# ECONOMIC GEOLOGY RESEARCH UNIT

University of the Witwatersrand
Johannesburg

## THE ROLE OF E.G.R.U. IN MINERAL EXPLORATION IN SOUTH AFRICA

D. A. PRETORIUS

INFORMATION CIRCULAR No. 77

UNIVERSITY OF THE WITWATERSRAND
JOHANNESBURG

# THE ROLE OF E.G.R.U. IN MINERAL EXPLORATION IN SOUTH AFRICA

*An Inaugural Lecture Delivered on 13 November, 1972, Consequent upon Taking up the Chair of Exploration Geology at the University of the Witwatersrand, Johannesburg*

by

D.A. PRETORIUS
*(Director, Economic Geology Research Unit)*

ECONOMIC GEOLOGY RESEARCH UNIT
INFORMATION CIRCULAR No. 77
*April, 1973*

# THE ROLE OF E.G.R.U. IN MINERAL EXPLORATION IN SOUTH AFRICA

## CONTENTS



* * * * * * * * * * * * * * * * * * * * * *

## THE ROLE OF E.G.R.U. IN MINERAL EXPLORATION IN SOUTH AFRICA

### ECONOMIC GEOLOGY AND EXPLORATION GEOLOGY

There are two stewardships of which I should give account. The first of these responsibilities relates to my thirteen years of association with the Economic Geology Research Unit, and the second to my occupancy for four years of the Chair of Exploration Geology. From the numbers of years mentioned, this lecture cannot be regarded as truly inaugural, the formal introduction to both honours being milestones lying some distance back along the road. It would be more appropriate, perhaps, to view the occasion, not as a ceremonial entry-point into new experiences, but rather as a high hill for looking down the road of a long march. If there has to be an inauguration, then let it be of a new direction for that road to follow towards realizing the very great opportunities that exist in South Africa for making a science - and an art - of economic geology and exploration geology.

One image of economics is that of a practical science concerned with the production and distribution of wealth. Alfred Marshall conceived of economics as examining that part of individual and social action which is most closely connected with the attainment and use of the material requisites of well-being. The mineral resources of the earth are as fundamental a material requisite for the production of wealth as there can be. The full spectrum of mineral economics covers the fields of prospecting, development, mining, treatment, and marketing. The role of geology shows a progressive diminution in each field, from one of almost total dominance in prospecting to one of no importance in marketing. Economic geology, then, is the use to which the science of geology can be put in finding, proving, and exploiting the mineral wealth of the earth. There is no discrete discipline of economic geology. In 1922, C.K. Leith said that it is not sharply marked off from the sciences of geology proper; almost any phase of geology may at some time or some place take on an economic aspect. No prohibition, alchemic or aesthetic, precludes the economic geologist from plundering the precincts of petrologists and paleontologists, of sedimentologists and seismologists, of geochronologists and geomorphologists, to seize upon ideas and implements that will enhance his measure of success in the exploration for, and exploitation of, those minerals that mean money to men.

To explore is to examine closely with a view to discovery. Exploration geology is a division of economic geology in which emphasis is placed on designing strategies and devising tactics that will hopefully lead to the discovery of new mineral deposits. When prospecting passes over into developing and mining the discovery, then exploration geology is superseded by mining geology. In the hierachy of applied geology - geology as a social action within the framework of economics - exploration geology is the vanguard; all else follows.

### THE COMPLEXITY OF EXPLORATION

The exploration for non-renewable natural resources, as seen by Griffiths and Singer (1971), is an exceedingly complex probabilistic problem. Stafford Beer, in 1959, set out the essential difference between a deterministic system and a probabilistic one. In the former, the parts interact in a perfectly predictable way, and there is never any room for doubt. Given a last state of a system and a programme of information, it is always possible to predict, without any risk of error, the succeeding state of the system. In a probabilistic system, no precisely detailed prediction can be given. The system is not predetermined, and any prediction concerning it can never escape from the limitations of the probabilities in which terms alone its behaviour can be described.

It is the nature of the history of the earth that a geologist has available to him only partial information. Occasional lines from disconnected paragraphs in obscurantist chapters are what can be read. Violence in the handling of the book through time has caused many of these chapters to be ripped and reassembled out of context. That the gist of the early chapters can be deciphered at all is a credit to perseverance and imagination not always associated with other sciences. The geologist operates at all times in an environment characterized by a high degree of uncertainty and ornamented with end-products which are the outcomes of the interactions of many complex variables. He sees only the end, and has to induce the processes and the responses that filled the time since the beginning.

To discover a new mineral deposit, a prediction must be made of where the target is most likely to occur. Amidst the prevalent uncertainty and complexity, there is frequently more art than science in such prediction. In discussing the realm of uncertainty under which decisions are taken in the oil industry, Grayson (1960) defined the process as follows : "A search activity is initiated. Information is gathered. A filtering process sifts, weighs, and evaluates; and a transmission network moves the information through prescribed channels. Along the way, information is added from other networks until a final assembly and selection point is reached, and a decision is made : accept, reject, or postpone ..... The decision process is basically one of evaluation, comparison, and selection". Evaluation, according to Flawn (1965), requires a great deal more than measuring known ore and calculating the economic factors that control costs; it requires consideration of the probability of finding more ore. This, he believes, is the vital contribution of the economic geologist; neither the economist nor the engineer is equipped to treat this aspect of the problem. Comparison, the operation of looking for similarities and differences, is an integral component of problem-solving. It rests on a structured base of classification of factual information from widely divergent fields, the base being composed of those geological, geophysical, and geochemical factors which emphasize the differences between the parameters that characterize economically exploitable mineral deposits and those that are more frequently associated with mineralization that cannot be mined at a profit. The identification and selection of the critical factors constitute the core of exploration geology. "The ability to classify must clearly involve a mechanism which can handle a system spread out in time as well as space, and also one that can handle incomplete patterns". Stafford Beer made that statement in 1959, when describing the role that cybernetics can play in management, and he added : "Foresight and selectivity are key attributes of management; they are also the major characteristic of intelligence ..... It therefore seems best to visualize the prospect for intelligence amplification in terms of amplifying selectivity ..... Intelligence involves as its paramount characteristic the capacity to select".

Research, then, in the system of economic geology should have as its objective the establishment of criteria upon which decisions can be made within the sub-system of exploration geology. It should aim for the amplification of intelligence in identifying, classifying, comparing, evaluating, and selecting those geological factors, within a complex probabilistic system, that enhance the chances of successfully choosing targets which ultimately will be transformed into mines. The research should take place in the belief that Beer's (1959) goal can be achieved of developing a generalized, comprehensive theory which is not only descriptive but predictive. The theory, relevant to the context of this inaugural lecture, would offer an explanation for the distribution patterns, in space and time, of the mineral deposits upon which man is so dependent for his survival, and would define the geological factors which are critical in making such mineralization also a source of money for men.

The manner in which adequate mineral resources can be provided for the future was considered by L.E. Preston in 1960. He stated that, although much could be achieved through conservation of presently known resources and through the development of new processes of beneficiation and extraction, the overriding conclusion was that "from a long-run point of view, the ore deposit is the basic source of mineral output and the maintenance or increase of output over time will require the development of new primary sources". How well is man faring, in the complex world of mineral exploration, in finding new primary sources?

