

**HYDROGEOLOGY OF THE QUEENSTOWN 1:500 000 MAP REGION
(SHEET 3126)**

THESIS

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MICHAEL CHARLES SMART

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ABSTRACT

The Groundwater characteristics of a portion of the Eastern Cape are depicted on a General Hydrogeological Map (Queenstown 3126) at 1:500 000 scale. The purpose of the map and accompanying text is to provide a synoptic overview of the hydrogeology of the area.

The “fractured and intergranular” aquifer type predominates in the more humid eastern part of the study area where the lithologies are more highly weathered whereas the fractured type predominates in the drier west. For the bulk of the area borehole yields are in the 0.5 - 2.0 ℓ/sec range. Higher yields (in the 2.0 - 5.0 ℓ/sec range) are common only in a small area in the south-west of the map. Lowest yields (0.1 - 0.5 ℓ/sec) are obtained in an area immediately north of East London and in the Dwyka Group near the NE coast. It is important to note that these yield ranges are merely a measure of the central tendency, and that higher yields - in excess of 3 ℓ/sec - could well be obtainable at optimal hydrogeological target features within these areas.

Highest borehole yields are obtained in folded areas (restricted to the southern edge of the study area) followed by rocks with dolerite intrusions (common over the bulk of the study area). Other targets include fractured sedimentary and volcanic rock and unconsolidated deposits. Yields obtained from dolerite contact zones vary across the area; differences correspond to spatial variations in the style of intrusion. Highest success rates are obtained in areas intruded by a combination of dykes, ring-shaped sheets and irregular sheets while poor results are obtained in areas intruded by thick massive sills.

Air photo and satellite image interpretation, geological mapping, magnetic, electrical resistivity and electromagnetic geophysical methods can be used to locate drilling target features. Groundwater quality is good since electrical conductivities over much of the area are lower than 70 mS/m and rarely exceed the South African Water quality guideline limit for human consumption of 300 mS/m. The volume of groundwater abstractable ranges between approximately 2 000 m³/km²/annum and 80 000 m³/km²/annum and is limited by either volumes of recharge or subsurface storage.

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Abbreviations and Units

CCWR	Computer Center for Water Research
CSIR	Council for Scientific and Industrial Research
DWAF	Department of Water Affairs and Forestry
EC	Electrical Conductivity
GIS	Geographic Information Systems
IAH	International Association of Hydrogeologists
IAHS	International Association of Hydrological Sciences
MAP	Mean Annual Precipitation
NGDB	National Groundwater Data Bank
NWQDB	National Water Quality Data Base
SABS	South African Bureau of Standards
UNESCO	United Nations Educational, Scientific and Cultural Organization

Units

a	annum
Ga	10^9 years
km	kilometre
km ²	square kilometre
ℓ/s	litre per second
m	metre
m ³	cubic metre
m ³ /a	cubic metre per annum
mg/l	milligram per litre
mm	millimetre
mS/m	milliSiemens per metre
°C	degrees centigrade

Preface

Groundwater is rapidly growing in importance in South Africa but not enough information concerning this resource is reaching planners, decision-makers and users. Although groundwater is a reliable resource when properly managed, uncertainty concerning its existence or character commonly results in it being used as second option to more expensive and less reliable surface water schemes. In order to address the problem of the lack of groundwater knowledge, the Directorate Geohydrology launched a regional mapping programme whereby South Africa's groundwater resources will be portrayed at 1:500 000 scale. The Queenstown map accompanying this thesis is one of twenty-three similar such maps to be produced.

The mapping exercise is intended to bring together all the information concerning the resource for analysis - thereby determining any regional scale variations in the groundwater characteristics. The findings are displayed on the map while more detailed information not readily portrayed on the map is given in the accompanying explanation which is a shortened and simplified version of this thesis.

The main theme displayed on the General Geohydrological maps is the groundwater occurrence and flow regime. For example aquifers in which flow is intergranular (usually unconsolidated material) are distinguished from aquifers in which flow is through fissures (fractures). In addition the productivity (dependent on permeability) is also ranked.

Settling on a legend for the South African 1:500 000 map General map series entailed much debate and revision between 1991 and 1996 inputs coming from parties within and outside Directorate of Geohydrology. The legend used is an adaptation of what is commonly known as the United Nations Educational Scientific and Cultural Organization (UNESCO) legend - published jointly in 1983 by the IAH (International Association of Hydrogeologists), IAHS (International Association of Hydrological Sciences) and UNESCO (IAH, 1983).

Classification of fissured (fractured) occurrence is particularly important in the South African context because this type underlies at least 90 % of the country. A modification to the UNESCO classification was considered necessary in order to incorporate a semi-quantitative expression of storage capacity of the rock interstices into the classification - distinguishing between a fractured and “fractured and intergranular” occurrence. The latter is applicable where weathering has imparted intergranular properties to the residuum overlying fractured bedrock. This weathered zone can provide significant groundwater storage, which can be transmitted to the underlying bedrock.

The South African approach to distinguishing groundwater occurrence requires the identification and comparison of “hydrogeological units”. These being defined as “reasonably homogeneous groundwater units which possesses some degree of internal lithologic homogeneity and similarities in rock properties that impact on groundwater conditions and on groundwater quality” and is “described in terms of lithology, stratigraphy and a combination of mode of occurrence and typical yields of boreholes” (Department of Water Affairs and Forestry (DWAF), 1994).

The groundwater occurrence classification adopted for the South African situation is:

- Fractured
- Fractured and Intergranular
- Intergranular
- Karst

Only the first two categories are important in the Queenstown 3126 map region. A maximum of five productivity ranges could be accommodated - this is the maximum number of distinguishable shades of color. The ranges accommodate yields for the country as a whole - based on an analysis of the yield frequency distribution of all boreholes on the National Groundwater Data Base (NGDB).

The General Hydrogeological Map gives an indication of where the groundwater resources are most accessible and the quality of the resources, but there is another important aspect - the volume of groundwater abstractable on a sustainable basis. A first attempt at quantifying the resource at a regional scale is therefore included in this thesis, and areas most vulnerable to over-exploitation are identified.

