RESOURCE APPRAISAL, TARGET GENERATION AND EXPLORATION METHODOLOGY WITHIN THE NAMAQUA METAMORPHIC PROVINCE

THOMAS U. KRASSMANN

Einführung :

Anfang Februar 1988, begann ich mein Aufbaustudium Wirtschaftsgeologie an der Rhodes University in Grahamstown, Südafrika. Bereits drei Wochen später unternahm unser Kurs eine einwöchige Exkursion ins geologisch ebenso interessante wie lagerstättenreiche Namaqualand. Nach dieser Exkursion hatten die Kursteilnehmer genau 4 Wochen Zeit einen Bericht mit dem Titel „Resource Appraisal, Target Generation and Exploration Methodology within the Namaqua Metamorphic Province“ über das Gesehene und Erlebte zu schreiben, der weit über das übliche Maß aller mir bisher aus dem Studium in Göttingen bekannten Exkursionsprotokolle hinausging.

Nicht nur sollte der Bericht mindestens 40 Seiten Text umfassen - ohne Abbildungen, Inhaltsverzeichnis und Literatur ! - sondern er sollte auch vernünftige Ideen zur Genese der Minerallagerstätten im Namaqualand sowie fundierte Vorschläge zur weiteren Exploration dieser Gegend enthalten. Und – dies kam besonders für einen italienischen Kollegen und mich erschwerend dazu – der ganze Bericht sollte in einem möglichst fachlich einwandfreien Englisch verfasst sein !

Wir Kursteilnehmer stellten uns gemeinsam dieser Aufgabe und machten uns ans Werk, standen früh auf und verbrachten lange Tage bis spät in den Abend hinein in der Bibliothek und am Schreibcomputer. Internetrecherche und Datenbanken waren noch so gut wie unbekannt und doch ließ sich viel recherchieren, was in unsere Arbeit einfloß. Zeichnungen wurden mit Tuschestiften angefertigt und viel über das Gesehene und Gelesene...und auch über das schon Geschriebene diskutiert. Und tatsächlich : wir schafften unser Arbeitspensum und gaben unsere Arbeiten erschöpft, aber zufrieden ab. Nie zuvor und nur noch selten danach habe ich mich durchgehend so intensiv auf eine Arbeit konzentrieren müssen wie auf diese. Aber es war eine gute Übung für den späteren Beruf als beratender Geologe.   Ich wünsche dem Leser eine angenehme Lektüre !

Introduction :

Beginning of February 1988 I attended the „Economic Geology Course“ at Rhodes University in Grahamstown, South Africa. Only three weeks later the first field trip to the geologically diverse and mineral rich Namaqualand region started. After return to Grahamstown the participants were given four weeks time for completion of a report called „Resource Appraisal, Target Generation and Exploration Methodology within the Namaqua Metamorphic Province“ which was a bit more than the usual field trip minutes I knew from my home university at Göttingen.

Our professors not only asked us to write at least 40 pages of text body – not counting images, tables, content and literature ! – but also this report should include some clever thoughts about the genesis of the mineral deposits of Namaqualand as well as some intelligent ideas about future useful exploration work. A further requirement was a good English language, which was particular demanding for an Italian college and myself.

We M.Sc. students together faced the task and started working, We stood up early and spent literally all day long in the library or typing texts until late night. Internet based work and digital data bases were things unheard off in these days, but we managed to find a lot of useful literature in dusty shelves. Drawings were painstakingly done with fine ink pens and many, many discussions were held about the seen, the unseen and the already typed. And indeed finally we handed in our reports just in time, exhausted but very satisfied with our work. Never before and seldom since I needed to work that hard and with such fervor and concentration on a single task...but it surely was an excellent exercise for my later work as consulting geologist !

I wish you a pleasant and interesting reading...

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1. INTRODUCTION :

The first fieldtrip of the M.Sc. Exploration and Economic Geology course 1988 led to the Namaqualand metamorphic belt. The class under the guidance of C.Mallinson followed a traverse line from the eastern border of Namaqualand at Prieska to the Okiep area in western Bushmanland during the period 7. to 15. march 1988.
Special emphasis was led on the structural evolution of the visited area, which was demonstrated in particular in two areas : the Aggeneys - Gamsberg lead/zinc/copper deposits and the Okiep copper district. One day was spent at an base metal prospect on the farm Lemoenspoort while another day was dedicated to the geology and alteration features in the porphyry copper system at Haib river / Namibia.
Participants of this fieldtrip included the five members of the M.Sc.class : Jako Badenhorst (ISCOR), Ian (Duck) de Klerk, Thomas Krassmann, Richard Niccols (AAC), Peter Winkler (AAC) ; the italian geologist Francesco Stefanelli and the guide Clyde Mallinson (lecturer, Geology Dept. Rhodes).

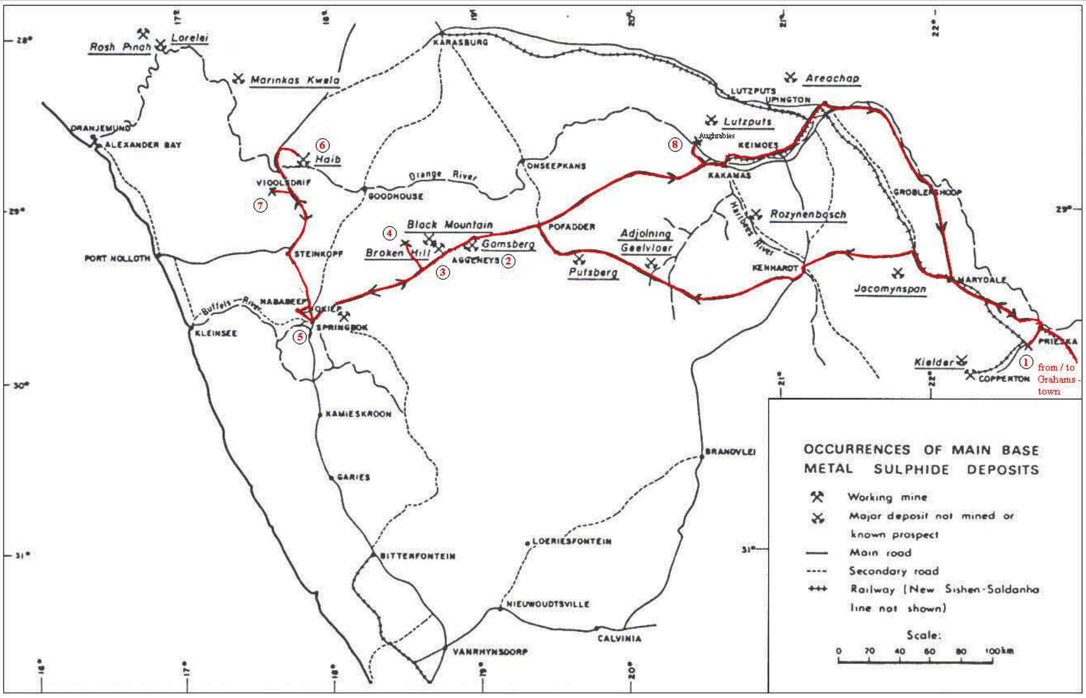

Figure 1.1 : Namaqualand : distribution of major sulphide deposits and route of M.Sc. fieldtrip 1988. (JOUBERT 1985)
1 = roadcuts W Prieska ; 2 = Gamsberg ;
3 = Broken Hill mine ; 4 = Lemoenspoort prospect ;
5 = Okiep - Nababeep area ; 6 = Haib porphyry ;
7 = Blesberg pegmatites ; 8 = Augrabhies waterfalls

2. OUTLINE OF SOUTH AFRICAN AND NAMAQUALAND GEOLOGY :

The geology of South Africa and adjoining areas is mainly controlled by the nuclei of old and huge granitoid cratons. The central Kaapvaal craton and the northern Rhodesian (or Zimbabwean) craton are believed to be older than 2500 m.y.(ANNHAEUSSER & BUTTON 1976). More to the west lies the Richtersveld craton which seemed to be younger than 2500 m.y..
(see figure 2.1)
These cratonic shields are embedded in a network of tectonic units , which show a somewhat more flexible habit to stress & strain influences. They are commonly known as "mobile belts". In opposition to the rather uniform lithologies of the cratons, the mobile belts exhibits a far wider range of different rocktypes - and consequently form a suitable environment for diverse ore deposits.
The contents of this field report deals mainly with the geological setting and the related ore deposits (and exploration techniques) of the western part of the so called Namaqualand - Natal metamorphic belt or short Namaqua metamorphic belt (NMB).
The best exposures of this belt lie on both sides of the continent: in the west near the Atlantic coast in Namaqualand and in the southeast near the Pacific in Natal. The area between both outcropping areas is covered with much younger sediments/basalts of the Karoo supergroup.
A significant linear gravity anomaly connects both areas, hence there exists - apart from the similar lithology - good evidence for the belt nature of both regions.
An excellent description of the different tectono - lithological units of the NMB has been given by P.JOUBERT (1985). From west to east exists the following tectonical subprovinces (see Fig. 2.2): Kheis ; Gordonia ; Richtersveld ;Bushmanland and West coast belt. A short description of these subprovinces is given in the following chapters.

FIGURE 2.1: Generalized geotectonic map of southern Africa illustrating the ancient and younger cratonic areas together with the encircling metamorphic and fold belts.

(Annhaeusser & Button, 1976)

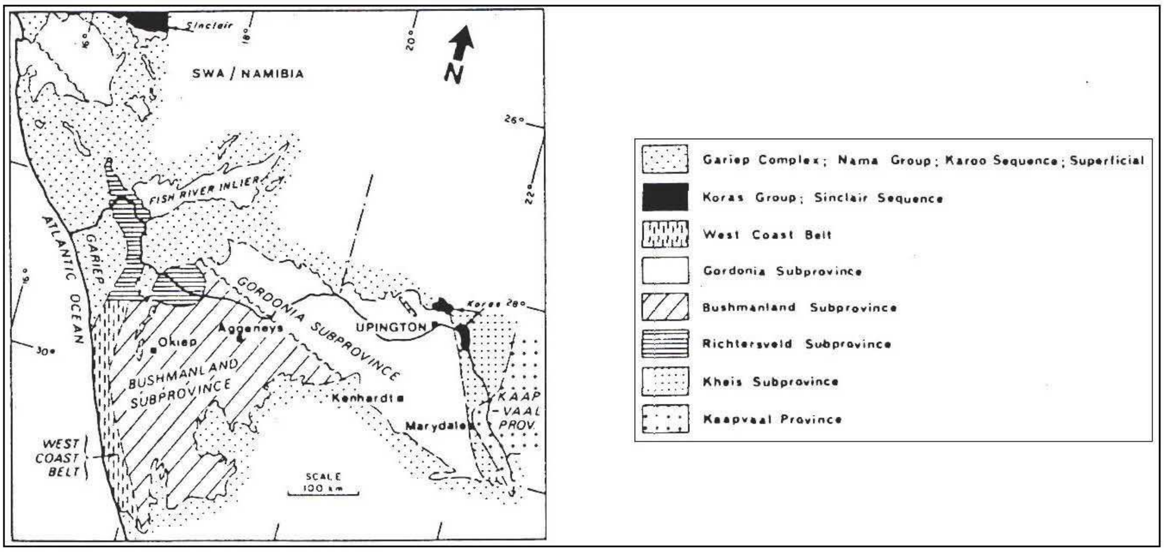

Figure 2.2 : Namaqualand Metamorphic Belt : tectonic subprovinces according to P.JOUBERT 1985

2.1 Kheis subprovince : The Kheis represents an elongated transition zone between the Kaapvaal craton and the "actual" NMB. The strike of the litho - units as well as the major thrust structures (e.g.Doornfontein fault) are orientated in a N - S direction , while the structural trend in the rest of the NMB is mainly an W - E one. These features plus the very high granulite facies metamorphism and the age of the rocks (2900 m.y. according to CORNELL & BARTON 1979) indicate a pre - Namaquanian formation and deformation of the area. A possible model is the sedimentation in a graben or rift structure , which was eventually backthrusted onto the Kaapvaal craton itself (C.MALLINSON personal communication).
Despite the versatile rocktypes in this subprovince - the M.Sc class studied highly folded/thrusted BIF, quarzites, various gneisses, phyllites, dolomites and intersecting mafic dykes in a single roadcut W Prieska - no significant ore deposits have so far been encountered in this subprovince.

2.2 Gordonia subprovince : This subprovince occupies, dependent on different authors, nearly the half of the surface of Namaqualand and extends further on to Namibia. It is divided into 8 subformations , starting with the Jannelsepan fm. and ending with the Goede Hoop fm.(see table 2.1).
The lithology is rather uniform : different types of quarzo - gneissic rocks prevail. However, there exists some more "coloured" lithologies in the Jannelsepan fm.(granulite , calcsilicate rocks) and in the Biesje Poort fm.(marble , amphibolites).
The structural evolution of the Gordonia subprovince is, as the rest of the NMB desperately complex and at least 4 or 5 deformation phases could be outlined. Additionally various ultramafic to felsic intrusions occur, which are distributed mainly in the western part of the area (Keimoes suite). Several major parallel NW - SE trending lineaments or shear zones are present. The most prominent are the eastern Tantalite Valley belt , starting in the Warmbad area in southern Namibia , and the more westernly Pofadder lineament , which acted - according to JOUBERT (1985) - as immediate border to the Bushmanland province.
The metamorphic grade of the Gordonia subprovince increases from east to west. Whenever a major shear zone is crossed, the grade increases sharply (VAN ZYL 1981). However the general metamorphism remains in the amphibolite facies with the exception of the central part of the belt ,

where granulite facies is reached. The age determination in the area provides results of 1300 +/- 110 m.y.(CORNELL 1975).
Mineralisation in the Gordonia subprovince is well developed and in fact the discovery of the Copperton orebody in the Jannelsepan fm. started the exploration boom in Namaqualand. Other known deposits in the Jannelsepan fm. include the Kielder, Van Wykspan, Boksputs and Annex orebodies near Copperton as well as the Areachap deposit more to the north.
Apart from that significant mineralizations occurs at Jacomynspan, Lutzputs and Rozynenbosch.

2.3 Bushmanland subprovince : The Bushmanland subprovince is the economically most important province of Namaqualand. The lithostratigraphy is subdivided into four units (see table 2.1), called Aggeneys, Hom, Goudan and Pella subgroups. The prevailing lithotypes in this province are gneisses and metasediments. In the western part lies the Okiep sequence with a different lithology, mainly comprising of granite gneisses which seems to have been formed by partial upmelting of former metasediments.
More than thousand irregular mafic intrusive bodies are distributed in the Okiep region. They are called Koperberg suite and form the hostrock for economic viable copper deposits.
The rocks of the Bushmanland province are heavily folded and again at least four different deformation events can be determined. A typical feature in this region is the occurence of "open" synforms with the hinge normally pointing to the west. While the hinges - often associated with sulphide bodies - frequently produce prominent topographical heights, the flanks of these synforms are mostly ill defined.
The metamorphism increases as in the Gordonia subprovince to the west and reaches granulite facies beyond the Ratelpoort shearzone near Springbok.
The age determination of the Bushmanland rock units is rather questionable due to the fact that most age dating was done on lead isotope ratios in sulphides. This method shows only the timespan to the last metamorphic resetting event, so that the obtained data (+/- 1300 m.y. and 2000 m.y.respectively) are probably too young. A more recent age determination - based on the Sm - Nd method - of the central Bushmanland amphibolites, which are believed to represent metamorphosed basalts, yielded 1649 +/- 90 m.y., a date which seemed to be somewhat more reliable (REID et. al. 1987).