In 1967, Paul Bailly analyzed the exploration results, over the previous 25 years, of seven major mining companies and three governmental organizations, which had examined definite prospects and alleged mineralization over the whole of the United States of America. No less than 16 962 exploration programmes, of considerably varying scales of magnitude, were mounted during this period, with the targets being mainly base metals and uranium. In 2 078 instances, equivalent to 12 percent of the total number prospected, possibly promising tonnages of new mineralization were discovered. Only 52 of these were subsequently proved to be mineable propositions, and one of this small group ultimately assumed the dimensions of an outstanding producer of the first rank. The percentage equivalents of these latter figures are 0,3 percent and 0,0006 percent, respectively. The odds against success were more than 300-1, and against striking a real bonanza more than 160 000-1. Griffis (1971) reported on the outcome of exploration conducted over 40 years by one of the largest mining companies in Canada. More than 1 000 properties were prospected, and only 78 (7 percent) warranted further work of any importance. Eighteen of these (1,5 percent) were developed, but only seven (0,5 percent) became profitable ventures. The odds against success proved to be of the order of 200-1.

As a pointer, not necessarily truly representative, of the returns which exploration might be expected to yield, one might bear in mind Sheehan's (1964) analysis of the Timmins discovery in northern Ontario, certainly one of the more significant base metal finds of the past two decades.

Geophysical prospecting revealed the presence of highly suggestive anomalies which were subsequently explored by 66 drillholes. Seven of these intersected an ore-body which, on the original assessment, was concluded to contain 25 million tons of mineralized rock averaging 1,18 percent copper, 8,10 percent zinc, and 3,8 ounces of silver per ton. The gross value of this amount of ore was placed at $850 million, and it was estimated that the deposit could be mined for a total profit of $250 million. The cost of exploration was determined as $3 million. The calculated nett return, measured against the amount of money required to find the ore deposit, was thus approximately 80-1.

Even the most deluded of gambling optimists would have to concede that the dice in the exploration game are very definitely loaded in favour of the House. If the chances against success are 300-1 and the odds being offered for a winning bet are 80-1, then man needs an amount of skill considerably greater than the amount of luck normally allocated to him in a lifetime. Such exceptional skill can be found only in an amplification of the intelligence which man uses to select the ventures upon which he places his bets. Wallace Pratt, at the end of a long career as a gambler in the petroleum industry, stated simply : "Oil is found in the minds of men".

## E. G. R. U. : AN OVERVIEW

It would be a strange genus of geologist, indeed, who was not prepared to consider any institution, artifice, or opportunity for reducing the degree of uncertainty which permeates all decisions taken in the world of gambling that is mineral exploration. Since that first shiny stone was picked up near Hopetown in 1867, the amphora of artifice and opportunity has never been less than half-full. But 90 years were to elapse before the first institution was created solely for the purpose of helping to find ways and means of placing better bets. In October, 1957, the then Transvaal and Orange Free State Chamber of Mines, acting collectively for the seven major mining groups which dominate the South African mining scene, established at the University of the Witwatersrand, for an initial period of ten years, the Economic Geology Research Unit. The mandate given to E.G.R.U. was simple : carry out research into any aspect of geology in such a manner that the results obtained might be used by the mining industry in selecting the best goals for exploration and in pursuing them by the most effective means. The first of the original three staff members were appointed in June, 1959, and the last, myself, in November of the same year. From the beginning of 1968, at the end of the experimental period, the Unit was absorbed into the University structure, and today is an autonomous institution operating within the overall programme of research supported by the University. Its links with the mining industry are maintained as closely as they were at the inception of the Unit, and its overall policy of research is still aimed at working, almost exclusively, on problems presented to it by various members of the industry.

When critically reviewing the decision of the Chamber of Mines to establish a research group which came into existence 13 years ago, it should be remembered that two further geological research institutions were sponsored subsequently by the mining industry - the Precambrian Research Unit at the University of Cape Town and the Institute of Mining Research at the University of Rhodesia. Consideration has also been given to possibly setting up a fourth unit at the University of Pretoria, to carry out investigations into the Bushveld Complex and its treasure-house of contained mineralization. A new concept in mineral exploration was generated by the creation of E.G.R.U. What it and its fellow institutions in Cape Town and Salisbury set out to accomplish has attracted the attention of universities and mining companies in Canada, the United States, and Australia, where possibilities are being studied of founding similar research groups to bridge the chasms between the industrial and academic worlds.

In choosing a course on which to sail E.G.R.U. and the stars by which to steer it, four influences marked the charts :

1. It was believed that what L.E. Preston wrote in 1960 could not be denied : "Although it is true that the total amount of mineralization in the earth's crust - or within any segment of it defined in terms of surface area and depth - is strictly limited, there is no reason to believe that these ultimate limits have ever been indicated by the present state of knowledge".

2. It could not be argued against that vast amounts of geological data relevant to Southern Africa had been accumulated in the century since the mining industry was born; that much of this material was available in a decidedly unorganized state; that there

existed a repletion of description, detail, and speculative theory, but a dearth of quantitative analysis and substantive synthesis; that the volume of the data, in their existing forms, was too great for a single mind, or even groups of minds functioning collectively, to absorb, process, and reorganize, and that some amplifier of the capabilities of the human mind was necessary for the analysis and synthesis; and that only a small amount of the data had been transformed into information, and an even lesser amount of this information into knowledge.

3. The literature showed that many of the problems which had revealed themselves in the early days of South African geology still remained without solution, often without even hope of a solution forthcoming. The same arguments were periodically being resurrected, with nothing new being added to the arena of debate. Not infrequently, what were claimed as arrivals at a new understanding of the geological history of the sub-continent and its mineral deposits were found to be, instead, departures from reality. It was apparent that, if progress were to be effected with a sense of purpose and direction, then many of the established barriers would have to be broken down, preferably through subtle undermining by new ideas. There existed situations where research was needed, not to solve a problem, but first to establish what the problem really was. If it were possible to reduce the odds against success in mineral exploration, then it would be necessary to develop a new philosophical basis of economic geology.

4. There was an early realization that, in its close association with the mining industry, the Unit would have to operate on a functional level quite distinct from that of the geological departments of its sponsors. Duplication of effort was not the only pitfall to be avoided, but also too great a dependency of the Unit on proprietary information belonging to the individual companies and mines, which could not be freely integrated into syntheses. The Unit could operate only in environments and not in locations, which are normally the precincts of mining companies. The canvas of E.G.R.U. would have to be essentially for the broad brush; filigree would have to be a less-favoured function.

The contribution which the Economic Geology Research Unit should make was thus seen as one of collation and synthesis of what had been learned of the environments and controls of mineralization in Southern Africa, of addition of new information, where necessary, by examining gaps in knowledge by means of new geological, geophysical, and geochemical techniques, and of creation of a descriptive and predictive, generalized, comprehensive theory of the distribution patterns, through the full spectrum of geological time and space, of ore and protore. What was conceived in 1959 was to fit well with the image given to research in mineral exploration by John Griffiths in 1971 : to combine the ability of the geologist to recognize significant patterns and make complex logical decisions with the ability of the computer to retrieve information, perform numerical calculations, and generate displays; to synthesize data according to several geological patterns; and to develop an underlying philosophy of search based on theoretical models of probable arrangements of exploration targets.