1 INTRODUCTION

1.1 Background

The importance of groundwater in South Africa is growing rapidly because of increasing pressure on scarce surface water resources and the Government's priority of supplying potable water to disadvantaged rural and urban communities (Braune in Smart, 1998). Because of the widespread occurrence of groundwater, boreholes can be drilled into geohydrological targets near the point of demand providing a relatively cheap water source requiring little infrastructure. This makes groundwater an attractive option for diffuse supply situations like scattered rural communities. In some instances it can be used to supply larger towns and for irrigation - either as a sole source or in conjunction with surface water.

A major obstacle to the optimal use of groundwater is that insufficient information about it is reaching planners, decision-makers, users and other affected parties (Braune in Smart, 1998). Due to the lack of information concerning groundwater resource base in South Africa, it is widely perceived to be an unreliable resource. As a result there has been an historical bias towards developing surface water resources even in instances where groundwater could have been a viable supply option (Department of Water Affairs and Forestry (DWAF), 1992).

According to Sarin (1989), hydrogeological maps are a good way of disseminating groundwater information to the general public and promoting water management. In his experience, decision-makers obtain a better grasp of the hydrogeology of an area if data are presented in map form. In addition to providing information to the public, Sarin (1989) believes that a mapping project serves an important educational role for the map author researching the hydrogeological character of a particular region.

A sound understanding of the groundwater resource will make it possible to make better water management decisions. For this reason DWAF is carrying out regional scale groundwater studies, and the information made available to the public as a series of maps supplemented by explanatory text.

1.2 Hydrogeological Mapping.

1.2.1 Map classification

The need to display hydrogeological characteristics on maps was recognised as early as the 1940's, and the concept gained popularity over the next 20 years. By 1960 it became evident that it was difficult to compare areas mapped by different authors because of the large variety of methods being used for displaying hydrogeological characteristics (Struckmeier and Margat, 1995). Over the ensuing years there have been a series of attempts at standardization but ongoing conceptual and technological developments have necessitated continual revision of standards. The United Nations Educational Scientific and Cultural Organization (UNESCO) drafted a standard legend in 1963, with revised publications in 1970 and 1983, to keep pace with developments in the field.

Two broad categories of hydrogeological map are recognised, namely general maps and special purpose / parameter maps. A joint UNESCO/World Meteorological Organisation publication (Anon, 1977) entitled "Hydrogeological Maps" first introduced the philosophy of "general purpose" and "special purpose" maps. A more recent publication (supported by the International Association of Hydrogeologists (IAH) and UNESCO, entitled "Hydrogeological Maps - A guide and Standard Legend" (Struckmeier et al., 1995), distinguishes the two groups of hydrogeological map according to their main roles and uses as follows:

- General hydrogeological maps are used as tools to introduce the importance of water resources in political and social development. These correspond to earlier stages of investigation and knowledge, presenting comprehensive information as a synthesis varying from "mere superposition to integration of different layers of data and information". According to Struckmeier (1989) General Hydrogeological maps are a synoptic output of a continuous programme of data collection and storage, evaluation and interpretation, aiming to cover large areas using a homogeneous form of interpretation, representation and scale. The maps produced for this thesis belong to this first category i. e. general hydrogeological maps.

- Parameter maps / special purpose maps are used for planning, engineering and management. They vary widely in content and representation according to their intended use and show with maximum accuracy a specific set of data, e.g. groundwater temperature or aquifer thickness. No attempt has been made to produce parameter maps for this study.

At an international hydrogeological mapping symposium held in Hannover in 1989, mapping activity was reported in Europe, Australia, Africa, USSR, China, India, Brazil, the Arab Countries, and “numerous international, national and sub-national territories” had already been mapped hydrogeologically (Sarin, 1989). At that stage South Africa did not even have a mapping programme and was therefore far behind the rest of the world in this field, the DWAF concentrating rather on establishing water supply schemes.

Attention turned to hydrogeological mapping only in the early 1990's, when a hydrogeological mapping programme was established for South Africa. The first priority was the production of a set of National hydrogeological maps which were published in 1995 (Vegter, 1995). These are currently being followed by a series of 23 General Hydrogeological maps at 1:500 000 scale to cover the country. This thesis covers the hydrogeological investigation for the first of the 1:500 000 series to be published - that of Queenstown (3126) for latitudes 31° S to 33° S and longitude 26° E to 30° 40' E. The Map (Fig. 1) is enclosed in the sleeve at the back of this document. The essence of this thesis has been compiled into an explanatory text to accompany the General Hydrogeological Map.

The Map depicts groundwater occurrence, distinguishing between main aquifer types as well as providing an indication of borehole yield. Information on groundwater abstraction, thermal springs, geology and surface hydrology are also included. Insert maps provide information on groundwater quality, borehole data distribution, surface elevation and precipitation. Some of these insert maps have been repeated in the text of this thesis for ease of reference.

1.2.2 Development of the map legend for RSA

Deciding on a legend for the DWAF 1:500 000 General Map series entailed much debate and revision between 1991 and 1996 when a Standards and Specifications working document (DWAF, 1996) was finally produced for map authors reference (Appendix 1a). Inputs came from parties within and outside the Directorate of Geohydrology. The legend used is an adaptation of what is commonly known as the UNESCO legend - published jointly in 1983 by the IAH, IAHS (International Association of Hydrological Sciences) and UNESCO (IAH, 1983).

The unmodified UNESCO legend distinguishes between the following types of groundwater occurrence:

- 1) Intergranular, of moderate to high productivity
- 2) Fissured, of moderate to high productivity
- 3) Intergranular or fissured, but only local with limited or no groundwater resources.

Each of the first two categories is subdivided into “extensive and highly productive” and “local or discontinuous productive aquifers or extensive but only moderately productive”.

Classification of fissured (fractured) occurrence is particularly important in the South African context because this aquifer type underlies at least 90 % of the country. Modification to the UNESCO classification of groundwater occurrence was considered necessary for two main reasons:

- Firstly, in order to incorporate a semi-quantitative expression of the storage capacity of the rock interstices into the classification - distinguishing between a fractured and a fractured and intergranular occurrence. This departure was necessary to accommodate a common feature in South Africa which occurs when weathered rock stores important quantities of water in the intergranular voids (Plate 1), but the water can only be economically abstracted via fractures in the underlying bedrock through a process of vertical drainage of groundwater from above.



Plate 1: Weathered dolerite - capable of intergranular groundwater storage.

