National Geoscience Programme

The Evolution of Earth Resource Systems

SACUGS

Programme developed by the South African National Committee
for the International Union of Geological Sciences

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PREFACE

During the past 20 years the South African geological community has participated on a coordinated basis in national geoscience programmes - first the Upper Mantle Programme and more recently the National Geodynamics Programme. Both these programmes formed part of international programmes undertaken at the time under the aegis of the International Union of Geological Sciences and the International Union of Geodesy and Geophysics. These programmes succeeded in mobilising a large section of the academic geological community and scientifically the NGP has achieved a striking improvement in knowledge of the nature of several southern African mobile belts and zones, their contacts with cratonic regions and their geological history. There has also been a major improvement in knowledge of the Karoo volcanic episode.

During 1977 the South African Committee for the IUGS which was responsible for coordinating the National Geodynamics Programme, considered the question of a successor to it. It was agreed that a new cooperative national programme should be developed which would place strong emphasis on earth resources. The reason for this stems from the growing concern that world resources of certain key mineral commodities are diminishing at an alarming rate and in many cases they seem to be insufficient to last beyond the end of this century at present rates of consumption. In order to maintain or even improve the standard of living of mankind it is imperative for earth scientists to locate new mineral resources. For this reason it was decided that the South African successor programme should concentrate on principles of element concentration in order to assist the mining industry, through research, to undertake exploration in areas hitherto considered as devoid of mineralization or at depths beyond which exploration is currently possible. While the programme would not be designed necessarily to correspond directly with the programmes being developed internationally to succeed the International Geodynamics Programme, it was anticipated that certain sections might well contribute to it.

Much effort has since been put into the development of the programme contained in this document and I should like to express my sincere appreciation to all those who contributed towards it. The programme represents the geo-scientific research which, in the opinion of the South African geological community, should be undertaken on a cooperative basis between earth scientists from government, university and private organizations. I am satisfied that the work proposed will be of great benefit to the country as a whole and therefore have pleasure in inviting all research groups in the country who have the necessary interest and expertise, to participate in it.

C F GARBERS
PRESIDENT OF THE CSIR and CHAIRMAN OF SACUGS

A B S T R A C T

This report contains an outline of the research proposed for the National Geoscience Programme which has as its main theme the study of the processes of ore formation in the earth's crust. Research will focus on the development of conceptual models for ore genesis which could be applied in the search for new ore concentrations.

In the first part of the report the existing knowledge in the field of ore genesis in the different geological environments (igneous, metamorphic and sedimentary) is analyzed and deficiencies are highlighted. The available geological maps are reviewed and maps still required are identified. The research and exploration techniques currently being applied in South Africa are outlined and areas which require more research and development are discussed.

It is recognized that to address all the identified problems at the same time would be impossible in the light of the manpower and finance available. In order, therefore, to ensure an integrated coordinated research effort, seven sub-programmes embodying some of the major problems, were selected. The second part of the report summarizes the existing knowledge in these sub-programmes and outlines their aims. Priority areas for research are noted and briefly described.

A guide for participants in the programme, including a code of conduct and a format for project proposals and for the reporting of research results is included.

O P S O M M I N G

Hierdie verslag skets die navorsing wat voorgestel word vir die Nasionale Geowetenskappeprogram, met as hooftema die bestudering van die ertsvormende prosesse in die aardkors. Die navorsing is gerig op die ontwikkeling van konseptuele modelle vir ertsgenese wat toegepas kan word in die soektog na nuwe ertskonsentrasies.

In die eerste gedeelte van die verslag word die bestaande inligting oor ertsgenese in die onderskeie geologiese omgewings (stollings, metamorfe en sedimentêre gesteentes) geanaliseer en die tekortkominge uitgewys. Die bestaande geologiese kaarte word kortliks bespreek en daar word aangedui watter benodig word. Die navorsings- en eksplorasietegnieke wat tans in Suid-Afrika toegepas word, word in oënskou geneem en die gebiede waarop verdere navorsing en ontwikkeling nodig is, beskryf.

Omdat 'n gelyktydige ondersoek van al die uitgekende probleme onmoontlik sal wees, veral met inagneming van beperkte mannekrag en fondse en om 'n geïntegreerde gekoördineerde navorsingspoging te verseker, is sewe subprogramme geformuleer om vir sommige van die belangrikste probleemgebiede voorsiening te maak. In die tweede gedeelte van die verslag word beskikbare kennis oor die subprogramme opgesom en hul oogmerke beskryf. Prioriteitsgebiede vir navorsing word ook aangedui en kortliks beskryf.

'n Gids vir deelnemers aan die program wat 'n gedragskode en riglyne ten opsigte van projekaansoeke en verslagdoening bevat, is ook ingesluit.

L I S T O F C O N T E N T S

INTRODUCTION

Since the early sixties the South African geological community has participated on a cooperative basis in first the Upper Mantle Programme and later during the seventies in the National Geodynamics Programme. During the Upper Mantle Programme the South African contributions concentrated mainly on a study of the composition of the mantle based mainly on inclusions found in kimberlites and on evidence from the greenstone belts using Barberton as a model. The National Geodynamics Programme which formed part of the International Geodynamics Programme, was a logical successor to the Upper Mantle Programme. It concentrated on dynamic processes in the earth's crust and resulted in a better knowledge and understanding of the major southern African mobile belts and zones as well as their contacts with cratonic regions. There has also been a major improvement in our knowledge of Karoo volcanics.

When the question of a successor programme to the National Geodynamics Programme was first discussed at a meeting of the South African National Committee for the International Union of Geological Sciences (SACUGS) in 1977, general consensus was reached on two issues and these views have been confirmed subsequently through consultation with the geological community. Firstly, it was agreed that the expertise which had been built up during the Geodynamics Programme should not be allowed to be dissipated and that a new programme should thus be formulated to utilize, as far as possible, the knowledge gained. Secondly, it was agreed that the new programme should have a strong economic emphasis and be designed to address geological problems which were of immediate national importance. It was known at the time that within the IUGS and IUGG community internationally, a successor programme to the International Geodynamics Programme was being considered, but felt that the content of the new programme in South Africa should be controlled by national rather than international considerations. Obviously international developments would be monitored and such parts of the new national programme as would fit in with what was being developed internationally, could be offered as a contribution to the global effort.

It is against this background that various groups of geologists and geophysicists in the country have over the past three years put a large amount of effort into the formulation of the new National Geoscience Programme in consultation with the broadest possible spectrum of earth scientists. These consultations culminated in agreement that the theme of the programme would be 'The Evolution of Earth Resource Systems' with, as its broad objective, an improved understanding of the principles and processes whereby elements concentrate in the earth's crust to form ore deposits. Although the programme would not involve itself with mineral exploration - emphatically acknowledged as the concern of commercial enterprise - the results obtained from the programme could be expected to form the basis for the development of models which could be used in the search for new mineral concentrations. In addition it was accepted that research aimed at improving search methods would form a valid component of the programme.

To formulate a programme which achieves these objectives various approaches are possible and were considered. One way would have been to divide economic deposits into genetic groups, another to classify them according to composition. Since, however, most mineral concentrations are formed by normal igneous, sedimentary and metamorphic rock-forming processes, it was decided to approach the formulation of the new programme with this as the basis.

Because it is recognized that the tectonic setting is of major importance in understanding geological processes, this was also incorporated in the approach. Furthermore, since certain economically important elements occur in all geological environments, it was accepted that the programme should also accommodate projects designed to study specific commodities irrespective of the environment in which they were concentrated.

Based on these considerations, six groups comprised of experts within each of the fields, were established and the overall framework contained in the next section of this document was developed. It contains a statement of the major deficiencies in current understanding of the ore-forming processes applicable in South Africa. Accepting, however, that the research suggested in this part of the document could not all be undertaken simultaneously, the overall framework was circulated amongst the geological community in South Africa with the aim of gauging participation interest and the available expertise and facilities. Based on the results of this process, the research to be undertaken in the first years of the programme was narrowed down to a number of sub-programmes described in a later section of the document. These sub-programmes were developed to concentrate the maximum possible multi-disciplinary effort into a limited number of narrowly defined, integrated studies. They will be regularly reviewed in the light of progress made in order to adapt to changing needs.

Management of the Programme

The National Geoscience Programme is coordinated through SACUGS who advises on the overall direction of the programme, guides its development within the agreed programme framework and, with a view to the optimum utilization of the available manpower and facilities, monitors progress within it and recommends on the dissemination of the results obtained. It also advises on the acquisition and allocation of funds obtained through the CSIR and other sources.

SACUGS in turn is advised by an Evaluation Committee, comprising a limited number of sage scientists who will not be directly involved in the research work being undertaken in the programme, together with a number of representatives of the groups undertaking the research. The Evaluation Committee will be responsible to SACUGS for:

- the balanced development of the research effort

- regularly reviewing the programme in the light of new information becoming available

- evaluating research proposals within the framework of the programme and in the light of the available manpower and recommending on their financing

- facilitating the logistics of the programme, and

- reviewing progress within the programme and ensuring the prompt publication of results.

The members of the Evaluation Committee not directly involved in the research being undertaken, constitute the Management Panel for the programme.

The Evaluation Committee will have the power to coopt members for specific meetings as required and it may also request the establishment of subcommittees to coordinate and to report to it on specific sections of the programme.

Convenors

A convenor is appointed for each sub-programme to assist with the coordination of the research within it.

OVERALL PROGRAMME FRAMEWORK

THE TECTONIC AND TEMPORAL FRAMEWORK OF SOUTHERN AFRICA

When comparing geoscience maps of southern Africa with those from any other part of the world, one is struck by the lack of meaningful tectonic or metallogenic maps for the region. At the same time, when examining specific studies done on tectonics or metallogeny in southern Africa, it is evident that much pertinent information on these two topics is available. It is suggested that the main contribution under this sub-programme should be synthesis and compilation of a large range of available relevant basic data in the construction of tectonic and metallogenic maps for South and perhaps southern Africa. Major tectonic episodes in the development of the southern African region should be identified and their timing, nature, distribution and economic importance documented. Models for the control of mineralization should finally be established for each major tectonic event and/or metallogenic province.

To establish a framework for the construction of the above maps the compilation of basic data should in the first instance be on a regional or semi-regional scale, perhaps 1:250 000 or 1:500 000 for specific well documented regions such as the granite/greenstone terrane of the northern and eastern Transvaal through 1:1 000 000 scale compilation up to scales of 1:2 500 000 for regional maps of southern Africa. Some of these maps already exist and others are being compiled.

At a later stage new information generated by other groups working on the cooperative National Geoscience Programme could be added to the basic data maps as well as new information from other sources. The final phase of the sub-programme would be the integration of all data in the compilation of tectono-metallogenic maps for South and southern Africa.

Stage 1 : Compilation of basic data maps

Under this theme it is envisaged that basic data maps will be made with a view to understanding the formation of earth resources within their tectonic and temporal settings and to facilitate the construction of conceptual models which could eventually be used in exploration.

A geological trend and fault map could be based on available regional maps and should depict major geological units. To this could be added details of lithology and stratigraphy as well as gneissocity trends, etc. The main emphasis, it is suggested, should be on the plotting of geological form and stratigraphic and/or structural trends. At the same time new information on geological trends, which could be obtained from the interpretation of computer enhanced satellite imagery, could be added to this compilation. All major faults, shear zones, mylonites, breccia zones, etc. should also be plotted on this map.

