THE IDENTIFICATION OF POTENTIAL GROUNDWATER ZONES IN THE KAMIESBERG REGION, NORTHERN CAPE PROVINCE, SOUTH AFRICA.

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A full thesis submitted in partial fulfillment of the requirements for the degree of Magister Scientiae in the Department of Earth Sciences, University of the Western Cape

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KEYWORDS

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Lineaments

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Stress

ABSTRACT

THE IDENTIFICATION OF POTENTIAL GROUNDWATER RESOURCES IN THE KAMIESBERG REGION, SOUTH AFRICA.

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The aim of the study is to apply remote sensing techniques to identify potential groundwater resources for the Kamiesberg region. This region, with vast water shortages relies solely on groundwater and is characterized by a fractured crystalline basement aquifer that lacks primary porosity. Groundwater in basement rock aquifers is likely to occur along open fractures and in weathered overburden zones.

The study consisted of remote sensing analysis, aerial photography and Landsat images, and field investigations to ground truth the conceptual understanding.

Field studies included geological mapping, lineament analyses and hydrogeological investigations. The Kamiesberg region is situated in the Namaqualand Metamorphic Complex (NMC), which is known for its mineral

and alluvial diamond deposits. The NMC primarily consists of an assemblage of low- to high-grade metasedimentary rocks, unmetamorphosed platform sediments and an array of granitic, basic and ultrabasic intrusive rocks. Three prominent deformations caused the general geological outline of the region, namely the Proterozoic deformations, Pan African orogenesis and Mesozoic breakup. The fracture and joint analyses confirmed a NNW mean trend. Secondary orientations are E-W, NW- SE and NE- SW. Fracture and joint analysis were contoured in lineament frequency/density and lineament intersection maps. The fractures and joints are zones of increased weathering and have a greater potential for groundwater storage. The maximum principle compressive stress (σ_1) or neotectonic stress is orientated in a NW direction. The present groundwater state inferred from the national groundwater database (NGDB) suggests that boreholes are predominantly dry (37%), low yielding <1 l/s (49%) and drilled in the weathered overburden at a depth of 40- 80m (90%).

The results of the research identified potential groundwater zones for the Kamiesberg region. These zones were identified from a combination of lineament frequency/density maps, lineament intersection maps, groundwater analyses and fieldwork. The zones are situated in and around the town of Kamieskroon and Leliefontein and south of Karkams. One of the potential sites identified, Kamieskroon, has current data on the groundwater state, and provides confidence to the conceptual understanding. The town has eight boreholes with yields ranging from 0.6- 1.6 l/s. Four of these boreholes are located in the weathered overburden (shallow boreholes), and the others are located along the NNW trending lineaments (deep boreholes). The zones identified from the study are potential groundwater resource sites, however, confirmation with geophysical surveys is essential. The data, however, has various shortcomings varying from lack of reliable data to the proximity of the potential resource to the community. It is critical to monitor existing and future groundwater resource sites (water levels, quality) and manage the resources in a sustainable way for optimal lifetime.

DECLARATION

I declare that *The identification of potential groundwater zones in the Kamiesberg region, SouthAfrica* is my work, that it has not been submitted before for any degree or examination in any other university, and that all sources I have used or quoted have been indicated and acknowledged by complete references.

SEAN DAVIDS FEBRUARY 2003

SIGNED: ....

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CHAPTER 1

1.1 General introduction

Groundwater is an important asset to rural communities where surface water is scarce or non-existent. In South Africa, over 90% of the water resources are located in fractured rock aquifers, which are normally exploited by means of boreholes (Pietersen, *et al.*, 1996). The variable geological terrains in South Africa pose different challenges to groundwater practitioners. The identification of potential groundwater resources is vital for the sustainability of the water resources, surface and groundwater, in South Africa. The study area, located between latitudes $17^{0}45'$E, $18^{0}15'$E, longitude 30^{0}S, and $30^{0}30'$S includes three towns, namely Kamieskroon, Leliefontein and Karkams, and various small farms (Fig. 1.1). Groundwater is the only source of drinking water for the inhabitants of this area, which is located within the Namaqua Province that forms part of the crystalline basements in the Northern Cape and southern Namibia. The Northern Cape (Namaqualand), an arid to semi arid region, has variable climate, periodic precipitation and scant vegetation. The study area covers the Kamiesberg mountain range and will be referred to as the Kamiesberg region.