Secondly, the South African occurrence and productivity ranges are a blend of the UNESCO categories making it difficult to assign them to any one particular category. The predominant groundwater occurrence in South Africa can be described as “local and / or discontinuous containing only moderate or limited groundwater resources, but also highly productive locally (DWAF, 1994). The Directorate Geohydrology argued that this type of occurrence is a blend of categories 2 and 3 of the UNESCO legend - and could therefore not be slotted solely into any one of the UNESCO subdivisions. i.e. it cannot fit into “local or discontinuous productive” category because it is not considered productive. At the same time this type of occurrence does not slot into the “extensive but only moderately productive” category because it is not extensive. (It is the author’s opinion that the UNESCO legend could have been utilized by clearly defining what constitutes productive or moderately productive).

The groundwater occurrence classification finally adopted for the South African situation is:

- Fractured
- Fractured and Intergranular
- Intergranular
- Karst

This system classifies the voids in the rock through which water is stored and transmitted, referring to the nature of aquifer that may be found, rather than individual aquifer boundaries. In cases where one aquifer type is overlain by a different aquifer type, the principal aquifer is portrayed on the map, i.e. the shallowest aquifer with the highest borehole yields and the best groundwater quality. In practice a deviation was permitted to allow for the case when the intergranular voids were primarily an important storage rather than a transmitting medium.

The South African approach to distinguishing groundwater occurrence requires the identification and comparison of hydrogeological units. These may be defined as “reasonably homogeneous groundwater units which possess some degree of internal lithologic homogeneity and similarities in rock properties that impact on groundwater conditions and on groundwater quality” and are “described in terms of lithology, stratigraphy and a combination of mode of occurrence and typical yields of boreholes” (DWAF, 1994).

As with the UNESCO legend, the type of groundwater occurrence is given a specific colour and the colour tone reflects the productivity, e.g. tones of blue for intergranular occurrence and tones of green for fractured occurrence (the darker the tone the higher the productivity). Tones of brown used for the UNESCO “local and limited” category is instead used for the “fractured and intergranular” category adopted specifically for the South African context.

The yield ranges corresponding to levels of productivity are not prescribed by the UNESCO legend - allowing for a measure of flexibility to accommodate hydrogeological character of the region being mapped. Yield ranges selected by the Directorate Geohydrology for the 1 : 500 000 General Geohydrological Map series are given in Table 1.

Table 1: Yield ranges selected for the 1:500 000 map series.

Litres per second (l/s)
0.0 - 0.1
>0.1 - 0.5
>0.5 - 2.0
>2.0 - 5.0
> 5.0

A maximum of five productivity ranges could be accommodated - this is the maximum number of easily distinguishable shades of a particular colour. The selected ranges accommodate yields for the country as a whole, based on an analysis of the yield frequency distribution of all boreholes on the National Groundwater Data Base (NGDB). The median borehole yield determines the productivity range for a particular set. Dry boreholes are excluded from the calculation for consistency sake as some areas of the country are without record of dry boreholes.

Lithological characteristics are depicted as a background ornament in accordance with the UNESCO legend. Depiction of dolerite posed a particular problem because portrayal of this abundant, intricately intruded rock type would result in a cluttered effect. A solution proposed by the author (Appendix 1b) has been accepted as the standard. Briefly, instead of showing all dolerite intrusions present in the region, only the bigger intrusions that cover a large surface area are assigned the dolerite symbol alone. Where dolerite intricately intrudes the host, a mixture of both the dolerite and host ornament is used.

1.3 Aims and objectives

The primary aim of the Queenstown General Hydrogeological Map was to produce a synoptic overview of the geohydrological character of the area by processing groundwater-related data according to a standard legend. The main features shown on the map are median borehole yield, aquifer type, groundwater quality, lithology and groundwater use.

This text was compiled to provide supplementary information on these features, and also to:

- outline the hydrogeological properties to consider in siting production boreholes,
- describe the hydrochemical character of the groundwater,
- make a preliminary estimate of maximum and optimum sustainable abstraction rates ($\text{m}^3/\text{km}^2/\text{a}$),
- focus future research directions by identifying gaps in knowledge.

1.4 Previous hydrogeological investigations

Political considerations have influenced the approach to, and locality of, investigations over time since the study area comprises the Republic of South Africa (RSA) Transkei and Ciskei (Fig. 2), each with its separate Government. Initially studies were focussed within political boundaries but with the changing dispensation and mutual cooperation that accompanied dissolution of these artificial barriers, regional scale studies have become possible.