An additional Landsat interpretation map is envisaged which would concentrate largely on the plotting of linear and circular features. Such features are of importance with respect to the process of vertical tectonics which appears to have controlled the development of the Precambrian sedimentary basins of South Africa. Certain commercial groups or companies in South Africa have already undertaken such studies and it might be possible to obtain information from them.

The emphasis for a small dimension intrusion map would be on the representatation of relatively small dimension geological features which may be indicators of tectonic episodes or characteristic tectonic environments. It would include the plotting of such features as kimberlites, carbonatites, alkaline intrusions, ultrabasic intrusions, basic intrusions, volcanic vents, diatremes, dyke swarms, sills, high level granite plutons, pegmatite swarms, etc. This information would probably best be displayed against the background of a tectonic map and could be added after such a map had been constructed. The information could be extracted largely from published and unpublished maps.

A metamorphic facies map would involve the compilation and interpretation of geological information to produce a map showing the distribution of metamorphic facies both regional and contact, on a scale of perhaps 1:2 500 000. Such a map has been constructed at Natal University and hopefully it might be possible to use this information in large part on a suitable scale. New information will be generated by the metamorphic terranes sub-programme and will be incorporated in this compilation at a later stage.

An earthquake centre map would be a regional compilation on a scale of 1:2 500 000 showing the location and intensity of all earthquakes recorded in southern Africa. The position and nature of all known hot and cold springs could also be indicated. Information could be obtained largely from official publications of the various geological surveys and compiled onto a suitable scale using a standard format. Contours of earthquake density could also be constructed.

On an isotopic age map the sites of isotopic age determinations could be plotted. The map could be at a scale of 1:2 500 000 and its format could be based on that of the isotopic age map of Canada so that each sample would be marked with a coloured symbol indicative of the type of rock analysed, and a code which would indicate the mineral analysed, the dating methods, the isotopic age and the laboratory at which the analysis was performed. On the map for Canada this information is presented against a simplification of the tectonic map and a similar background could be used for the map of southern Africa once a tectonic map has been constructed. Although complicated, an attempt could be made to outline and demarcate major regions of similar age while at the same time indicating regions where reworking has occurred and where a range of different ages has been obtained.

A basement basin and dome map would indicate axes of major troughs and/or basin centres as well as regional upwarps of dome centres developed on the crystalline basement of southern Africa. In large part the map would be based on the thinning and thickening features of the younger sedimentary and volcanic supracrustal rocks of southern Africa. Many companies or groups have compiled this type of information and much of it would probably be readily available.

Although gravity maps of South Africa and SWA are available, the results of the recently completed gravity survey of Botswana as well as the results of further national gravity surveys, and surveys undertaken by groups or companies, could be added to produce a Bouguer gravity anomaly map of southern Africa. It is envisaged that such a map could highlight gravity anomalies and also distinguish between those that can be explained in terms of known geological features and those that are not readily accounted for.

Systematic aeromagnetic surveys are currently only being flown by the Geological Survey of South Africa and published in the form of 1:50 000 and 1:250 000 sheet maps. Only a limited number of such maps have been published to date. In addition information is also being produced by other privately flown aeromagnetic surveys, for example by various mining companies in the North-west Cape and other areas. The compilation of a magnetic anomaly map of southern Africa is required. As in the case of the gravity data, anomalies could be highlighted and those that can be interpreted in terms of known geology distinguished from those that cannot be explained.

Systematic radiometric surveys are being conducted simultaneously with the airborne magnetic survey by the Geological Survey of South Africa and published as map sheets at scales of 1:50 000 and 1:250 000. Private radiometric surveys have also been conducted by individual mining companies. Using this information it is proposed that radiometric maps of southern Africa at perhaps several different scales could be constructed. Once again anomalies explained in terms of known geology could be highlighted and distinguished from those that are not readily explained.

A series of maps displaying the position and nature of all recorded mineral occurrences in South and perhaps southern Africa could be compiled. Information could be based on such publications as 'Mineral Resources of South Africa', the new series of 1:250 000 mineral occurrence sheets, the data file on mineral occurrences at the Geological Survey and any other suitable source. Symbols could be used for different occurrences to indicate the nature and geological setting of the occurrence as well as its relative significance. Such symbols could follow the nomenclature used on the Carte Minêralogique de l'Europe. A map of this type is at present being compiled by the Geological Survey and may well cover what is envisaged here.

In addition to the above examples of the type of information that would probably be necessary for the compilation of the tectonic and metallogenic maps envisaged in stage 2 below, other kinds of basic maps may also be considered.

Stage 2 : Synthesis based on the interpretation of basic data maps

As the final task towards the end of the programme, it is envisaged that information contained in the data maps will be interpreted and synthesised for the construction of a major tectonic episode map and a metallogenic domain map.

The major tectonic episode map would show the distribution as well as highlight in chronological sequence, episodes of major tectonic or geological importance in southern Africa. This would probably be in the form of two or more maps, the first depicting the tectonic episodes of the crystalline basement and the second and third, more recent tectonic events.

The metallogenic domain map would probably be the most important of the maps produced and would be complementary to the tectonic episode map. For example, because of the association of the platinoids with the mafic rocks of the Bushveld Complex, the distribution of these rocks will constitute a metallogenic domain for the platinoids. Similarly the North-west Cape represents a region consisting of several very distinctive major domains. These include copper mineralisation in noritoid bodies of the O'okiep area and the copper-molybdenum mineralization associated with the Vioolsdrift granodiorite suite. In the case of the former the extent of noritoid occurrences and certain structural features demarcate this distinctive province, whereas in the latter the extent of the granodiorites demarcates the extent of the Cu-Mo metallogenic domain. When finally compiled, it is envisaged that much of southern Africa would be divided into metallogenic domains each with its own distinctive (and perhaps unique) mineral occurrences.

THE CONCENTRATION OF EARTH RESOURCES RELATED TO IGNEOUS PROCESSES

Igneous complexes are the source of a large variety of ores of magmatic origin. Mafic and ultramafic complexes, both the large stratiform type and the mostly ultramafic intrusive and extrusive bodies, house the world's principal deposits of elements of the platinum group (PGE), Ni, Cr and V. Rare earth elements, apatite, magnetite, Nb, F, Cu, U and Th are recovered from alkaline carbonatitic complexes, whereas concentrations of Sn, F, Mo, W, Li, Cu, Pb, Zn, U, etc. can be related to late stage crystallization processes in plutons of granitic composition. A better understanding of the processes responsible for the concentration of these elements forms the basic objective of the research in this sub-programme.

Theme 1 : Ni-Cu mineralization at the base of mafic/ultramafic complexes

An important type of Ni-Cu mineralization is found as either massive ore or as disseminations at the base of the larger layered intrusions such as Sudbury, Duluth, Stillwater and Bushveld and also smaller intrusives such as Insizwa. Considerable controversy prevails amongst researchers as to whether these deposits were formed by gravitational settling of an immiscible sulphide liquid containing sulphur derived from the mantle together with the host silicate magma, or whether part of the sulphur was derived through contamination of the magma by crustal rocks.

What is required for ores of this nature to form are processes by which the solubility of sulphur can be reduced rapidly in order for a significant amount of sulphide liquid to become immiscible at a particular stage in the crystallization history of a silicate magma. The sulphur in excess of that required to saturate the magma can then settle to the floor of the magma chamber as a sulphide melt to form a Ni-Cu-sulphide deposit. Experimental work suggests that the solubility of sulphur in a mafic melt can be reduced by oxidation of the magma, silicification through assimilation of felsic rocks, a decrease in temperature and possibly also by a decrease in pressure.

Geological evidence indicates that peridotitic komatiites associated with Ni-sulphide deposits were probably saturated in sulphur at the time of emplacement and that immiscible sulphide liquids were concentrated from a large volume of magma to form the ore deposit. The larger layered and other smaller mafic intrusions, on the other hand, were probably undersaturated in sulphur at the time of emplacement and sulphide concentrations are considered to be the result of one or a combination of several of the processes listed above. Assimilation of sulphur is an attractive mechanism to account for sulphide disseminations at the base of gabbroic intrusions. The precise mechanism, however, is not understood and questions that are still unanswered are, amongst others: What are the required sulphur concentrations in the country-rock for effective contamination? How do sulphur isotopes behave during assimilation? Does contamination take place through a process of degasification during metamorphic reactions or is large scale assimilation of the country-rock required?

Scientists are still faced with considerable problems when it comes to recognizing sulphur saturated magmas. Various approaches have been adopted recently, such as the Ni/forsterite ratio in ultramafic parts of intrusions. Investigations also indicate that PGE are much more sensitive to the separation of sulphide melt and these elements may possibly become an important aid in the distinction between saturated and undersaturated intrusions. However, in order to attempt modelling of this nature, a much better understanding of the interaction of sulphur and silicate melt as a function of temperature, pressure, fO_2, fH_2O and composition is required, as well as knowledge of the partition coefficients of the principal elements involved.

In addition, world wide comparison of economic Ni-Cu ores has shown that those of the synvolcanic association in Archaean greenstone belts are of considerable importance. Ni-Cu deposits of this type are moderately sized, high grade ores at the base of flows of peridotitic komatiite. Large, lower grade deposits are found with associated intrusive dunitic lenses.

No significant Ni-Cu deposits are known from the Archaean greenstone belts of South Africa even though such deposits occur in similar rock-types in Zimbabwe. The reason for this is not understood and detailed investigations on all aspects of these intrusive and extrusive komatiitic rocks are necessary in order to define the parameters which determine whether a komatiitic suite is barren or mineralized.

Massive Cu-Pb-Zn base-metal sulphide deposits are known to be associated with the felsic to mafic components of ancient volcanic complexes. These are dealt with within a theme of the sub-programme on sedimentary processes.

Theme 2 : Mineralization within mafic/ultramafic complexes

Considerable attention has been focused in recent years on the petrogenesis of PGE concentrations in layers of large layered intrusions containing disseminated sulphide and various hypotheses have been advanced to account for these. It seems unlikely that the Bushveld magma was unduly enriched in PGE and, as the partition coefficent for PGE is such that an immiscible sulphide liquid would contain in the order of 6 ppm, the near to 100-times enrichment of the sulphides of the Merensky Reef and the UG2 chromitite layer in these elements remains enigmatic. Different processes have been called upon, therefore, for the PGE enrichment in the weakly disseminated sulphide layers in layered intrusions. Suggested models are that chromite acted as collector for the PGE, precipitation of Pt-Fe-alloys directly from the magma and enrichment of PGE in ascending, intercumulus fluids and their precipitation in weakly disseminated sulphide layers.

Our understanding of these ores, and consequently also our ability to reconstruct the events which led to their formation, is hampered by our lack of knowledge of how the PGE partition amongst the precipitating phases in mafic magmas occurs and also by our lack of knowledge of the nature of the late magmatic liquids and their effect in concentrating the ores. Evidence for the presence of such late magmatic liquids abounds in the Bushveld Complex and the relatively little studied mafic/ultramafic pegmatoids are probably a manifestation of these.