The necessity was seen of accreting an *auberge* of applied geologists, in which creativity could be accommodated as an act of bringing together and combining known facts and ideas from widely divergent fields to produce new patterns and new concepts. Room had to be found for a new system of economic geology in which a cohesive collection of items of information and the dynamic interactions between them could be brought into a new focus.

Another view of the principal goals of a research group in economic geology, with which the Unit's record can be seen to comply, is that put forward by Thomas Mitcham in 1969 : to generate improved or new conceptual models for various types of ore-bodies and their settings; to define better places for the deployment of exploration efforts; to design improved or new data-gathering techniques; to develop improved or new interpretative techniques; and to upgrade the performance of exploration personnel through educational publications, seminars, and workshops.

In the long ago, before men started seeking minerals and money in the interior of Africa, the nomadic Bushmen had a saying : "If you want to hunt elephants, go to elephant country". If elephants and ore-bodies can be equated, then the fundamental problem of exploration geology is simply : where and how does one find the best elephant country? At the source of the Blue Nile is the home of the *agageers*, the professional elephant and rhinoceros hunters. If the geologists of the mining companies fill this role, then the purpose of the Economic Geology Research Unit might be similar to that of an essential member of the Mindassas of Gabon and the Middle Congo, the *njanga djoko*, master of the elephant rite.

## PHILOSOPHY AND POLEMIC

Since its inception, the policy of the Unit has been set by a Consultative Committee on which all seven major mining groups in South Africa are represented by their Consulting Geologists. How best to execute that policy, to realize the hopes held out for the experimental creation of an applied research group, to influence decision-making in mineral exploration, these have been the responsibilities attached solely to the directorship of the Unit. Perforce, those responsibilities have been discharged within the ambience of a personal philosophy of the nature and nuances of science, geology, economic geology, and exploration geology.

Firstly, it was seen that, if the establishment of E.G.R.U. represented a new concept in finding further mineralization, then it would have to do something new. Repetition and regurgitation were spectres that had ghost-walked through too much of academic economic geology in South Africa. Secondly, the dictum was appreciated that, when a new school of thought attempts to displace an older one, the resulting boundary disputes are likely to be bitter and protracted. The course selected would probably be into strong headwinds and rough waters. Thirdly, with a small staff and limited financial resources, it was obvious that the luxury could not be afforded of exploring virgin ground, and that the best chance of quick success lay in reworking the old dumps of geological knowledge which had been pyramided in the days when the percentage extraction of information from observational data was small. To take what had been seen and done and recorded, and to look at it another way, was the framework that was designed to support the research programme of the Unit and to produce usable results before the bloom was taken off the experiment.

To develop new lines of thinking in the complex world of mineral deposits and exploration for them required a philosophical base for viewing the total complexity. This was found in aspects of the work of Herbert Simon, which were brought together ultimately in the Karl Taylor Compton series of lectures delivered in 1968 at the Massachussetts Institute of Technology. In these, Simon (1969) commented on understanding the natural and artificial worlds, the psychology of thinking, the science of design, and the architecture of complexity. He declared that : "The central task of natural science is to make the wonderful commonplace : to show that complexity, correctly viewed, is only a mask for simplicity; to find pattern hidden in apparent chaos ..... How complex or simple a structure is depends critically upon the way in which we describe it. Most of the complex structures found in the world are enormously redundant, and we can use this redundancy to simplify their description. But to use it, to achieve the simplification, we must find the right representation ..... Empirically, a large proportion of the complex systems we observe in nature exhibit hierarchic structure ..... In their dynamics, hierarchies have a property, near decomposability, that greatly simplifies their behaviour".

The fact that many complex systems have nearly decomposable hierarchic structures is a major facilitating factor enabling us to understand, to describe, and even to see such systems and their parts. Hierarchic systems, composed of interrelated subsystems, each of these, in turn, being hierarchic in structure, will evolve far more quickly than non-hierarchic systems of comparable size. The time required for the evolution of a complex form from simple elements depends critically on the numbers and distribution of potential intermediate stable forms. The larger the number of stable subsystems, the more rapid the development of the complex system. The problem of finding relatively simple descriptions for complex systems is essentially one of decomposing the dynamic properties of hierarchically organized systems into subsystems. Simon regarded problem solving "as a search through a vast maze of possibilities, a maze that describes the environment. Successful problem solving involves searching the maze selectively and reducing it to manageable proportions .. ... We pose a problem by giving the state description of the solution. The task is to discover a sequence of processes that will produce the goal state from an initial state ..... Problem solving requires continual translation between the state and process descriptions of the same complex reality".

In the context of the specific research problems of E.G.R.U., Simon's philosophy was transformed into : (i) developing taxonomies in order to classify the kinds of information available in South Africa, (ii) eliminating the redundancy in this information, so as to reduce the volume to manageable dimensions, (iii) inducing, from the processed information, the generally complex environments of mineralization in space and time, (iv) decomposing these complex systems into relatively simple subsystems representing the intermediate stable states in the evolution of the environments, and (v) constructing a model, embracing selected simple components, to serve a descriptive and predictive purpose for decision-makers in the game of exploration geology.

The fundamental underlying belief is that complexity in the geological environment is generally an end-state resulting from the interaction and superimposition of a number of relatively simple processes. If the parameters of the end-state can be quantitatively defined, then passing the complexity through a series of mathematical filters might well separate out the critical, simple, intermediate states. From a postulate of simplicity comes a generalization of known facts, which, in turn, leads to scientific progress.

Bronowski (1964) has emphasized that man does not invent by following either use or tradition. To improve success in problem-solving in the geosciences, Griffiths (1970) said that it is necessary to adopt not only new tools of analysis but new ways of thinking about the problems and new ways of using these tools. He added that "there may be many questions within a specific scientific system, such as that of geoscience, which are unresolvable in terms of the language of the system; these questions require the invention of a metalanguage which may be used to define the questions in a form amenable to solution". Creativity, according to de Bono (1971), is concerned not only with generating new ideas, but with escaping from old ones. Continuity is the reason for the survival of most ideas, not a repeated assessment of their value. To organize information into new patterns, to break out of established patterns in order to look at things in a different way, it is imperative to explore beyond the obvious. He also said : "An idea will change of its own accord long after it could have been changed".

To anticipate the changes, and to precipitate them, it seemed to me, in the formative years of the Unit, that the factual data which were available in great volume could be turned into new information, could be restructured into new concepts, and could be woven into a repertoire of new patterns by combining these data with other data gathered, not only from the earth sciences, but from the whole realm of knowledge; by classifying the data according to taxonomies that extended beyond the limits of convention; by submitting the data to the presses of computer technology so that more wine could be squeezed from the grapes of rock; by challenging the absolute validity of assumptions, boundaries, limits, and specifications implicit in the data - de Bono's prescription; and by synthesizing the outcomes of these various operations so that the new information could be looked at in the more translucent light of concepts, factors, values, and relationships.