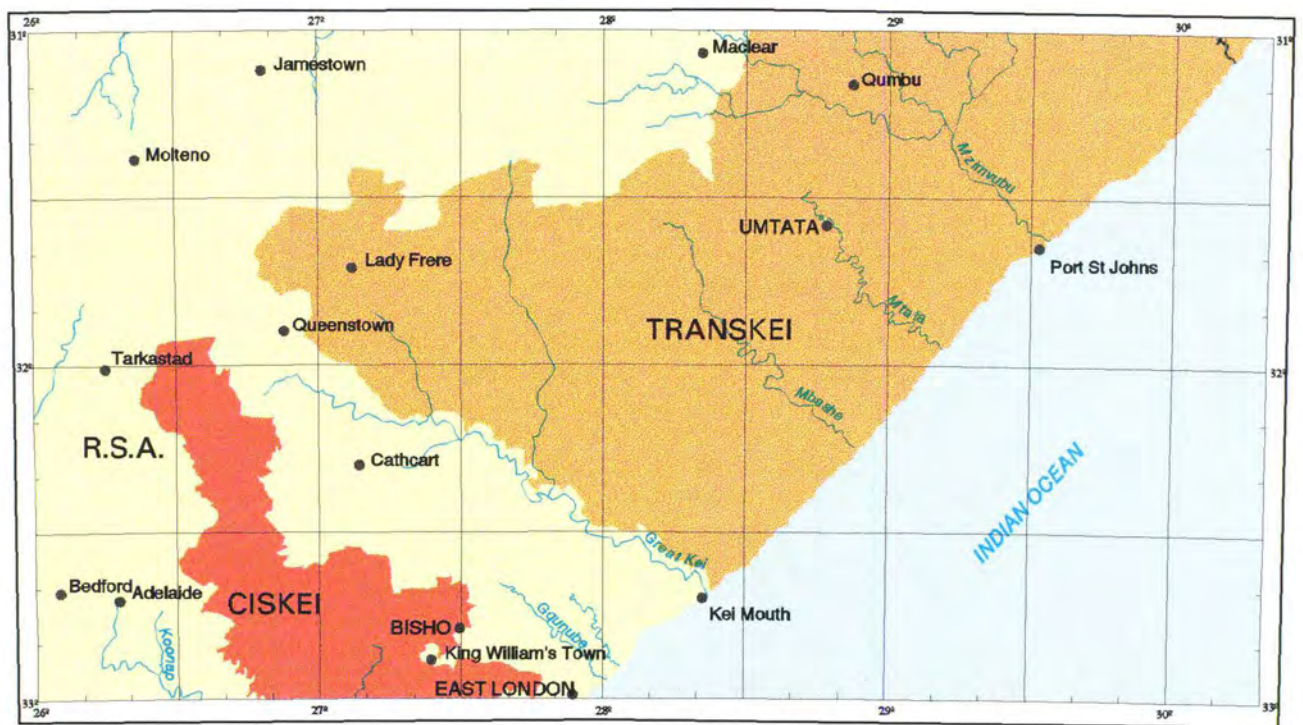


Fig. 2: Historical political boundaries.

1.4.1 Ciskei National Water Development Plan

The former Ciskei Government prepared a Ciskei National Water Development Plan between 1986 and 1990 which included identification of groundwater resources (Hill Kaplan and Scott) HKS, 1991). The author was responsible the bulk of the fieldwork and contributed to the compiling of the groundwater report. Before this investigation very little was known about the groundwater potential on a regional and national basis (Rosewarne et al., 1987). A National map for the Ciskei at 1:250 000 scale was produced distinguishing areas of “poor”, “moderate” and “good” groundwater potential based on a combination of lithology, geological structure, groundwater quality and recharge potential (precipitation). Six hydrogeological regions were identified and each was described in terms of aquifer types, borehole yields, water quality and target features for groundwater exploitation.

1.4.2 Transkei National Groundwater Plan

The former Transkei Department of Agriculture and Forestry embarked on a National Groundwater Plan for Transkei commencing in 1986 (SRK, 1993). A hydrogeological overview was obtained from existing borehole information and published geological maps. The expected range of borehole yields per lithological unit, as well as expected groundwater quality water and potential drilling targets, were briefly described. A computerized database (*Hydrocom Version 4.0*) was then compiled from existing borehole data, supplemented by hydrocensus information. The Natal Group Sandstones were selected for more detailed drilling investigation to determine the hydrogeological potential (SRK, 1993).

Assessments were made of the groundwater resources of the Xonxa catchment to the east of Queenstown (SRK, 1987). In Northern Transkei, the Northern Zone Village Water Supply Study (SRK, 1991) was carried out in parallel with the National Groundwater Plan. This investigation entailed compiling an inventory of water supply schemes, borehole drilling and aquifer testing.

1.4.3 Republic of South Africa

Up to 1993 Departmental investigations were of a localized nature, the focus being on development of groundwater supply schemes. A groundwater investigation was undertaken by DWAF for a portion of the Swart Kei River catchment to the west of Queenstown (Vandoolaeghe, 1980) to evaluate the Groundwater supply potential. The study entailed detailed drilling of geohydrological target features and aquifer testing - providing in particular an understanding of groundwater occurrence in association with dolerite for that locality. Small scale groundwater development investigations at various towns, inter alia: Bedford (Simonis, 1987), Jamestown (SRK, 1992), Tarkastad (GCS, 1992), Sterkstroom (SRK, 1993), Komga (Venables and Woodford, 1985), Dordrecht (Meyer, 1984) have also provided some insight into groundwater occurrence. Sami (1996) compared the potential of various geohydrologic target features and estimated the groundwater recharge in the Bedford vicinity.

1.4.4 Integrated studies

1.4.4.1 Upper Kei Basin Study (Kei Basin Consulting Engineers (KBCE), 1993)

The Upper Kei Basin is about 11 500 km² in extent and centered around Queenstown. At the time the study was implemented the catchment fell within South Africa, former Ciskei and Transkei, but re-incorporation of the latter two “homelands” into the RSA was imminent. Dissolution of these political boundaries would enable integrated management of the scarce water resources for which there was increasing demand. A basin study was therefore implemented by DWAF to gain a holistic view of the water-related issues. A key part of the investigation was the provision of an overview of groundwater resources based on a review of the literature. The author carried out this groundwater study. Hydrogeological regions were identified and expected aquifer types, borehole yields, target features and groundwater quality were assessed. Groundwater exploitation potential was calculated, based on recharge and storage estimates extracted from the literature on Karoo aquifers.

1.4.4.2 Exploitation potential (Seward et al., 1996)

The Queenstown map sheet (3126) was chosen for a project by DWAF to demonstrate the use of Geographic Information Systems (GIS) for determining groundwater exploitation potential in terms of $\text{m}^3/\text{km}^2/\text{annum}$. This formed part of the regional groundwater characterization programme. The author was one of the three member team carrying out the study. Responsibilities were inter alia: assistance with developing the methodology, evaluation of the validity of the results at the local scale and determination of the cost of groundwater abstraction. The main elements considered were recharge, storage and transmissivity. Exploitation potential was taken as the lesser of mean annual recharge, aquifer storage required to tide across drought periods, or abstraction potential limited by transmissivity. It was found that aquifer matrix transmissivity would most probably limit groundwater exploitation at the regional scale. This is because the large fractures intersected in higher yielding boreholes usually rely for their replenishment on inflow from the much lower permeability microfractures in the aquifer matrix where the bulk of the groundwater is stored. The slow rate of replenishment of the larger fractures will limit abstraction.

1.5 Data collection

The first step in the data collection phase was to gather all available information from files, reports, maps and databases for analysis. The three main categories of information identified as being necessary for characterization of the groundwater resource are:

- hydrogeological, in the form of borehole data, reports and published literature,
- geological literature and maps,
- climatic and topographic.

1.5.1 Hydrogeological information

Only a limited number of borehole parameters were needed for the production of the General Hydrogeological Map. The most important borehole data requirement was the locality, yield and groundwater water quality.