The origin of virtually monomineralic layers of chromitite and vanadiniferous titanomagnetitite remains a problem area in igneous petrology. Different processes have been proposed to enhance the crystallization of oxides and the gravitational settling of these to form magnetitite and chromitite layers. The problem with most of these is that they fail to account for the tremendous lateral continuity of the layers in e.g. the Bushveld Complex. For this reason, fluctuations in total pressure seem to be a very attractive mechanism, although it still has to be demonstrated that phase boundaries can be shifted by the required extent under the changes in pressure which can be expected in intrusions such as the Bushveld Complex.

From textural evidence it is obvious that enlargement of crystals must also have taken place after their accumulation as a layer on the floor of the intrusion. Crystal growth by adcumulus processes is not clearly understood and for this reason a post-cumulus process of annealing or sintering has been proposed to account for the in-place enlargement of chromite and magnetite grains.

A revolution in this thinking seems to be taking place at present amongst student of layered intrusions and serious doubt is being expressed as to whether crystals will actually sink in a magma. In order to gain a better understanding of the reason for layering in intrusions and of the origin of layers of economic importance within them, detailed modelling is required of especially the physical parameters within magmas, such as temperate, pressure, viscosity, yield strengths of magmas and crystals, density differences at high temperatures between crystals and the magma from which they crystallize, etc.

The recognition that domes in the Bushveld Complex may have been active during the emplacement and crystallization of the mafic magma, may also be of economic significance. Such areas would enhance the chances of an interaction between sediments and the magma and may explain the irregular distribution of sulphides within the complex. The presence of transgressions of the Bushveld into floor-rocks, and the associated uplifting of sediments, may also have significant implications, but require considerable basic research before it can be used as a conceptual model for exploration, the eventual aim of the programme.

In addition to the layered complexes, significant elemental concentrations also occur in smaller intrusions, the most notable of which are the copper deposits at O'okiep and the chromite deposits at Lemoenfontein and Shilo as well as those described from the eastern Soutpansberg area. The lateral limits of the ore occurrences and the source bed concept are aspects which require particular attention in the case of the noritoid complexes, whereas the chromite concentration and distribution within tectonically emplaced complexes are still poorly understood.

Theme 3: Mineralization associated with granitic intrusives

Our understanding of the mechanisms controlling the concentration of metals in granite intrusions has advanced considerably in recent years. It is conceivable however, that the efficiency of the processes may vary in different intrusions and this may be responsible for the fact that only certain intrusions are mineralized.

A further important aspect of mineralization associated with granitic intrusives are the processes which lead to final concentration and deposition of the ores, either as endo- or exogranitic bodies. Liquid immiscibility of highly fractionated liquids enriched in incompatible elements has been proposed to explain the derivation of certain of the mineralizing fluids. The conditions required to produce these highly fractionated liquids, the conditions favourable for immiscibile liquids to form and the partitioning of incompatible elements into these highly fractionated liquids, are not understood.

Interaction between fluids of hydrothermal origin and surrounding rocks is considered an important aspect of vein deposits. Some work in this direction has recently been done on a vein deposit in Bushveld granite and it was possible to draw certain analogies with the classic alteration patterns associated with the porphyry copper-type deposits. The nature and type of the wall rock seems to have important control especially in the origin of the exogranitic deposits.

It is generally agreed that pegmatites can form in two different ways, namely pegmatites of igneous affiliation (which form from the residual, volatile-rich fractions of magmas) and metamorphic pegmatites (which represent a concentration of the more mobile constituents of a rock subjected to regional metamorphism). Both types occur over large areas in the granite terrane of the North-west Cape. In view of the strategic minerals they contain, their importance cannot be underestimated. The realization that important mineral assemblages are associated more with albititic or plagio-granitic rock types rather than with granitic (sensu stricto) pegmatites is a matter which warrants careful consideration.

Theme 4 : Mineralization in alkaline complexes

Subvolcanic intrusions, breccias and diatremes of alkaline rocks are hosts to interesting concentrations of a large variety of metals. Concentrations of metallic elements are probably related to late stage gaseous or magmatic fluids as a result of strong fractional crystallization of magma.

Differences in alkaline rock types and associated element concentrations within them, cannot only be related to different, highly effective fractionation processes, but must also be related to a variety of original liquid compositions. Liquids of alkaline composition may be generated by small amounts of partial melting in fairly deep parts of the upper mantle where depletion of incompatible elements has not taken place during a previous melting episode. A topic of fundamental importance in this regard and one with obvious implications for exploration is the question as to whether the carbonatites of alkaline complexes are ultimately derived from kimberlitic magmas.

The coexistence of carbonate-rich and silicate magmas in alkaline complexes is widely accepted as being the result of liquid immiscibility. The fractionation of elements into one or the other of these two liquids is considered an important metal concentrating process. Low temperature assemblages with which hematite, barite and fluorite are associated are most likely to be the host rocks for incompatible elements such as uranium, thorium and the rare earths.

Where concentrations of apatite and magnetite are associated with pyroxenite and carbonatite in alkaline complexes they are considered by some investigators to be cumulates, in which case they may be associated with other refractory minerals such as baddeleyite, olivine, pyroxene and perovskite. In other complexes apatite-magnetite assemblages show textures suggestive of immiscibility.

At Phalaborwa late hydrothermal activity is postulated to account for the copper mineralization. If gaseous phases evolve then uranium tends to fractionate into these and is ultimately deposited in veins. This would be significant in F-rich magma where the uranium is complexed with fluorine and precipitated when the complex breaks down through reaction with Ca-rich rocks or minerals.

Study of the fractionation and partitioning of elements into liquid and minerals respectively may be of considerable assistance in understanding ore forming processes and in the evaluation of potentially mineralized or unmineralized intrusions. Dolomitic carbonatite assemblages are generally considered to be of late-stage origin compared to the earlier calcitic assemblages. The processes responsible for these differences are not clearly understood and the relative importance of magmatic processes vs gaseous activity needs to be evaluated.

THE CONCENTRATION OF EARTH RESOURCES RELATED TO SEDIMENTARY PROCESSES

The sub-programme comprises four broad themes. The purpose in restricting the number is to focus attention on particular fields appearing to need research and also to facilitate interaction among individuals or groups of scientists working on closely related topics. Conceptually oriented proposals are required dealing with fundamental controls on the concentration and localization of particular types or associations of mineral resources in sedimentary basins. The aim will be the establishment of models based on well documented occurrences which may contribute to a better understanding of more obscure or complex situations elsewhere. The intensive study of key areas may offer the best approach and these should be carefully chosen to yield the greatest scientific return.

Theme 1 : Placer deposits, ancient and modern

The types of sedimentary environment in which placers may occur are well known and include the upper parts of tidal and storm beaches, shorefaces of barrier bars and destructive deltas. Alluvial deposits of meandering and braided streams are also important and there are indications from Australia that aeolian dune fields may in certain circumstances contain placer deposits.

A prerequisite for placer formation is the availability of heavy minerals in the necessary quantity and size distribution. Given known primary source areas, detailed palaeogeographic and palaeoslope analyses may be essential aids to the location of depositional sites where placers have formed. A case in point may be the distribution of heavy minerals, derived from the Bushveld Igneous Complex and possibly deposited in the Waterberg basin, in respect of which a notable lack of information exists.

Granted suitable heavy mineral provenance areas and a sediment receptacle, a major problem remains the manner in which the heavy minerals are concentrated. Our knowledge of how heavy minerals behave hydrodynamically is minimal and much more research is needed to study the mechanics of sediment movement, the localized sedimentary sub-environments in which deposition is affected and the relevance of these factors to prospecting techniques.

It has been shown that settling velocities of grains may be of great importance in the search for heavy mineral deposits. The theory deserves careful study to determine its applicability in placer deposit prospecting. An obvious pathway to understanding such matters would be via flume studies with follow-up work in modern braided streams and on recent fans. There is scope for studying heavy mineral behaviour in our rivers along gravelly reaches, and if arrangements could be made for adequate notice of the intention to release water from dams, interesting bedforms and heavy mineral behaviour might be monitored downstream. Studies of present day placer deposits are imperative for the full understanding of the processes involved, as much of the literature deals only with experimental work.

In the field of mineralogy the identification of 'pathfinder' minerals or elements may prove a valuable aid. Trace elements within particular minerals may be of particular relevance and detailed descriptions of mineral varieties may also be valuable (e.g. blue and pink tourmalines have been found to be closely associated with cassiterite).

Pilot studies could be carried out by initially defining broad target areas on the basis of palaeogeography and known location of favourable sedimentary palaeo-environments. Within such areas attention might be concentrated on the identification of sub-environments in which placer-forming processes would be most active and also on the mineralogy, size and settling velocity of grains.

Theme 2 : Mineral deposits of the U, Mo, As, Cu, V association in siliciclastic rocks

An important consideration in the development of this theme is that although detailed data is available for certain restricted areas where exploration is being conducted, notably the western part of the main Karoo basin, the overall picture is still far from complete. It is in this context that the following framework for research is proposed.

It is expected that mining companies will cooperate in making available ore samples from their prospects, in which case it will become possible to carry out investigations of mineral associations in known ore bodies. Suitable subjects for study would then be the mineral equilibrium in the ore, the mineral paragenesis, relationships with sulphides and carbonates and the relative age of the minerals.

Stratigraphic relations between known uranium occurrences in the Beaufort provide further research opportunities. Known uranium mineralization is present in the western Karoo but the relationships between the occurrences are at present unknown. Explanations are also needed for the presence of mineralized zones at specific horizons within tectonic cycles in the Beaufort. The investigation of all aspects of the relationships between uranium mineralization and associated sedimentary facies in the Beaufort Group and also in the Molteno and Elliot Formations will provide further subjects for research under this theme. Such projects would inevitably be concerned with the controls on uranium mineralization and would aim at the establishment of sedimentary models to account for the presence of ore minerals. Attention would have to be given to the nature of the source rocks of the mineralized zone, as well as to palaeoclimatological and palaeodrainage considerations. Aspects such as the presence of palaeosols and dericrusts, availability of organic matter and mineralogy of the host rocks may be of great significance. Because accessible uranium mineralization is at present restricted to the main Karoo sedimentary basin the above suggestions are made in that context. Proposals relating to other actual or potential sources of this group of minerals, are by no means excluded from consideration.

Theme 3: The origin and formation of carbonaceous deposits

It is commonly known that coals owe their origin to the formation of peat in ancient swamps, yet only recently have palaeo-environmental studies of coal measure sedimentary sequences begun to be used to recognize and classify specific physiographic and sedimentary associations in which different types of coal had their origins. Following from this it has become clear that each such association gave rise to particular characteristics of geometry (lateral extent, continuity, planimetric shape, thickness and orientation relative to the depositional dip and strike) and quality (calorific value, ash and sulphur content, etc.) of the coal seams.

The reconstruction of the palaeo-environmental history of the coal-bearing sediments and establishment of models for the origin and formation of coal seams have so far taken place largely in the United States although some work has been done in this country and further work is currently in progress under the aegis of the National Energy Programme. Our knowledge in this field is still very limited and much remains to be done. That such work ought to be encouraged is clearly evident when it is realized that sedimentary models of the kind referred to are not only important for use as a predictive tool in coal exploration but may also be of great practical value in mine planning and mining operations. An understanding of the nature of the controls exerted by the depositional environment on the character and distribution of coal seams is particularly relevant to problems of seam correlation and in the recognition of areas of non-deposition, pinch-out and seam splitting. It is also important in the prediction of roof and floor conditions, of areas where wash-outs or stone rolls are to be expected and of areas where high ash content is likely to result from inorganic clastic influx during peat accumulation.