Lithostratigraphy of the Namaqualand Metamorphic Complex (SACS, 1980)

Pretectonic Metasedimentary and Metavolcanic Rocks					
Area	Group	Subgroup	Formation and Lithology	Syntectonic Intrusives	
Western Namaqualand	Okiep	Een Riet (Steinkopf)	Metaquartzite, feldspathic quartzite, aluminous schist and gneiss, leptite, conglomerate, fine-grained biotite and/or hornblende gneiss, amphibolite, crystalline limestone, calc-silicate rock	Koperberg Suite (noritoids of Okiep)	
		Khurisberg (Springbok)		Spektakel Suite	Kweekfontein Granite Rietberg Granite Concordia Granite
Steinkopf — Springbok —		Aardvark (E. of P. Nolloth)		Little Namaqualand Suite	Konkyp Granite Nababeep (Brandberg, Modderfontein) Gneiss *Areb Gneiss*
Bitterfontein to west coast		Garies Bitterfontein		Gladkop Suite	Noenoemasberg Gneiss Brandewyn Gneiss Steinkopf Gneiss
South of the Orange River between *Pofadder and* Goodhouse	Bushmanland	Pella	Metaquartzite, quartz–muscovite schist, conglomerate and iron-formation	Small unnamed late-tectonic granites	
		Gaudom	Mafic gneiss with intercalated metasediment	[Hoogoor Suite (Haramoep Gneiss)]	
		Hom	Leucocratic grey gneiss with intercalated metasediment	Little Namaqualand Suite — Aroams Gneiss — Eendoorn Granite	
		Aggeneys	Quartz–muscovite schist and conglomerate unit		
			Gams Formation — Iron-formation and sulphides	Basic intrusive bodies	
			Metaquartzite unit		
			Namies Schist Formation — Aluminous schist		
Richtersveld Subprovince	Orange River	Haib (Vioolsdrif–Goodhouse)	*Nous Formation* — Andesitic lava, volcaniclastic rocks, felsic lava *Tsams Formation* — Feldspar and quartz-feldspar porphyry, volcaniclastic rocks	Vioolsdrif Suite	6. Leucogranites 5. Adamellites 4. Granodiorites 3. Tonalites 2. Diorites 1. Basic–ultrabasic intrusives (In order of decreasing age, Reid, 1977)
		De Hoop (E. Richtersveld)	*Kuams River Formation* — Melanocratic lava, quartz porphyry, metasediment *Kook River Formation* — Quartz porphyry *Abiekwa River Formation* — Leucocratic to melanocratic lava, tuff, pelitic rock *Windvlakte Formation* — All volcanic rocks south of Rosyntjieberg *Rosyntjieberg Quartzite Formation* — Quartzite, ferruginous quartzite, schist and volcanic rock *Paradys River Formation* — Leucocratic volcanic rock, welded tuff, fan conglomerate *Klipneus Formation* — Tuff, lava, conglomerate, chert, quartzite		
Gordonia Subprovince	Korannaland		*Goede Hoop Formation* — Metaquartzite, muscovite quartzite, conglomerate *Rautenbach se Kop Formation* — Quartzo-feldspathic gneiss *Kenhardt Formation* — Leucocratic biotite gneiss	Friersdale Charnockite Unfoliated granitoids	Elandslaagte Muscovite–Granite *Brakbos Biotite Granite* Eindgoed Granite Lat River Biotite Granite
			Biesje Poort Formation — Calc-silicate rock, leucogneiss, biotite gneiss, marble, amphibolite *Kokerberg Formation* — Quartzo-feldspathic gneiss, metaquartzite *Toeslaan Formation* — Aluminous gneiss, garnetiferous quartzo-feldspathic gneiss, biotite gneiss, amphibolite	Upington Granitoids	Strausberg Granite Colston Granite Gemsbokbult Granite Hartbeespan Granite Sonderpan Granodiorite
			Eierdoppan Formation — Conglomerate, schist *Jannelsepan Formation* — Hornblende/biotite gneiss, calc-silicate rock, aluminous gneiss, garnetiferous leucogneiss, granulite	Unnamed basic and ultrabasic intrusives	
Kheis and Gordonia Subprovinces	Kaaien		*Uitdraai Formation* — Grey metaquartzite, subordinate quartz–sericite schist *Sultanaoord Formation* — White metaquartzite, subordinate phyllite *Dagbreek Formation* — Quartz–sericite schist, quartzite, amphibolite	Basic intrusives Anorthosite Unfoliated granitoids (Brakbos, etc.)	
	Marydale		*Spioenkop Formation* — Quartzite, quartz-sericite schist, amphibolite, metagabbro, metasediment	Basic intrusives	
		Doornfontein	*Uitzigt Formation* — Amphibolite *Modderfontein Formation* — Greenstone, iron-formation, limestone/dolomite, amphibolite, quartzite	Unfoliated granitoids (Skafkseput Granite)	
		Prieskaspoort	*Perdeput Formation* — Amygdaloidal basaltic lava, tuff, quartzite, amphibolite, ultramafic layers *Steenkop Formation* — Conglomerate, grit, sub-greywacke, volcaniclastic rock, minor lava and quartzite	(Draghoender Granite)	
Kheis Subprovince	Wilgenhoutsdrif		*Leerkrans Formation* — Mainly volcanic rocks *Zonderhuis Formation* — Quartzite, dolomite, schist, jaspilite, minor volcanic rock		
	OLIFANTSHOEK SEQUENCE				
	Volop		*Groblershoop Schist Formation* — Mainly quartz-sericite schist		
			Brulsand Quartzite Formation — Quartzite, subgreywacke *Matsap Quartzite Formation* — Conglomerate, brown to purple subgreywacke, sandstone, quartzite		
			Hartley Andesite Formation — Lava, breccia, tuff, quartzite, conglomerate *Lucknow Quartzite Formation* — Quartzite, minor dolomite and flagstone *Mapedi Shale Formation* — Phyllitic slate, subordinate quartzite and lava		

Table 2.1 : Stratigraphy of the Namaqualand Metamorphic Belt (SACS 1980) Source : JOUBERT 1985

Beside the major and well investigated ore deposits of this region as Gamsberg and the Aggeneys orebodies in the east and the Okiep copper orebodies in the west there exist minor sulphide orebodies located in the Springbok area (Oranjefountain ,Kouberg : JOUBERT 1985). Exploration is again under way in the eastern part of the area and a base metal prospect on the farm Lemoenspoort - Kamasoas W Aggeneys was visited by the M.Sc.class.

2.4 Richtersveld subprovince : This subprovince forms the northwestern part of the NMB. The lithostratigraphy is divided into nine subunits, starting with the Klipneus fm.(see table 2.1). Main rocktypes in this province are quarzitic metasediments and metamorphized lavas/tuffs. In the vicinity of the Oranje river at least four porphyry copper (~ molybdenium) systems are developed : Haib, Lorelei, Marinkas Kwela and Rooiberg, which indicate the plate boundary nature of this region. The zircon age determination at Haib yielded 2000 m.y. and it is therefore considered to be the oldest presently known prophyry system wordwide (R.C.A. MINITT 1985).
Various mafic to felsic bodies intruded in post - Namaqua time, some of which are orientated along the WSW to ENE running Kuboos-Bremen lineament. The deformation in the Richtersveld province is, like in the whole Namaqualand intense. Beside the actual Namaqua event deformation and metamorphosis, which resulted in folding and strong foliation of the rocks, there exists evidence for a second younger deformation event, which is particulaly effective in the western part of the province. This second deformation act is probably related to the Pan African event and to the formation of the Damara orogen. A third deformation of post Nama age resulted in the formation of long N - S striking fault zones.
Despite these complex deformation history the observed metamorphism grade is commonly low, hardly exceeding greenschist facies.
Timing in the Richtersveld subprovince is difficult. Apart from the Haib zircon age data all other age determination seemed to be influenced by the Pan African event and are therefore highly unreliable.
Beside the porphyry systems there are scheelite occurences bound to metalavas within the Vioolsdrift suite (Kaalbeen, Nous and Noubestaum).
The mineral content of the various pegmatites in these region is dicussed further below.

2.5 West Coast belt subprovince : The West Coast belt subpovince occupies the western edge of the NMB adjoining the Atlantic ocean. As the Kheis subprovince in the east, this region displays a transitional behaviour and is heavily influenced by the much younger Damara event.
The lithology is quite similar to the eastern part of the Bushmanland subprovince (Okiep area) although metasediments are more abundant, especially in the south at Bitterfontein (Zoutpan schist fm.).
The tectonic structures trend NE - SW i.e. the original Namaqua event trend is overprinted by the younger Pan African event. The metamorphic grade is high and reaches the border of granulite facies.
The age determination show only data around 500 m.y. which is in good correspondence with the age of the Pan African event, but not with Namaqua age. No major mineralisation have been proved so far, but base metal sulfides are known in the Zoutpanschist fm. and copper stainings are common in the Steenbook shear zone near Port Nolloth. Additionally tungsten has been mined in the Kamaggas area on a small scale in former times.

2.6 Post - Namaqua geology : The northern continutation of the NMB is hidden by thick +/- flat lying fossiliferous sediments of the Nama and Karoo subgroups. Only small and scarcely occuring windows allow an insight into the bedrock geology and not much is known about this part of the NMB.
Apart from these economically rather uninteresting sediments there are two types of post - Namaqua igneous rocks, which attract more attention by the exploration geologist:

Kimberlites : Numerous kimberlite pipes are known in the southern part of Namaqualand, concentrated around the village Gamoep. Although no data is available wether they are diamond bearing or not, the region was explored intensively by mining companies in the seventies (see chapter 3.8).

Pegmatites : Pegmatites of various shapes and size (up to 1.5 km length) occur in a narrow belt exceeding 450 km length in northern Namaqualand (see figure 3.9). Though they do not warrant large mining operations they have enabled small scale workings to exploit lithium, beryllium, niobium and tantalum ores as well as feldspar and mica profitably over the past thirty years (see chapter 3.6). One of the major pegmatites, the Noumas I or Blesberg pegmatite, situated between Steinkopf and Vioolsdrift, was visited during the fieldtrip.
Tertiary and alluvial deposits cover the most of the bedrock of the NMB and give the eastern part a rather boaring appearance.

3. RESOURCE APPRAISAL & EXPLORATION METHODOLOGY :

This chapter summarizes the variety of ore occurences in the NMB. The deposits are listed according to their metal contents, whereas the major deposits are described more detailed.
Most of the deposits in the NMB were discovered through geological mapping or by means of geophysical methods. The exploration case histories of the Okiep area, the Gamsberg - Aggeneys deposits and the Putsberg deposit are recorded below.

3.1 COPPER, MOLYBDENUM, NICKEL

Copper is the metal with the longest mining history in Namaqualand. Beside the peculiar copper deposits of the Okiep region there are five different types of Cu ore deposits observeable in the NMB : 1. massive sulfide deposits of volcano - exhalative origin, combined with lead/zinc and baryte (see paragraph 3.2); 2. porphyry copper - molybdenum systems with disseminated ores; 3. hydrothermal deposits; 4. ultrafmafic intrusives associated with nickel; 5. small pegmatite Cu orebodies.

3.1.1 Okiep type deposits : The Okiep copper deposits are characterised by their linkage to late mafic intrusions in highly metamorphized gneiss terranes (Koperberg suite).The lithology of these intrusives varies from dioritic to noritic composition. A typical pattern is the flattening off of the mafic bodies at medium depth, followed by renewed steepening at greater depth (see figure 3.1). Another characteristic of these deposits is their simple mineralogy : the prevailing ore minerals are chalcopyrite and bornite with minor amounts of pyrrhotite, chalcocite and sometimes native Cu. Oxydation minerals such as malachite and azurite are abundant, but never reach deeper than 40 meters..
The Okiep copper bodies have long been regarded as unique, and only recently have similar deposits been announced from Caraiba/Brazil (TOWNEND et.al. 1980).

Of the approximate 1500 mafic bodies present in the Okiep region only 27 have been found to carry viable copper deposits. Since the beginning of modern mining in 1937 about 70 Mio tonnes of copper ore has been mined. The proven reserves (LOMBAARD et.al.1985) total to 26 Mio tonnes at a grade of 1.9 per cent, mainly concentrated in the Carolusberg deep orebodies. Two peculiar surface features are present in the Okiep area, called "steep structures" and " megabreccias". Since their pathfinder nature for hidden mafic bodies has been perceived they were mapped with great accuracy (LOMBAARD et.al.1985). Steep structures are - generally speaking- anomalies in the dip of the normally gently inclining granite gneisses. They display a steep to vertical dip and form sharp elongated antiformal shaped structures, which may reach a strike length of several kilometers. Plate 3.1 shows a picture of a well developed steep structure present at the Klondike prospect near Nababeep.
Some of the steep structures display a core of Koperberg suite at the surface, the others possess such cores at greater depth. At the very important Carolusberg mine the steep structure lies directly above the main orebodies (according to geological map : Nababeeep mine museum).
Plate 3.2 shows a photograph of a typical megabreccia, where the varying foliation strike of different gneissic blocks can be clearly seen. Apart from gneissic blocks "exotic" blocks occur as well, originating from higher stratigraphic units. While the megabreccias show normally elliptical shapes at the surface,the vertical continuation exhibits pipe like bodies.

Whereas the steep structures could be explained by updoming of the gneisses due to intruding mafic bodies of relatively low temperature and volatile contents, the formation of the megabreccias needs a more elaborate model. Figure 3.2 tries to give such a model : After the intrusion of a hot and volatile rich body, a gas bubble develops continously at the top of the intrusion (I). At the same time the rocks surrounding the mafic body are heated up until they become soft and partly molten (II).Eventually the gas bubble is too large to remain stable and escapes from its source rock.
In an explosive act the hot gases force their way to the surface, leaving a pipe like void behind them (IV). Shortly after the pipe cavity collapses and debris of different stratigraphical units fill in the pipe. Some of this debris reach the half molten rock at the bottom of the pipe, where it is embedded and fixed.

Plate 3.1 : Okiep area : well developed "steep structure" at the Klondike prospect.

Plate 3.2 : Okiep area : typical "megabreccia" showing individual strike direction in single blocks.

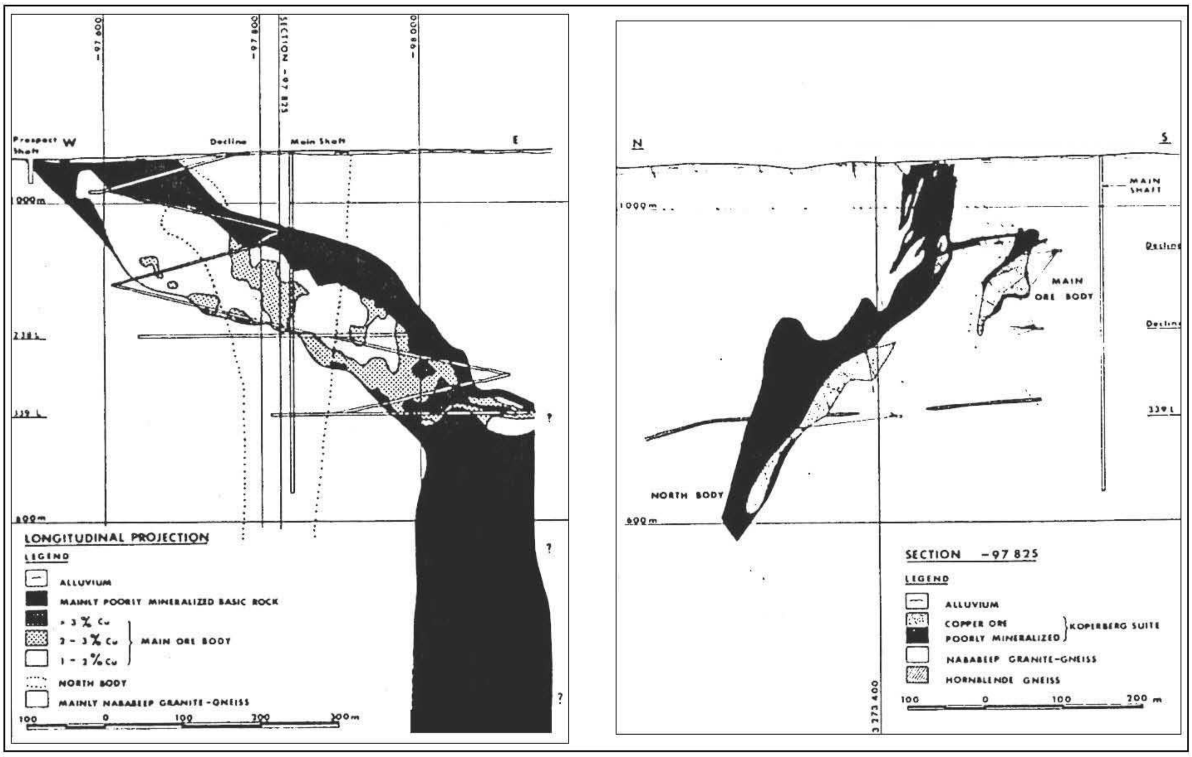

Figure 3.1 : Okiep area / Hoits mine : typical section of an Okiep type orebody showing characteristical flattening off of mafic intrusive body. (LOMBARD et. al. 1985)

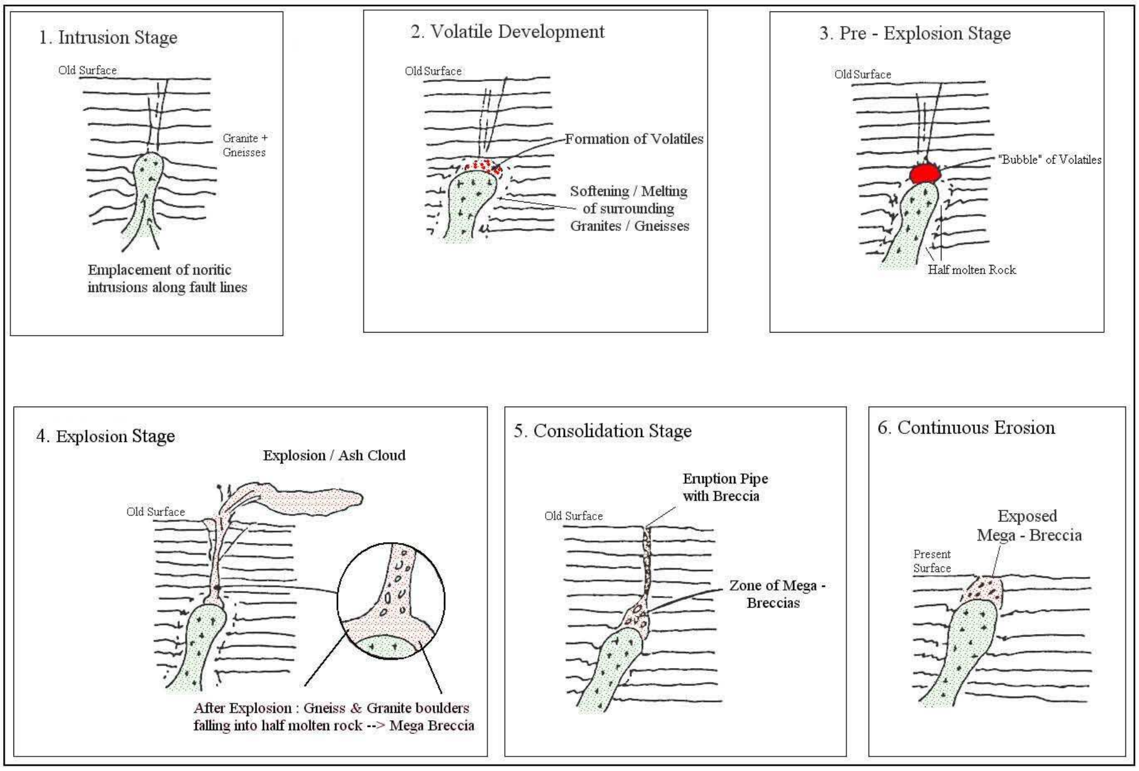

Figure 3.2 : Okiep area : Explanation model for the developing of megabreccias.