For the General Hydrogeological Map, immediate to short term borehole yields are taken as an index of aquifer productivity. The yield is the reported “blow” yield on completion of the borehole, or the maximum yield after a test of short duration (usually 8 hours). It is therefore only controlled by the local permeability of the aquifer, not the sustainable / long term borehole yield which depends on local circumstances like rainfall, topographic setting, matrix permeability of the strata, subsurface storage capacity, number of other boreholes abstracting water from the same aquifer unit.

The borehole locality and yield information were used to distinguish areas of lower borehole yield from those where higher borehole yields are obtained. An overview of the typical distribution of borehole yields expected in various areas assists in determining where groundwater exploitation is likely to be most economical. Water quality information was needed to compile the water quality contour map, which is intended to assist a planner or potential groundwater user to assess the suitability of the groundwater of a particular area for the desired use. Combined use of the borehole yield and groundwater quality maps can therefore assist planners with deciding on water supply options for these areas.

Additional borehole information required for determination of groundwater characteristics to be dealt with in the text of this thesis includes: -

- rest groundwater level as well as depth and yield of water interceptions. This information was used to determine optimum drilling depth.
- hydrogeological descriptions of drilling targets and corresponding borehole yields to evaluate yield ranges to be expected in the various settings.
- results obtained from chemical analysis of the groundwater were required to establish how the hydrochemical character varies across the area and to determine whether concentrations of elements potentially hazardous to health are too high.

The author established what information was available, where housed and the format in which it existed. This entailed liaison with the then - Transkei Department of Agriculture and Forestry, Ciskei Department of Public Works, the Information Section of the Directorate Geohydrology, and various geohydrological consultants. All relevant hydrogeological reports were gathered for the author's review. Borehole data for Transkei existed in a computerized database (*Hydrocom*) while information for the remainder of the area was in hard copy files requiring encoding and entry into the National Groundwater Data Base (NGDB). A. Brooksbank, R. Lippert and the Information Section carried out encoding and data entry. All data were then compiled into a single Arc-Info Geographic Information System (GIS) database by J. Baron and E. Louw. Examination of the available data by the author revealed a paucity of water quality / hydrochemical information which were supplemented by reconnaissance field surveys carried out by DWAF personnel under the authors supervision: H. Calitz and H. Van Kleef concentrated in the western half of the study area, B. Zenzile the eastern half while W. Nomqophu concentrated in the north-eastern corner. The purpose of these surveys was to determine broad regional groundwater quality and hydrochemical variations. As a result, the emphasis was placed on obtaining a spread of representative information rather than from every borehole or spring which would be too time consuming. Electrical conductivities (ECs) were measured in the field and samples analysed for major inorganic ions - some analyses being undertaken at laboratories of the Council for Scientific and Industrial Research (CSIR) and others at the Hydrogeological Research Institute (HRI). A field survey by H. Calitz, under the author's supervision aimed at hydrogeologically explaining some of the higher yielding boreholes throughout the area, had to be prematurely abandoned after only covering the north-western quarter of the map. The survey was curtailed in favour of the Directorate Geohydrology's more pressing drought relief commitments.

1.5.2 Geological information

Published literature and geological maps were reviewed by the author to identify lithological and structural characteristics likely to influence the hydrogeology, particularly distribution continuity and intensity of fracturing because these aspects influence secondary permeability.

1.5.3 Information concerning precipitation (climate) and topography

Precipitation data were required for making estimates of available groundwater resources of the study area. These data were obtained from the Computing Center for Water Research (CCWR), University of Natal, Pietermaritzburg and are of hydrogeological importance in that a proportion of the precipitation recharges the groundwater resource.

The topographic inset map was obtained from the CCWR. This information is included because it influences precipitation distribution (e.g. rainfall and snow concentrated on the mountain ranges) as well as regional groundwater flow directions. Topographic information also assists with hydrogeological interpretations such as explanation of groundwater water quality variations.

1.6. Methodology

1.6.1 Borehole yield

The author subdivided the area into twenty-five relatively homogeneous hydrogeological “yield regions” within which the properties affecting borehole yield are considered to be similar. These were initially delineated on the basis of lithology and geological structure, climate and topography. Some of these areas were further subdivided by taking into account borehole yield information. Concentrations of distinctly higher yielding boreholes than the surroundings were selected and assigned to individual hydrogeological “yield regions”.

The author carried out statistical analysis of the borehole yields within each of the identified regions in order to determine central tendencies and yield frequency distribution. Yield characteristics of these regions were compared on the basis of these results and grouped according to the standard yield ranges for portrayal on the General Hydrogeological Map.

For the map series the median borehole yield determines the productivity range for a particular data set. Although data for dry boreholes are available for the study area, they had to be excluded from the map in order to conform to the standards set by the DWAF. The reason for excluding dry boreholes is that this map was to be compared with maps covering other parts of the country that do not have records of dry boreholes. Dry boreholes are however included in yield frequency histograms compiled for this thesis because they form an important part of the data set, enabling distinctions to be made between regions that would not have been evident otherwise. In addition the author determined the best drilling targets by comparing borehole yield statistics for various geohydrological settings.

1.6.2 Aquifer Type

The “fractured and intergranular” and fractured aquifer types are by far the most widespread in the study area. The intergranular aquifer class is not depicted on the General Hydrogeological Map since there are no areas within the map sheet where unconsolidated deposits yield significant amounts of water. The typical settings for fractured aquifers and “fractured and intergranular” aquifers are illustrated on the schematic hydrogeological diagram below the main map in Fig. 1.

In *fractured* aquifers the groundwater occurs in joints, fractures, fissure systems and faults. The water table / piezometric surface is usually deeper than the weathered zone which is unsaturated as a result. This differs from “*fractured and intergranular*” aquifers where the water table lies within the weathered zone, with the result that the lower portion of the weathered zone is saturated. Groundwater stored in this zone is available to replenish groundwater in the hydraulically connected underlying fractured rock by downward leakage.