It is evident that the establishment of sedimentary models relating to the palaeo-environment of coal seams has direct application in the coal industry as a predictive tool in field exploration, as an important aid in mine planning and as a means of combating or avoiding sedimentary-based problems encountered during mining operations.

The petrography of coal is a technologically important aspect of coal studies that has for too long been neglected in South Africa. Most of the work currently taking place in this country is concerned with the practicalities of recognizing coking coals for the metallurgical industry. Other fields of application have been left untouched or are only now beginning to be investigated. Only limited petrographic work has been done on the effects of dolerite intrusions on coal and very little has been published on the characterization and geochemistry of the seams. It is well known that coals show considerable variation in characteristics, not only from one seam to another but also laterally within the same seam. Petrographic examination should be able to reveal the nature of corresponding compositional and textural variations and may provide some of the reasons for their presence. A systematic programme of research aimed at the characterization of coal seams could provide invaluable data of immediate relevance in correlation problems where, for technological reasons, the lateral equivalent of a particular seam is sought. It is to be expected that coal utilization in the future will follow a more stringent pattern, in relation to which petrographic data on technological properties will have the greatest relevance.

Some of the work proposed under this theme would also fit into the framework of the National Energy Programme. In order to ensure that the two programmes complement each other, a certain degree of overlap would be unavoidable and may be desirable. Duplication of work will be avoided through close collaboration and mutual information exchange.

Theme 4: Mineralization associated with chemical and volcano-chemical sedimentary sequences

This theme is concerned with the stratigraphy, sedimentology and mineralogy of chemical sedimentary assemblages and mineral deposits, both metalliferous and non-metalliferous (such as zeolites, perlite and bentonite) in relatively unaltered volcanic sequences. The object is the formulation of models relating to the concentration of volcanogenic sedimentary ore deposits, so that such models may be used as tools in mineral exploration. The theme offers good prospects for fruitful cooperation between sedimentologists, stratigraphers and igneous petrologists. Results obtained from relatively unaltered chemical sedimentary rock sequences may provide an invaluable aid in understanding the genesis and deposition of sulphide and other ore bodies situated in complex structural and metamorphic settings, such as those of Namaqualand. Possibilities therefore also exist for cooperation with workers in the metamorphic sub-programme.

CONCENTRATION OF EARTH RESOURCES RELATED TO METAMORPHIC PROCESSES

Metamorphism is defined as 'the mineralogical and structural adjustment of solid rocks to physical and chemical conditions which have been imposed at depth below the surface zones of weathering and cementation, and which differ from the conditions under which the rocks in question originated'. The processes of diagenesis in sediments and of deuteric alteration in igneous rocks are ruled out by this definition.

The kinds of resource concentrations considered here were involved in a metamorphic cycle and comprise two broad categories:-

- concentrations older than and modified by metamorphism
- concentrations contemporary with and generated by metamorphism.

The first category above includes many major metal ore occurrences throughout the world, especially in the shield areas of Canada, Fennoscandia, Africa and Australia. The highly varied deposits are generally classified according to widely accepted models involving essentially magmatic, volcanic and sedimentary processes of concentration. Migration of rock-forming elements in the mineralized environment has been found to be very limited, whereas movement of sulphides during metamorphism and dynamism is known to have occurred through distances of tens or even hundreds of metres.

Research on the primary evolution of ore concentrations affected by metamorphism is rendered difficult because the orginal mineral make-up and textures of the rocks may have been completely destroyed. In addition the geometric form of the deposits could be extremely complex. Thus the ore petrology must be translated into its original identity and setting from the present data base of varied metamorphic facies. Such studies will involve interpretation of stability fields of mineral assemblages rather than single minerals, and the effects of isomorphous substitution.

<u>Theme 1 : The metamorphic evolution of pre-existing resource concentration</u>

Under this theme is included the study of the metamorphic processes by which pre-existing sedimentary, igneous or even syn-metamorphic deposits have been modified. It is on the one hand aimed at recognizing and understanding the origin of the pre-existing concentrations and on the other hand at studying the behaviour of resource concentrations during metamorphism. Due to the complexity of this type of problem, and the fact that in many cases the processes by which the original sedimentary or igneous concentrations formed are not even understood, this research would most likely have to be undertaken in collaboration with scientists working on similar deposits in undeformed rocks.

Granite greenstone terranes vary in metamorphic grade from the green schist to the granulite facies and while they contain significant mineral occurrences at low grade, e.g. gold and antimony in Barberton, Murchison and Sutherland, they do not at high grade, e.g. the southern marginal zone of the Limpopo Belt. The mechanisms responsible for this distribution are not clearly understood and deserve study under this theme.

A study of the stratabound base-metal sulphide deposits, e.g. Aggeneys - Gamsberg type, could also be included within this theme. Deposits such as these occur world wide yet each district presents special characteristics that must be fitted to the genetic model. Though the local stratigraphic sequence and structure may be understood, there is scope for greatly refined studies of petrology, geochemistry including isotope work, thickness and facies changes of individual rock units and history of mineral deposition. Further exploration will depend greatly on the development of a regional interpretation map of the geological environment of ore concentration.

Similarly the origin of the copper-zinc deposit of the Prieska mine, as well as the zinc ore-body at Areachap, is not clearly understood. Although these deposits have many features in common there are pervasive uncertainties about the stratigraphic and structural relationships of the intervening belt that parallels the north-eastern front of the Namaqua metamorphic province. Much research is still needed to establish whether these deposits are directly related to an exceptional environment in a metavolcano-sedimentary sequence.

Other possible stratabound deposits of either sedimentary or igneous origin carrying concentrations of antimony, graphite, tungsten and molybdenum are known from both the Kaapvaal Craton and the northern Cape. All of these have undergone metamorphism and their initial mode of concentration could be studied under this theme.

Theme 2 : Resource concentration contemporary with and as a consequence of metamorphic processes

This theme includes a study of the evolution of ore concentrations due to the process of metamorphism and can be ascribed to either essentially isochemical transformations (andalusite and asbestos) or metasomatic alterations (skarn deposits). Hydrothermal accumulations are also included here although they could, *sensu stricto*, also be included with ore concentrations related to igneous processes. The latter, however, has been defined to include only accumulations within the complex itself.

With regard to the isochemical ores due to contact metamorphism, it is primarily the andalusite deposits within the thermal aureole of the Bushveld Complex and the formation of coking coal in the vicinity of dolerite intrusions which should be studied. Although the broad concepts of andalusite formation are known, the chemical controls on the composition of the andalusite and the crystallographic controls on the rejection or incorporation of inclusions are still poorly understood.

The low grade metamorphism within the Karoo and younger volcanics has produced a large variety of zeolite mineral species, the formation of which is poorly understood. Due to the growing importance of zeolites as industrial minerals, notably as ion-exchangers, catalysts and carriers for animal feeding, research on the mode of formation and concentration of these minerals is warranted.

Scheelite mineralization is known to be associated with skarn formation in many foreign countries. The occurrence of scheelite as well as molybdenum in Ca-bearing rocks has been recorded from both the eastern Transvaal greenstone belts and Namaqualand metamorphics and could thus be investigated to establish their mode of concentration under the theme of syn-metamorphic mineralization.

South Africa is particularly well endowed with a large variety of hydrothermal deposits, especially Au, Sb, Pb, Ag, F and Ba, but owing to the limited reserves at individual deposits these occurrences have been neglected in the past. The existing models used to explain their origin are largely old ideas and mostly relate them to the nearest 'granite'. Advances in understanding of hydrothermal deposits, especially in the USA and New Zealand (hot springs, geysers, geothermal cells and plumes), necessitate a completely new assessment of our insight into the processes by which hydrothermal mineralization took place. The rapid growth in the application of scarce elements, such as Au, Hg, Bi, Cd, Co, Ag, Tl, etc. in industry accentuates the importance of this type of deposit, which was formerly in most cases looked upon mainly as a gold source.

SEARCH TECHNIQUES

Large areas of South Africa are covered by younger formations or a thick superficial cover which hide the older formations in which most of our mineral resources are located. This sub-programme is aimed at developing and/or improving methods to 'look through' this cover to locate concentrations of metals and minerals below it and to recognize potentially important geological features. For purposes of convenience the sub-programme is divided into two themes, dealing with geochemical and geophysical techniques respectively.

Theme 1: Geochemical search techniques

Research under this theme, though fundamental in nature, could be of direct relevance in mineral exploration and would endeavour to obtain a scientific understanding of the behaviour of elements or minerals in soils or in the processes of ore formation (lithogeochemistry). The eventual aim is the construction of search models which can be applied to exploration. Principally two approaches may be adopted in the geochemical search for mineral deposits and these can be defined as soil geochemistry (including all the different variables such as heavy mineral concentrates, river sediments, etc.) and lithogeochemistry involving the study of 'fingerprint' and halo-forming elements.

Research in soil geochemistry should centre around the study of the behaviour of elements and minerals during weathering under South African conditions, i.e. the separation or accumulation of elements and minerals, and the evaluation of sampling parameters, analytical techniques and interpretation procedures which could be used by exploration companies to find ore deposits here. The former aspect finds particular application in the geochemical evaluation of gossans and in the interpretation of anomalies which are obtained during soil surveys. An appropriate example is provided by experience in Australia, where high nickel gossans were found to be unconnected with nickel deposits, though high Pd and Ir gossans were found to be directly related to nickel deposits. This is ascribed to the fractionation of these precious-metal-containing minerals during weathering of nickel-sulphide deposits.

The application of lithogeochemistry to exploration is illustrated by the abnormal thallium halos usually encountered around hydrothermal gold mineralizations in volcanic geysers, and by the alkaline/alumina ratio found to be an excellent indicator of the potential ore grade of copper porphyries in the United States. Besides the investigation of these parameters which are directly related to the presence or absence of ores, the more conventional approach could also be used. In this regard it is significant to reflect on the absence of knowledge on the geochemistry of different ore-bearing rock types. Do, for instance, the tin-bearing granites of the Bushveld contain more or less Sn in unmineralized areas than granites which contain no tin deposits? On the other hand, are the tin-bearing granites enriched in other elements such as F, B, Be or Mo in comparison with non-tin-bearing granites? The recognition of such patterns and the overall multi-element variations within specific rock types would clearly be very important in defining exploration targets.

Theme 2: Geophysical search techniques

Under this theme two types of research may be considered. The first is the application of remote sensing techniques (satellite imagery) and the second is the development of geophysical techniques capable of penetrating through either weathered bedrock or younger sedimentary formations.

The former technique has developed largely from the earth resources satellite missions, and has found considerable application in geological exploration. A part of this research consists of the making of colour composite images, which accentuate specific structures, whereas the second part largely revolves around the computer manipulation of the image data. These images, if generated with sufficient knowledge, could accentuate gossans and other subtle structures and even produce element-dependent images. Because of the importance of this type of research and the limited expertise available in South Africa, further research should be encouraged.

As far as geophysical research is concerned, it is quite clear that the development of a technique which could penetrate either the calcrete (Kalahari beds) or the Karoo sediments to detect ore bodies below, would be of considerable advantage to exploration companies. The methods which show the greatest promise for improvement along these lines are the electrical and the seismic methods. The trend in Australia, which, like large portions of South Africa, is characterized by a thick conductive overburden which may either be due to a sedimentary sequence or deep weathering, is to develop pulse electromagnetic methods to penetrate the overburden. Similar research and development work should be carried out in the South African context.