Exploration history : Although the copper occurences in the Okiep area are among the earliest known in southern Africa (pre - european mining history, Simon van der Steel copper expedition 1685), a regular mining industry began to develop not earlier then 1857. In those times the copper stained outcrops of the Koperberg suite were the main places of interest and dozends of shafts were sunk on every promising location.
Modern exploration started shortly after the foundation of the OKIEP COPPER COMPANY in 1937. Beside regional airphotos and detailed ground mapping several geophysical techniques have been extensively used. Aeromagnetism, groundmagnetism, gravity and electrical methods are some of the employed tools in this region. Especially the aeromagnetic method has been found to be very sucessful, delineating obviously all of the buried mafic bodies. Final evaluation is done by percussion and diamond drilling.
Okiep staff geologists proved to be outstandingly sucessful in discovering new orebodies during the sixties and seventies. Since that time no further important orebody has been found.

3.1.2 Porphyry copper - molybdenum systems : There are at least four known occurences of copper - molybdenum bearing porphyry systems in the NMB at Haib, Lorelei, Marinkas Kwela and Rooiberg, which are all placed along the Oranje river(see figure 3.3). Additionally a - probably copper bearing breccia pipe type deposit occurs at Kanabeam near Marinkas Kwela, but no further data is available.
Whereas in the Marinkas Kwela and the Rooiberg deposit molybdenum is the dominant metal, the Lorelei and the Haib deposits contain copper as dominant constituent. Lead and zinc are minor components of the porphyries.
The Richtersveld porphyries are the oldest known worldwide (around 1950 m.y.)and it is an interesting fact that they are concentrated in a comparatively small area adjoining the Oranje river (see figure 3.2).
The porphyries are bound to calc alkaline intrusion complexes and typically show an intense alteration pattern (see figure 3.3 and 3.4).
Plate 3.3 shows the internal part of the Haib porphyry stock looking eastward. If we take the Haib as typical and good documented example, (R.C.A. MINITT 1985) three strongly developed alteration zones are present :

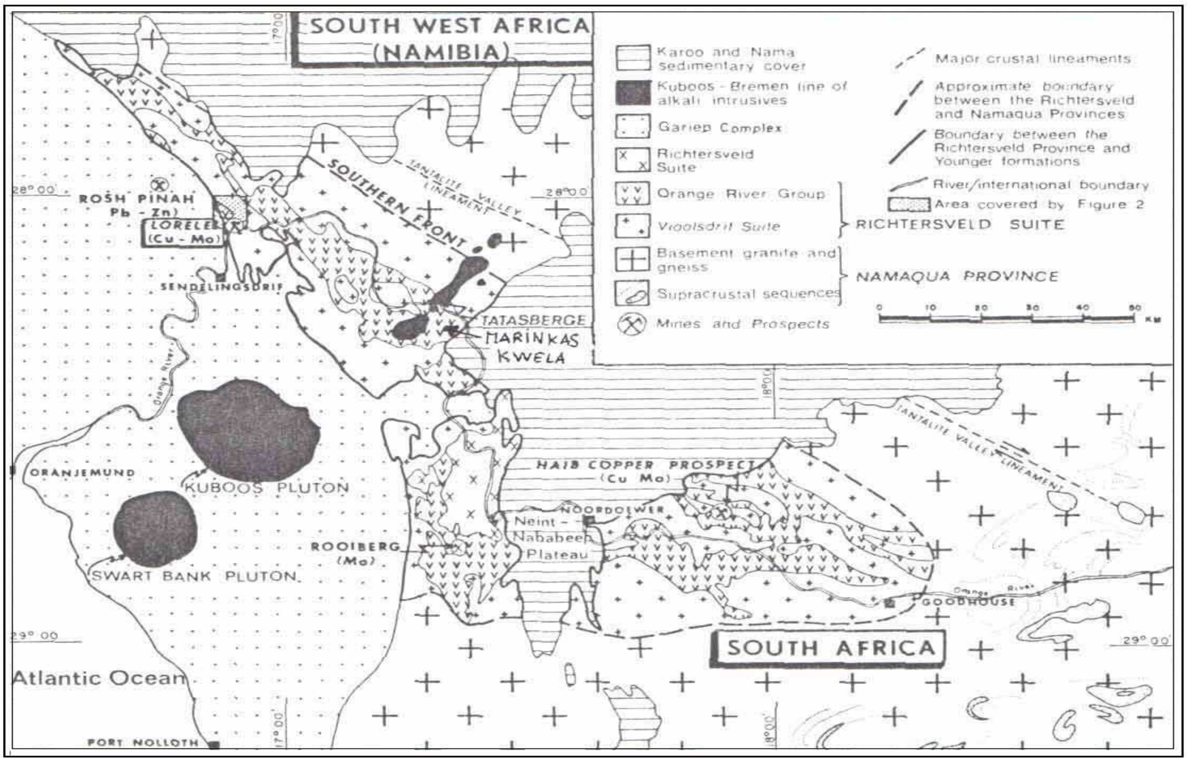

Figure 3.3 : Geological setting and position of porphyries in the Oranje river area. (R.P. VILJOEN et. al. 1985)

Plate 3.3 : Haib : view of the centre of the porphyry stock. The dumps indicate the main ore outcrop.

a) *prophylitic or outer zone :* This large zone is characterised by the chlorite - epidote - carbonate mineral assemblage. The rock often displays a distinctive green colour and is very tough. The outer margin of the zone is ill defined and slowly grades into unaltered rocks - here mainly dacites and andesites. Another typical feature of this zone are quartz veins with a width up to more than 25 centimeter, which show a polyphase veining history (see plate 3.4). The quartz filling is well developed and commonly form vugs with clear quartz crystals up to 10 cm, which indicates a surface near development of these quartz veins. Since the quartz veins are epithermal formed and originate from the porphyry system activity, they represent a good exploration target for gold mineralization (see chapter 5).

b) phyllic zone : Phyllic alteration is the most common form of alteration in porphyry systems (DE GEOFFREY & WIGNALL 1972). It causes complete replacement of the feldspars by a sericite - quartzite intermixture. Pyrite xenomorphs as well as idiomorphic cubes (or their weathered pseudomorphoses) occur abundantly. A typical pattern of this zone is the so called Trellis type rockfracturing (see plate 3.5) , which is caused by secondary water boiling in microscopical fractures and cavities.
Malachite staining is often observeable on the rocks of this zone.

c) potassic or core zone : The central zone of the Haib porphyry stock is characterised by secondary hydrothermally formed K - feldspars, which are mainly found in cracks, shear zones and Trellis type fractures(see above). Minor amounts of sericite, Na - feldspar and anhydrite occur as well.
The zone is rich in secondary copper minerals such as malachite and chrysokolla, which are handpicked for the mineral market.
Fresh unoxidized sulphides like pyrite and chalcopyrite are rare, but can be ocassionally seen in the centre of malachite aggregates. An occurence of relatively pure gypsum crystals near the houses at the main outcrop indicates the still ongoing sulphide weathering.

Intense exploration efforts and major capital expenditure has been carried out by RIO TINTO ZINC CORP. at the Haib porphyry and 240 km of drill cores can still be seen at the coreshed in the former exploration camp.
However the prospect has finally turned out to be to poor and remote to warrant further development.

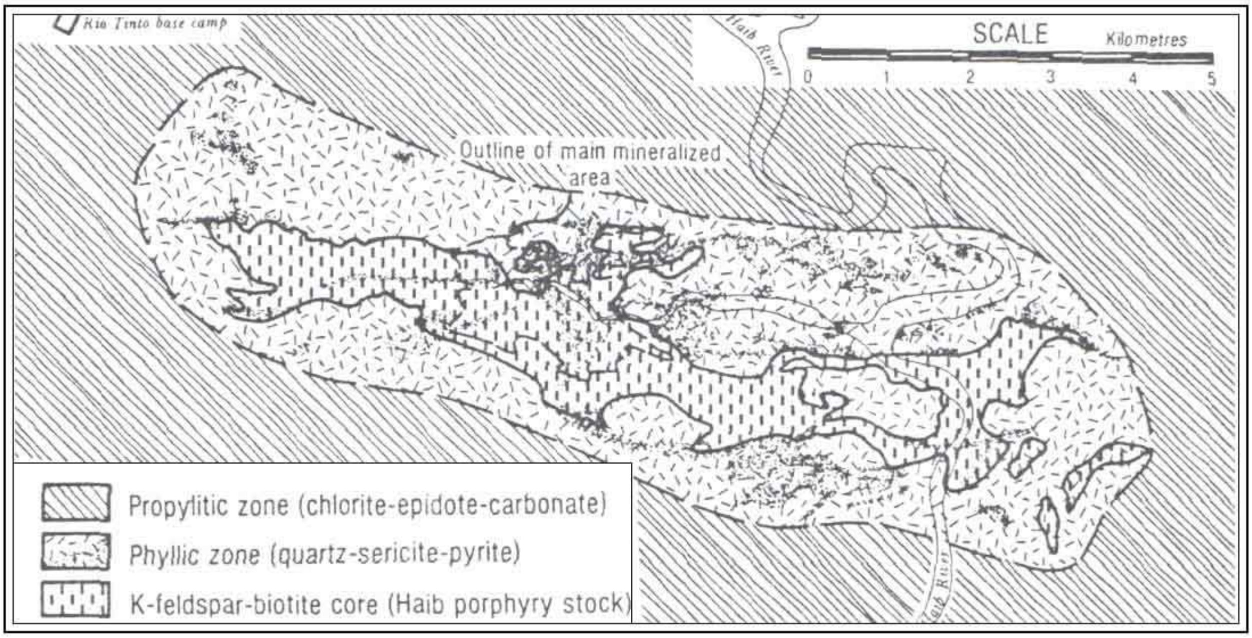

Figure 3.4 : Haib : schematic representation of the alteration zones. (R.C.A. MINITT 1985)

Plate 3.4 : Haib : polyphase quarz veins with open vugs in the outer zone. These veins form an exploration target for epithermal gold deposits.

Plate 3.5 : Haib : Trellis type fracturing caused by secondary water boiling (hydro - fracturing) in the phyllic zone.

Plate 3.5a : Haib : copper stained dumps from trial mining in the core zone.

3.1.3 Hydrothermal copper deposits : Numerous quartz veins, shear zones and fractures all over the NMB show copper staining and isolated copper sulphide blebs (HAMMERBECK in : COETZEE 1976), but there is only one well documented example for a major hydrothermal Cu - deposit. At Lutzputs, 30 km SW Upington a major cupriferous gossan has been investigated (BICKER & WING 1985).
A complex mineral assemblage containing Fe - Cu - Ag sulphides has been found below the gossan , which is controlled by narrow shear zones. The main copper minerals are chalcopyrite, chalcocite, bornite and digenite, the latter three being part of a secondary enrichment zone. Despite the significant silver contents of the deposit, which is bound to fahl - ores, the veins have been considered to be to small and erratic for exploitation.

3.1.4 Intrusive ultramafic copper deposits : Strictly speaking the term "ultramafic intrusives" could be used for the Okiep type deposits as well. At this place it should be confined to ultramafic intrusives associated with serpentinites and Cu - Ni mineralization.
A steeply dipping tremolite schist dyke with some serpentinite was outlined by means of airborne electromagnetic surveys on the farms Jacomynspan and Hartebeestpan 15 km W of Putsonderwater (ATTRIDGE 1985). The dyke, situated in quartz - feldpar gneisses, displays an average width of 50 m and can be traced for more than 4500 m. Sulphide mineralization has been proved in the upper part of the layered dyke, most commonly associated with serpentine rock. Higher sulphide values up to 20 per cent have been found in schistose hypersthenites. The ore minerals : pyrrhotite, pentlandite, cubanite and chalcopyrite occur predominantly in disseminated form, but specks of massive pentlandite have been observed as well.
An ore reserve evaluation down to 900 m proved 114 mio Tonnes grading 0.25 per cent Cu and 0.17 per cent Ni. No mining development has taken place due to the low grades and the vertical development of the orebody.

3.1.5 Pegmatite copper orebodies : Copper minerals are widespread minor constituents of the pegmatite mineral paragenesis and malachite staining can be seen frequently. Big lumps of high grade copper ore , mostly almost pure chalcocite with malachite and azurite crusts, occur within the Blesberg (Noumas) pegmatite S Vioolsdrift as well as in other pegmatites of the NMB. They reach a weight of several tonnes and may ocassionally justify separate exploitation and selling. However, no larger economic copper deposits are known to occur within the pegmatite bodies of the NMB.

3.2 LEAD, ZINC, BARYTE, (COPPER, SILVER) :

Large stratabound exhalative lead - zinc - copper - baryte deposits such as Gamsberg, Aggeneys, Areachap and Copperton has been the principal ore discoveries during the exploration boom in the early seventies.
It was these dicoveries which makes the Namaqualand - formerly nearly unknown to anybody - well renowned in the geological and mining world and which triggered the wealth of investigations and publications now available.
Beside the exhalative deposits there exist as well small hydrothermal Pb/Zn mineralizations in the NMB.

3.2.1 Sedimentary - exhalative deposits I : Gamsberg - Aggeneys orebodies :

The Gamsberg deposits and the Aggeneys orebodies form a chain of major Pb/Zn - copper - baryte occurences in the central part of Namaqualand.
The combined geological reserves of all four deposits total to at least 400 mio tonnes sulphide ore grading over 5 per cent combined Pb/Zn/Cu. Although only the Broken Hill deposit at Aggeneys is mined at present, there can be no doubt that the Gamsberg and the Black Mountain deposits will be put into production as soon as base metal prices recover. A detailed description of the Gamsberg and the Aggeneys deposits was published by ROZENDAAL (1985) and RYAN et. al.(1985) respectively.

Gamsberg : The Gamsberg, situated 50 km W of Pofadder, shows the outer appearance of a relatively low table shaped inselberg, similar to many others in the vicinity. However, the bowl - shaped interior displays a complex geology and several econcomically viable mineral occurences (see plate 3.6 and figure 3.5). Baryte had been mined long before the actual discovery of the metal ores.

The general stratigraphy of Gamsberg and the Aggeneys area is shown in table 3.1 . An often pink coloured granite gneiss (Haramoep gneiss) forms the lowermost part of the sucession, followed by aluminous schists (Namies schist), which is intermixed with calc silicate - sillimanite bodies.
The main part of the higher Gamsberg is formed by a coarse grained quartzite (Pella quartzite), which ocassionally shows a rose colour.