The “fractured and intergranular” aquifers exhibit combined hydrogeological properties of both fractured and intergranular aquifers. They form where weathering processes preferentially decompose minerals in the rocks adjoining fracture planes as well as at or near the ground surface. Sufficiently advanced decomposition can result in the transformation from solid crystalline rock (e.g. dolerite) to a “granular” material with similar hydraulic properties to intergranular aquifers. These aquifers are most prevalent in humid areas where dolerite is abundant. The reason for this is

that dolerite is rich in minerals susceptible to decomposition, the degree of which is greatest in warm areas where precipitation is high. Weathering has been noted up to 30 m depth in the more humid eastern parts of the area.

Weathering is a self-intensifying process, which can cause a reduction in aquifer permeability, but the storativity is increased. The weathering process softens the rock, which becomes more readily erodable than in its fresh state. Removal of the weathered material by erosion reduces vertical load pressure on the underlying rock resulting widening of joints, and permits deeper penetration of the weathering agents. The groundwater conduits thus formed (fractures and intergranular) contain residual clay weathering products which retard groundwater flow rates but at the same time increase the storativity due to the increased pore space and high specific retention of the clay. Immediate yields of boreholes drilled into highly weathered material are therefore relatively low but are likely to be sustainable due to the relatively high storativity. Highest immediate yields can be expected in the less weathered zones for example where fracturing coincides with the transition zone from weathered to fresh material. The intensely-weathered less-transmissive (lower yielding) portions of these aquifers might not be important for direct abstraction but they do provide storage for the underlying, fresher fractured rocks, where higher yields can be expected.

Throughout the area, low permeability fractures occur in the rock matrix, concentrated mainly within the in the upper 20 – 30 metres of the saturated zone. These less-transmissive fractures might not be important for direct abstraction but do provide an important near surface groundwater storage function on lower hillslopes and in topographic depressions

Due to insufficient information on weathering depth it was not possible to distinguish in any detail the areas underlain by fractured aquifers only, from those underlain by “fractured and intergranular” aquifers. It is likely that difficulties in mapping these two aquifer types would still have occurred even if more weathering information was available. This is because the boundaries between the two aquifer classes are transitional in nature, both often being represented within a single aquifer unit. For the same reason they cannot be individually delineated and no attempt has been made to portray individual aquifers of these types separately on the General Hydrogeological Map (Fig. 1). Instead the following were used to determine prominence of these two aquifer classes at the regional scale:

- The national scale saturated interstices map (Vegter, 1995),
- A national scale contour map indicating weathering intensity and mode of weathering of basic igneous rocks (Weinert, 1974).

Vegter's national scale "Saturated Interstices" map (1995)

This map distinguishes between areas in which groundwater occurs in:

- fractures only,
- "pores in disintegrated / decomposed, partly decomposed rock and fractures".

The method used by Vegter (1995) to differentiate these two types of groundwater occurrence entailed an analysis of depth and frequency of water strikes encountered in boreholes. The water strike frequency distribution in the zone immediately below the water table was adopted as the criterion for distinguishing the type of saturated interstice.

In the case of aquifers possessing an upper zone of saturated weathered material there is an initially low water strike frequency immediately below the water table followed by an increasing trend in water strike frequency at greater depth. The initial low water strike frequency is attributed to the low transmissivity of the weathered material penetrated. The water strike frequency increase at greater depths is due to the progressively less intense weathering and resulting higher transmissivity of the saturated interstices. Vegter (1995) interpreted areas of the country where boreholes typically display an initial low water strike frequency followed by an increase in the frequency as having a saturated decomposed zone. In the remaining areas of the country where this initially increasing water strike frequency is not observed, the interstices are interpreted as being fractures only.

Weinert's national scale weathering map (1974)

Weinert (1974) defined, in terms of an "N" value, the climatic conditions which lead to predominance of disintegration due to physical weathering over decomposition due to chemical weathering. He produced contours ranging from 1 (in the humid eastern part of the country) to 50 in the dry north-west. North-south trending contours cross the study area ranging from 1 in the east to 7 in the west.

According to Weinert (1974) the N = 5 contour, coinciding roughly with 26.5° longitude situated toward the western edge of the study area is the most important. This is because decomposition is the predominant mode of weathering to the east of N=5 and disintegration prevails to the west of this contour.

Weinert's and Vegter's maps were therefore jointly used by the author as a guideline to delineate the transition from predominantly fractured to "fractured and porous" aquifers on the General Geohydrological map (Fig 1), hence the change in occurrence from fractured at the western edge of the map to "fractured and intergranular" further east. In addition, published 1:250 000 Geological maps were used by the author to identify areas of low susceptibility to weathering by decomposition - namely those parts of the study area where dolerite is rare. These parts are a wedge along the southern edge of the map roughly south of the road between Bedford and East London and in the north-eastern corner. The Natal Group sandstone outcrops in the north-east of the mapped area has a low susceptibility to weathering on two counts: - the relatively inert nature of the quartz rich sediments, of which it consists, plus the rarity of dolerite intrusions.

1.6.3 Aquifer thickness

The author determined the aquifer thickness by plotting the probability of intercepting groundwater versus the depth of water interception below surface. The base of the aquifer was taken as the depth at which there was an inflection indicating the lower limit of the more highly fractured near surface zone. Probabilities were determined as follows:

$$\text{Probability} = \frac{T_b}{T_s}$$

Where:

T_b = Total boreholes drilled per depth interval

T_s = Total water strikes in that depth interval

1.6.4 Groundwater quality and hydrochemistry

Regional scale groundwater quality trends were distinguished using water quality data points which were contoured by E. Louw using GIS and the contours manually adjusted by the author to take into account geological structure and topography. The presence of selected hydrochemical constituents, which could pose a threat to health, is highlighted. In addition results of hydrochemical analyses were used to determine regional variations in groundwater character as defined by ionic ratios.

1.6.5 Groundwater potential

An estimate of the groundwater *Harvest Potential* is required in order to determine the theoretical volume of groundwater that can be abstracted from an area on a sustainable basis. The groundwater *Development Potential* is a different aspect that deals with the practicality of accessing the resource given economic and physical constraints.

Extensive use was made of a Geographic Information System (GIS) in the determination of the groundwater potential of the study area. It was employed in the execution of the required calculations and output of the results in map form. The GRID module of the Arc/Info GIS was used to manipulate various sets of data (eg. precipitation/recharge, storage, drought length, abstraction potential). All the GIS support required for this exercise was given by E. Louw.