S U B - P R O G R A M M E S

This section describes the scope and content of the sub-programmes currently included in the National Geoscience Programme. Research projects which would address any of the problems outlined and which would integrate into one of the sub-programmes will be considered for inclusion in the NGP and can be funded through it.

SUB-PROGRAMME 1 : COAL GEOLOGY

Although several aspects of coal geology in South Africa demand intensive research, it has been decided to start with two approaches. The one is a sedimentological and lithological study of coal-bearing strata, having as its main aim the reconstruction of the palaeo-environments of peat accumulation. The second is a systematic geochemical characterization of the coals with the major aims being the better usage of coal and an understanding of the geochemical imprint left on the coal by its method of formation and the sources of its inorganic constituents.

The sedimentological and lithological studies should be carried out on the Northern Natal, Eastern Transvaal, Springbok Flats, Waterberg, Pafuri, Molteno-Indwe, Limpopo, Soutpansberg, Orange Free State Vierfontein and Central Transvaal coalfields and could also be expanded to include the younger Cretaceous and Tertiary lignite and peat deposits. The study of the latter could contribute substantially to our understanding of the processes by which the organic material accumulated. The field studies are thus aimed at:-

- the derivation of sedimentary models for peat accumulation and a reconstruction of the sequence of events which led to the formation of these coal measures, and

- attempts to establish relationships between the depositional environments in which the peat formed and the mineralogical and chemical characteristics of the coal.

Recent work in the United States has suggested that peat bodies (hence coal seams) show distinctive characteristics of extent, thickness and quality which vary according to the geomorphological situation in which deposition took place. Thus, coal seams which formed in upper and lower delta plains, in fringing coastal environments or in fluvial channel fills may be differentiated, and the same is said to be true for the coal seams which formed immediately prior to a marine transgression or following a rapid marine regression. If parallel relationships can be established for South African coals then recognition of the sedimentary environments of deposition become a matter of practical relevance in exploration and mine planning.

An integrated sedimentological study including all the South African coalfields would thus enable the reconstruction of the palaeogeography in which peat accumulation took place, provide an account of the possible sedimentary controls on coal formation, and give an insight into the distribution of the sedimentary facies. This unified reconstruction, together with the envisaged 'Basement topography map' which is proposed in the tectonic sub-programme may lead to the recognition of new targets for coal exploration. This information, together with the coal data bank of the Geological Survey would provide South Africa with a reasonable basis on which to base its future coal utilization planning and this deserves support from all sectors.

The field investigations will be based on both surface and sub-surface (borehole) data, and it is hoped that sedimentological data from existing boreholes will be made available for this purpose. Permission to make further sedimentological observations in existing mines will also be sought. The collecting of the sedimentary data related to the sedimentary environment would necessitate enquiry into such matters as the variability in seam thickness from place to place, the occurrence of pinch outs and of seam splitting. Detailed examination of wash-outs and stone rolls would also be required and the nature of the roof and floor of the seam would merit attention.

The sedimentological studies should be complemented by mineralogical and geochemical investigations, for very little is known about the inorganic constituents of South African coals. This work should entail the determination of major, minor and trace elements, and the study of allogenic and autogenic minerals in the coal seams of the different coalfields. This type of study would aim at the correlation of different coal seams or coal provinces and could place constraints on the sedimentological models with respect to the source areas of the allogenic minerals, the palaeogeography and the size and shapes of individual peat accumulations. In addition the trace element data would also be used in the evaluation of specific coals as potential sources for Al, Ga, Mo, Pb, Co, U and V. Because several elements which occur in above normal concentrations in coals are toxic, the geochemical information would also be available to evaluate potential pollution from tailings and washing dumps.

An important contribution to our understanding of the nature of the organic material which constitutes the coal can be obtained from a study of the coal petrography. As this research is funded through the National Energy Programme, it will not be duplicated in this sub-programme, but the results should eventually be incorporated in the synthesis which will provide an overview of the characteristics of the South African coals.

SUB-PROGRAMME 2 : MINERALIZATION OF THE GRIQUATOWN-OLIFANTSHOEK-GROBLERSHOOP SEQUENCES

This sub-programme is devised to study the mineralization in the Griquatown-Matsap Sequences in Griqualand West. It addresses three separate but yet related questions and is primarily designed to study the pattern of mineralization along the Vaalian-Mokalian-transition zone. During the first years the investigation will consider i) the characteristics of mineralization in the dolomite sequences below the transition, ii) the widespread mineralization along the transition zone and iii) the placer deposits in the clastic sediments above.

The mineral deposits which are present in the rocks below the transition consist essentially of lead-zinc deposits in the dolomite of the Ghaap Plateau and are either synsedimentary or Mississipi Valley-type deposits, but some may even be hydrothermal as they appear to be associated with intrusive dykes and sills.

These studies should aim at the development of sedimentological models to explain the accumulation of sulphide minerals in the chemical carbonate sediments and should be done on a comparative basis with similar deposits in the Transvaal basin. Special attention should also be given to the behaviour of fluorine in these chemical sediments as it could contribute to the understanding of the fluorite deposits in the Transvaal basin (the largest in the world), which have variously been explained as hydrothermal and synsedimentary deposits. Besides these sedimentological studies, detailed geochemical, mineralogical, petrographical and geochronological studies could also contribute to a better understanding of these deposits and should receive high priority in this sub-programme.

The mineral deposits along the transition are essentially oxide mineralizations and include iron, manganese and aluminous deposits. The exact sedimentary conditions under which the iron and manganese deposits were formed are not fully understood, nor are the relative age relationships between them clear. It is nevertheless certain that these deposits correlate in age with similar deposits in Brazil, Senegal and India. It is also generally accepted that these deposits may also be correlated with the change in the atmospheric composition of the earth and that it coincides with the first appearance of an oxygen atmosphere. Because South Africa is well endowed with sediments which were deposited during this time span, the further development of this approach could have future economic implications and thus requires further research.

The presence of Fe and Mn mineralizations in the Transvaal basin has been attributed to the processes of chemical precipitation and/or to volcanic exhalative activity, but the mineralization along the transition is commonly attributed to secondary enrichment processes along a palaeo-erosion plane. The fundamental questions relating to the source of the Fe, Mn and Ba have not yet been answered however. The causes of the chemical precipitation and the separation of aluminium, iron, manganese and barium during the process of sedimentary differentiation are completely unresolved. The influence of the composition of the earth's atmosphere, the presence of favourable palaeo-environments and the nature of the palaeo-climatic conditions on the accumulation of these elements also require thorough consideration. Once again, the questions are fundamental and if satisfactory answers are to be found the solutions lie in a multi-disciplinary approach. The reasons why the base of the time equivalents of the Matsap elsewhere in South Africa have not been mineralized, should be an aim of this study and could greatly aid future exploration.

The sediments of the Matsap Group consist essentially of clastic sequences which may contain placer deposits and these could merit further study. Because the source areas of the Matsap are essentially the granite-greenstone terranes of the Kaapvaal Craton and sedimentary and volcanic sequences overlying it, the possibility of gold and uranium concentrations in such placers cannot be excluded. Specific members of the Matsap Group are also known to be radio-active, but the radio-activity is ascribed to the decay of thorium. The formation of placer deposits within the Matsap should thus not receive a high priority and it would first have to be proved that placers exist within these sequences.

SUB-PROGRAMME 3 : SULPHIDE MINERALIZATION IN THE NORTH-WEST CAPE

Much of the terrane of the North-west Cape, including the Richtersveld, Namaqualand, Bushmanland and Korannaland areas, is underlain by Early to Middle Proterozoic gneissic rock which includes a variety of granites, metasediments and metavolcanics of different ages and which exhibit differing degrees of metamorphism and deformation. These rocks contain a variety of base metal sulphide mineral deposits and mineral occurrences which occur in differing host rocks and tectonic settings. Since this sub-programme deals with stratabound or stratacontrolled sulphide mineralization associated with rocks belonging to or associated with the Namaqua Metamorphic Complex, distinguished by the strong metamorphic events imprinted at 1,0 - 1,2 b y, it is concerned with resource concentrations which have been variably modified by metamorphism. Understanding the origin of the pre-existing concentrations together with study of the behaviour of ore elements during metamorphism are thus necessary facets of the various projects which consequently will all be directing attention to common problems such as:

- the nature, extent, source and age of the rocks in which the sulphide mineralization occurs, or with which it is associated,
- the source, the mode of transport and concentration and the age of the sulphide mineralization,
- the nature of the metamorphic and deformational events affecting the host rock and the mineralization and the relationship between mineralization and major structural features,
- the concentration and dispersal of ore-forming and ore-indicator elements by metamorphism, and
- the influence of the wider processes of crustal evolution on the localization and formation of these ore accumulations.

The proposed studies will consider these problems using a variety of approaches centred around specific sulphide occurrences, their associated volcano-sedimentary host rocks and the basement rocks which form the floor to these supracrustal sequences. Major known stratabound or stratacontrolled Cu, Pb, Zn sulphide mineralization occurs in the Aggeneys-Gamsberg and Copperton-Areachap regions of the North-west Cape. However, although the local stratigraphic sequences and structures associated with these sulphide ore bodies may be understood, these need to be compared and correlated with similar stratigraphic sequences elsewhere in the North-west Cape and this will be a major component of several studies. This sub-programme will attempt to provide structural, stratigraphic, sedimentological and geochemical models to explain the genesis, location and present day three-dimensional configuration of such stratabound sulphide bodies. Basin analysis should be aimed at understanding the palaeo-environment of ore deposition and should endeavour to relate volcanic centra and major structural features, which may have been active through time, to the ore deposits. Studies dealing with the regional geology and geochemistry of the paragneisses (quartzite-schist associations and calc-silicate rocks) in these regions could serve to characterize these stratigraphic units for correlation purposes to ascertain which of them are more likely to be associated with viable concentrations of base metals, and to identify indicator trace elements which fingerprint the environment of ore deposition. Studies involving the geochemical and isotopic characterisation of the metavolcanics in these stratigraphic successions and an evaluation of their role as possible sources for the metals and sulphur now found in the stratabound deposits should also be undertaken. Detailed Pb-isotope studies which would deal with direct measurement of base metal minerals (notably galenas) and with U-Th-Pb studies on whole rock samples should be encouraged. These measurements should provide critical information on the sources and ages of mineralization, together with information on the ages of the Bushmanland and Korannaland sequences. These studies should also be integrated with complementary H-, O- and S-isotope measurements on the ore minerals and their host rocks and with other studies on the ore minerals and their characteristics in order to elucidate the origin of the ore forming fluids involved.

Although the main thrust of the sub-programme will be directed at studying the controls of the stratabound sulphide mineralizations described above, there are other sulphide occurrences in the North-west Cape which could also provide information in this regard. Complementary petrographic, geochemical and isotopic studies on such sulphide mineralizations could also shed some light on the possible sources of the base metals, their method of concentration and the eventual tectonic imprint on the stratabound deposits mentioned above. This is particularly so in the case of the less metamorphosed and less deformed Cu and Pb mineralizations in the Richtersveld. Similarly the possibility that partial melting of the supracrustal rocks which contain such stratabound deposits may have given rise to 'apparently igneous' sulphide deposits, could also be studied.

