.

Health and Safety

In the past, mining was associated with poor, dangerous, unhealthy, dirty conditions, and only the lower classes were employed in mines. The toil and suffering of miners, first described by Herodotus, persisted into fairly recent times, and phthisis, fires, explosions, floods, rockfalls, hot and filthy conditions, scars on the landscape, slag heaps, chimneys belching smoke were the order of the day.

Pollution of the environment by harmful substances is controllable. The introduction of the necessary safeguards to achieve this and provide safe, healthy places of work will take on added importance and make considerable demands on ingenuity in the future. The minerals industry will be called upon to consider a wide range of processes and equipment to protect the environment. The reduction of harmful emissions, purification of waste water, control of noise, reprocessing of utilizable waste, landscaping of worked-out surface excavations, and vegetating of tailings dumps will add to the capital requirements for future projects.

It should not be too difficult for an exciting and vital industry (embodying many skills and the talents of a variety of engineering disciplines) to reduce the incidence of rock falls, pressure bursts, machinery accidents, phthisis, general injury to persons, and damage to equipment, while the preservation of the environment is maintained. For, unless dynamic scientifically planned management approaches are employed, the industry risks the imposition of environmental standards that go beyond health- and safety-threshold requirements and are neither technically nor economically justified.

Environmental pollution and other side effects of new technology are legitimate concerns in an advanced society. Technology has created these problems, but, to solve them, better-managed technology is needed, and not no technology. It is the anti-technology movement, conducted by an articulate well-organized minority wise in the ways of the media and adept in politics and legal matters, that is perhaps the most serious threat to the environment, and a serious threat to the minerals industry. Management has the choice of either waiting for legislation to enforce change, which invariably leads to the setting of unrealistic standards, or taking the lead and ensuring that the legislation is reasonable. The only solution is a total accident-prevention and industrial-health programme coupled with continuous environmental-preservation planning.

The rewards of such a positive approach will undoubtedly include improved productivity from sufficient numbers of healthy and dedicated people motivated by an image of resource management for the environmental enrichment of all men.

Conclusion

The discovery of metallurgy after thousands of years of Stone Age darkness introduced the use of metals, and the resulting search for metallic ores stimulated the widespread diffusion of civilization and man's social and cultural development. With the power age came a demand for a larger tonnage of metal and the production of still greater power for larger production. Never in the history of mankind have mineral resources of the earth been so essential to human existance as they are today; nor has proof of their influence upon man's progress and destiny been so obvious.

It is up to us who work in this field in South Africa to meet the new and demanding challenges by developing new technology and adopting new approaches; by persuading young poeple to join us so that there will be continuity of effort; by giving them the education and training that they require; and by seeing that our efforts do not constitute a hazard to man or his environment. By so doing we shall be responding positively to the challenges posed by nature's niggardly bounty when she showered her minerals on us but distributed the values so sparingly.