A similar method to that used by Seward et al. (1996) was employed to determine groundwater Harvest Potential, using a combination of recharge and storage estimates. It is important to note that this method does not take account of groundwater water quality or socio-economic factors such as environmental considerations, cost of bringing water to the point of demand and value of the water.

The method used by the author in this study differs from that Seward et al. (1996) in that the author took cognizance of a more recently published method for estimating recharge (Bredenkamp et al., 1995) as well as storage variations. Empirical estimates of recharge at the regional scale were made

by referring to a version of Bredekamp's (1995) rainfall / recharge relationship, which had been slightly modified by the author to take account of local information. Typical aquifer storativity ranges, also obtained from the literature, were applied across the area. Variation in the storativity assigned by the author to various portions of the area was based on mode and intensity weathering of the rock.

As a general rule the higher the rainfall of an area, the greater the recharge potential and therefore volume of groundwater which can be abstracted on a sustainable basis. Variability of precipitation (drought length and drought precipitation) was considered when determining recharge during dry periods. In this instance drought coverages compiled from CCWR precipitation data by E. Louw for a groundwater potential study of the Queenstown (3126) map region (Seward et al., 1996) were used to estimate the available storage to tide across drought cycles as well as recharge during drought.

The groundwater *Development Potential* was taken as the lesser of the Harvest Potential and the maximum volumes of groundwater feasibly abstractable if transmissivity is the only limiting factor (Abstraction Potential). The Abstraction Potential was determined by assuming a particular borehole distribution, and abstraction rates based on typical borehole yield. In addition areas of highest risk over-exploitation were identified by determining where the Abstraction Potential is likely to exceed the Harvest Potential.

1.6.6 Major groundwater use

An indication of where groundwater might be under threat of over exploitation can be obtained by identifying locations of major groundwater use. Estimates of abstraction for agricultural purposes were made from information on the area under groundwater irrigation, crop type and the irrigation requirement to sustain the crop. The author interviewed personnel from the Department of Agriculture to obtain the required information. The volume abstracted was then calculated using the crop irrigation requirement and area under irrigation as shown in Table 2.

Table 2: Crop irrigation requirements used for calculating groundwater abstraction.

Crop Type	Irrigation requirement per annum (mm)	Volume per hectare under irrigation (m³/ a)
Lucerne	1 463	14 630
Wheat	700	7 000
Maize	900	9 000
Rye grass	1 100	11 000
Oats/Barley	750	7 500
Pastures	1 200	12 000
Onions	500	5 000
Walnut trees	750	7 500

Information on large-scale domestic abstraction was obtained from a variety of sources including the literature, Departmental and consultant's reports and interviews with personnel responsible for groundwater supply schemes.

2 PHYSICAL ENVIRONMENT

2.1 Topography and Surface hydrology

Fig. 3 shows the topography and surface hydrology. The bulk of the area lies on the seaward side of the Great Escarpment, which traverses the north-west of the area. The Great Escarpment (Fig. 1) comprises the Bamboesberg, Stormberge and Drakensberg mountain ranges which rise from about 1500 m to between 2 000 and 2 600 m above sea level. On the seaward side of the Great Escarpment drainage is generally south-easterly. In the eastern half of the area the often deeply dissected terrain slopes gradually toward the Indian Ocean. Northward draining tributaries of the

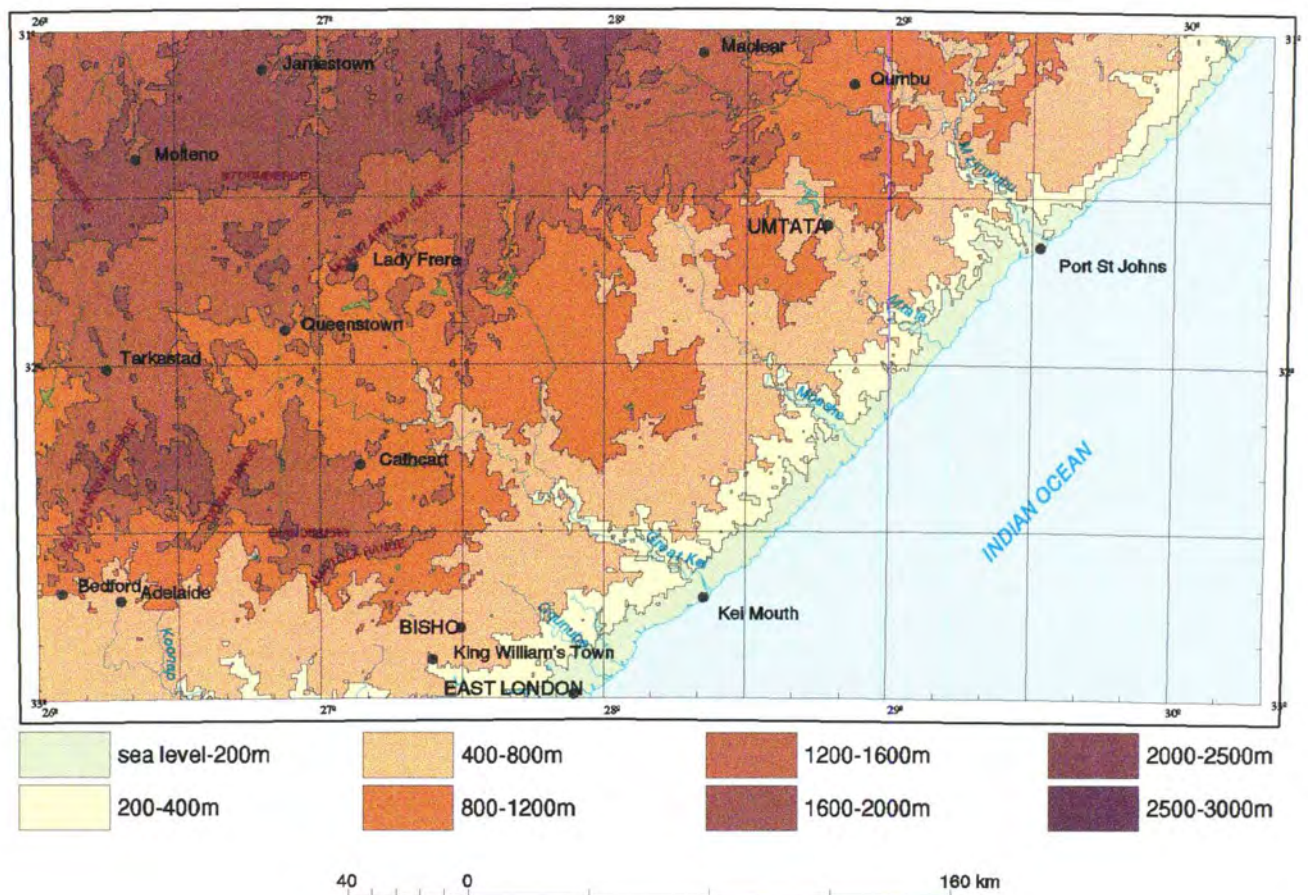


Fig. 3: Topography and surface hydrology.