1.2 Climate

Climatic conditions within the Namaqualand region vary sporadically. The area is located within the Cape winter rainfall region, where anticyclonic conditions off the west coast are due to the cold, northward flowing Benguela current. The determining factors that control the climate is the altitude, topography and the distance from the sea. Air movement is blocked by the mountainous region, causing fluctuation of inland temperature plus condensation of moist coastal air allowing for the survival of endemic flora. Hot, bergwind conditions are common during the winter months. According to Williamson (1990), the mid-year escarpment temperature before dawn is at frost level compared to the coastal plain, which might be about 6^0C.

1.3 Vegetation

The vegetation is characterized by the Nama Karoo biome, which is dominated by a mixture of grasses and low shrubs to the east (Low and Rebelo, 1996). The western part is characterized by the succulent Karoo biome, whilst dwarfs and succulent shrubs with deep root systems dominate the vegetation. The Kamiesberg mountain range has a sclerophyllous bush type (op. cit).

Vegetation is highly dependent on groundwater. Plant species such as *Prospis* (moderately drought tolerant, facultative phreatophytes) indicate where groundwater is available (Low and Rebelo, 1996). Acacia Karoo (riparian shrubs and trees) is found in the alluvial aquifers of the Buffels River.

1.4 Precipitation

The region is situated within an arid to semi arid area of South Africa. Maximum rainfall occurs within the higher lying areas of Kamiesberg mountain (Table 1.1) south of Springbok. The high rainfall is due to the orographic effect. Snow during winter months is common in the Kamiesberg mountains. Potential evapotranspiration can be between 12-15 times the precipitation, and in some areas this factor is as high as 22 times (Titus, *et al.*, 2002). This high evaporation to precipitation ratio means that salts will easily be formed on the subsurface.

Run-off is 0- 2,5 mm and as high as 5mm along the Kamiesberg mountains. Soil depth is shallow, with a sandy texture along the steep relief (Midgley, *et al.*, 1994).

Table 1.1 Climatological data for the three catchments that comprise the Namaqualand region (After, Adams, *et al.*, 2002).

Catchments	Gross Area (km^2)	MAE* (mm)	MAP* (mm)	MAE/ MAP
F30	9756	2200	143	15
F40	5346	1900	140	14
F50	4869	1900	159	12