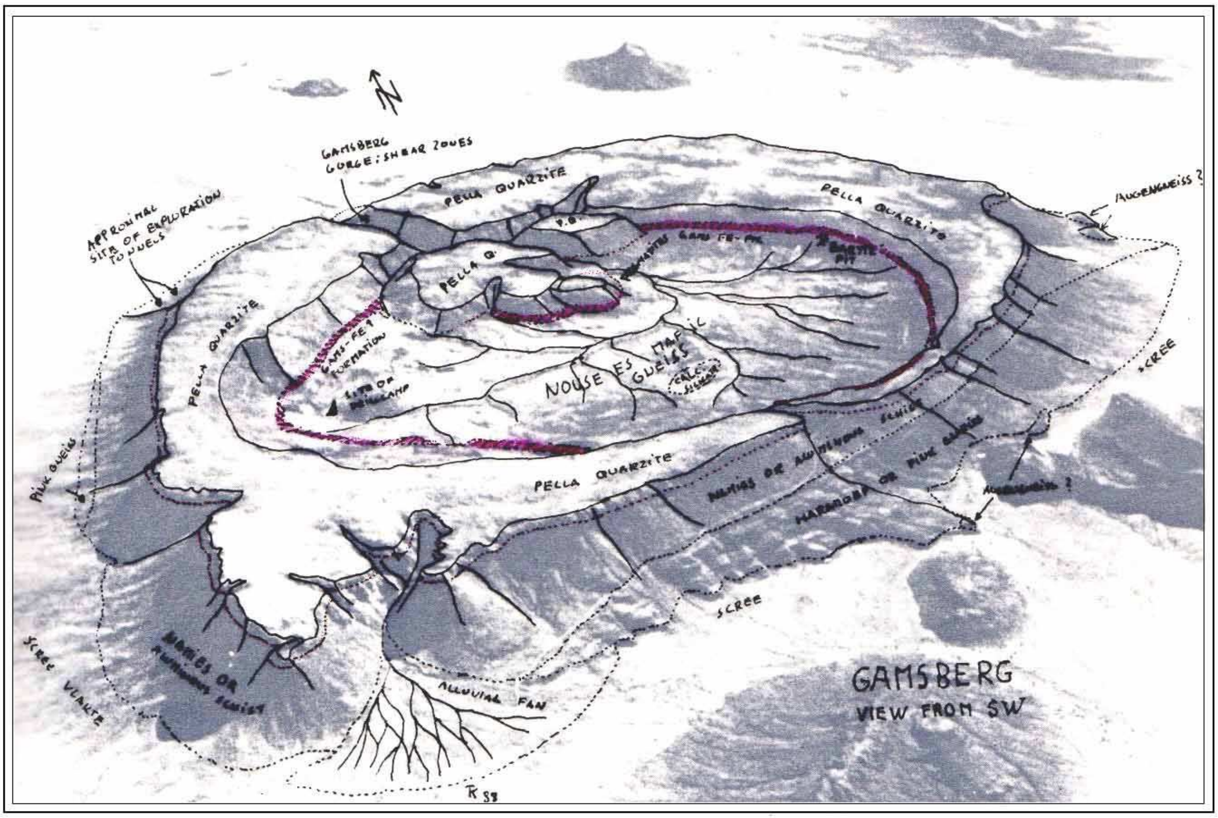

Plate 3.6 : Gamsberg : aerial view from SW with outlined geology (Source : ROZENDAAL 1985).

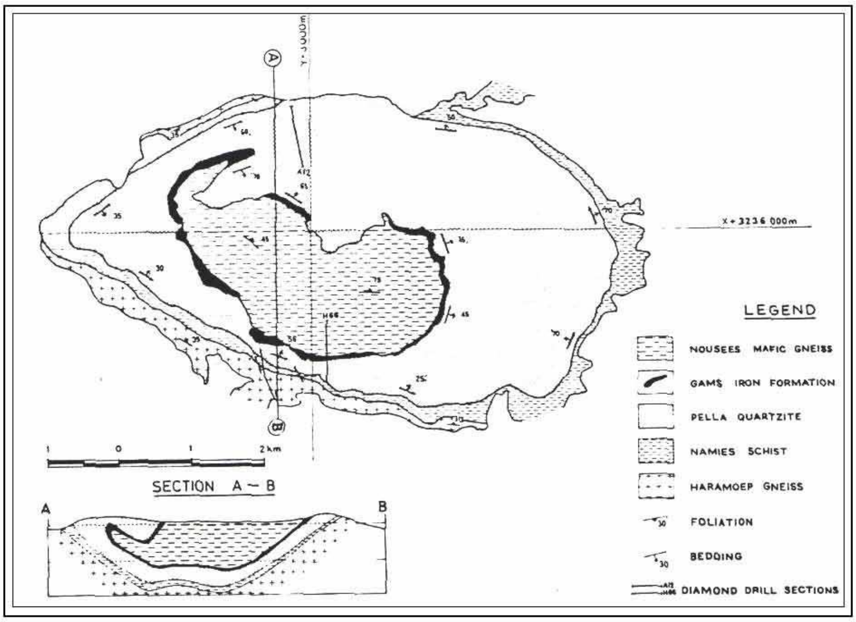

Figure 3.5 : Gamsberg : general geological map and section, showing the internal overfolding. (ROZENDAAL 1985)

The economically important Gams formation form gossaneous outcrops along the inner wall of the basin. The mineralogically very complex unit is characterized by predominant dark coloured magnetite - garnet - quartzites, but several other lithotypes occur as well. The magnetite - garnet - quartzites can be interpreted as metamorphic equivalents of the cherty oxide facies in an exhalative basin environment (metamorphosed Lahn - Dill type iron ores).
The uppermost stratigraphic unit comprises out of mafic gneisses, which hosts several boudinage - elongated pegmatites. Other pegmatites in the vicinity are characterized by their green amazonite - feldspar contents.
The tectonic deformation of the rocks in the basin is intense and numerous tectonic features such as mullions and boudinages can be observed.

A somewhat enigmatic rock unit was studied by the M.Sc.class in greater detail and is portraied in plate 3.7 . A quartzitic conglomerate unit laterally slowly grades into magnetite - garnet - quartzites with well developed quartz pebbles slowly changing into boudined quartz lenses.
The (unsolved) question remains, wether this is an original quartz conglomerate , which has been partly altered during the metamorphosis or wether it is a quartz segregation caused by the metamorphosis itself, which sometimes form pebble like aggregates.

At Gamsberg 150 mio tonnes averaging 7.1 per cent zinc and 0.5 per cent lead have been delineated. Main ore minerals are usually fine grained sphalerite and galena, followed by the iron sulphides pyrite, pyrrhotite and marcasite. Chalcopyrite is relatively rare, according to the general lack of copper in the deposit.
The gossan mainly consists out of iron minerals as magnetite, hematite and goethite (limonite). COETZEE (1958) reported the occurence of several manganese minerals from here (see chapter 3.3). Apart from very rarely visible copper stainings no signs of the underlying sulphide bodies can be observed at the surface.

Exploration history : The Gamsberg was one of the last refuges of the Bushmen population in Namaqualand up to their extinction here in the middle of the last century. No signs of ancient exploitation of iron or lead has been found. In 1954 the prospector NIEMOLLER discovered several million tonnes of baryte in the Gamsberg basin (COETZEE 1958). Open pit mining was started subsequently which is still in progress today.

The iron ores of the gossan were recognized and studied as well, but "were considered to be too small or too poor in quality to be exploited " (ROZENDAAL 1985).

In 1970 the OKIEP COPPER COMPANY, forced through the discovery of the Copperton orebody at Prieska (see below), started a regional mapping program together with the University of Cape Town. A preliminary examination of the interior of the Gamsberg was executed by OKIEP and NEWMONT geologists in 1972, which led to the recognition of the true nature of the "iron ores" as well developed gossan capping overlying a major sulphide body.

Geophysical and geochemical methods helped to establish the outline and the potential of the deposit, whereas the geochemical survey showed a strong negative zinc anomaly (!) over the gossan, caused by obviously complete leaching of all zinc minerals.

Surface diamond drilling commenced in June 1972 and the second hole intersected 102 meters of massive sulphides averaging 6.24 per cent zinc and 0.82 per cent lead respectively. Until 1978 more than 70 km combined surface and underground drilling has been performed.

The construction of two adits at the northern side of the mountain for further exploration and bulk sampling started in July 1975 and 3660 meters has been developed so far.

Exploration work and mine development was suspended in May 1978 due to low metal prizes and since that time the prospect is on a care and maintenance level.

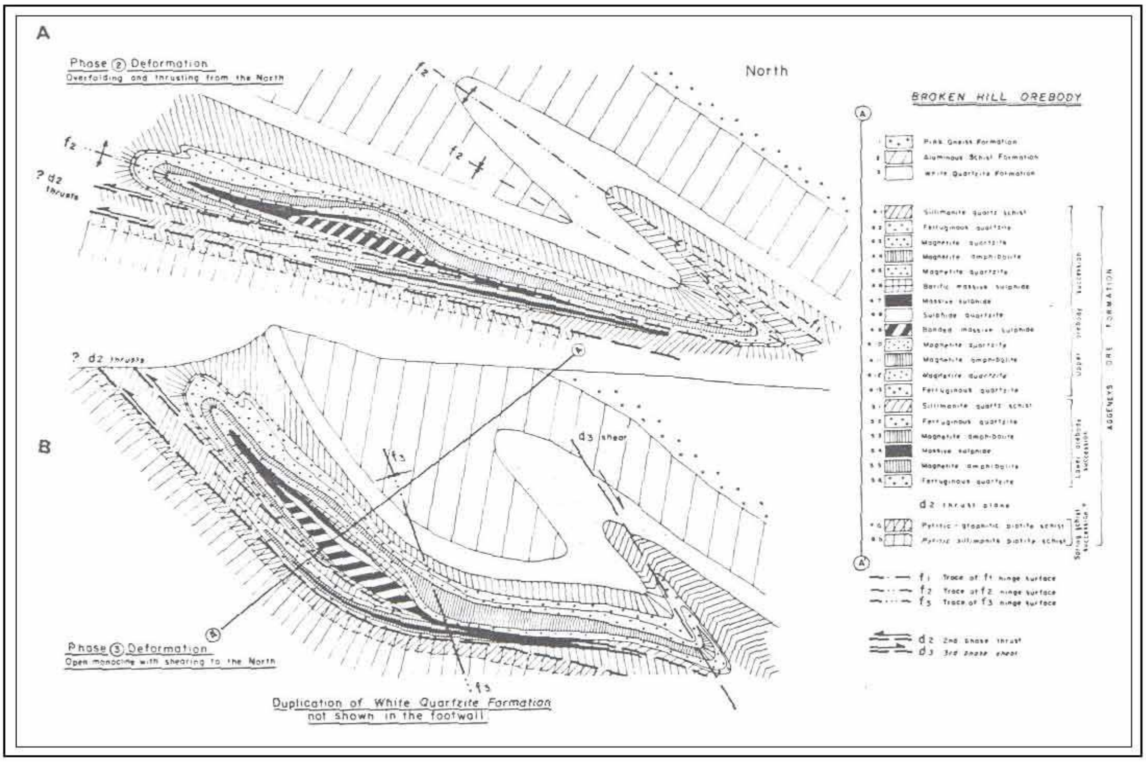

Figure 3.6 : Broken Hill mine : two sections showing the develop - ment of the complex folding of the orebodies. (RYAN et. al. 1985)

Plate 3.7 : Gamsberg : enigmatic conglomerate or quarz segregation (see text for discussion).

Plate 3.8 : Black mountain : isoclinal folding marked by prominent magnetite - garnet - quartzites with gossan depression in the centre.

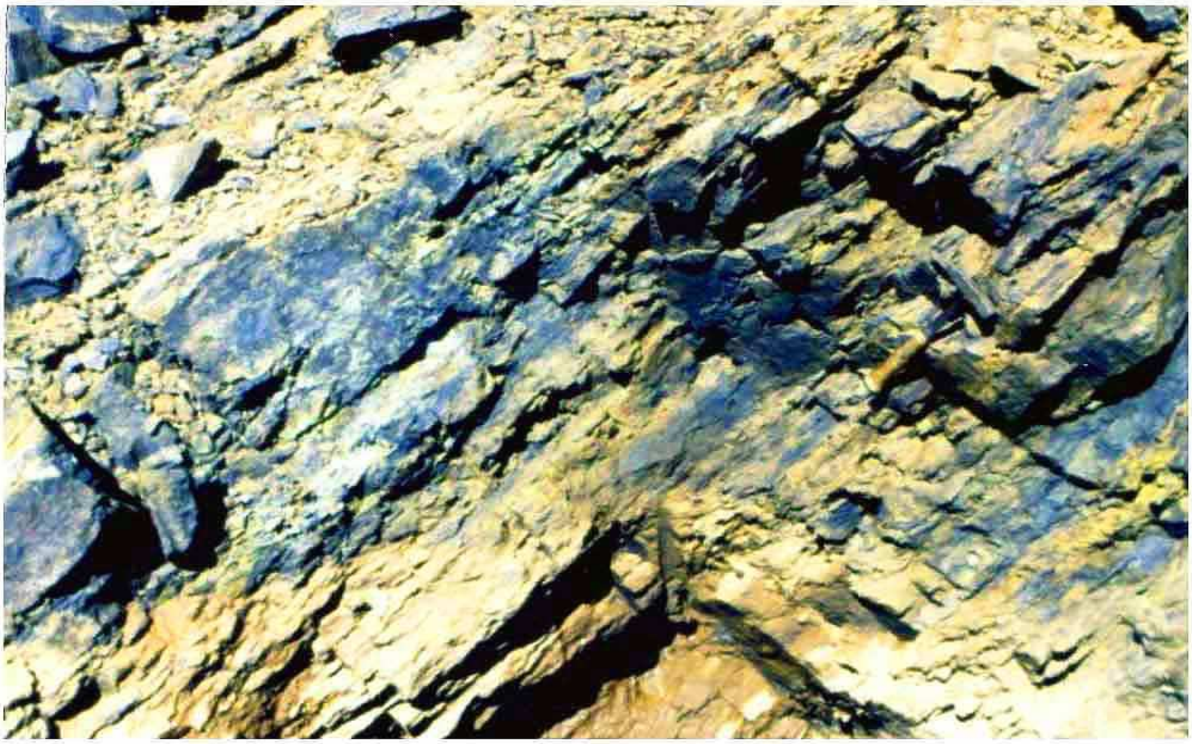

Plate 3.9 : Black mountain : copper staining (malachite) in early exploration pit immediately north of gossan.

Aggeneys deposits : Three major orebodies are known at Aggeneys : the most westerly lying Black Mountain deposit with 81.6 Mio tonnes at 0.75 per cent Cu, 2.67 per cent Pb and 0.6 per cent Zn ; the central Broken Hill deposit with at least 85 Mio tonnes grading 0.34 per cent Cu, 3.87 per cent Pb and 1.77 per cent Zn (concentrated in two separate - upper and lower - orebodies) and the easterly lying low grade Big Syncline deposit with 101 Mio tonnes at 0.1 per cent Cu, 2.1 per cent Pb and 2.45 per cent zinc. Exploration started 1971 through PHELPS DODGE CORP and reached a peak in the midth of the seventies. In January 1980 the Broken Hill deposit was brought into production after completition of a new town at the site of the former farm Aggeneys. Exploration is still under way in this region - though on a limited scale.

The stratigraphy of the rocks adjoining the Aggeneys orebodies is very similar to the Gamsberg stratigraphy, but the ore bearing rock suite - again characterized by widespread magnetite - garnet - quartzites and by the baryte content - is called Aggeneys ore formation. At Black Mountain and at Big syncline the succession is normal, while at Broken Hill the stratigraphy is inverse owing to overfolding (see figure 3.6).

The deformation history of the Gamsberg - Aggeneys area is - as in the whole Bushmanland subprovince - complex and at least four different deformation phases has been active.

Since the mineralogy of the Broken Hill deposit is quite complex and about 40 different minerals are known - including the zinc spinel gahnite as major ore constituent and secondary ferrisulphates and phosphates like jarosite and vivianite in the well developed oxydation zone - relatively little is published about the mineralogy of Black mountain and Big Syncline. However the mineral assemblage garnet - magnetite - sulphide - quartzite seemed to be a typical paragenetic pattern of these deposits.

Extremely coarse grained intergrowths of the ore minerals (with grains up to fifty cm !) sphalerite, galena and chalcopyrite occur as well and indicate extensive recrystallisation of the deposits during their metamorphic course.

The M.Sc.class visited the outcrop of the Black mountain deposit under the guidance of DANY VENTER (AAC). The photograph (see plate 3.8) show two prominent magnetite - garnet - quartz ridges at the southern slope of Black mountain, which form the two limbs of an isoclinal fold, whereas the morphological depression in the center represent the actual gossan zone of the deposit, situated in the core of the fold hinge.
An early (dating 1927) exploration pit at the northern edge of the gossan displays marcant copper staining (see plate 3.9). However the pit missed the actual sulphide zone and 45 years passed before this gossan was sucessfully reinvigasted.

Genetical considerations of the Gamsberg - Aggeneys deposits :
The similar geological setting and stratigraphy of both the Gamsberg and the Aggeneys orebodies indicate a +/- simultaneous formation. Further more the metal grades of the four deposits show a clearly visisble zonation with the copper highs in the west and the zinc highs in the east, as listed below :

	Black Mountain	Broken Hill	Big Syncline	Gamsberg	Unit
Cu	0.75	0.34	0.04	traces	per cent
Pb	2.67	3.57	1.01	0.5	per cent
Zn	0.59	1.77	2.45	7.0	per cent
Ag	29.83	48.10	12.90	not rec.	gr/tonne
Baryte	rare	lim.distr.	not rec.	pure deposits	

(Source : RYAN 1985 , extended)

Lead and zinc behave similarly, probably due to the fact, that galena is the main silver bearing mineral, with the maximum at Broken Hill and a clear decline to the east. Although baryte seems to be present at all of the orebodies, Gamsberg is the only place with baryte forming independent and pure deposits on its own.
The ore metal distributiton pattern correspond well with a model implying a hot exhalative centrum in the west with mainly copper and lead precipitation and a cooler and more distal environment in the east with mainly zinc and baryte formation. According to this model the Gamsberg - Aggeneys deposits could have been formed through a single isochroneous exhalative phase in a spreading back arc environment with sulphide transport by east running currents.

During the metamorphosis the ore was concentrated in the fold hinges, where it now forms huge masses of massive sulphides.