If E.G.R.U. were required to develop a specialization, then my vision of it, conceived in full awareness of the seeming contradiction, was that it should be a speciality of generalization.

Over the years, a certainty fixity had become attached to the image of economic geology. For too many people, it was virtually nothing more than a catalogue of descriptions of individual mineral deposits. I could see no sense in the establishment of a research institution if it were to concern itself with perpetuating that image. The walls were more than well-hung with fine etchings of ore-bodies. There were very few broad-brush murals depicting the panoramas of environments in which the ore-bodies are grouped like Boschian figures. In the hierarchy of exploration targets, ore-bodies are the elephants, the environment is elephant country. The Unit might better comply with its mandate if it directed its activities towards writing the guide-books to elephant country, and left the hunting and the dissecting of the elephants to the *agageers*. The library shelves of South African geology held few volumes that told the story of the stratigraphic environments, the sedimentological environments, the structural environments, and the geochemical environments of mineralization in the southern part of the African continent. Those were the subsystems within the complex system of economic geology that particularly needed looking at in a new way. The unifying theme, the framework of synthesis, was the decipherment of the pattern of evolution of the whole crust in Southern Africa in the light of its being the super-environment - the total system - housing the metallogenic provinces (the environments, the subsystems) which contain the mineral deposits (the ore-bodies, the sub-subsystems).

Lasky made the point in 1947 : "Instead of looking for information indicating that ore is likely to be present, we ought ..... to balance and fit together the observed facts so as to discover whether it could be present. In other words, the geology need be only permissive instead of definitely indicative". A research goal that was envisaged for the Unit was the establishment of criteria for recognizing a permissive geological environment. Rather than describing metal concentrations, it would be more sensible to define metallotects, the structural, magmatic, metamorphic, geochemical, or lithological factors, or conjunctions of several of these, that favour the formation of mineral deposits. In the conventional schools of thought, these metal concentrations were seen as something quite apart from the rocks which surround them. They were members of an exclusive world, islands of exception, well-insulated from the commonplace geological milieu. Yet, evidence continued to mount through the years that many ore-bodies had formed from local reconstitutions of protore, and that protore was often nothing more than ordinary rock with a slight leavening of elements useful to man. There was justification for looking afresh at mineralization in South Africa, not as an exotic interloper from some far-off and mysterious domain, but as an integral, home-grown part of the rock containing it.

It was appreciated that the type of thinking described had already influenced the philosophy of exploration in the petroleum industry. Oilfield was the key-word instead of ore-body. Advantage could therefore be taken of what had proved useful in this industry, and, in the early days of E.G.R.U., much was lifted from the realm of petroleum geology and adapted to the world of metal mining. There was a firm subscription to the belief that innovation could be equally well effected by adapting established ideas to a new context as by originating novel ideas. This tenet was particularly applied to computer-based techniques of processing and displaying geological, geophysical, and geochemical data. The petroleum industry had shown, beyond question, that the quantitative assessment of such data contributed much more useful information than intuitive, qualitative interpretation. As geophysics was the new exploration tool of the 1930's and geochemistry of the 1950's, so geomathematics became the new dimension in geology in the 1960's. There was no question of the Unit's not taking a leading role in the development of this field in South Africa.

There remained one consideration that had to be included in my concept of what E.G.R.U. should be, and that referred to its structure and organization as an operating entity. The aim was to create a centre for excellence. It was believed that this could be achieved only by ensuring that the Unit consist of a group of men, strictly limited in number and capable of gaining great personal satisfaction in defining and solving the complex problems of economic geology. The fate of the dinosaurs is perhaps more firmly implanted in the minds of geologists than of other scientists. The continued growth of any organism can lead only to its ultimate extinction. Long before finality, mediocrity and decay become its distinguishing features. More often than not, there is an inverse relationship between size and quality in an institution originally set up to cultivate the latter. To provide an optimum environment for creativity, it was believed that the Unit should be kept small, that it should stand as a compact island, projecting high above the possibility of submergence in an ever-widening sea of bigger projects requiring more men. To prevent insularity of thought, it would have to maintain frequent and firm contacts with other researchers in economic geology throughout the world. Its vision would have to retain a long focus by comparative studies of South African environments of mineralization and those in other continents. If it were to serve the mining industry well, then it would have to communicate effectively and directly the results of its research. Publication in the accepted journals of the scientific world would have to be a second-order obligation.

Conscious of the sponsors who dared to experiment in the founding of a research institution specifically concerned with economic geology and mineral exploration, I believed that E.G.R.U., above all else, had to be useful to the mining industry. My views were those of Leopold and Langbein (1963) : "In science, usefulness is measured in part by ability to forecast, i.e. to predict relations postulated by reasoning about associations and subsequently subject to verification by experiment or field study. With this in mind, it is apparent that preoccupation with description could lead to decreasing usefulness because classification and description are usually insufficient bases for extrapolation and thus for prediction".

## THE EXAMPLE OF MINERALS AND MONEY

It has been stressed more than once in the course of this lecture that one of the functions which the Economic Geology Research Unit included among its objectives was the looking at accumulated data in a new way, the restructuring of available information so as to develop new directions of thinking. A mining industry that started with the discovery of diamonds in 1867 has progressively developed to the stage where South Africa is today one of the foremost mineral-producing countries in the world. Since the late 1890's comprehensive records of production and of the value of sales have been kept by various governmental departments. Prior to that period, useful information, although less reliable and less complete, is to be found in various publications and in the reports of mining companies. There is thus no problem in ascertaining what metals, minerals, mineral aggregates, and solid fuels have been won from the crust in South Africa over the past 105 years. For many decades now, annual reports on mineral production have been prepared and issued by the Department of Mines. These tabulated data have remained as straight statements of fact, and, beyond totalling according to the normal classifications of precious metals and stones, base metals, industrial minerals, and fuels, have not been subjected, at least in published form, to any processing. In short, the figures have been left as substantial quantities of data, and apparently no attempts have been made to transform these data into information which might be useful to decision-makers in their selection of targets for exploration. What follows is an indication of how a transformation, according to a few of several possible taxonomies for ordering the production figures, can point to elephant country.

In Table 1, the relative contribution to the South African economy of the different mineral products so far mined is indicated by a sequential ranking according to the total realized value of the sales of each from the earliest records up to the end of 1971. No less than 57 different types of elements, minerals, and mineral aggregates have been economically exploited, and the total production of these has been sold for almost R26 700 000 000. South Africa is regarded almost universally as gold-diamond-platinum country, but the rankings show some surprising intrusions into this assumed order of importance. Gold is unquestionably the greatest contributor to the country's realized mineral wealth, but diamond production is in third place, and platinum fills only the sixth position. Coal has so far proved to be the second most valuable mineral product, and uranium and copper both attain a more elevated rank than platinum. Limestone and building stones come unexpectedly high on the list, and such products have obviously not been afforded their rightful place in the assessment of the value of the earth's crust in South Africa.