**MAE- mean annual evaporation*

**MAP- mean annual precipitation*

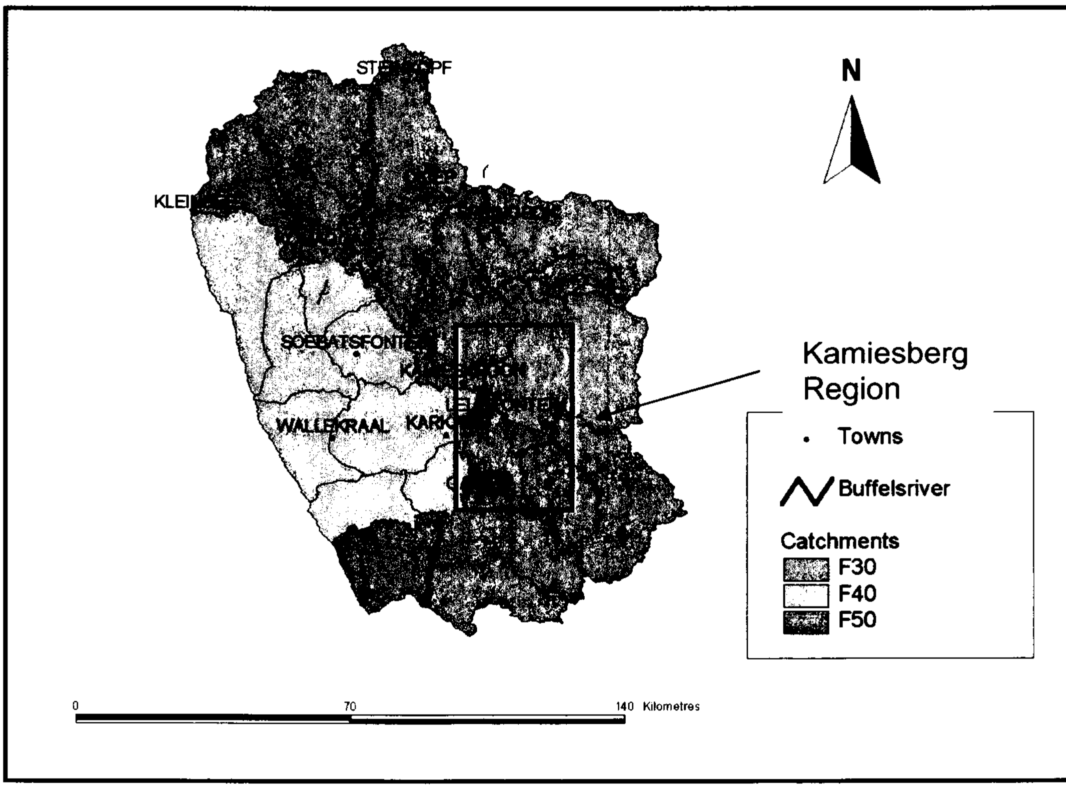

Figure 1.1. Locality map of the study area, the Kamiesberg region.

Groundwater in crystalline basement rocks or 'hard rocks' (Wright, 1992) occurs mainly along fractures, faults, shear zones and in the weathered overburden (Titus, *et al.*, 2002). A high degree of fracture density/ frequency results in greater weathered overburden (Edet, *et al.*, 1994).

The weathered overburden zones are inferred to be the optimal sites for potential groundwater resources (Greenbaum, 1992). The focus of the thesis is to apply remote sensing techniques to identify potential groundwater resources in the Kamiesberg region. Remote sensing techniques aid with mineral, groundwater and petroleum exploration (Siegel and Gillespie, 1980).

1.5 Background of the study

This study forms part of a two year Water Research Commission (WRC) funded project entitled: "Sustainable management and utilization in the semi-arid Northern Cape: Geomechanical mapping as a tool for groundwater exploration of fractured rock aquifers".

The rural region of the Northern Cape experiences vast water shortages primarily due to the low rainfall and the complex nature of the geology. The large towns, Springbok, Nababeep, Okiep and Kliensee, (figure 1.1) have water supplied from the Orange River. The area has a complex geological history of fractures, faults, folds and shears. The region is characterized by a fractured crystalline basement aquifer that lacks primary porosity. Groundwater occurs mostly along fractures and no serious attempt has previously been made to identify potential groundwater resources for the area.

There is a lack of reliable data on the present groundwater state in the Northern Cape. The conceptual understanding is based on field investigation and discussions.

1.6 Aims and Objectives

The aim of the study is to apply remote sensing techniques to identify optimal zones as potential groundwater resources in the Kamiesberg region.

The objectives are to:

- Understand the flow and storage of groundwater in a fractured crystalline basement rock environment;
- Infer the influence of palaeo-stress and neotectonic activity and their influence on fractured basement aquifers;
- Investigate the present groundwater state of the region, i.e. borehole location, yield and depth; and
- Infer the optimal zones for borehole location

1.7 Organization of the study

The first three chapters concentrate on the descriptive and observed characteristics of the area. The remaining chapters focus on the presentation of results and discussion. A case study of Kamieskroon is presented in these chapters.

Chapter 1- General introduction.

Chapter 2- Literature review.

Chapter 3-Methodology.

Chapter 4- Results and a case study. A discussion follows the presentation of the results.

Chapter 5- Conclusions and recommendations.