The precise nature of the floor rocks and their relationship with the overlying supracrustal sequences which contain the sulphide mineralization are not known. Structural, stratigraphic, geochemical and isotope studies on these floor rocks should also be pursued in order to understand their role in controlling the environment of sulphide deposition and in determining the possible existence of basement older then 2,0 b y in the Namaqua Metamorphic Complex. These studies should be integrated with comparative heat flow and deep seismic studies in order to obtain a better understanding of the crustal framework in which the sulphide occurrences are located and the inter-relationship between crustal evolution and resource concentration processes.

Integration of detailed field studies with intensive laboratory investigations will be an essential component of all the projects within this sub-programme. The ultimate success of this scientific venture, however, will depend heavily on real and effective coordination and cooperation between university personnel, representatives of the mining industry and state organisations involved. Only in this way can this sub-programme achieve its aims of providing both conceptual models of ore formation for existing sulphide deposits and working models for designating and testing of future exploration targets. Ultimately realization of these aims must be viewed in the wider context of a unified picture of the development of sulphide resource systems in relation to the evolution of the continental crust in the North-west Cape.

SUB-PROGRAMME 4 : CONTROLS OF MINERALIZATION IN GRANITE-GREENSTONE TERRANES OF THE KAAPVAAL CRATON

The granite-greenstone terranes of the Kaapvaal Craton contain some of the oldest rocks recognized on Earth, which have been metamorphosed to various degrees. In places the metamorphism barely attained the greenschist facies whereas in other areas granulite facies conditions prevailed. This area is disproportionately enriched in gold, antimony and mercury and contains significant concentrations of barium, silver, bismuth, tungsten, lead, copper, zinc and arsenic. In addition to these elements, deposits of corundum, magnesite, chrysotile asbestos, graphite, beryl and pegmatitic minerals also occur.

Besides the one large antimony mine in the Murchison Range and the gold mines in the Barberton area, very little is known about these deposits and no fundamental research on the mechanisms of ore-concentration within them has been published. In the case of the gold deposits in the Barberton area, the work done by the many researchers has provided a vast amount of data and consequently these deposits may initially receive a lower priority.

Because the same pattern of mineralization occurs in rocks of this age elsewhere in the Kaapvaal Craton, stretching from northern Natal to the northern Transvaal and outcrops at isolated occurrences in the Cape Province and Transvaal such as at Schweizer-Reneke, a detailed study of the processes which control the mineralization could be carried out in areas where anomalous imprints do not exist. The diversity of the mineral associations in the different types of gold, antimony, barytes, scheelite and mercury occurrences thus lends itself particularly well to a comparative study of the different kinds of deposits. Such a comparative study could lead to the recognition of specific environments which may again be a useful tool in the selection of exploration targets. The strongly contrasting grades of metamorphism and the relatively sharp transition from one facies to another also offers a unique opportunity to study the behaviour of specific elements under different grades of metamorphism.

Most of the studies which will be carried out in this sub-programme will be multi-disciplinary because these mineral deposits are structurally, petrologically, mineralogically and geochemically complex and would have to be studied as fully as possible to be able to construct conceptual models for their formation. The second important approach to be followed would be to relate these deposits to specific volcanic, sedimentary and metamorphic environments and to find criteria for the recognition of such environments. The fundamental problems of hydrothermal deposits will also have to be addressed and answers to the following questions will have to be sought:-

- What is the origin, nature and composition of the mineralizing fluids?

- In what form were the the ore-elements being transported in these fluids?

- Were the traps for the ore bearing fluids structural, physical or chemical?

- What caused some of the deposits to be enriched at a later stage and others not?

- Which criteria could be used to recognize similar enrichments elsewhere in the Kaapvaal Craton?

The non-metalliferous mineral deposits, with which this area is richly endowed, have also received very little attention in the past and still offer ample research opportunity. Of particular interest are the graphite and corundum deposits in the highly metamorphosed rocks and the chrysotile asbestos, pegmatite and magnesite occurrences in areas where a lower grade of metamorphism prevailed.

The fundamental questions which are appropriate here are:-

- Are these deposits the consequence of special metamorphic conditions or do they simply reflect the original rock composition?

- What were the mineral transformations which gave rise to these ores?

- What criteria should be used to find similar deposits elsewhere?

SUB-PROGRAMME 5 : CONTROLS OF MINERALIZATION WITHIN LAYERED PLUTONIC COMPLEXES

Whilst most of the research in this sub-programme will be directed at understanding the processes which may have led to the concentration of ores within the Bushveld Complex, a limited amount of work could also be done on other smaller layered intrusions. In the latter case, the studies should be aimed at understanding the formation of specific magmatic ores within specific complexes and should have a direct bearing on the ores which may have formed in the Bushveld Complex.

The Bushveld Complex is marked by many structual and stratigraphic complexities and these may have profound influences on the occurrence and quality of ores within the Complex. Research on these aspects of the Bushveld Complex should thus be undertaken and it is foreseen that structural geologists and geophysicists could make a substantial contribution to this sub-programme. The compilation of basic data maps, be they metallogenic, structural or petrographical maps, would also aid in understanding the distribution and causes of ore formation within the Complex.

The fact that the Bushveld is the largest repository of ores in South Africa justifies more intense study on it and gives it a special importance. Given all the interest centred on the mafic rocks of the Bushveld Complex and the accumulation of specific elements therein, it is foreseen that the mafic rocks should be viewed as the point of departure. The vast resources in the granitic rocks of the Complex and the equally large reserves in the country-rocks, which formed as a consequence of this large intrusive Complex, however, should not be excluded in the longer term.

The research in this sub-programme could thus be pursued along the following three topics simultaneously.

Studies related to the accumulation of ores within the layered sequence of the Bushveld Complex

The prime consideration of studies on this topic is that it should be multi-disciplinary in nature and that the geological, structural, mineralogical, petrographical and geochemical aspects should be addressed in a coordinated effort. As most of the deposits in the layered sequence formed as a consequence of the processes of crystallization differentiation, gravity accumulation and/or *in situ* crystallization and enrichment, a better understanding of the factors influencing and controlling these processes is also essential. The influence of parameters such as changes in pressure during the crystallization of the Complex, variations in the partial pressure of oxygen and sulphur, silica activity, liquid immiscibility and the mobility of the intercumulus liquid all require closer scrutiny and would aid in a better understanding of these processes by which the different elements fractionated to give rise to the ores. The influence of structural aspects, such as contemporaneous faulting, on the processes of ore accumulation also deserves further study. The factors contributing to the formation of specific ore layers are essentially the same as those which caused the layering in the Complex and the processes of gravity settling, bottom-growth by nucleation, convection cells, etc. would also require further study, as these processes were primarily responsible for the ore accumulations.

Apart from the well known ore deposits of vanadiniferous magnetite, platinum-group elements in the Merensky Reef and the Upper chromitite layers, the chrome deposits and the sulphide deposits at the base of the Complex, several other important element concentrations exist which have to date received very little attention yet. The most notable of these are the sulphide occurrences which are present at various places in the Upper Zone of the Complex, the nickeliferous-bronzite, the magnetitite pipes, the platinum-bearing hortonolite dunite pipes, the cobalt deposits and the cobalt-gold deposits in the Eastern Transvaal. Apatite-enriched layers are also known from the Complex, but the mechanism of formation of these layers and the role of phosphorus in the crystallization history are still unknown.

Because cobalt and gold are both present in the Merensky Reef and in fact mined as a by-product, a comparative study of the gold and cobalt concentration in the different deposits would also materially contribute to understanding the behaviour of the other precious metals in the Bushveld Complex.

Studies related to the accumulation of ores in other layered complexes

Apart from the Bushveld Complex, which should be considered as the main topic of research in this sub-programme, the study of the smaller mafic and ultramafic complexes could also have a direct bearing on the processes which may have operated within the Bushveld Complex. These smaller bodies, which range in age from over 3 000 million years to 200 million years or younger, do contain limited concentrations of specific ore-types which are also represented in the Bushveld Complex and which could be studied in them. Since the principle of problem orientated research was adopted as the basic premise in this sub-programme, the formation of any specific ore in one of these complexes may shed some light on the genesis of similar deposts in the Bushveld.

Since these small complexes have less complicated structures, more uniform rock sequences and were perhaps influenced by fewer physical parameters, the possibility of assessing the consequences of these parameters on the genesis of ores within them and as a consequence within the Bushveld Complex, is generally better. Most of the aspects listed in the section on ore accumulation in the Bushveld Complex above, apply to the study of these small complexes and require closer scrutiny. The fact that most aspects pertaining to the total fractionation and solidification of these small complexes can be understood during a specific study also offers the opportunity for understanding the ore-forming process within the totality of the igneous evolution of the mafic and ultramafic complexes. This is naturally impossible in the case of the Bushveld Complex. On the other hand, the development of conceptual models for ore-genesis within the small to very small complexes would have very little practical relevance unless they address the universal principles of ore-formation which may have operated in the larger complexes, such as the Bushveld.

Studies related to the accumulation of ores in the granitic rocks of the Bushveld Complex

Whereas the processes which controlled the accumulation of the minerals within the mafic rocks of the Complex are closely related to those which gave rise to the rocks of the layered sequence, the situation is considerably more complex in the case of the roof rocks of the Bushveld Complex.

The processes which led to the formation of the different types of mineral deposits are varied and range from intramagmatic to pegmatitic and pneumatolitic, but in most cases probably resulted from epigenetic and hydrothermal processes. The disproportionately high concentrations of tin, molybdenum and fluorine in these granites are anomalous and still require research. In the case of the granites the questions relating to their origin and the source of the various ores which occur within them, the nature of the mineralizing fluids, the structural and chemical traps for the ores and their subsequent crystallization, are still unresolved. Because of the complexity of these ore deposits, the studies must be undertaken on a collective basis with structural geologists, petrologists, geochemists, mineralogists and geochronologists all contributing to each study. Besides focussing the attention on the processes of mineralization, fundamental studies on the red granite, granophyre and leptites should also still be pursued. Apart from the vast number of tin, molybdenum and fluorine deposits throughout the area, a large number of occurrences of tungsten, bismuth, cobalt, copper, zinc and even gold are known and have received even less attention than the Sn, Mo and F.

It is hoped that an understanding of the source, emplacement and crystallization of the roof rocks may lead to a better understanding of the ore accumulations in them. Such an understanding, which includes a thorough analysis of the behaviour of specific elements in the granitic magma during its crystallization, pegmatitic and pneumatolitic stages, would point to new target areas and to conceptual models in the search for new and/or more viable deposits in the Bushveld granites.

SUB-PROGRAMME 6 : EXPLORATION TECHNIQUES

The research proposals for 1981 demonstrate a very limited interest in geophysical exploration techniques. In view of the importance of geophysical techniques in the search for hidden ore-deposits, they were retained as a part of the sub-programme with a view to stimulating research.

A comparison between the success record of geochemical exploration techniques in North America and South Africa shows that much could still be done to improve the technique in South Africa. Perhaps the main contributing factor to this state of affairs is the absence of sufficient fundamental research into the techniques of exploration geochemistry for our climatic conditions. It is obvious that the penetration of the thick calcrete, black turf, Kalahari-beds and the sandy plains is perhaps the most challenging problem facing exploration geologists in South Africa. The inability of the scientific community to master these problems is perhaps best illustrated by the fact that the "inselbergen" of Namaqualand are still the prime exploration targets.