The dominance of gold can be readily seen in that this metal alone has been responsible for no less than 66 percent of the total value of all mineral products. The next highest on the list, coal, has accounted for only one-tenth of this relative amount. The sales of five minerals only have been valued in excess of R1 000 million, and of 12 of the 57 in excess of R100 million. The first ten mineral products in the list account for over 96 percent of the total value of production, so that the remaining 47 have realized only four percent of the R26 700 million. That the country is particularly well endowed with respect to gold, coal, diamonds, uranium, copper, platinum, asbestos, manganese, iron ore, limestone, chrome, and antimony is clearly revealed in Table 1. However, it shows with equal clarity the disturbing deficiency in zinc, lithium, bismuth, arsenic, molybdenum, and cobalt.

Whether South Africa is truly lacking in these minerals, or whether they are present to the same extent as they are in other well-mineralized countries, but remain still to be discovered in major concentration, is, of course, a question for which an answer must be found.

When great mining countries are discussed, prominence is always given to the United States of America, Canada, Australia, and South Africa. How these rate, one against the other is also something which can be determined from ranked tabulations such as have been compiled in Table 1. From data supplied by Griffiths and Singer (1971) for the U.S.A., Canada, Australia, and New Zealand, and from a summary of the data for South Africa, Table 2 has been prepared to permit a quantitative comparison of mineral production from these five countries up to the end of 1971. The conventional breakdown of mineral products into metals, non-metals, and fuels has been followed, and the figures are the realized values at the time of sale.

The contents of the earth's crust have proved particularly enriching to America, the total value of all minerals produced being of the order of R435 000 million, sixteen times that of South Africa's production. What has been mined in this country is equivalent to three-quarters of the value of Canadian mineral production, but to almost twice the value of that of Australia. Overall, South Africa ranks third out of the five countries considered, behind the U.S.A. and Canada, and ahead of Australia and New Zealand. It occupies second position with regard to metals, third position with respect to non-metals, and fourth position with regard to fuel. The low status of South Africa in the field of fuels is due to the non-discovery, thus far, of oil. The old disturbing question raises its head here again : does the non-appearance of oil and gas in the list of minerals produced mean that they are not here to be found, or does it mean that we have not succeeded in adequately establishing the local criteria for identifying the location of potential oilfields?

To cast a provocative pigeon among the commercial cats, I would like to use these production figures to calculate the Cedric Industrial Index for each country. This index is claimed to reflect the level of national economic development, and represents the ratio of the total value of non-metallic minerals produced to the total value of metallics. The assumption is made that metals contribute mainly to the manufacturing industries, whether in the country of production or in

| Rank | MINERAL PRODUCT | Value in mill.Rands | % of Total | Rank | MINERAL PRODUCT | Value in mill.Rands | % of Total |
|---|---|---|---|---|---|---|---|
| 1 | Gold | 17 627.283 | 66.07 | 30 | Andalusite | 6.197 | 0.02 |
| 2 | Coal | 1 800.418 | 6.75 | 31 | Osmiridium | 6.163 | 0.02 |
| 3 | Diamonds | 1 730.400 | 6.49 | 32 | Feldspar | 6.055 | 0.02 |
| 4 | Uranium | 1 180.420 | 4.42 | 33 | Phosphate | 4.831 | 0.02 |
| 5 | Copper | 1 114.495 | 4.18 | 34 | Mica | 3.701 | 0.01 |
| 6 | Platinum | 867.599 | 3.25 | 35 | Titanium | 3.652 | 0.01 |
| 7 | Asbestos | 500.968 | 1.88 | 36 | Mineral Pigments | 3.215 | 0.01 |
| 8 | Manganese | 353.294 | 1.32 | 37 | Corundum | 2.928 | 0.01 |
| 9 | Iron Ore | 275.873 | 1.03 | 38 | Marble | 2.659 | 0.01 |
| 10 | Limestone | 224.451 | 0.84 | 39 | Shale | 2.429 | 0.01 |
| 11 | Chrome | 158.943 | 0.60 | 40 | Lead | 2.061 | 0.01 |
| 12 | Building Stones | 127.810 | 0.48 | 41 | Soda-Ash | 1.921 | 0.01 |
| 13 | Antimony | 90.055 | 0.34 | 42 | Beryllium | 1.701 | 0.01 |
| 14 | Vanadium | 83.073 | 0.31 | 43 | Monazite | 1.380 | 0.01 |
| 15 | Tin | 80.383 | 0.30 | 44 | Talc | 0.787 | <0.01 |
| 16 | Silver | 65.269 | 0.24 | 45 | Zircon | 0.623 | <0.01 |
| 17 | Nickel | 64.132 | 0.24 | 46 | Barytes | 0.582 | <0.01 |
| 18 | Pyrite | 61.839 | 0.23 | 47 | Graphite | 0.474 | <0.01 |
| 19 | Salt | 45.356 | 0.17 | 48 | Tantalite | 0.440 | <0.01 |
| 20 | Clays | 39.406 | 0.15 | 49 | Mercury | 0.413 | <0.01 |
| 21 | Vermiculite | 24.373 | 0.09 | 50 | Carbon Dioxide | 0.386 | <0.01 |
| 22 | Sillimanite | 23.400 | 0.09 | 51 | Kieselguhr | 0.198 | <0.01 |
| 23 | Fluorspar | 22.303 | 0.08 | 52 | Zinc | 0.178 | <0.01 |
| 24 | Silica | 17.874 | 0.07 | 53 | Lithium | 0.139 | <0.01 |
| 25 | Gypsum | 14.342 | 0.05 | 54 | Bismuth | 0.085 | <0.01 |
| 26 | Tungsten | 9.303 | 0.03 | 55 | Arsenic | 0.026 | <0.01 |
| 27 | Magnesite | 8.823 | 0.03 | 56 | Molybdenum | 0.014 | <0.01 |
| 28 | Apatite | 7.580 | 0.03 | 57 | Cobalt | 0.001 | <0.01 |
| 29 | Gemstones | 6.544 | 0.02 | 1-57 | All Minerals | 26 679.248 | 100 |

Table 1 : Ranked Total Value (millions of Rands) of Individual Minerals Produced in South Africa from Earliest Recorded Mining Up to the End of 1971.

any other country to which they are exported in an unprocessed form, and that the non-metallics are used mainly in the construction industries which are restricted to the country being considered, with exports of such materials being of relatively minor importance. The greater the value of construction materials in relation to manufacturing materials, the more developed the territory. When a ratio of 1.00 is attained, a country is alleged to have a mature, 'self-sustaining economy'. The farther the ratio below this figure, the more dependent the country is upon trade with other nations for its economic prosperity. The indices determined from Table 2 are as follows : U.S.A. 1.21, New Zealand 0.77, Canada 0.57, Australia 0.19, and South Africa 0.13. That America should exceed the 1.00 level is only to be expected, but that South Africa should fall so low on the C-I Index is cause for concern that the pace of economic development in this country is unnecessarily leaden.