CHAPTER 2

Literature review

2.1 Introduction

The application of remote sensing techniques is a necessary preliminary tool to plan any groundwater assessment study for a region or a catchment (Hartnady and Hay, 2000). This chapter reviews remote sensing techniques, tectonic stress and its influence on the region, the geomorphology and its weathered profiles and the current groundwater state. The literature reviewed in this and subsequent chapters investigate the influence of these different variables.

2.2 Previous work

No previous work relating to this research has been attempted in the Namaqualand region to date. The Department of Water Affairs and Forestry (DWAF) and consulting companies, Toens and Partners, are responsible for existing groundwater supply to communities in the Northern Cape region. The University of the Western Cape (UWC) in partnership with the Water Research Commission (WRC) conducted numerous projects in the Northern Cape. These projects are based on the groundwater assessment and strategies for sustainable resources supply in arid zones (Titus, *et al.*, 2002), and groundwater recharge to crystalline basement aquifers (Adams, *in prep.*).

Additional research consists of:

- A hydrochemical evaluation of groundwater in parts of the Namaqualand region (Stevens, 1999),
- Quantitative estimation of groundwater recharge methods of crystalline basement rock aquifers in Namaqualand (Davids, 2000, Flanagan, 2000, Mafanya, 2000),

- An approach to aquifer test pumping in fractured crystalline aquifers (Hassan, 2002) and,
- Measurement of intrinsic porosity and permeability of fractured crystalline basement rock aquifers (Flanagan, *in prep.*).

2.3 Remote sensing

The application of remote sensing techniques has aided with various mineral, petroleum and groundwater exploration. Kneppe, *et al.*, (1994) used remote sensing (aerial photographs) and air borne geophysics for the detection and mapping of potential aggregate sources. Rowan, (1998) used it for the location of mineral resources in the eastern United States whilst Tavaglia (1998), applied the technique for the exploration of groundwater in the Syrian Arab Republic. In South Africa, remote sensing techniques are used widely in all aspects of earth and environmental science. Hartnady and Hay (2000), applied it to the groundwater exploration in the Table Mountain Group aquifer and Sami, et al., (2002) applied it to groundwater exploration in geological complex terrains in South Africa.

Kearey (1996), defines remote sensing as the recording of images of parts of the Earth's surface using electromagnetic radiation, normally from an aircraft or satellite at sufficient height for a broad area to be covered. Siegel and Gillespie (1980), define it as the science of gathering information in areas that are inaccessible (i.e. rugged, political turmoil, hazardous location). Modern techniques analyze multispectral images that record the way solar energy is reflected or emitted by the materials exposed at the Earth's surface (Rowan, 1998). Remote sensing systems collect digital measurements that are processed, analyzed and interpreted using computer techniques, and are easily incorporated into geographical information system (GIS) databases (Kneppe, *et al.*, 1994). The technique includes passive aerial photography and Landsat satellites using multispectral scanner and thematic mapper, and the SPOT-1 satellite, and active techniques, such as radar, which show the topographic texture in the presence of cloud cover.

The uses of remote sensing techniques to groundwater practitioners are:

- To identify rock types, fracture zones, fault zones, drainage patterns and various types of unconsolidated deposits or different vegetation patterns that possibly act as groundwater indicators;
- To identify features in hard rock areas with limited regolith cover;
- To infer potential fracture or fault systems or magnetic structures like dykes and sills that can show up as linear features, commonly referred to as lineaments;
- To find possible targets, which can be corroborated by field visits and geophysical surveys.
- To use as a necessary preliminary tool for the planning of any regional catchment management study;
- To facilitate planning for the collection of data for modeling.

The electromagnetic spectrum is divided into wavelength bands of various lengths and frequencies. The short wavelengths (high frequencies) are the ultraviolet bands (UV), whilst microwave and radio bands have long wavelengths (low frequencies). The resolution of Landsat thermal mapper bands is 30m (Rowan, 1998), except for band 6, which is 120m. Table 2.1 gives a list of the seven spectral bands used by Landsat TM and their application to geological features (Sami, *et al.*, 2002).

Table 2.1. Spectral divisions used by Landsat TM and their application to geological features (after Sami, *et al.*, 2002).