The lithogeochemical exploration techniques which have proved to be so successful in the USSR and the USA have never come into their own in South Africa. In recent years, however, the mining community and the Geological Survey have each started working in this direction but the research is still in its infancy and completely uncoordinated. The need for basic fundamental research in this direction is obvious, because it is generally acknowledged that very few major deposits still remain to be discovered at surface and that the surface lithogeochemistry will have to be used to extrapolate to depth, or to evaluate a geological unit for its mineral potential.

A twofold approach to the problems of geochemical exploration techniques should thus be pursued in this sub-programme. The geochemistry of the secondary environment should concentrate on problems relating to the formation of a specific environment, the concentration of elements within it, the interpretation of anomalous concentrations, the analytical techniques which could give the best anomaly contrasts and the follow-up procedures to be applied to such anomalies. This research should be aimed at the development of sampling, analytical and interpretive procedures which can be used in the exploration for specific ore deposits. The results of such research, together with the regional geochemical stream-sediment maps being produced by the Geological Survey, would assist exploration geologists in defining new exploration targets and in using refined geochemical techniques for exploration.

Initially this research would centre on the study of calcrete environments and the formation of geochemical and mineralogical anomalies typical of specific ore-bodies in them. In conjunction with this study, research would also be carried out on the interpretation of geochemical anomalies in areas overlain by black turf, which are characteristic of the secondary environments overlying large areas in the Northern Transvaal and much of the Bushveld Complex.

The lithogeochemical approach could be followed either in this sub-programme or any of the others, because the behaviour of specific indicator trace elements is often an integral process in the formation of the ores themselves. The study of specific geochemical parameters, such as the distribution of metallo-halogen and metallo-sulphur compounds, the distribution of volatile heavy metals and the behaviour of specific elements in magmatic processes could constitute viable indicator trace elements. The study of the mineral chemistry, and the fluid inclusions in minerals have also been applied very successfully in the search for new ore deposits, and should be encouraged. The lithogeochemical research would be aimed at the establishment of specific indicator trace elements for the recognition of specific types of mineral deposits and for the development of mineral chemical and rock geochemical parameters which can be used to predict the potential which a unit may have for mineralization of specific elements. It is hoped that the results thus obtained would assist the mining industry in defining target areas of high and low potential which could be explored in future years.

As far as geophysical exploration research is concerned, it would appear that the development of techniques, which would allow for the detection of hidden ore-bodies, below a thick overburden of calcrete, Kalahari-beds and/or the weathered zone, would be of the highest priority. Breakthroughs in this direction are most likely in electrical techniques, where the problem is the detection of a conductive or polarisable ore-body below a conductive overburden such as is common in the North-west Cape, or below a resistive overburden as is present in certain parts of the Transvaal and the Karroo.

SUB-PROGRAMME 7 : THE TECTONIC FRAMEWORK OF THE MINERAL DEPOSITS IN SOUTH AFRICA

During the first three years the research within this sub-programme will consist of the compilation of specific data maps and when the maps have been completed, work will concentrate on the development of models to relate major sedimentary, igneous and metamorphic episodes in South Africa to the structural framework of the country and to one another. Because the mineral deposits are inextricably part of the major geological episodes which have occurred, this approach could explain the placing of ore deposits both in the temporal and structural framework of South African geology.

In order to ensure a minimum of duplication the programme framework was developed to complement the existing research programme of the Geological Survey. In this development it became clear that two kinds of maps still require attention.

Firstly, there are maps which still require the active collection of data and field-work. These include the following:

- Aeromagnetic maps
- Air radiometric maps
- Gravity maps
- Geochemical maps
- Soil-type maps.

As it is unrealistic at this stage to expect that the collection of the detailed data for these maps, which is extremely costly, could be financed out of the existing budget of NGP, no further consideration will at this stage be given to their compilation. The Geological Survey will continue with some of these maps and the results will be released on Open File from time to time and will be made available to researchers in the sub-programme.

Secondly, there are maps for which the information is already largely available but for which it has to be selectively retrieved for specific purposes. They include the following:

- A metamorphic map
- A geological map
- A metallogenic map
- An epicentre map
- A structural map
- Basement topography maps.

The Geological Survey is currently engaged in compiling the first four of these maps on a scale of 1:1 000 000 and target dates for their completion have already been fixed. At this stage the compilation of similar maps within NGP would be duplication.

The Geological Survey also intends to compile a 1:1 000 000 structural map but before this can be done a series of structural maps on a scale of 1:250 000 is considered essential. A coordinated effort to construct such a series is thus being assigned the highest priority in this sub-programme.

Several components will have to be integrated on each 1:250 000 map. Components which should be considered are:

- Faults
- Joint systems
- Dykes and sills
- Folds
- Fabric
- Small and large intrusions
- The form of sedimentation basins and associated domes
- Linear structures and shear-zones
- The distribution and orientation of discontinuities
- The distribution of extrusion centra and lavas.

The interpretation of, amongst others, Landsat images, aerial photographs, the available aeromagnetic maps, gravity data, the existing mineral occurrence maps etc, will naturally be important facets in the compilation of these maps, and should as far as possible be integrated.

The project is of such magnitude that a single person or group could not reasonably be expected to complete it for the whole of South Africa in a reasonable time (three years) and the logical approach was thus to compartmentalize the task into specific units.

The opportunity is thus given to each potential participant to compile one or more such structural maps on a scale of 1:250 000 in his area of choice. The accompanying map of South Africa indicates the different 1:250 000 maps which could be considered as well as those on which work has commenced. It is also appreciated that specific participants may only be interested in parts of 1:250 000 maps, and they could thus also work within natural boundaries (eg formations, rivers etc) within specific maps if the entire map is not considered. Should specific areas (eg Karoo) constitute unattractive projects and it prove impossible to find suitable candidates in the NGP, the Geological Survey has undertaken to compile these maps.

In order to ensure the successful completion of this sub-programme, it is hoped that other institutions or persons, not financed by NGP, would also contribute their basic data to it.

After completion of the first phase, during which these maps will be compiled, the options would exist for the compilation of the large number of maps indicated below:

- Structural maps of specific tectonic units in South Africa (eg Namaqualand) on a scale of 1:500 000.

- Basic data maps of South Africa on a scale of 1:1 000 000 depicting specific structural elements such as a fault map, a fold map etc.

- An integrated structural map of South Africa on a scale of 1:1 000 000.

Indications are that sufficient data for the compilation of a geomorphological map may not be available in the immediate future. This, however, should not deter the inclusion of geomorphological features which can further highlight a structural map.

Similarly, it is considered that sufficient data may not be available for the compilation of a basement topography map for the whole of South Africa. For some areas however, such as the northern and central Orange Free State where large numbers of boreholes have been drilled, enough data should be available to construct basement topography maps. They would be a series of contour maps depicting the topography of the floor on which the major sedimentary and volcanic successions were deposited through geological time.

PROJECT PROPOSALS

Within these guidelines prospective participants are invited to submit project proposals on CSIR/CSP NP10 forms, available for the purpose. Participants are expected to be as specific as possible with their proposals - indicate clearly how they correspond with the objectives of and fit into the programme, provide a realistic list of key questions to be answered and prepare a well defined workplan according to which the project will be undertaken in a specified time (typically one, two or three years).

Projects should be designed to study problems within the borders of the Republic. Suggestions for work in neighbouring territories should only be included if it would be necessary to follow these problems across borders in order to arrive at full answers and not if satisfactory answers can be found within our borders.

It is recognized that a need may exist to import expert manpower for certain projects where the necessary expertise does not exist in the country. Such a procedure is acceptable provided the normal CSIR/CSP policy regarding such matters is adhered to. In well motivated cases provision may also be made for South African scientists with the necessary background to work in foreign laboratories for limited periods. Salaries which can be offered to researchers working on projects are also provided for in the policy referred to.

For the purposes of the National Geoscience Programme specifically, it has been agreed that standard rates will be allowed for transport, subsistence, ad hoc assistance, labour and field allowances. These rates will be revised regularly and are available on request.

The groups who formulated the programme were clearly aware of the need to improve the availability of certain specialized research techniques. Groups proposing projects are requested to state clearly their requirements for such services - the extent of their requirements, dates when services will be required and suggestions as to how the requirements may be met. Research groups who feel that they can provide such services for other groups participating in the programme, are requested to indicate the nature and extent of such services, the conditions under which they could be provided and the support that would be required. From these indications, steps will be taken to attempt to ensure that the requirements can be met without unduly restricting the development of the programme.

Finally, as was indicated in the introduction, it is recognized that certain participants may wish to work on specific commodities which occur in more than one of the environments which have been taken as the sections of the programme. Their wishes will be respected and they are encouraged to submit such proposals.

REPORTING

ANNUAL REPORTS

The agreed format for annual progress reports in the National Geoscience Programme is:

(a) Identification

Title of project, names and addresses of project leaders and project researchers, date of report, period of report, maximum five keywords of contents for indexing purposes.

(b) Objectives

(c) Background

Concise history of project to allow (b) and (d) to be read in context.

(d) Scientific Progress

Scientific progress made since submission of last report, with emphasis on scientific findings and achievements during the year, as measured against the objectives and target dates provided in the project proposal.

(e) Publications

Full bibliographic details of publications emanating from the project and which have appeared since submission of the last report (including published, accepted for publication and unrestricted internal reports). Copies of these should be attached.

(f) Activities Report

An activities report as an addendum to the main report, if it is felt, that for some reason, activities and not scientific progress have to be reported.

As a guideline, the length of the body of the report ((d) above) should be about four typed A4 pages, although it has to be accepted that this varies from project to project.

Progress reports are required by 30 June annually from all those supported in the programme. Those not supported but who are engaged on projects which complement the work supported from the programme are encouraged to submit reports on their work in the same format by the same date.

The progress reports, in addition to serving as the basis for the evaluation of progress in specific projects with a view to continued support, will also be compiled into a single volume entitled 'Progress Reports on the NGP, 19..'. These will be reproduced in an inexpensive form and distributed to all participants in the programme and its committees.

FINAL REPORTS

No project will be regarded as complete until a final report has been submitted and copies of the data obtained have been lodged in the National Geoscience Data Bank of the Geological Survey.

A final report can take the form of a full scientific account of the work undertaken, the results obtained and the conclusions reached. Such reports will be released on open file by the Geological Survey unless alternative publication arrangements are made by the participant concerned. They will be abstracted in the annual Progress Reports for the year concerned.

Alternatively, or in addition, a final report could contain reference to the publications which have resulted from the research and emphasize achievements, conclusions and recommendations. These reports will be included in the annual Progress Reports for the year concerned.

CODE OF CONDUCT FOR PARTICIPANTS

The programme has as its primary aim research into the understanding of the ore forming processes and the development of models of mineralization that may eventually assist the mining community in the location and development of new ore deposits. In order to achieve this goal, participants in this programme will, of necessity, have to investigate known concentrations of mineral occurrences and may, in the course of their investigations, also come across hitherto unknown mineralization. Because such field oriented investigations will necessitate liaison between the investigator and the holders of the surface rights and the mineral rights, the following guidelines must be adhered to by prospective investigators. These guidelines can be further developed or modified during the course of the programme if it should prove necessary.