3.2.2 Sedimentary - exhalative deposits II : Eastern Namaqualand deposits

Several massive sulphide orebodies has been delineated in the eastern part of Namaqualand since the initial discovery of the Copperton orebody, which are believed to be of sedimentary - exhalative origin.
Papers has been published on the Copperton deposit (WAGENER & VAN SCHALKWYK 1985), on the Areachap orebody (VOET & WING 1985) and more recently on the Boksputs Cu - Fe occurence (GEIRINGER et. al. 1987).
Other deposits belonging to this group include the Rozynenbosch, the Kielder and the Van Wykspan pyrite deposit (for locations see Figure 3.8).
Unfortunately not much data has been published about these deposits so far. However their presence indicate the potential for new discoveries of massive sulphide deposits in the region.

Copperton orebody : Although malachite was known from the place (formerly called the Vogelstruisbult farm) since the last century and an attempt to develop the deposit was made as early as 1913, the real dicovery of the orebody was made in 1968 by ANGLOVAAL geologists. Soon a mine was developed and exploration activity started to spread out over the NMB as whole.
The rocks present at Copperton are predominantly hornblende bearing gneisses, which show a streaky to banded structure. They form part of the tightly folded Copperton - Areachap belt in the Jannelsepan fm., whereas the local structure is that of a major synform. Figure 3.7 displays the surface geology and a vertical section of the sequence, showing the elongated shape of this and the neighbouring Annex sulphide body, which have been found to be too small for commercial exploitation.

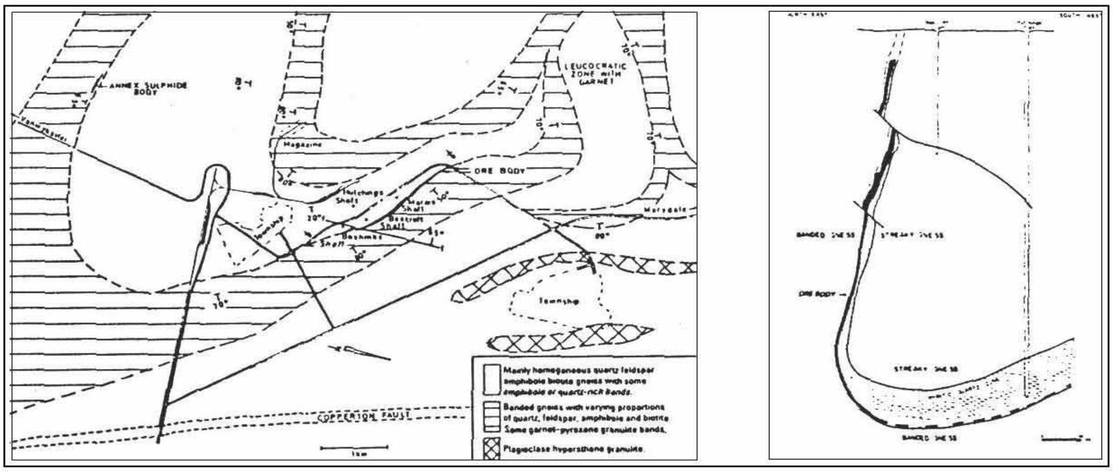

Figure 3.7 : Copperton : *Surface geology and section.* (WAGENER & VAN SCHALKWYK 1985)

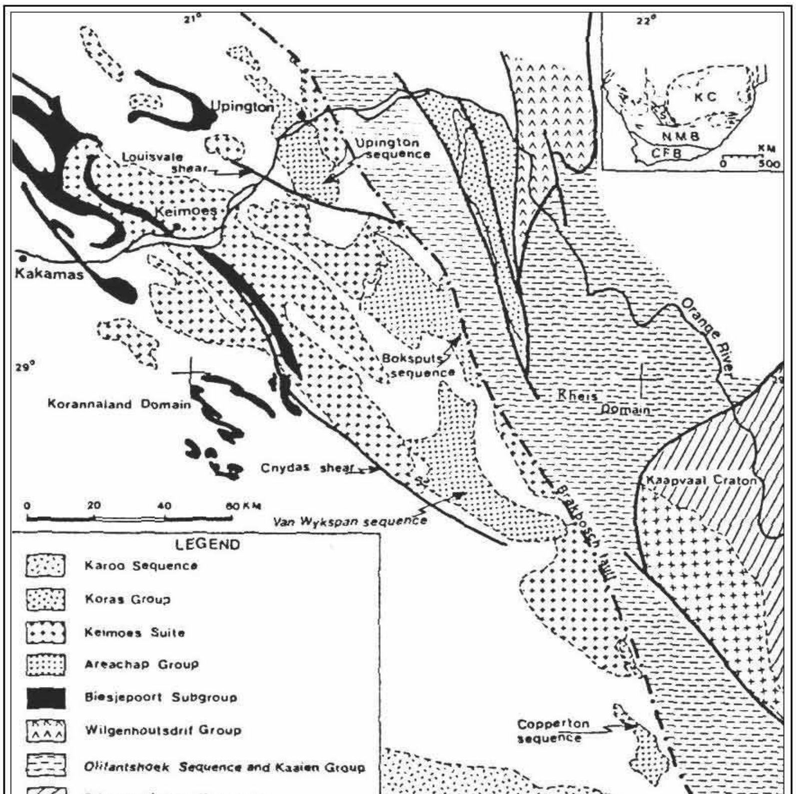

Figure 3.8 : *Schematic geological map showing the geological setting* of the Copperton - Areachap belt (Areachap group). *Location of deposits :*
Copperton sequence = Copperton, Annex and Kielder
Van Wykspan sequence = Van Wykspan pyrite deposit
Boksputs sequence = Boksputs Cu - Fe sulphide bodies
Upington sequence = Areachap Cu - Fe sulphide bodies
(GEIRINGER et. al. 1987)

The gneisses contain a 10 to 100 m thick sulphide rich sucession, which is bound to a very "coloured" mineralogically complex rock suite (see below). The sulphide zone consists out of an outer quartz rich and an inner sulphide rich sequence, mainly sphalerite, chalcopyrite and galena, totalling to at least 50 Mio tonnes at 1.7 per cent copper and 3.8 per cent zinc. The orebody is overlain by generally more than 80 meters of deeply leached gossan.
An interesting aspect is the occurence of the so called " manganese rich magnetite zone " in juxtaposition to the sulphides. This zone mainly consists out of magnetite, carbonate and andradite - spessartine garnets with minor amounts of diopside and rhodonite and the rare minerals bustamite and tephroite. However, apart form the higher manganese contents - resulting in the formation of Mn - silicates instead of of quartz - and the carbonate contents this sequence can be considered as the Copperton equivalent of the magnetite - garnet - quartzites of Gamsberg and Aggeneys.

Areachap orebody : The Areachap copper - zinc (- silver) orebody is situated 15 km NW Upington at the northern end of the Copperton - Areachap belt.
The site is covered almost completely by sand, calcrete and Karoo cover, nevertheless a prominent gossan is developed.
Copper rich portions of the gossan with the main minerals malachite, azurite and cuprite and of the underlying supergene enriched zone with the secondary sulphides covellite and chalcocite has been mined from 1906 to 1919.
During the sixties and the seventies the property was reinvestigated and drilled by ISCOR, CAPE ASBESTOS and ANGLO AMERICAN, but was finally found to be too small for further development.
The steeply dipping sulphide body is confined to a biotite - garnet schist, which is themself embedded in an amphibolite gneiss sequence. No magnetite - garnet - quartzite or an equivalent has been recorded so far.
The total thickness of the sulphide bearing zone varies from 0.1 to 24.2 meters. Reserves has been calculated to 6.7 Mio tonnes of massive sulphides grading 0.95 per cent copper and 2.88 per cent zinc with additional reserves of 3 Mio tonnes of disseminated low grade sulphides.
Main ore constituents are pyrite, pyrrhotite, chalcopyrite and sphalerite with minor amounts of galena and the rare minerals native tellurium, native bismuth and the silver telluride altaite. The ore minerals are generally coarse grained due to intense recrystallisation.

Although only few volcanic rocks are observable at the surface or in drill cores, the Areachap orebody was probably formed in a restricted fracture controlled basin in an back arc environment with the ore fluids deriving from a deep seated magma chamber (VOET & KING 1985).

Boksputs orebody : The mineralization at Boksputs in the Copperton - Areachap belt was described only recently by GEIRINGER et. al. (1987).
The sulphide occurences are associated with the so called Kraalkop fold zone very close to the Brakbosch fault, which separated the Gordonia subprovince from the Kheis subprovince. The host rocks are massive amphibolites and amphibolitic gneisses and schists.
Ferrugineous gossan with box work texture and malachite staining reveal the presence of sulphides in the depth. An assemblage of pyrite, chalcopyrite, sphalerite, pyrrhotite, ilmenite and iron oxides form several lens shaped bodies, which are severely fractured and affected by late stage chlorite - carbonate - quartz hydrothermals. Figure 3.8 show the regional setting of this and the other known sulphide deposits in the Copperton - Areachap belt.

.2.3 Sedimentary - exhalative deposits III : Pofadder area deposits

Two peculiar sulphide deposits, which may be related to sedimentary - exhalative formation, are known in the Pofadder area : the Putsberg and the Adjoining Geelvloer orebodies. While no adequate information has been released about the latter, a paper on Putsberg has been published by VILJOEN et. al. in 1985.

Putsberg : The Putsberg deposit is located about 50 km SE of Pofadder in an area, which is characterised by almost complete lack of topographical features, gossan development and outcrops. The exploration in this flat and unexposed terrain has therefore turned out to be rather difficult and several exploration techniques has been employed (see below).
The rocks surrounding the deposit are ferrugineous cherts with magnetite, sillimanite and cordierite as well as gneisses of different colour, which may contain some pyrite and garnet. The sulphides are concentrated in a magnetite - quartz rich succession with a maximum thickness of approximately 20 meters. However, finely disseminated sulphides can be found over a far wider range, up to 50 m thickness.

The major sulphides are, in order of decreasing abundance : pyrite, pyrrhotite, chalcopyrite, iron rich sphalerite (marmatite) and galena.
The structure of the Putsberg deposit is complex and at least three deformation events are present, although the macrostructural setting of the deposit has not been fully understood to date due to the lack of outcropping rocks. Though the disseminated nature of sulphide distribution the deposit is believed to have formed by sedimentary - exhalative processes.

Exploration history : The Putsberg deposit is a classic example of the employment of various interacting exploration methods in order to outline a viable sulphide deposit.
The JOHANNESBURG CONSLIDATED INVESTMENT CO. (JCI) decided in 1972 to establish an exploration program in order to delineate new Sedex type deposits. The initial criteria for target generation, based on the Gamsberg - Aggeneys area, were the following : 1) Sedex type deposits in Namaqualand are commonly associated with quartzitic micaceous schists ; 2) they are also associated with magnetite and baryte occurences.
Fortunately some of the very first available Landsat satellite images in 1972 covered the NMB and soon helped to outline exploration targets.
In 1973 an initial aeromagnetic survey was undertaken over the Pofadder area, which indicated an elongated anomaly on the farm Putsberg. Subsequently the farm was leased and extensive mapping and an Induced Polarisation survey was executed, which helped to establish the ground outline of the anomaly. Three areas of high copper values, obtained by means of an following geochemical survey, indicated accurately the site of the three individual orebodies. A major trenching and waggon drilling program was started next, whereas the latter produced encouraging assay results.
Diamond drilling commenced in late 1973 and totaled to more than 13000 meters, indicating 1.5 Mio tonnes disseminated sulphide ore grading 1.5 per cent copper with minor amounts of zinc and silver.
The small proven reserves of the deposit has been considered to be of too limited scale for further development.

3.2.4 Hydrothermal lead - zinc - (copper) deposits

An uncountable number of fractures, shear zones and joints are present in the NMB, most of which are filled with quartz of hydrothermal origin. Many of these quartz veins carry at least traces of lead, zinc and copper mineralization as well. Typical examples have been published chiefly from the western Namaqualand. At Kuboos lumps of galena and sphalerite were found adjactent and in quartz veins. Another quartz vein sporadically containing lead and copper minerals together with calcite and baryte is located about 16 km ESE of Stinkfontein. These and other hydrothermal deposits have been described in greater detail by DE VILLIERS & SOEHNGE 1959.
Hydrothermal lead - silver bearing veins with oxydation minerals as anglesite, cerussite and calamine (a mixture of hemimorphite and smithsonite) are known from the northern extension of the NMB towards Namibia (HAUGHTON & FROMMURZE 1934). There are definetely far more occurences of hydrothermally formed lead - zinc - copper mineralizations throughout Namaqualand to be found, but not much is published about it.
However, all the known hydrothermal deposits never had any economical importance but a very local one.

3.3 IRON, MANGANESE :

There exists two principal sources for iron ore in Namaqualand : a) the sedimentary cherty banded iron formations in the western edge of the NMB near Prieska and their metamorphic equivalents all over the place ; and b) the gossan outcrops of the sulphide bodies.
The group of iron rich sediments can be observed in the road cuts W Prieska, where they were studied by the M.Sc.class. The thick folded BIF sequence yields up to 40 per cent Fe bound in hematite form. Although big reserves are easily obtainable this deposits can in no way compete with the high grade deposits in the other parts of the Republic. The same is true of their metamorphic equivalents which, although higher in iron contents, are too erratic and poor in grade to warrant exploitation.

The gossan outcrops of the sulphide bodies are generally rich in iron and in fact up to the end of the sixties the gossans were mistaken for simple iron deposits. Several of these gossans has been investigated in great detail by mining companies in the fifties with poor sucess.
The Gamsberg gossan hosts - apart from at least 0.5 Mio tonnes iron ore grading up to 56 per cent Fe - considerable amounts of manganese bound to the minerals jacobsite, cryptomelane, bixbyite, pyrolusite and psilomelane. The ore is exposed over a strike of almost 8 km and reaches a maximum thickness of 3.7 meters, grading up to 26.3 per cent Mn. Comparable mineralizations have been reported from the gossans at Aggeneys (COETZEE 1958 ; 1976).
A vein deposit of manganese minerals, occuring in granite gneiss on the farm Zandkops Drift between Garies and Bitterfontein in the western Namaqualand has been described by DE VILLIERS 1960. The Putsberg deposit contains significant amounts of manganese bearing minerals as well, as discussed above. Sulphide bodies of sedimentary exhalative origin with a very pure pyrite contents are known to occur at Van Wykspan in the eastern part of Namaqualand (see figure 3.8). Although the deposit seemed to be subeconomic, no further data is available.
All iron and manganese deposits known to date in the NMB are small and/or of low grade and has been found to be of no commercial value.

3.4 TIN, TUNGSTEN, (GOLD) :

Several occurences of tungsten and tin are known in the NMB. A working mine, owned by RIO TINTO, exploits an alluvial deposit at Rhenosterkop near Augrabhies. Unfortunately no further data is available. Peculiarly only very few pegmatites (on farm N`Rougaas and the Straussheim II pegmatite) seems to contain visible cassiterite grains (GEVERS et. al. 1937)

3.4.1 Deposits with wolframite as major mineral

Two major tungsten deposits are known in the NMB with minerals of the wolframite group being the commercially important minerals : Van Roois Vley near Upington and the former tungsten mining district in the Okiep area.

Van Roois Vley : The Van Roois Vley deposit - located 15 km W of Upington - was discovered by the owner of the farm in 1943. Subsequent exploitation lasted till 1958, when declining tungsten prices forced operation to close. Renewed interest in the property followed the exploration boom in the mid seventies with PhELPS DODGE being the company in charge. 2.5 Mio tonnes of mixed cassiterite - scheelite - wolframite ore have been indicated so far (WHEATLEY & DE BEER 1985). The W - Sn orezone is controlled by six steeply dipping quartz - tourmaline veins crosscutting metasediments and metavolcanics, which form a tight synform. A closely situated anatexic granite is thought to be the source for the ore generating brines.
Smaller depsosits of a similar setting are known from the farms Kakamas Suud, Kalksloot and McTaggart, all located in the Gordonia district (CROCKER in : COETZEE 1976).

Okiep area : A succession of leptites and sillimanite - garnet - magnetite - mica schists with intergrown apatite and zircon is locally known as "wolfram - schist". Only very few exposures are observable throughout the region with the schist always embedded in Nababeep granite gneiss.
The wolfram schist hosts occasionally quartz veins and lenses ranging from a merely few centimeters to a meter and more in width. Members of the wolframite series are the main ore minerals present in the quartz with minor amounts of native bismuth, bismuthinite, pyrite, chalcopyrite, scheelite and molybdenite. Higher grade mineralization seemed to be bound to sillimanite rich parts of the host.
The wolframite was exploited predominantly by the OKIEP COPPER COMPANY from 1941 to 1949 and again from 1952 to 1956, with mines at Kliphoog, Nababeep and Tweedam. A small privately owned deposit is located on the farm Biesies W of Okiep, which has been intermittently operated since 1953.
The origin of the deposits is believed to be either by metamorphic differentation of former sedimentary rocks or by a specialized pegmatite formation deriving from local intrusives (COETZEE 1976).
A detailed description of the Nababeep West tungsten mine was published by SOEHNGE in 1950.