Perhaps a fairer way of comparing the mineral wealth of countries is through the unit regional value concept which Griffiths and Singer (1971) applied to the figures for America, Canada, Australia, and New Zealand, that have been quoted in this lecture. The size of a country is a factor that must be considered. In Table 3, the areas of these four countries, as well as that of South Africa, have been tabulated against the values of metals, non-metals, fuels, and all mineral products, and the unit regional values, in rands per square mile realized from the earliest records up to the end of 1971, have been calculated. With respect to size, the five countries are not strictly comparable; the U.S.A., Canada, and Australia qualify as very large countries, South Africa as intermediate, and New Zealand as small. However, in regard to the average exploited value of the crust thus far, America and South Africa stand out as giants, with the other three countries casting short shadows in comparison.

On average, each square mile of South Africa has been worth the not unimpressive amount of almost R57 000. This is about one-third the value of the crust in America, but is six times that in Canada, and twelve times that in Australia. Despite its small size, New Zealand deserves a higher status in the mining fraternity, its unit regional value being three times that of Australia. In the field of metals, South Africa is singularly well endowed, the value of more than R46 000 per square mile being twice that of the U.S.A. and four times that of the average for the five countries combined. The excess is so conspicuous that it might be suspected that South Africa represents a truly anomalous situation in the world order of metal concentrations. The same can be said for the quantities of fuels, particularly oil, which have been located so far in America.

Two basic philosophies can be developed from the unit regional values which have been presented. An exceptionally high value might be interpreted as indicating that a particularly well-mineralized portion of the crust can be regarded as an almost limitless treasure-house meriting continued exploration, or it might be read as indicating that the full mineral potential has been realized and that there is little likelihood of finding much more mineralization. There have been no suggestions as yet of the maximum possible unit regional value that might be anticipated for any large segment of the earth's crust.

There is no gainsaying the conclusion that South Africa has been very good elephant country up to now. Whether it has been shot out, or whether there is still some good hunting left, is one of the assessments in which E.G.R.U. is involved. I subscribe to the latter view.

Bearing in mind the considerable similarities that have been established in the geology of Southern Africa and Australia, the gross differences in the unit regional values for all types of mineral production from the two territories can be interpreted only as meaning that the true mineral potential of Australia has come nowhere near to being realized. The unit regional value of its metals so far exploited is only one-quarter that of the average for the five countries dealt with, of its non-metals one-eleventh, and of its fuels one-twentieth. Its size is of the same order as that of the United States, and its geology is as good as that of South Africa. If Horace Greeley were an old elephant hunter standing at the southern tip of Africa today, he would undoubtedly say : "Go east, young man".

I would like to give one further example of how the mineral production figures of South Africa can be restructured so as to give new information on the manner in which the mineral wealth is distributed through geological time. If a very broad view is taken, then the rock assemblages which constitute the crust in this country can be classified according to three main categories : sequences consisting mainly of sediments, with varying volumes of volcanic material, contained within sedimentary basins; complexes of igneous rocks derived from the upper mantle and emplaced at various levels of the crust; and migmatitic terranes composed of the metamorphosed equivalents of rocks that were originally either sedimentary or igneous. On a geographical-chronological basis,

| COUNTRY | Value of Metals (millions of Rands) | % of USA | Value of Non-Metals (millions of Rands) | % of USA | Value of Fuels (millions of Rands) | % of USA | Total Value of All Minerals (millions of Rands) | % of USA |
|---|---|---|---|---|---|---|---|---|
| U.S.A. | 67 918.571 | 100 | 82 459.285 | 100 | 284 417.000 | 100 | 434 794.856 | 100 |
| CANADA | 16 259.246 | 24 | 9 416.211 | 11 | 10 541.720 | 4 | 36 217.177 | 8 |
| SOUTH AFRICA | 21 985.618 | 32 | 2 893.212 | 4 | 1 800.418 | <1 | 26 679.248 | 6 |
| AUSTRALIA | 8 309.546 | 12 | 1 650.949 | 2 | 4 046.649 | 1 | 14 007.144 | 3 |
| NEW ZEALAND | 516.856 | <1 | 398.690 | <1 | 695.992 | <1 | 1 611.538 | <1 |
| TOTAL | 114 989.837 | 169 | 96 818.347 | 117 | 301 501.779 | 106 | 513 309.963 | 118 |

Table 2 : Total Realized Value of All Metals, Non-Metals, and Fuels Produced in the U.S.A., Canada, South Africa, Australia, and New Zealand from Earliest Recorded Mining Up to the End of 1971. (Values in millions of Rands)

| COUNTRY | Area (square miles) | Value of Metals (Rands per sq. mile) | Value of Non-Metals (Rands per sq. mile) | Value of Fuels (Rands per sq. mile) | Total Value of All Minerals (Rands per square mile) |
|---|---|---|---|---|---|
| U.S.A. | 3 022 387 | 22 470 | 27 280 | 94 110 | 143 860 |
| CANADA | 3 851 809 | 4 220 | 2 440 | 2 740 | 9 400 |
| SOUTH AFRICA | 472 359 | 46 540 | 6 130 | 3 810 | 56 480 |
| AUSTRALIA | 2 971 081 | 2 800 | 560 | 1 350 | 4 710 |
| NEW ZEALAND | 103 736 | 4 980 | 3 840 | 6 710 | 15 530 |
| AVERAGE | 2 084 274 | 11 030 | 9 290 | 28 930 | 49 250 |

Table 3 : Unit Regional Value of All Metals, Non-Metals, and Fuels Produced in the U.S.A., Canada, South Africa, Australia, and New Zealand from Earliest Recorded Mining Up to the End of 1971. (Values in South African Rands)

nine sequences have been recognized, four major periods of emplacement of igneous complexes, and five metamorphic terranes. Using the publications of the Geological Survey and the reports of mining companies, all the mines that have contributed to the total mineral production up to the end of 1971 have been placed in one or other of these eighteen different environments. The total value of all minerals produced from each of these has been compiled in the tabulation shown in Table 4.

Again, the dominance of the gold deposits of the Witwatersrand Basin in the mineral economy of the country is very conspicuous. The staggering contribution of 68 percent of the value of the gross production has come from this one assemblage of sediments, stretching over a distance of about 500 kilometres in the northern Orange Free State and the southern Transvaal. Surprisingly, the Bushveld Complex, home of platinum, chrome, tin, nickel, vanadium, and fluorspar, and automatically assumed to be the second most important environment after the Witwatersrand Basin, is revealed as lying in fourth place. It has produced five percent of the country's mineral output to date. Ranked above it are the Karroo Sequence and the Transvaal Sequence in which the main sources of wealth are coal, gold, iron ore, manganese, limestone, and asbestos. More than 90 percent of the money realized from the exploitation of mineral deposits has its source in the first six of the 18 environments defined. The remaining twelve environments have contributed less than nine percent.

Knowledge of the various stages in the development of the crust in South Africa has advanced sufficiently so that ages can be attached to the different sequences, complexes, and metamorphic terranes. The Basement granites and greenstones, for example, were formed, for the most part, more than 3 100 million years ago; the Witwatersrand sediments were deposited between 2 500 and 2 800 million years ago; the Bushveld Complex was intruded between 1 900 and 2 000 million years ago; and the Karroo Sequence had its inception about 400 million years ago. The 18 different assemblages have been grouped into 500-million year intervals, as defined in Table 5, and the value of all mineral products removed from all rock formations within each interval has been deduced from Table 4.