- The investigator is required to obtain the permission of the surface owner prior to commencing any work on the property.

- The investigator should, wherever possible, determine the identity of the mineral rights holder (this need not necessarily be the owner of the mineral rights as an option to acquire the mineral rights may have been granted to a third party) and acquire his/her written permission to carry out the investigation on the said property. The investigator should also ascertain what the conditions for the release of the information are and must be able to furnish a written contract of the agreed conditions.

- The CSIR will provide each investigator with a letter of introduction that must be displayed on request to any interested person or concern.

- It is imperative that the conduct of the investigator will at all times be completely ethical in respect of both the surface owner and the holder of the mineral rights.

- As an earth scientist it is the duty of the investigator to preserve important outcrops and the environment.

- Should the investigator, in the course of his research activities find a mineral deposit of potential economic importance or develop a conceptual model of ore formation that may have economic implications, he shall treat such information as confidential and report it as soon as possible to the President of the CSIR. The President of the CSIR in consultation with the Director of the Geological Survey or their authorized representatives shall then, at his discretion and in accordance with the established procedures used by the Geological Survey, make details available to the holders of the mineral rights and negotiate with the relevant persons or concerns to release the information for publication.

- Investigators are liable for their own conduct and they can expect no assistance from the CSIR where unethical conduct leads to prosecution. In case of unethical conduct by an investigator the CSIR shall immediately cease further funding for the project concerned.

TITLES IN THIS SERIES

1. *A description of the Savanna Ecosystem Project, Nylsvley, South Africa. December 1975. 24 pp.

2. *Sensitivity analysis of a simple linear model of a savanna ecosystem at Nylsvley. W M Getz and A M Starfield. December 1975. 18 pp.

3. *Savanna Ecosystem Project - Progress report 1974/1975. S M Hirst. December 1975. 27 pp.

4. Solid wastes research in South Africa. R G Noble. June 1976. 13 pp.

5. *Bibliography on marine pollution in South Africa. D A Darracott and C E Cloete. June 1976. 131 pp.

6. *Recycling and disposal of plastics waste in South Africa. R H Nurse, N C Symington, G R de V Brooks and L J Heyl. June 1976. 35 pp.

7. *South African Red Data Book - Aves. W R Siegfried, P G H Frost, J Cooper and A C Kemp. June 1976. 108 pp.

8. South African marine pollution survey report 1974-1975. C E Cloete and W D Oliff (editors). September 1976. 60 pp.

9. Modelling of the flow of stable air over a complex region. M T Scholtz and C J Brouckaert. September 1976. 42 pp.

10. Methods and machinery for pulverising solid wastes. M J Simpkins. October 1976. 29 pp.

11. *South African Red Data Book - Small mammals. J A J Meester. November 1976. 59 pp.

12. Savanna Ecosystem Project - Progress report 1975/1976. B J Huntley. March 1977. 41 pp.

13. Disposal and recovery of waste paper in South Africa. G R de V Brooks. April 1977. 35 pp.

14. South African Red Data Book - Fishes. P H Skelton. July 1977. 39 pp.

15. *A checklist of the birds of the Nylsvley Nature Reserve. W R Tarboton. September 1977. 14 pp.

16. *Grondsoorte van die Nylsvley-natuurreservaat. H J von M Harmse. September 1977. 64 pp.

17. Description and manual for the use of DRIVER - an interactive modelling aid. P R Furniss. September 1977. 23 pp.

18. South African Red Data Book - Large mammals. J D Skinner, N Fairall and J du P Bothma. November 1977. 29 pp.

19. Introducing you to satellite operated Data Collection Platforms (DCP's). C C Stavropoulos. September 1977. 9 pp.

20. A Phytosociological classification of the Nylsvley Nature Reserve. B J Coetzee, F van der Meulen, S Zwanziger, P Gonsalves and P J Weisser. December 1977. 31 pp.

21. An annotated checklist of the amphibians, reptiles and mammals of the Nylsvley Nature Reserve. N H G Jacobsen. December 1977. 65 pp.

22. *Cooperative National Oceanographic Programme. SANCOR. January 1978. 19 pp.

23. South African Red Data Book - Reptiles and amphibians. G R McLachlan. February 1978. 53 pp.

24. Guidelines for the disposal of dangerous and toxic wastes so as to minimize to prevent environmental and water pollution. R T Rudd. January 1978. 12 pp.

25. Richards Bay mesometeorological data. Vertical profiles of air temperature and wind velocity and surface wind statistics. M T Scholtz, E T Woodburn, C J Brouckaert and M Mulholland. March 1978. 104 pp.

26. *Studies of mineralization in South African rivers. G C Hall and A H M Görgens (editors). March 1978. 24 pp.

27. Nylsvley - A South African Savanna Ecosystem Project: objectives, organization and research programme. March 1978. 37 pp.

28. A description of the Fynbos Biome Project. June 1978. 25 pp.

29. Savanna Ecosystem Project - Phase I summary and Phase II progress. B J Huntley and J W Morris. July 1978. 52 pp.

30. Review of Coastal Currents in Southern African Waters. T F W Harris. August 1978. 106 pp.

31. Report of the Task Group on Fermentation Technology. R J Andrews, J A de Villiers, P M Lategan, F G Neytzell-de Wilde, J P van der Walt and Professor D R Woods. September 1978. 16 pp.

32. South African programme for the SCOPE mid-term project on the ecological effects of fire. September 1978. 36 pp.

33. Fire in South African ecosystems: an annotated bibliography. G U Schirge and A H Penderis. October 1978. 114 pp.

34. Inland water ecosystems in South Africa: a review of research needs. R G Noble and J Hemens. November 1978. 150 pp.

35. South African Antarctic Research Programme, 1978-1982. SASCAR. December 1978. 39 pp.

36. Aboveground biomass subdivisions in woody species of the Savanna Ecosystem Project Study Area, Nylsvley. M C Rutherford. January 1979. 33 pp.

37. Marine Line Fish Research Programme. SANCOR. April 1979. 17 pp.

38. *The Southern Ocean - South African Cooperative Research Programme. SANCOR. May 1979. 26 pp.

39. The Transfer of Pollutants in Two Southern Hemispheric Oceanic Systems. Proceedings of a workshop held at Plettenberg Bay, South Africa, 23-26 April 1979. 188 pp.

40. Fynbos ecology : a preliminary synthesis. J Day, W R Siegfried, G N Louw and M L Jarman. December 1979. 166 pp.

41. Bibliography of Marine Biology in South Africa. D A Darracott and A C Brown. 250 pp.

42. Advances in understanding phosphorus cycling in inland waters - their significance for South African limnology. A J Twinch and C M Breen. March 1980. 22 pp.

43. Terrestrial ecology in South Africa - project abstracts for 1978. February 1980. 92 pp.

44. A manual of methods for use in the South African Marine Pollution Monitoring Programme. R J Watling. April 1980. 82 pp.

45. Threatened plants of Southern Africa. A V Hall, M de Winter, B de Winter and S A M van Oosterhout. May 1980. 244 pp.

46. South African legislation with respect to the control of pollution of the sea. André Rable, January 1981. 73 pp.

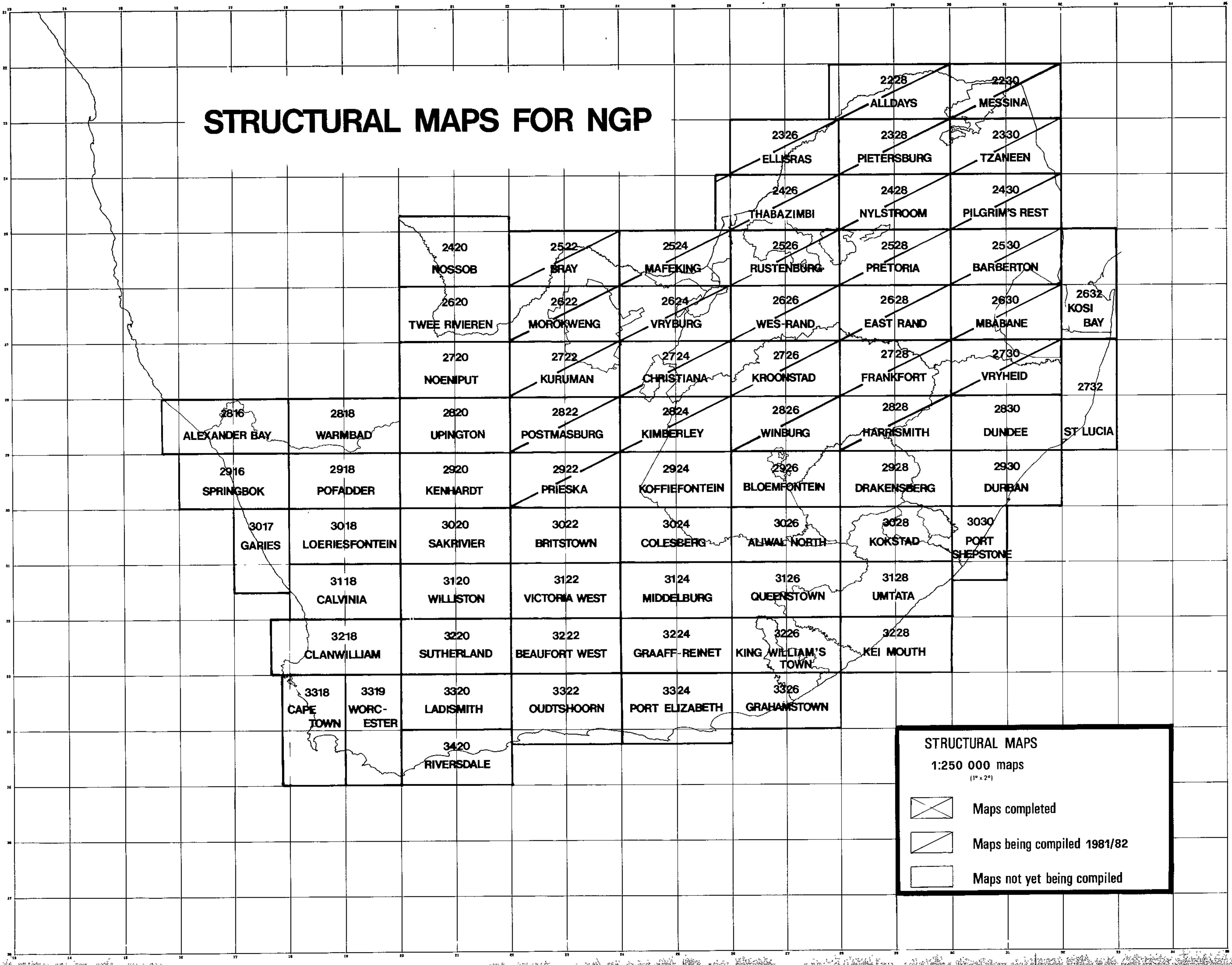
47. Terrestrial ecology in South Africa and South West Africa - project abstracts for 1979. May 1981. 107 pp.

48. A bibliography of seabirds in the waters of southern Africa, the Prince Edward and Tristan Groups. J Cooper and R K Brooke. In preparation.

49. National Geoscience Programme. The Evolution of Earth Resource Systems. SACUGS. June 1981. 42 pp.

*Out of print.

STRUCTURAL MAPS FOR NGP



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