3.4.2 *Deposits with scheelite as major mineral*

The calcium wolframate scheelite is a minor constituent of many quartz veins in the northern part of the NMB, but the major occurences are concentrated along the lower part of the Oranje river. The quartzitic to pegmatitic vein type deposits are often found to intersect highly sheared ultramafic rock suites. Some more important deposits are listed in the following in alphabetical order : Altemooi, Armbank, Bitterfontein, Boesmanslepel, Coboop, Goodhouse, Groendoorn, Isis, Kaalbeen, Koalknie, Koubankkopie, Nous and Xochasib (Keyser in : COETZEE 1976).
The size of the scheelite bearing veins seldom exceeds 40 cm in width and 10(meters in strike. The scheelite is often intimately associated with black tourmaline ; other accompanying minerals include copper sulphides and rarely cassiterite.
Although the scheelite deposits are of only very limited commercial value due to their small size and erratic distribution, they could be an important clue for future tungsten exploration (see chapter 5.2).

Furthermore, small gold nuggets has been found associated with some of the scheelite veins , e.g. the Xochasib vein (GEVERS et. al. 1937). This seemed to be - apart from the very low grade gold values reported from the major base metal deposits - the only published gold find in Namaqualand to date.

3.5 URANIUM, THORIUM, RARE EARTH ELEMENTS :

Major uranium exploration programs have been realized in the seventies throughout the NMB (ROBB 1985), whereas HAMBLETON - JONES et. al. (1985) give a summary of the surficial uranium deposits.
Apart from small and scattered REE amounts in pegmatites, represented predominantly by the minerals monazite, xenotime, samarskite and gadolinite, there exist lenticular bands of allanite with a maximum thickness of 50 cm near Cnyda West / Gordonia (HUGO 1961). Some of the pegmatites carry thorium and uranium in the form of thorianite (orangite), uraninite and secondary uranium phosphates and arsenates (e.g. the Blesberg or Noumas pegmatite).

ROBB (1985) describes the geological setting of Roessing type uraniferous alaskite deposits on the farm Nooitgedacht SW Springbok. The alaskite intrusions, which are anomalously enriched in uranium and thorium, have been evaluated during the seventies by SOUTHERN SPHERE URANIUM LTD.
Detailed surface mapping, diamond drilling and assaying has been undertaken, but ceased when it became clear that the alaskites were too small and of too low grade. However, the whole Okiep - Springbok area show an anomalous high natural radiation background and may contain some more promisisng exploration targets.
Another type of uranium deposits in Namaqualand is represented by secondary uranium minerals enriched in unsolidified sediments (ROZENDAAL 1984).
A good example is the Dirkskop deposit in the dune area occupying the Koa valley near the farm Ou Taiboschmond - Kamasoas (Lemoenspoort), where 1.7 Mio tonnes of carnotite - gypsum mineralization grading 138 gr/ton uraniumoxide have been delineated. Figure 3.9 shows the geology of the deposit. Several other of these lacustrine environment carnotite - gypsum deposits have been described by HAMBLETON - JONES et.al. (1985), namely Brulkolk SW Kakamas, Abikwaskolk near Geelvloer and Kannikwa 15 km E Port Nolloth.

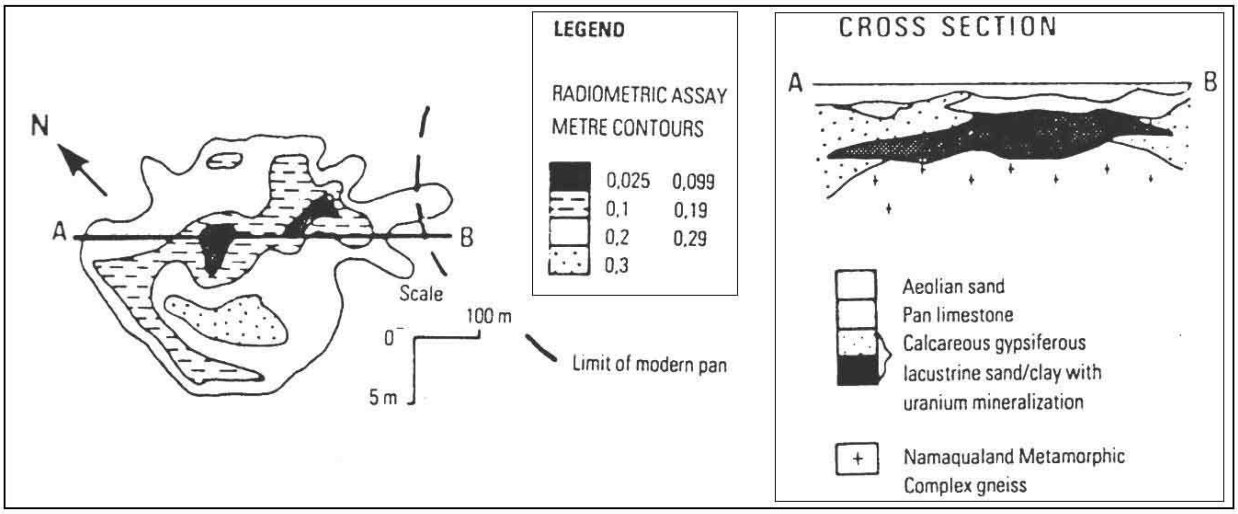

Figure 3.9 : Koa Valley : Geology of the carnotite - gypsum deposit at Dirkskop. (HAMBLETON - JONES et.al 1985)

Although all these specific deposit have been considered to be subeconomic, there remain vast sand covered areas in the NMB for the future explorationist.

3.6 PEGMATITE RELATED METALS :

The pegmatite deposits of Namaqualand are a viable soruce for metals including beryllium, bismuth, lithium, niobium, tantalum ; and to a minor extent for copper (see above), uranium, thorium and REE.
Furthermore the pegmatites contain considerable amounts of the industrial minerals mica and feldspar.
The pegmatites in the NMB are concentrated in a narrow belt like distribution pattern along the Oranje river , which strikes for almost 450 km roughly E - W wards (see figure 3.10). The shapes of the pegmatites vary from plug like appearances (Spodume Kop) to elongated dykes (Noumas, Straussheim, Swartkop, Marchard) to completely irregular forms (Sidi Barrani).
The pegmatites can be classified into three groups (HUGO 1985) :
1.) homogenous unzoned (primitive) pegmatites, which seldom carry minerali - zations of economical value ; 2.) unhomogenous simple pegmatites with up to four distinguishable zones. These pegmatites are the most abundant ones and usually contain andalusite, corundum, apatite and/or rare earth minerals as monazite and xenotime. They often display a large quartz - feldspar core, which may be suitable for exploitation ; 3.) unhomogenous complex pegmatites with more than four and often very complex zones. This type of pegmatites is commonly associated with greisen alteration, resulting in the formation of beryl, lithium ores as lepidolith and spodumen, tantalite - columbite and bismuth minerals. A good example for this type is the visited large Blesberg (Noumas) pegmatite. Plate 3.8 shows a member of the fieldtrip in front of the inner core zone of the Noumas I pegmatite. In the upper right corner there are big feldspar crystals, underlied by mauve coloured spodumene aggregates. The black patches to the left comprises masses of the manganese phosphate triplite, which is surrounded by a halo of secondary manganese phosphates and oxides.
Radiometric age determination on the pegmatites and on the surrounding granite gneisses indicated that the gneiss was formed only shortly before the emplacement of the pegmatites (around 1000 m.y. (HUGO 1969)).
Conferring to that the pegmatites may originate from late metamorphic rest melts with a high fluid contents in the immediate surrounding.

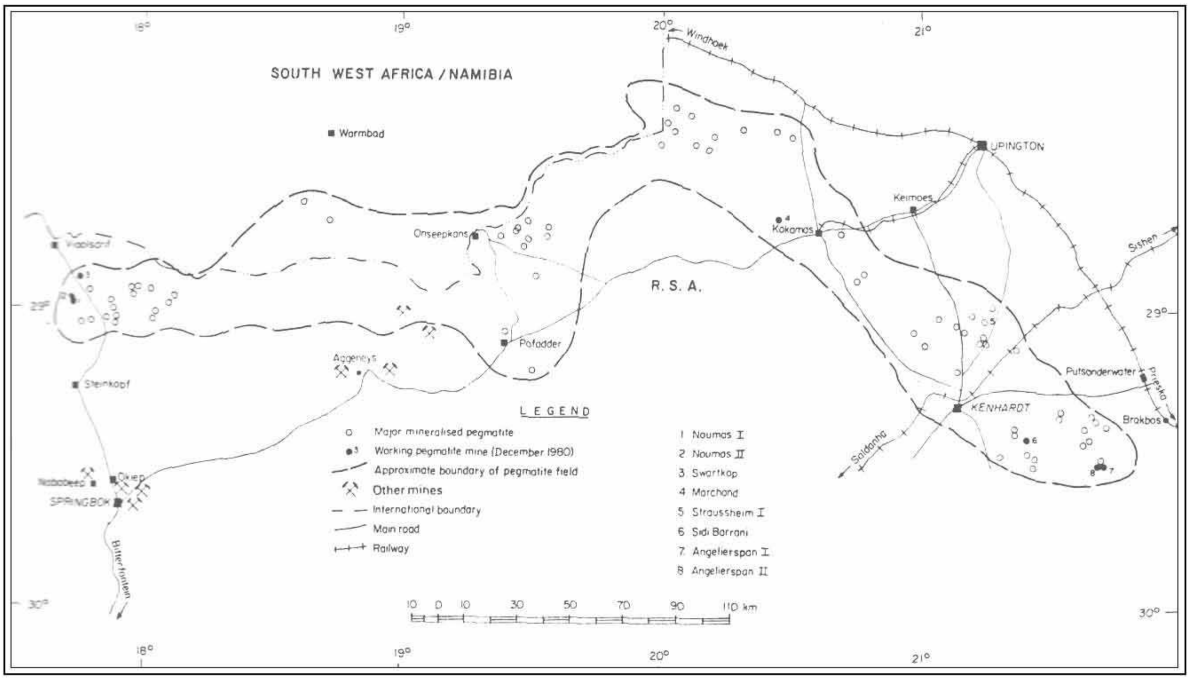

Figure 3.10 : Northern Namaqualand pegmatite belt showing the recently mined pegmatites (black circles). (HUGO 1985)

Plate 3.10 : Noumas - Blesberg pegmatite : core zone displaying large feldspar (FS) and spodumene (S) crystals and triplite (manganese phosphate - black patches). Note the Mn - halo surrounding the triplite mass.

No development of the pegmatites took place up to the so called " Beryllium boom " in the 1930`s, when many prospectors were attracted by the wealth of beryl containing pegmatites in the northern Namaqualand. Many of the pegmatites as Noumas, Straussheim and Sidi Barrani have been mined nearly continously since that time with changing emphasis on beryl, mica, feldspar, bismuth (especially Noumas), spodumene, cassiterite and tantalite/columbite.

3.7 DIAMOND BEARING GRAVELS :

Apart from the surficial carnotite - gypsum deposits and the alluvial tungsten workings mentioned further above, numerous other diamond bearing gravel deposits exist along the banks of the Oranje river and other major, though only perennial rivers (VAN WYK & PIENAAR 1985). Beside the large and long operating alluvial mines at Alexanderbay new gravel mines have been established along the Oranje river since the early sixties. Here the NAMEX Company owns small, but very profitable operations at Bloedrift, Reuning, and Grasdrift, which all together form the Octha diamond mine.
Production figures for the years 1973 to 1984 amount to 20 Mio tonnes processes gravel with a gain of more than 700.000 cts diamonds. The gravel consists of well rounded to subangular cobble sized clasts embedded in a pebbly sand matrix. The average size of the diamonds varies - dependent on the deposit - from 0.85 to 1.30 cts with the largest ever recorded stone weighing 107 cts.
The whole Namaqualand coastal strip down to Hondeklip bay has been declared as state diamond prospect with restricted access, where no private prospecting is allowed.

The influence of the transport distance seemed to be very limited in the rivers of the considered region, but trapping by potholes and palaeo - rapides is avery important concentration factor : a single pothole reported from the Octha area yielded over 100 cts/ tonn. Another obvious feature is that the gravel of the older and higher terraces are richer in grade than the more recent ones.

Since all the rivers running to the Namaqua coast have been found to contain more or less diamonds, there must be an hitherto unknown source, which cannot be related to the distant hinterland. None of the kimberlites in the Gamoep district has found to contain enough diamonds to explain the diamond wealth of the rivers. Hence there must be some to date unknown - probably deeply covered - diamond rich kimberlite pipes or an other diamond bearing intrusive. Or, what seemed to be more likely, the diamond occurences in the rivers reflect an independent palaeo - drainage pattern, which needs further investigation.

4. STRUCTURAL EVOLUTION OF THE NAMAQUA METAMORPHIC BELT :

4.1 PREVIOUS MODELS

This chapter gives an overview over the different models offered by various authors to explain the genetic history of the NMB.
Finally the author of this field report tries to develop a model of his own, based on the distribution of ore deposits and their relation to each other.

All the recent approaches to explain the evolution of the NMB are based on plate tectonics and rifting models. The relatively simple mantle plume model, as had been formulated by PRETORIUS (1979) and STOWE (1981), is somewhat unsatisfactory, since this model does not explain the E - W trend of all the major structural elements in Namaqualand - unless we do not assume a hitherto unknown form of elongated mantle plume.

Much investigation work has been done recently in the eastern part of the NMB, mostly in connection with the Upington geotraverse program. The resulting genetical models of BOTHA & GROBLER (1979), VAN ZYL (1981) and - more recently - HUMPHREY & VAN BEVER - DONKER (1987) base only on this specific part of the NMB without taking the western part in account. Hence, they are unable to explain " the whole story " of the NMB, although they might be reliable on the Pre - Namaqua rifting movements in the Kheis subprovince.
The model of BOTHA & GROBLER (1979) implies a four stage evolution history of the Kheis subprovince : Lithospheric thinning, caused by tensional stress, resulted in a shallow intracontinental basin, where continental clastic sediments are collected (Volop group, Dagreek formation). In the second stage further mantle separation formed an increasingly deeper trough, the ocean opens and deep water sediments are collected. Granite emplacement and extrusive volcanism with exhalative activity resulted in the formation of the Copperton - Areachap belt.

The third stage commenced with the deposition of the Wilgenhoutsdrift formation. Reversed crustal tension, caused by delamination of the lower crust, resulted in extensive folding. When compression ceased in the fourth stage, the folded block was uplifted and backthrusted onto the Kaapvaal craton. Late stage graben formation formed suitable depressions for the deposition of the Koras group sediments.

The models of VAN ZYL (1981) and STOWE (1981) are quite similar to that presented above. However, VAN ZYL puts more emphasis on the kinematic efforts of the deformation, while STOWE considered the evidence of a continent - back arc collision instead of a continent - continent collisison event, as postulated by BOTHA & GROBLER.
Although VAN ZYL (1981) tries to expand the field data base of his model beyond the Kheis subprovince into the western part of the NMB, there exist no real genetical model for the NMB as a whole unit to date.

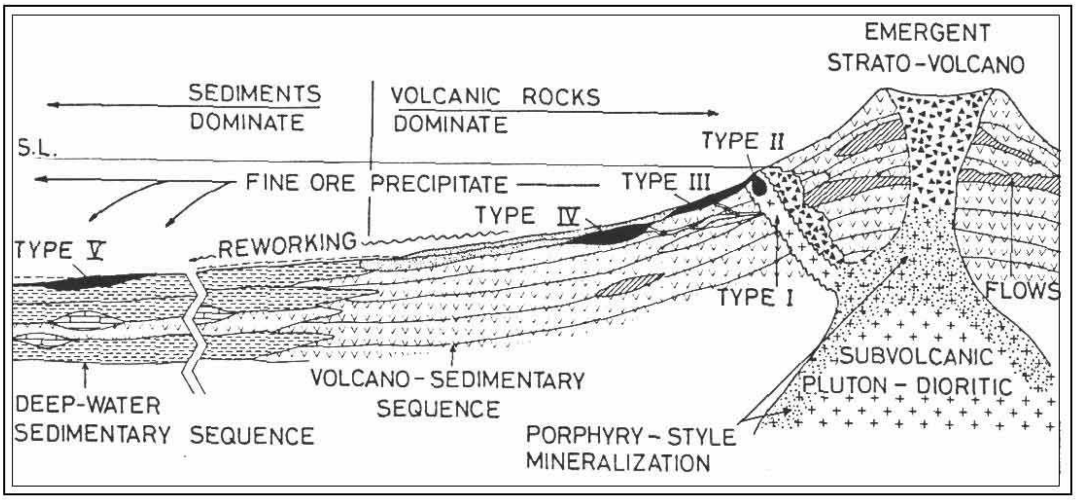

Figure 4.1 : Genetical setting of some of the ore deposits in the Namaqualand region. (ROZENDAAL 1985)

4.2 STRUCURAL & GENETICAL MODEL PROPOSAL

At least three facts supports the idea, that the NMB was formed by plate tectonical processes : Geophysial data ; the predominant elongated E - W strike of many major structural elememts ; the distribution of ore deposits e.g. the porphyry systems and the massive sulphide bodies.
The geophysical evidence has been summarized by DE BEER & MEYER (1983) as follows :
" Combined geophysical data indicate the presence of a highly conductive, magnetic and dense rockmass at relatively shallow crustal depth, possibly partially serpentinized rocks marking oceanic crust subducted from the south. This suggests that the Namaqua Province did not form intracratonically, but rather along a continental margin as the Cordillerean or Andean type mountain belts. "
The geological setting of some of the main ore deposits in the NMB is presented in figure 4.1 . JOUBERT (1985) reckoned the Gamsberg - Aggeneys orebodies could be distal deposits deriving from the Haib volcanism. However, neither the large distance nor the metal zoning in the Gamsberg - Aggeneys deposits as discussed above (see chapter 3.2.1) fit into this simple model. Furthermore, SAWKINS (1984) pointed out, that porphyry systems are chiefly confined to compressional plate boundarys, since massive sulphide deposits - generated by sedimentary exhalative processes - are always linked to extensional arc environments. If we take a look to the Pacific area, we find indeed that the major porphyry lineament along the American westcoast is formed near a compressional plate boundary, where no visible secondary back arc spreading occurs. On the other hand the well developed island arcs along the Pacific westcoast as the Aleuten, Kurilen and Japan arcs with their famous massive sulphide bodies bear no sign of porphyry formation.