Visible region (0.4- 0.7 μm)	Band 1 (0.45- 0.52 μm)	Designed for water body penetration-useful for coastal water mapping Differentiation of soil from vegetation and deciduous from coniferous flora
	Band 2 (0.52- 0.6 μm)	Designed to measure green reflectance peak of vegetation for vigor assessment
	Band 3 (0.63- 0.69 μm)	A chlorophyll absorption band important for vegetation discrimination
Reflected Infrared (0.7- 3 μm)	Band 4 (0.76- 0.9 μm)	Determining biomass content Delineation of water bodies Tectonic analysis
	Band 5 (1.55- 1.75 μm)	Vegetation moisture Soil moisture content Differentiation of snow from clouds
	Band 7 (2.08- 2.35 μm)	Discrimination of rock types Hydrothermal mapping
Thermal Infrared (3- 5 μm and 8- 14 μm)	Band 6 (10.40- 12.50 μm)	Useful in vegetation stress analysis Soil moisture discrimination Thermal mapping

Several different enhancing techniques can be employed to highlight groundwater-controlling features. Those considered of relevance to groundwater investigations are listed in Table 2.2 (Sami, *et al.*, 2002).

Table 2.2. Purpose of different digital techniques (after, Sami, *et al.*, 2002)

Digital technique	Purpose
Linear stretching	Normalization of raw data
False colour composite	Extraction of geology, Hydrogeomorphic features
Band combination	Extraction of vegetation distribution within valley zones and lineaments
Principle component analysis	Extraction of hydrogeomorphic features
Filtering	Extraction of linear features like fractures, faults, dykes, joints using algorithms

2.4 Tectonic stress

The Kamiesberg region is characterized by a crystalline basement aquifer that lacks primary porosity. The groundwater is mainly found along fracture conduits and faults resulting from brittle deformation and active seismic zones.

The Kamiesberg region displays relatively low intensity (<5M) stress release recorded from the Vaalputs nuclear waste depository site (Andreoli, *et al.*, 2001, Figure 2.1). There is a distinct diffuse distribution of seismicity with scattered occurrences of localized zones of concentrated seismicity in South Africa (Meus and Chevallier, 2000). These epicenters are responsible for variable intensity earthquakes in the region. More energetic earthquakes are at present recorded near Leliefontein close to the intersection between the Griqualand- Transvaal and the Kamiesberg axis (Andreoli, *et al.*, 1996). The Kamiesberg region is affected by two important uplift axes activated between Miocene and Pliocene-Pleistocene times (Brandt, 1998).

The Kamiesberg region is situated along energetic seismic zones, which, because of the influence on the fractures and faults, has a positive effect on the groundwater state of the region (Andreoli, *pers. comm.*, 2002).