A time-dependent pattern to the distribution of mineralization in South Africa becomes apparent, when the relative percentage contributions of each period are considered. The trend over 3 500 million years shows two distinct discontinuities - one between Precambrian 6 (the Basement Complex of granites and greenstones) and Precambrian 5 (the period of formation of the Pongola and Witwatersrand Sequence), and the other between Precambrian 1 (the Cape Granites) and the Post-Precambrian (the period of development of the Cape and Karroo Sequences and the emplacement of the bulk of the diamond-bearing kimberlite pipes). Between Precambrian 5 and Precambrian 1, there is a clear, progressive diminution in the value of minerals produced from each successive period. These two discontinuities in the pattern of mineral wealth coincide with two equally well-defined change-points in the style of development of the earth's crust in Southern Africa. It would seem that the optimum times for the concentration of minerals have been the periods immediately following the two discontinuities. If these latter phenomena represent times of maximum change, then it might be anticipated that, as time passed, so there was an evolution towards maximum stability and minimum mineralization. On the field of exploration, where crustal disruption leads, human diggers follow.

One more point can be made from Table 5. Up to the end of 1971, no less than 84 percent of the total value of minerals won from the crust had come from the various sedimentary basins. The igneous complexes had contributed 11 percent and the metamorphic terranes only 5 percent. With so much of the mineral wealth housed in sediments, it would be natural to assume that South Africa stands in the forefront of the field of applied sedimentology, and that it has made as many significant contributions to a knowledge of sedimentary environments as has the oil industry of America. Such an assumption would be very wrong, indeed. To this day, for some inexplicable reason, the geology of sediments occupies a lowly position in undergraduate curricula in almost all universities in the country. An opportunity to lead has been lost.

What I have mentioned is only a part of the processing to which the mineral production data for South Africa have been subjected. The amounts of each of the 57 minerals which have been won from each of the 18 formations have been determined, as well as the totals of each mineral from the sedimentary sequences combined, the igneous complexes combined, and the metamorphic migmatitic terranes combined. The ores have been classified into native elements, sulphides, oxides, oxyphiles, silicates, halides, and biophiles, and the totals of such ores have also been calculated for each formation and for each general environment. The relative percentage distribution of siderophile, chalcophile, lithophile, and biophile elements through time has been tabulated. But the details of these analyses more appropriately belong in a scientific paper than in an inaugural lecture. Suffice to say here that among the points that have emerged are : the sedimentary sequences are particularly favourable hosts to all the types of ores, with the notable exception of sulphides; the wealth of the

| MAIN GEOLOGICAL UNITS | Value in mill.Rands | % of Total | MAIN GEOLOGICAL UNITS | Value in mill.Rands | % of Total |
|---|---|---|---|---|---|
| Witwatersrand Sequence | 18 350.268 | 67.78 | Malmesbury Sequence | 52.586 | 0.20 |
| Karroo Sequence | 1 907.363 | 7.15 | Cape Granite | 25.384 | 0.10 |
| Transvaal Sequence | 1 479.086 | 5.55 | Natal Migmatites | 11.999 | 0.04 |
| Bushveld Complex | 1 345.170 | 5.05 | Cape Sequence | 6.254 | 0.02 |
| Post-Karroo Complexes | 859.617 | 3.22 | Ventersdorp Sequence | 2.164 | 0.01 |
| Post-Karroo Sequences | 633.581 | 2.37 | Pongola Sequence | 0.834 | <0.01 |
| Post-Waterberg Complexes | 600.292 | 2.25 | Waterberg Sequence | 0.089 | <0.01 |
| Basement Migmatites | 530.759 | 1.99 | Post-Pongola Complexes | 0.000 | 0.00 |
| Namaqualand Migmatites | 523.092 | 1.96 | Total Mineral Production | 26 679.248 | 100 |
| Limpopo Migmatites | 350.710 | 1.31 | | | |

Table 4 : Ranked Total Value (millions of Rands) of All Minerals Produced from the Main Individual Geological Units in South Africa from the Earliest Recorded Mining Up to the End of 1971.

| STRATIGRAPHIC ASSEMBLAGE | Age (millions of years) | Sedimentary Sequences mill. Rands | Igneous Complexes mill. Rands | Metamorphic Terranes mill. Rands | Total Mineral Production | % of Total |
|---|---|---|---|---|---|---|
| POST-PRECAMBRIAN | 0- 500 | 2 547.198 | 859.617 | - | 3 406.815 | 13 |
| PRECAMBRIAN 1 | 500-1000 | 52.586 | - | 25.384 | 77.970 | <1 |
| PRECAMBRIAN 2 | 1000-1500 | - | 600.292 | 535.091 | 1 135.383 | 4 |
| PRECAMBRIAN 3 | 1500-2000 | 0.089 | 1 345.170 | - | 1 345.259 | 5 |
| PRECAMBRIAN 4 | 2000-2500 | 1 481.250 | - | 350.710 | 1 831.960 | 7 |
| PRECAMBRIAN 5 | 2500-3000 | 18 351.102 | - | - | 18 351.102 | 69 |
| PRECAMBRIAN 6 | 3000-3500 | - | - | 530.759 | 530.759 | 2 |
| TOTAL PRODUCTION | 0-3500 | 22 432.225 | 2 805.079 | 1 441.944 | 26 679.248 | 100 |
| PERCENT OF TOTAL | | 84 | 11 | 5 | 100 | |

Table 5 : Ranked Total Value (millions of Rands) of All Minerals Produced from 500-m.y.-long Stratigraphic Assemblages in South Africa from the Earliest Recorded Mining Up to the End of 1971.

igneous complexes is essentially in sulphides, halides, and oxides; by far the greatest amounts of sulphide ores have been mined in the metamorphic terranes; the only other minerals that have economic significance in these environments are the silicates; the crust of South Africa seems to have been more favourable for the accumulation of native elements than for all the other types of ores; it is apparently unusually deficient in sulphur.

I have attempted to show the type of service which the Economic Geology Research Unit has been providing for the mining industry which founded it. Without sophisticated laboratories and numerous staff, it has been able to create new frameworks for future decisions in mineral exploration. The simple operation of taking dry statistical data from dusty shelves and converting them into information of another kind has yielded distribution patterns of mineralization in time and space that give a quantitative base to the old intuitions of what ores are preferentially concentrated where in South Africa. The shifting of emphasis from the worth of individual deposits to the valuation of the whole of the environment in which they occur perhaps satisfies the recommendation of Griffiths and Singer (1971) that, to guarantee the future success of the search for ore, it will be necessary to reorient the outlook on exploration by redefining the objective from prospecting for a single type of individual deposit, such as an oilfield or a gold deposit, towards looking at exploration as an attempt to set up a regional inventory of natural resources.

## THE NEXT PROBLEMS

I have taken as the theme of my inaugural lecture the beginnings of the Economic Geology Research Unit, the reasons why it came into existence, the objectives it set itself, and the directions it chose to follow. I have also spoken briefly of some of the things it has done in the past thirteen years. To end the lecture, perhaps I should speculate upon the end of the Unit.