We must therefore conclude, that we have to deal with more than one simple subduction zone, in fact at least with two subduction zones and plate boundaries : An compressional plate boundary in the north with porphyries, but no massive sulphides ; and an extensional plate boundary in the south with massive sulphides, but no porphyries.

If we consider the eastern part of the Namaqualand, e.g. the Kheis zone and the above discussed previous genetical models, we get a third plate boundary.

A compilation of all these and other aspects is given in figure 4.2, which shows the evolution of the NMB from about 2300 m.y to 1200 m.y.. The figure is divided into six block models, which are all cut in half to display the change of the important inner structures. The north of the blocks is always to the left i.e. the view is looking to the east. The lower dotted layer in the models represents mantle material, the upper colourless layer continental or oceanic crust. Double arrows mark tectonic and/or plate movements ; single arrows indicate prevailing sediment transport.

Block model I : 2300 m.y. or 2.3 Ga : A mantle plume inititated the tectonical evolution of the Namaqualand. As immediate result of the magma rise a triple junction formed with the Kheis branch (I) along the edge of the Kaapvaal craton (K), the Natal branch (II) to the east and the Namaqua branch (III) to the west. All the branches are shown in an early, but active rifting process with the continental crust breaking up. Clastic sediments from the Kaapvaal craton are deposited in the Kheis branch basin, forming the Volop group of the Dagreek formation (see table 2.1).

Block model II : 2200 m.y or 2.2 Ga : The model showed the volcanic activity at the edge of the Kheis region, resulting in the formation of the Copperton - Areachap belt (or : Jannelsepan fm.) in the Gordonia subprovince.
The extension in W - E direction terminates, resulting in an aborted rift enviroment. Later (not shown) the continenal crust reverses its movement and the basin starts to close again. Subsequently the volcano - sedimentary rift filling is intensely folded and metamorphized (in correspondence with the model of BOTHA & GROBLER as discussed above). Meanwhile the rifting in the Namaqua and the Natal branches continue and oceanic crust start to form.

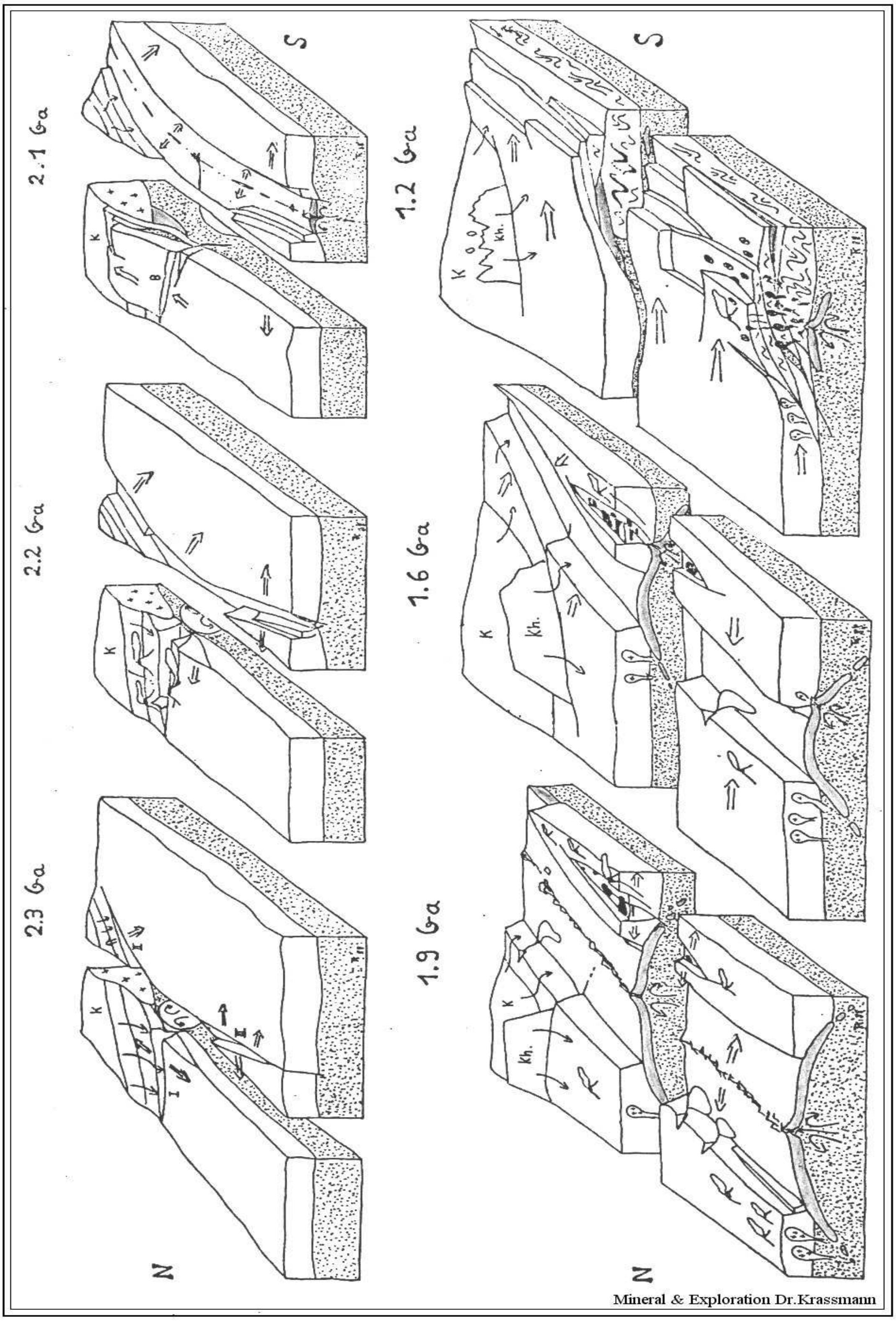

Figure 4.2 : Genetical & strucutural evolution of the NMB, displayed in six block models.

Block model III : 2100 m.y. or 2.1 Ga : The now metamorphized Kheis unit is uplifted and backthrusted onto the Kaapvaal craton. A major fracture zone, the Brakbosch fault (B) is formed simultaneously and survived to the present day. Small pockets and lenses of mantle material are assimilated by the Kheis metamorphics and included in the backthrusting process, which may be an explanation for the widespread amphibolites in this unit.
The Kheis unit consolidates and forms from now onward an erosion area.
While the Kheis branch terminates its tectonic evolution, the Namaqua and the Natal branches remain in full rifting activity and starts to develop a mid ocean ridge. Minor amounts of clastic sediments, deriving from the Kaapvaal craton are deposited in the widening ocean, which possibly can be correlated with the conglomerate and the schists of the Eierdoppan formation (see table 2.1).

Block model IV : 1900 m.y. or 1.9 Ga : 200 million years later the rifting process reaches its peak with the ocean being at least several hundred kilometers wide and subduction active on both sides. At the northern plate boundary no secondary back arc spreading take place, but several porphyry stocks intrude with subsequent effusive volcanism at the surface.
At the southern plate boundary an extensional back arc basin is present and heavy metal bearing brines, originating from the Benioff zone force their way to the surface, where exhalative sulphide and oxide deposits,(see chapter 3.2.1) - marked by black patches - are formed.
Ocassionally turbidites find their way into the deep sea and deposit greywackes, which may be the source material for the quartzo - feldspathic gneisses of the Kokerberg formation in the Gordonia subprovince.

Block model V : 1600 m.y. or 1.6 Ga : The extensional stress reverses and the ocean begins to close again. The block model V shows a late stage of the ocean closing with the emphasis on the mid ocean ridge, which is subducted under the southern continental crust (see discussion further below).
In the back half of the model the subducted ridge is situated immediately below the back arc basin. The situation is thought to be responsible for a second " metal push " in the formation of the giant Bushmanland sulphide deposits. In fact, a constellation as such could well have formed the bulk of the present sulphides.

Anyway, this arrangement may as well - and in partcular - explain the geochemical differences in different, but closely associated orebodies, as reported from the orebodies of the Black Mountain mine (Mine geologist : personal communication).

Block model VI : 1200 m.y. or 1.2 Ga : The last block model shows the final stage of the evolution of the NMB. The ocean is closed with the oceanic crust completely subducted (apart from minor amounts, which have been assimilated by continental crust). The following continent - continent collision resulted in intense deformation and overthrusting of Alpine style nappe tectonics. The original back arc basin with the sulphide bodies was eventually strongly deformed with the sulphides being concentrated in the hinges of major folds (black : see back section). While the sulphides were apparently not chemically affected by the metamorphism, the exhalative oxides was turned into an iron rich garnet - quartz rock assemblage (see chapter 3.2.1).
Caused by the very intense deformation the ancient and probably long inactive subducted mid ocean ridge is reactivated, as shown in the front section, and generates small copper rich mantle diapirs which intrude into highly metamorphosed granite gneisses (Okiep region). Some of the diapirs were rich in volatiles, which ocassionally forced their way - in an explosive event - to the surface. They produced pipe like channels, which soon collapsed and refilled with rocks from higher stratigraphic units (see dicussion about megabreccias : chapter 3.1.1).

The 1000 m.y. old pegmatite belt of northern Namaqualand (not shown) can be explained as late stage derivatives of the partial upmelting of crustal metamorphites, caused by the intense crustal thickening and regional metamorphosis in the overthrusted area.

4.3 DISCUSSION

The author of this field report is fully aware that the given model is hardly more than an early stage compilation of some published and self observed data within the NMB, which needs further and detailed improvement.
However, there are some additional assumptions and possible weak points to be pointed out separately :

1. The time aspect : The whole model as presented above would fit nicely in a timespan not longer than about 200 million years, e.g. the represented period of 1200 m.y. seems to be extraordinary long for a relatively simple development as such. To explain and possibly solve this time problem, there exist at least two possibilites : a) Age determination in the NMB seemed to be a difficult task and most of the reported data is - caused by repeated metamorphic resetting events - unreliable. We must therefore consider, that most age data is too young, and that the actual evolution of the Namaqua province took less time than thought. b) Nobody knows how large and wide the evolving ocean was and for how long sea floor spreading was effective. Until detailed investigation has revealed some more facts , we could assume, that the lifespan of the ocean (with no obtainable geological record) was several hundred million years.

2. Subducted ridges : To the best knowledge of the author the behaviour of a active ridge in the final stage of ocean closing is only poorly documented. Hence the author feels free to assign the role of a "secondary metal donator" to a subducted ridge. However, the ore deposits of the Okiep area are - apart from Caraiba in Brazil (see chapter 3.1.1) unique and may justify a somewhat unusual explanation approach.

3. Porphyry distribution : One of the corner stones of the model is the distribution pattern of the porphyry systems. Since the known porphyries in the NMB show an oval shaped " point " concentration along the Oranje river, there remain more porphyries to discover along the hypothetical lineament for future exploration. However, if this porphyry lineament for one or another reason does not exist we need a new model.

5. EXPLORATION TARGET GENERATION :

Although intense exploration has been carried out during the seventies, this programes were obviously mainly concentrated onto the search for base metals (lead,zinc,copper) and uranium. However, there remain interesting targets for the future explorationist. Proposals are presented in the following for the quest for base metals, gold, tungsten and diamonds.
Additonally some remarks on exploration techniques are given.

5.1 EPITHERMAL BASE METAL & GOLD VEINS

As shown in chapter 3.1.2 vuggy quartz veins can be observed in the outer zone of the Haib porphyry stock, which sometimes grade laterally into minor base metal sulphide veins (C. MALLINSON : personal communication).
They form an interesting eploration target for epithermal base metals and gold mineralization. Although the base metal veins alone will probably not warrant separate exploitation, a combined gold & base metal mine might work profitably.
Figure 5.1 displays the ideal zoning of an epithermal vein deposit with several different mineral zoness. The quartz veins at Haib seem to resemble a high and empty level due to their vuggy nature and the obvious rareness of sulphide mineralzation - though the latter can be explained as well by intense weathering dissolving the sulphides and the carbonates. The quartz veins in the outer zone form fracture orientated and likewise thick veins, which grade nearer to the core into a thinner stockwork type quartz mineralization of a less vuggy nature.
Although the observed quartz veins were only thin, there remain plenty of room for a systematical investigation around this and the other known porphyry systems such as Lorelei and Marinkas Kwela - which may prove denser and thicker possibly gold bearing quartz veins.
An other promising area could be the whole northern NMB adjoining the Oranje, where - according to the above presented model - there is a good potential for finding new porphyries. A detailed investigation of the quartz veins in this area, weather ore bearing or not, could reveal hidden porphyry stocks.

However, an exploration program on quartz veins seemed to be a promising approach. A viable tool to delineate gold mineralization could be the employment of geochemical methods by using tellurium haloes as pathfinder element, since tellurium shows in epithermal environments a close affinity to gold.

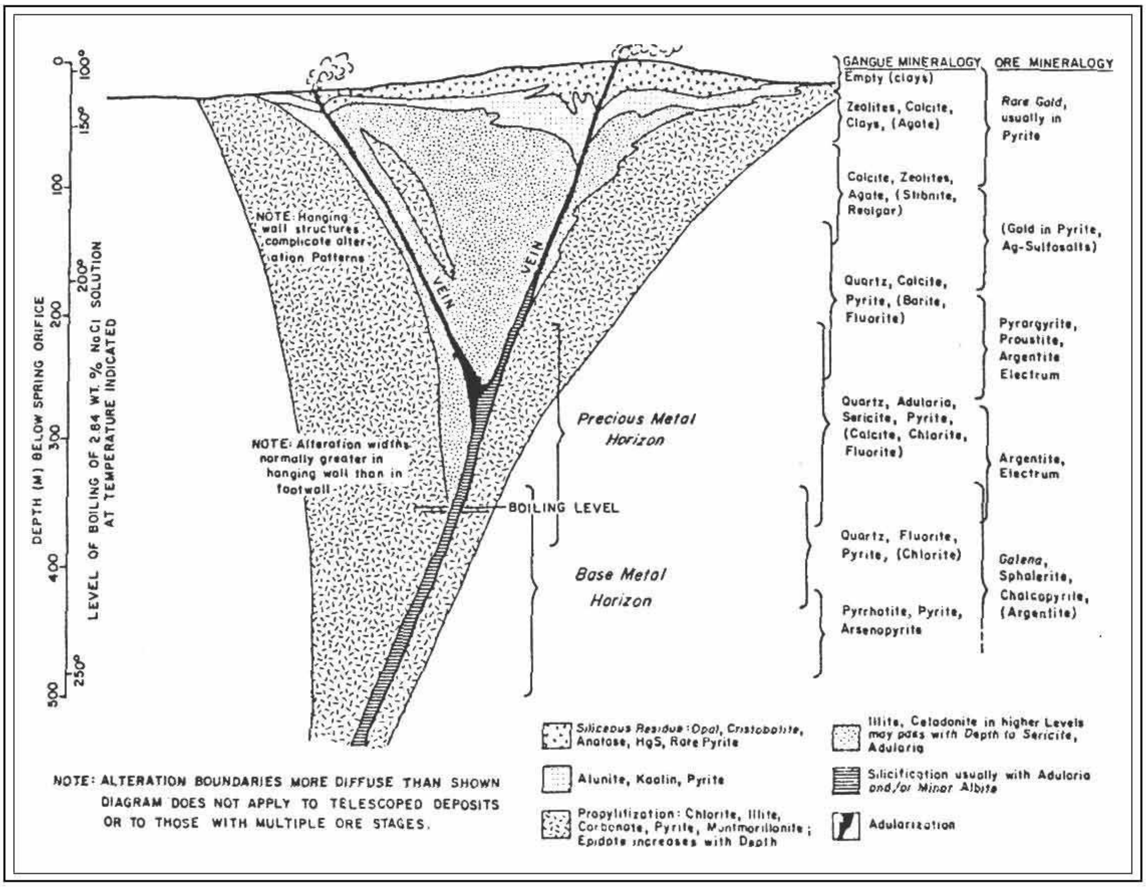

Figure 5.1 : Idealized model of epithermal vein zoning. Note : in most veins only some of these characteristics are realized. (SAWKINS 1984)

5.2 EXHALATIVE SCHEELITE DEPOSITS

The NMB seemed to be an excellent target area for exhalative scheelite deposits, if we take closer look abroad to the following case history :

Scheelite bearing quartz veins have been noted since decades in great number in the Austrian Alps. None of them was large enough for any exploitation - apart from that of keen mineral hunters.
In the midth of the sixties Prof. MAUCHER from the Munich University published a model on the possible exhalative formation of large stratabound Sb - W - Hg deposits, whereas the quartz - scheelite veins were interpreted either as feeder veins or as descending recrystallization products (MAUCHER 1965). Two years later, a combined mapping - economic geology course with Munich geology students was led by MAUCHER and HÖLL to the Felbertal area (Salzburg / Austria). In the course of the mapping large scheelite bearing boulders were found, which revealed the existence of the predicted exhalative tungsten deposits. METALLGESELLSCHAFT and VOEST ALPINE took over and soon a major tungsten mine came into production (HÖLL 1969).