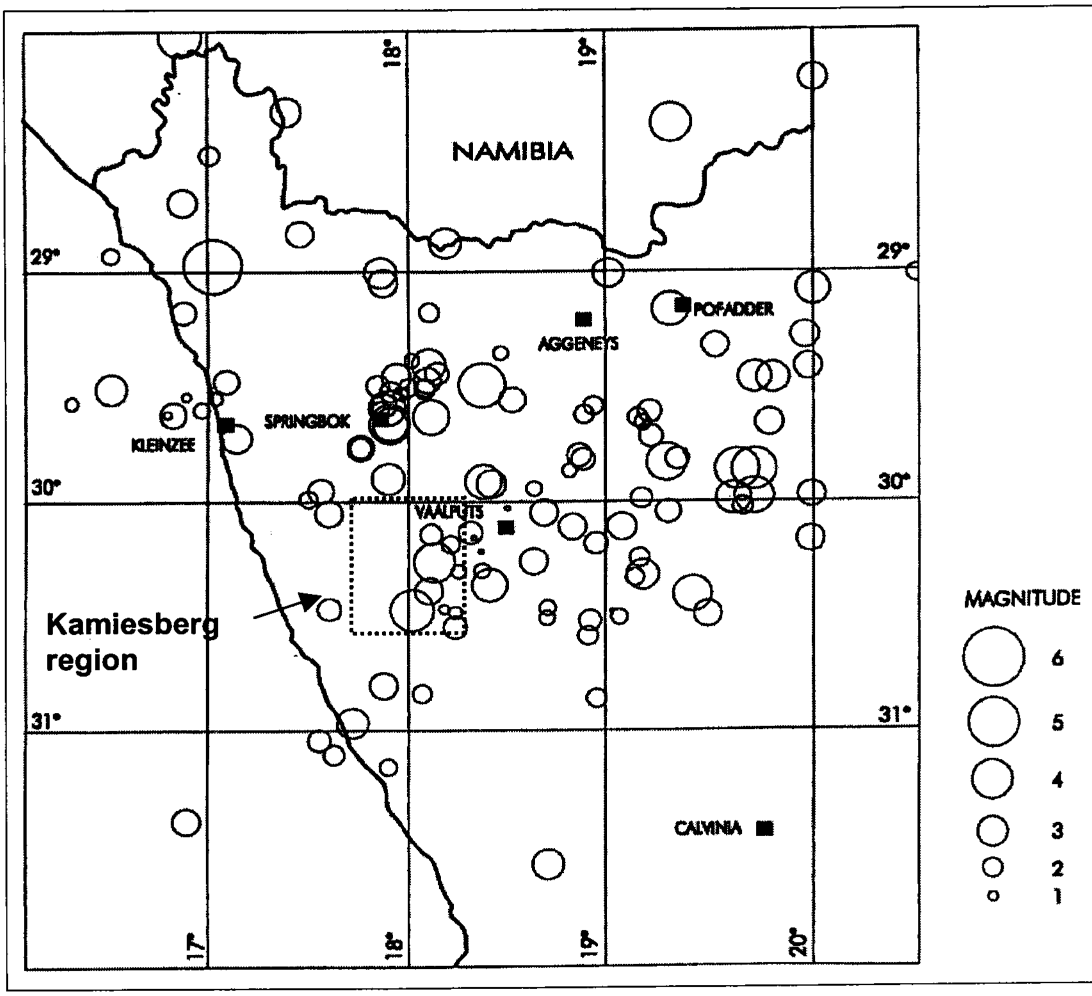

Figure 2.1. Epicenters of seismic events recorded by the A.E.C. in the northwestern Cape (after Brandt, 1998).

2.5 General geology

The area under investigation forms part of the Namaqualand Metamorphic Complex (NMC) that has been intensely studied and mapped. The Bushmanland Subprovince is not only the largest part of the NMC, but is also the most important as far as mineral deposits are concerned. This area includes the unique noritoid ore bodies of Okiep, the stratiform deposits of Aggeneys and Gamsberg, a number of other small base metal deposits, the bulk of the pegmatite's yielding minerals of economic value, (Joubert, 1986), and the alluvial diamond deposits along the coast and the

Buffels River. Previous authors in the NMC have all concentrated on specific aspects of geology. The region referred to as the NMC includes the western part of the Namaqua- Natal mobile belt.

The Proterozoic Namaqualand Metamorphic Complex (NMC) encompasses a large region. Van der Merwe (1995) defines it as that domain which was subjected to the 1000- 1200 Ma Namaqua orogeny, and it also includes rocks of the 1700- 2000 Ma Richtersveld Province (Blignault *et al.*, 1983). Joubert, (1971, 1974b; 1986,1986a) completed a detailed study of the lithology, structure, deformation and metamorphism in the NMC. His work concluded that the NMC is a polyphase deformed and metamorphosed gneissic terrain consisting of paragneisses derived from various sedimentary and volcanic rocks, intruded by a great variety of igneous rocks. Gibson *et al.*, (1996) relates the complex deformational and intrusive history to two main orogenic events, at ~1200- 1250 Ma and ~1030 Ma.