All institutions outlive their usefulness. Very few die in full flower of their glory, if they achieve this latter state. The beginning of the end will come for the Unit when it is no longer of use to the mining industry in South Africa. It would be a sad event were the Unit to continue its existence beyond such a point. Its uniqueness has lain in its being a bridge between the industrial and the academic worlds. When the bridge will become a useless structure is beyond the focus of my clairvoyance. I believe that it could stand for a long time because I believe that there is still much to be discovered in the course of mineral exploration, that men will continue to search for minerals as long as they think that they can make money from the contents of the earth, and that, as the search becomes more and more difficult, so ideas, rather than implements, will become more and more the keys to success. As long as E.G.R.U. can continue to generate some of those ideas, it will survive.

From the high hill which the journey has now reached, the road ahead looks good and exciting. Two new challenges have been presented by the mining industry. After a decade in which the main effort of research was spent in the sedimentary basins and their contained mineralization, particularly of gold, work has started on the problems of mineral deposits in the igneous complexes and the metamorphic terranes. These two mega-environments have so far contributed only 16 percent of the mineral production of the country. Is this a true reflection of their relative potential worth, or is it a measure of the limitations of the concepts employed in exploration so far? Is there a new way of looking at the problems, which will give rise to a different conceptual model of target areas? And, most important, how much is really known, not postulated, about the origins and geological histories of the igneous complexes and metamorphic terranes, and of the chapters within those histories when the milieu of mineralization was in full magnificence? Ahead is another decade, perhaps two, one for each mega-environment, of defining new problems and proferring new solutions, of carrying out useful research.

In 1963, Leopold and Langbein said : "Any aspect of science may flounder temporarily on the shoals of small questions, of details, as well as on the dead-end shallows of description. Resurgence of activity and interest can revitalize a subject when the questions posed are big ones, questions, which, if answered, have wide applicability or lead to broad generalization. But generalization is the broadening of associations, the spreading of a foundation for reasoning. The big question is one the answer to which might open up new or enlarged areas of inference or association". The goal of the Unit will continue to be the asking of the big questions.

One such first-order question is whether or not the geology of South Africa can be accommodated within the new thinking that has revolutionized the earth sciences in the past decade. Sylvester-Bradley (1971) has said : "It almost seems that we are in sight of formulating a new 'theory of the Earth', a general theory embracing all geological processes, including those now becoming clear as a result of our understanding of global tectonics". The concepts of continental drift, ocean-floor spreading, and plate tectonics have caused geologists to take a new view of the manner and style of evolution of the whole earth. As in all revolutions, there is a tendency for the mob to over-react. Today, virtually everything, from the generation of gold deposits to the disappearance of the dinosaurs, is being accounted for according to the models devised for the new global tectonics. The contemporary heretic is the scientist who does not religiously subscribe to the infinite infallibility of plate tectonics as an explanation of all that has happened throughout the whole of geological time.

There is excitement and challenge in the particular period of geogenic innovation through which the earth sciences are now moving. There are great expectations that a better and more comprehensive understanding of geological history is about to be revealed. To help prevent the tide of optimism from ebbing into a dead sea of arrogance, it is imperative that the problems of crustal evolution and ore genesis continue to be looked at through models other than that of plate tectonics. It is not too long ago that South Africa's was one of the very small number of voices crying out from the wilderness in support of the then new hypothesis of continental drift; the rest of the scientific world would have no part of it. Now, that same world is jam-packed on the band-wagon of plate tectonics. Perhaps, for tradition's sake, there should be marchers in South Africa stepping to the sound of a different drummer. Let the full spectrum of geology in this country be looked at within the framework of the plate-tectonics model, by all means, but let there be room, also, for the presently less fashionable models. Let there always be some group of geologists somewhere, no matter how small, prepared to look at the big questions in a different way.

In the heady environment of the present revolution, the tribunals can see no reasonable man's not being joyously converted to the new 'theory of the Earth'. It would be well to remember what Bernard Shaw said : "The reasonable man adapts himself to the world; the unreasonable one persists in trying to adapt the world to himself. Therefore all progress depends on the unreasonable man".

* * * * * * * * * * * * * * * * * * * * * * *

*References*

Bailly, P.A. (1967) - Mineral Exploration and Mine Developing Problems - Statement presented to the Public Lands Law Conference, University of Idaho, Boise, Idaho, 44 pp.

Beer, S. (1959) - Cybernetics and Management - John Wiley and Sons, Inc., New York, 214 pp.

Bronowski, J. (1964) - Science and Human Values - Penguin Books, Harmondsworth, Middlesex, 94 pp.

de Bono, E. (1971) - Lateral Thinking for Management - McGraw-Hill Book Co., Maidenhead, Berkshire, 225 pp.

Flawn, P.T. (1965) - Who Took the "Economic" Out of Economic Geology? - Economic Geology, Vol. 60, No. 1, p. 172-175.

Grayson, C.J. (1960) - Decisions Under Uncertainty : Drilling Decisions by Oil and Gas Operators - Graduate School of Business Administration, Harvard University, Boston, Massachusetts, 402 pp.

Griffis, A.T. (1971) - Exploration : Changing Techniques and New Theories Will Find New Mines - World Mining, Vol. 24, p. 54-60.

Griffiths, J.C. (1970) - Current Trends in Geomathematics - Earth Science Reviews, Vol. 6, p. 121-140.

Griffiths, J.C. (1971) - Geometrics - unpublished notes for a post-graduate course at the Pennsylvania State University, University Park, Pennsylvania.

Griffiths, J.C., and Singer, D.A. (1971) - Unit Regional Value of Non-Renewable Natural Resources as a Measure of Potential for Development of Large Regions - Special Publication No. 3, Geological Society of Australia, p. 227-238.

Lasky, S.G. (1947) - The Search for Concealed Deposits : a Reorientation of Philosophy - Technical Publication 2146, American Institute of Mining and Metallurgical Engineers, Mining Technology, Vol. 11, No. 3, 8 pp.

Leopold, L.B., and Langbein, W.B. (1963) - Association and Indeterminancy in Geomorphology - p. 184-192 in Albritton, C.C. (ed.) : The Fabric of Geology, Addison-Wesley Publishing Co., Reading, Massachusetts, 372 pp.

Mitcham, T.W. (1969) - Economic Geology Research - Economic Geology, Vol. 64, No. 1, p. 72-74.

Preston, L.E. (1960) - Exploration for Non-Ferrous Metals : an Economic Analysis - Resources for the Future, Inc., Washington, D.C., 198 pp.

Sheehan, R. (1964) - Great Day in the Morning for Texas Gulf Sulfur - Fortune, Vol. 70, No. 7, p. 137-130, 254-258.

Simon, H.A. (1969) - The Sciences of the Artificial - Massachusetts Institute of Technology Press, Cambridge, Massachusetts, 123 pp.

Sylvester-Bradley, P.C. (1971) - Processes of Geological Evolution - Journal of the Geological Society, Vol. 127, p. 477-481.

* * * * * * * * * * * * * * * * * * * * *