The scheelite bearing series has a width of several hundred meters and is characterized by a suite of hornblendites, amphibolites, schists and gneisses, which form the metamorphic equivalents of a huge volcanic succession of ultramafic to rhyodacicitic nature. The high grade ores are particularly associated with hornblende rich amphibolite rocks. The mean average grade of tungsten in the scheelite ore is 0.75 per cent with an annual output of about 300.000 tonnes combined scheelite - molybdenite ore.

An interesting parallel in Namaqualand is the frequent occurence of quartz scheelite veins in an intensely metamorphized environment, which seemed to be an excellent background for a possible exploration program on large stratabound scheelite deposits.
Another interesting aspect is the similarity of coarse to fine grained scheelite to quartz, which can lead easily to confusion without using ultraviolet light. Thus, surface signs of scheelite mineralization in metamorphozed volcanic sequences could have been overlooked in former exploration programes.

However, an airborne survey over suitable geological settings, using an UV - sensitive film, seemed to be a rewarding exploration approach.

5.3 EXHALATIVE OXIDE FACIES

As outlined in chapter 3.2.1 the " Fe-mineral - garnet - quartzite " mineral assemblage (whereas the Fe mineral is - depending on the oxygen and suplphur fugacity during the metamorphic process - either pyrite or hematite and magnetite respectively) in the neighbourhood of massive sulphide deposits such as Gamsberg - Aggeneys and Copperton is believed to represent the oxide facies of sedimentary exhalative formations (Lahn - Dill type). If this interpretation proved to be correct, this rocktype forms a viable marker horizon for the discovery of new massive sulphide deposits in the NMB - a probably better one than the pure magnetite - hematite targets of previous times, which can be formed through different processes , e.g. the metamorphism of banded iron formations.

The author gives two recommendations : 1.) Detailed investigation of the relationship between unmetamorphosed Lahn - Dill type iron ores and the " Fe-mineral - garnet - quartzite " assemblage with the emphasis on geochemical studies. This investigation could be done well in the course of an M.Sc. or Ph.D. thesis. 2.) If the " metamorphic eqivalent " model should prove to be correct : a subsequent regional mapping programe on this characteristic mineral assemblage by means of an airborne magnetometer survey and ground follow up. Possible drilling targets are to be exspected in fold hinges, where the sulphides tend to concentrate in the course of metamorphosis.

5.4 AUGHRABIES DIAMONDS

This target proposal might be a somewhat silly one and the author wonder, if an examination such as the following has not been done long before. However, during a final visit of the M.Sc. class at the beautiful Oranje waterfalls at Aughrabies the author had the inspiration, that the potholes and cavities on the ground of the Aughrabies gorge could have worked for long time as an ideal trap for diamonds. The author would therefore recommend to a start a "test sucking" with a sort of long vacuum pump (as used in under water archeology on the excavation of ancient ships) during a drought time with low water rates, to perceive the diamond contents of the potholes.

5.5 NEW EXPLORATION APPROACHES

As shown for several times in the preceeding, a broader use of geochemical exploration methods in the NMB seemed to be a rewarding idea under certain circumstances.
Yet there is another tool to introduce into South African exploration, which is obviously hardly known at all in this country : The use of BIOGEOCHEMICAL METHODS, e.g. the tracing of heavy metal indicating plants.
This method was predominatly developed by the Russians, where many gold deposits have been discovered by tracing of metal accumulating plants. However, the method is well established in the western world as well and is of increasing importance in Canada and Australia. A recent discovery by means of biogeochemistry is the Viscaria copper mine 2 km N of the famous Kiruna iron ore mines in northern Sweden. This orebody was found by drilling in an area, which was marked by the abundancy of the copper tolerant flower VISCARIA ALPINA. An interesting aspect is that Kiruna staff geologists were investigating the area for at least fifty years without finding any significant copper showings.

Some metal tolerating plants are able to accumulate amazing amounts of metals in their leafs ; copper and nickel values of more than 10.000 PPM (= 1 per cent !) are reported from certain species. An updated bibliography of papers dealing with " netal plants " was given by ERDMAN & OLSON (1985). A case history of an exploration program based on the Cu - indicator plant HELICHRYSUM LEPTOLEPIS in the Kalahari desert was reported by MASON (1987) from the INCO company.

If we only take the well known spring flower wealth of the western part of Namaqualand, we get at least 150 different contributing plant species all over the place. If only five per cent proved to be interesting for biogeochemical exploration, we get seven flowering plants which indicate heavy metal anomalies. Since the flowering period is only short, exploration geologists have to hurry. However, the climatic period suitable for th. is sort of exploration is short as well in northern Canada and Russia and still there have been remarkable sucesses. The use of airborne spectral resolution images could be another key to enhance and accelerate the exploration process.

In the biogeochemical approach lies an excellent future potential and it is definitely rewarding to spent more investigation and expenditure on this almost untapped resource in order to apply it sucessfully to exploration programs in the NMB and elsewhere in southern Africa.

6. SUMMARY AND CONCLUSION :

A general outline of the geology of the Namaqualand Metamorphic Belt and its tectonic setting is given ; followed by a detailed resource appraisal - with selected exploration case histories - of the important ore discoveries during the last twenty years and smaller prospects and mines as well.

The resulting genetic model of the geological evolution of Namaqualand is given in a six stage model covering 1200 million years of earth history. The model assumed a mantle plume as initial force behind the continental break up, commencing with a triple junction some 2300 million years ago. While an oceans opens in W - E direction, the Kheis arm of the triple junction turned into an aborted rift with extrusive volcanism and sulphide formation, which was subsequentally metamorphosed and backthrusted onto the Kaapvaal craton.
The E - W trending palaeo - ocean developed two subduction zones with compressional tension with calc alkaline intrusions (Cu - Mo bearing porphyry systems) on the northern edge and extensional stress with secondary back arc spreading and sulphide generation on the southern edge. Several hundred million years later the tectonic forces reversed and the ocean closed again. In the final stage the mid ocean ridge itself was subducted beneath the southern continent. Here it acted - reactivated through crustal thickening in the course of continental collision - repeatedly as metal donator for late stage sulphide deposits.

Based on this evolution model the following suggestions can be given for the exploration geologist :

I Epithermal quartz veins in the surrounding of porphyry systems may contain significant gold and base metal mineralizations. On the other hand they form a target for hitherto unknown porphyry systems, which can be postulated along a lineament following roughly the Oranje river.

II A possible target for tungsten exploration are metamorphic suites of volcanic origin not too far form scheelite bearing quartz veins. They may contain large stratabound scheelite deposits as have been discovered in the Austrian Alps in a similar geological setting.

III A proposal is given on the relationship between massive sulphide bodies and the frequently associated " Fe-mineral - garnet - quartzite " mineral assemblage. Although the proposal needs further investigation, this specific paragenesis could be possibly used as viable marker horizon for the delineation of new massive sulphide bodies.

IV The Oranje gorge at Augrabhies may yield economically interesting quantities of diamonds and should be investigated in greater detail.

V Generally speaking geochemical exploration methods should be used more frequently in future exploration, as outlined for several situations above. Another virtually unknown, but great exploration potential lies in the application of biogeochemical methods, which are being used at an increasing rate in other classical exploration countries.

7. LITERATURE - REFERENCES :

N.B. : The references of this report originates mainly from the " Mineral Volume " published by the Geological Society of South Africa in 1986. All references marked with an asteriks refers therefore to the following reference :

ANNHAUSSER, C.R.& MASKE, S. , Eds. (1986) : Mineral Deposits of southern Africa Vol. II Geol. Soc. S. Afr. - 2376 pp.

ANNHEUSSER, C.R. & BUTTON, A. (1974) : A review of Southern African stratiform ore deposits - their position in time and space - 48 pp.
Univ. of the Witwatersrand , Econ. Geol. Res. Unit Information Circular No. 85

* ATTRIDGE, R.C. (1985) : The Jacomynspan Copper - Nickel Occurence, Kenhardt district p. 1539 - 1545

* BERNASCONI, A. (1985) : The Marikas Kwela alkali intrusive - A porphyry molybdenum system of cambrian age in southern South West Africa / Namibia p. 1587 - 1591

* BICKER, R.E. & RALSTON, I.T. (1985) : The Lutzputs iron - copper (- silver) deposit p. 1547 - 1552

BOTHA, B.J.V & GROBLER, N.J. (1979) : The geotectonic evolution of the middle to late Precambrian Namaqua mobile belt in eastern Namaqualand, South Africa p. 33 - 41
Precambr. Research Vol. 36 No. 2

COETZEE, C.B. (1958) : Manganiferous iron ore, hematite, barite and sillimanite on Gams (Portion I), Namaqualand - 27 pp.
Bull. Geol. Surv. S. Afr. No. 28

COETZEE, C.B., Ed. (1976) : Mineral Ressources of the Republic of South Africa - 462 pp. Dept. of Mines and Geol. Survey Handbook 7

CORNELL, D.H. (1975) : Petrology of the Marydale metabasites
Ph.D. thesis (unpubl.) Univ. Cantab. - 216 pp.

CORNELL, D.H. & BARTON, E.S. (1979) : Age of the Marydale group banded iron formation by the Pb - Pb method
Abstr. Geocongr.`79 , Geol. Soc. S. Afr. I, p. 111 - 114

CORNELL, D.H. & BARTON, E.S. (1979) : Age of the Marydale group banded iron formation by the Pb - Pb method
Abstr. Geocongr.`79 , Geol. Soc. S. Afr. I, p. 111 - 114

DE BEER, J.H. & MEYER, R. (1983) : Geoelectrical and gravitational characteristics of the Namaqua - Natal mobile belt and its boundaries p. 91 - 100 Geol. Soc. S. Afr. Spec. Publ. No. 10

DE GEOFFREY, J. & WIGNALL, T.K. (1972) : A statistical study of geological characterists of porphyry copper molybdenum deposits in the Cordillerean Belt - An application to the rating of porphyry prospects Econ. Geol. ; Vol. 67 p. 656 - 668

DE VILLIERS, J. (1960) : The manganese deposits of the Union of South Africa Geol. Surv. S. Afr. Handbook 2 - 280 pp.

DE VILLIERS, J. & SOEHNGE, P.G. (1959) : The geology of the Richtersveld Mem. Geol. Surv. S. Afr. : No. 48 - 266 pp.

ERDMAN, J.A. & OLSON, J.C. (1985) : The use of plants in prospecting for gold : A brief overview with a selected bibliography and topic index p. 281 - 304 Journ. of Geochem. Exploration Vol. 24

GEVERS, T.W. ; PARTRIDGE, F.C. & JOUBERT, G.K. (1937) : The pegmatite area south of the Orange River in Namaqualand Geol. Surv. S. Afr. Memoire No. 31 - 180 pp.

GEIRINGER, G.J. PRETORIUS, J.J. & CILLIERS, F.H. (1987) : Strata bound copper iron sulphide mineralization in a Proterozoic front arc setting at Boksputs, North West Cape, South Africa - A possible Besshi type deposit Mineralium Deposita Vol.22 No.2 p. 81 - 89

HAMBLETON - JONES, B.B. ; LEVIN, M. & WAGENER, G.F. (1985) : Uraniferous surficial deposits in Southern Africa p. 2269 - 2287

HAUGHTON, S.H. & FROMMURZE, H.F. (1934) : The geology of the Warmbad area, South West Africa - 64 pp. SWA Dept. of Mines Memoire No. II Windhoek

HOLL, R. (1969) : Scheelitprospektion und Scheelitvorkommen im Bundesland Salzburg / Oesterreich p. 185 - 203 Chemie der Erde , Vol. 28 , No. 1

HUGO, P.J. (1961) : The allanite deposits on Vrede, Gordonia district, Cape Province Bull. Geol. Surv. S. Afr. No. 37

HUGO, P.J. (1969) : The pegmatites of the Kenhardt and Gordonia districts, Cape province Mem. Geol. Surv. S. Afr. No. 60 - 54 pp.

* HUGO, P.J. (1985) : Some deposits of feldspar, mica and beryl in the north western Cape Province p. 1651 - 1662

HUMPHREYS, C.H. & VAN BEVER - DONKER, J.M. (1987) : Aspects of deformation along the Namaqua province eastern boundary, Kenhardt district, South Africa p. 39 - 63
Precambr. Research Vol. 36

* JOUBERT, P. (1985) : The Namaqualand Metamorphic Complex - A summary p. 1395 - 1420

* LOMBAARD, A.F. et. al. (1985) : The copper deposits of the Okiep district, Namaqualand p. 1421 - 1445

MASON, M. in : DUNN, C.E. (1987) : Report on workshop I : Biogeochemistry Jour. of Geochem. Exploration Vol. 29 p. 355 - 357

MAUCHER, A. (1965) : Die Antimon - Wolfram - Quecksilber Formation und ihre Beziehung zu Magmatismus und Geotektonik
Freiberger Forschungshefte Reihe C No. 186 p.173 - 188

MINITT, R.C.A. (1985) : Porphyry copper - molybdenum mineralization at Haib river, South West Africa / Namibia p. 1567 - 1588

PIRAJNO, F. & JACOB, R.E. (1984) : A review of archean, proterozoic tectonic provinces and patterns of crustal evolution in southern Africa - 114 pp. (unpubl.) Dept. of Geology , Rhodes University

PRETORIUS, D.A. (1974) : The structural boundary between the Kapvaal and the Sonama crustal provinces - 27 pp. Inform. Circle Econ. Geol. Res. Unit - Univ. of the Witwatersrand No. 88

REID, D.L. et. al. (1987) : Comparisition, age and tectonic setting of amphibolites in the central Bushmanland group, western Namaqua province, South Africa p. 99 - 126
Precambr. Research Vol. 36 No. 2

* ROBB, L.J. (1985) : Uraniferous leucogranites from the Namaqualand Metamorphic Complex - Part I : Geology, geochemistry and petrogenesis p. 1609 - 1627

ROZENDAAL, A. (1984) : Review of exploration on the farms Ou Taibooschmond Ptn 3 and 4 (Kamasoas) - 8 pp. Handout to M.Sc.class

* ROZENDAAL, A. (1985) : The Gamsberg zinc deposit, Namaqualand district p. 1477 - 1488

* RYAN, P.J. et. al. (1985) : The Aggeneys base metal sulphide deposits, Namaqualand district p. 1447 - 1473

SAWKINS, F.J. (1984) : Metal deposits in relation to plate tectonics - 325 pp. Springer Verlag,

SOEHNGE, P.G. (1950) : The Nababeep Near West tungsten mine, South Africa Amer. Min. ; Vol. 53 p. 931 - 940

STOWE, C.W. (1980) : Preliminary report on geodynamics in the Upington geotraverse p. 24 - 48
A. Rep. Prec. Res. Unit Univ. Capetown No. 17

TOWNEND, J. et. al. (1980) : Caraiba, new copper deposit in Brazil Inst. Min. Metall. Trans.; No. 89 p. 159 - 164

* VAN WYK, J.P. & PIENAAR, L.F. (1985) : Diamondiferous gravels of the lower Orange river, Namaqualand p. 2309 - 2321

VAN ZYL, C.Z. (1981) : Structural and metamorphic evolution in the transitional zone between craton and mobile belt, Upington Geotraverse - 243 pp.
Bull. Precambr. Res. Unit Univ. Capetown ; No. 31

* VILJOEN, R.P. ; KUYPER, J. & PARSONS, C.F. (1985) : The Putsberg copper deposit, Pofadder district p. 1489 - 1502

* VILJOEN, R.P. ; MINITT, R.C.A. & VILJOEN, M.J. (1985) : Porphyry copper - molybdenum mineralization at the Lorelei, South West Africa / Namibia p. 1559 - 1565

* VOET, H.W & KING, B.H. (1985) : The Areachap copper zinc deposit, Gordonia district p. 1529 - 1537

* WAGENER, J.H.F. & VAN SCHALKWYK, L. (1985) : The Prieska zinc copper deposit, North - western Cape province p. 1503 - 1527

* WHEATLEY, C.J.V. & DE BEER, L.J. (1985) : The Van Roois vley tungsten tin deposit, Gordonia, Northern cape p. 1553 - 1558

If the only tool you have is a hammer,
everything begins to look like a nail...

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Kontaktadresse des Autors :

Anschrift des Autors : Dr. Ing. Thomas Krassmann Diplom – Geologe Tel. 09841 – 7302
91438 Bad Windsheim Email : tkrassmann(at)hotmail.com Web : www.mineral-exploration.de

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Author Contact Details :

Anschrift des Autors : Thomas Krassmann, Ph.D. M.Sc. Phone : 0049- (0) 9841 – 7302
D - 91438 Bad Windsheim Email : tkrassmann(at)hotmail.com Web : www.mineral-exploration.com