Tankard, *et al.*, (1982) referred to a 'missing basement' whilst Joubert (1986), proposed a model of Proterozoic accretion as the origin of the basement of the area. Waters, (1986), van Aswegen, *et al.*, (1987), and Moore (1989), investigated the metamorphic effects and concluded that high-grade metamorphism of upper amphibolite facies occurred throughout the NMC. The metamorphic peak postdates tight and recumbent folding and metamorphic fabrics imprint upon granitic augen gneisses, which are believed to represent early, or syntectonic intrusions (Joubert, 1974b; Waters, 1986). Van der Merwe (1995) discussed the tectonic development of the Namaqua mobile belt with specific reference to thrusting, vertical shearing and folding in the three tectonic domains recognized by Blignault, *et al.*, (1983). Joubert, (1971, 1974b, 1986a) and Gibson, *et al.*, (1996) recognized four phases of deformation D_1- D_4, with a main (D_2) event. However, Marais, *et al.*, (2001), recognized six phases, the first four are represented by folding and the last two by faulting and shearing events. The geology of the NMC is inherently complex and was investigated by various authors through different times.

According to Joubert, (1971,1974b, 1986a), Blignault, *et al.*, (1983), Gibson, *et al.*, (1996), Moore, (1989) and van der Merwe, (1995), the four deformation phases recognized in Namaqualand are:

D_1: The early deformational episode (D_1) is seen in the metavolcanics of the Orange River Group. It involves isoclinal folding with planar and linear fabrics (Blignault, *et al.*, 1983). Evidence for the D_1 deformation phase is not apparent and is poorly defined.

D_2: evidence of the D_2 deformation event is recorded in the supracrustal gneisses of the NMC. According to Blignault, *et al.*, (1983), the D_2 event is responsible for the subhorizontal, east west structural trends in the Bushmanland Subprovince. The D_2 deformational event resulted in the highest intensity of structural modification, (Moore, 1989), and created major isoclinal folds, thrust planes and large-scale re-orientation of primary fabric features (van der Merwe, 1995). A prominently developed mineral lineation occurs as a *b*- fabric in the minor folds belonging to the D_2 generation (Blignault, *et al.*, 1983). Pegmatites and emplaced basic bodies are seen as part of the D_2 deformation (Joubert, 1971). Within the Okiep District (Gibson, *et al.*, 1996), the most characteristic D_2 feature is a heterogeneously- developed, generally pervasive, subhorizontal S_2 gneissose foliation. The S_2 foliation is associated with a regional, subhorizontal, east-north-easterly- trending mineral lineation, L_2, which is defined by flattened feldspar augen, quartz aggregates, and mafic aggregates. According to Gibson, *et al.*, (1996), the D_2 commenced shortly before the intrusion of the Spektakel Suite. The L_2 lineation is recognized throughout the area and is expressed by alignment of the high- grade metamorphic minerals (Joubert, 1986).

D_3: Joubert, (1971), recognized folds deforming the earlier structures and resulted in the formation of large periclinal structures due to the interference with F_2 folds. The deformation occurred throughout the area and is responsible for the east- west lithological banding over large parts of the area. The D_3 structures are generally asymmetric, with steep northerly dipping axial planes. They trend east- west and has a shallow plunge of variable intensities ranging from large open structures to tight, nearly isoclinal structures (Moore, 1989).

D_4: The D_4 deformation event is marked by structures with variable intensity, style and trend. According to Blignault, *et al.*, (1983), minor folds deforming D_3 structures have axial planes striking northeasterly with steep northwesterly dips and are referred to as D4 folds. The deformation is concentrated on the open D3 structures.

2.6 Lithostratigraphy

An extensive lithostratigraphic breakdown of the Namaqualand Metamorphic Complex (NMC) is given in SACS, (1980), whilst subsequent authors, Visser (1989) and Marais, *et al.*, (2001) provide a crisp summary. The area is characterized by an assemblage of low- to high-grade metasedimentary rocks, unmetamorphosed platform sediments and an array of granitic, basic and ultrabasic intrusive rocks varying in age from early Mokolian (Kheisian) to Namibian (Marias, *et al.*, 2001). Extensive Cenozoic deposits characterize the coastal area. However, a lithostratigraphic investigation is treated with caution within this multi-deformational region, mostly because all the authors working in the area assign different names to the units making correlations virtually impossible.