Orange River traverse the landward side of the escarpment in the north-west corner of the map. At the western edge of the map tributaries of the Great Fish River drain to the south-west.

In the western half of the map area a plateau separates the Great Escarpment from the Winterberg and Amatola mountain ranges further south. The latter ranges rise to approximately 1600 m. Inland drainage from these ranges is initially toward the north in the Tarkastad area and then to the south-east trend, characteristic for the area.

2.2 Climate

2.2.1 Precipitation

The lowest mean annual precipitation (MAP) occurs in the west of the area (Fig. 4), typically 400 mm. In the eastern area MAP is typically around 800 mm. The highest MAP (ranging from 1 000 – 1 400 mm) occurs along the coastal belt and against mountain ranges comprising the Great Escarpment and the Amatola range.

Rainfall maxima generally occur in late summer, but in the northern parts the rainfall is relatively evenly spread throughout summer (October to March). In the coastal area in the vicinity of East London it is more evenly spread throughout the year. Snow falls on the mountain ranges during winter.

2.2.2 Temperature and evaporation

Mean annual surface temperatures (Fig. 5) are highest along the coastal belt in the south-east, decreasing inland towards the north-west due to the higher altitude and greater distance from the moderating influence of the sea. Over most of the area mean annual temperatures range from 15.0 to 17.5 °C. Along the coastal belt the range is 17.5 to 20.0 °C while in the north-west it declines to between 12.5 and 15.0 °C. The average annual potential evaporation (Fig. 6) ranges from less than 1 200 mm in the more humid areas near the coast, to 1 800 mm in the drier inland areas to the north-west.

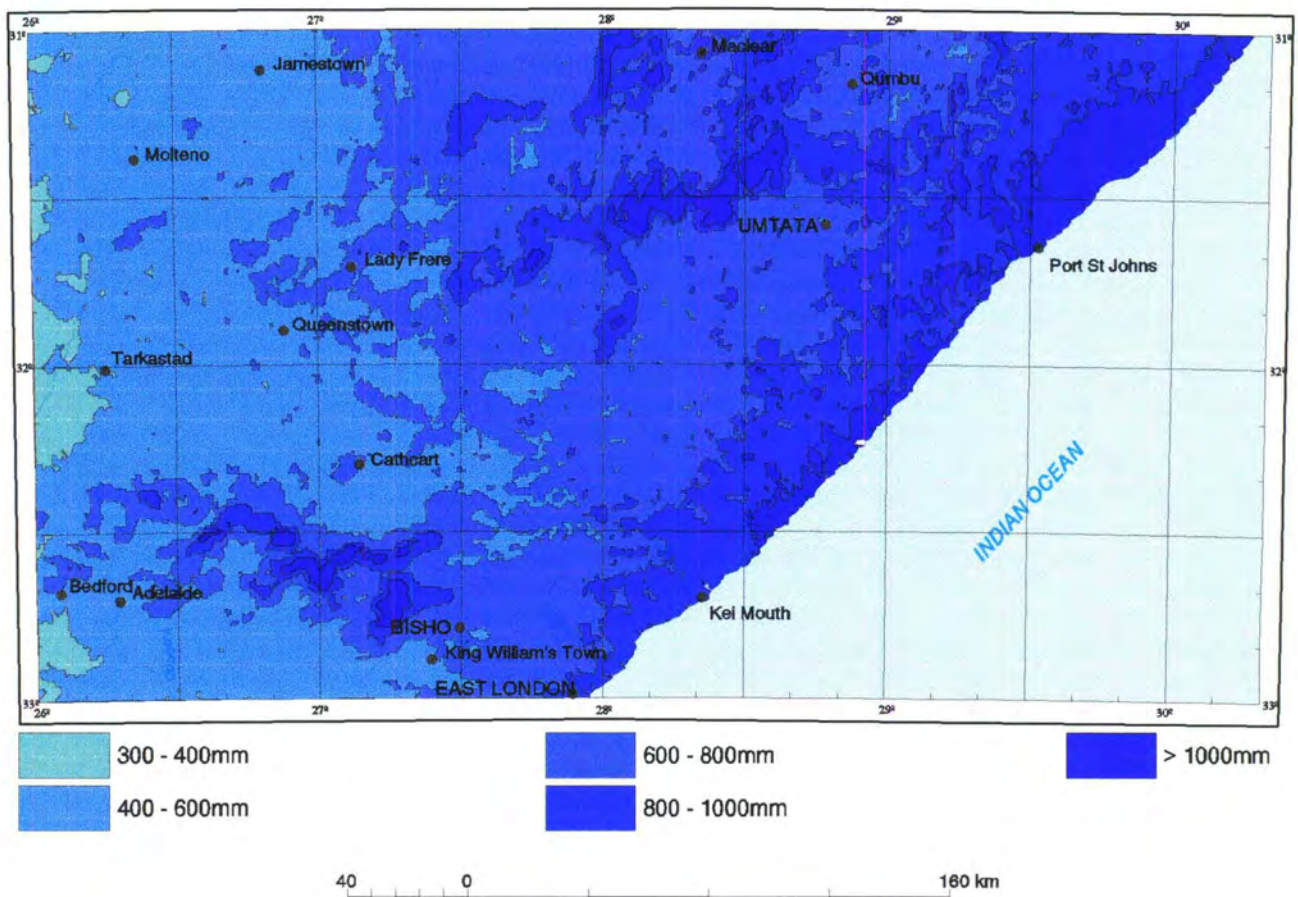


Fig. 4: Mean annual precipitation.

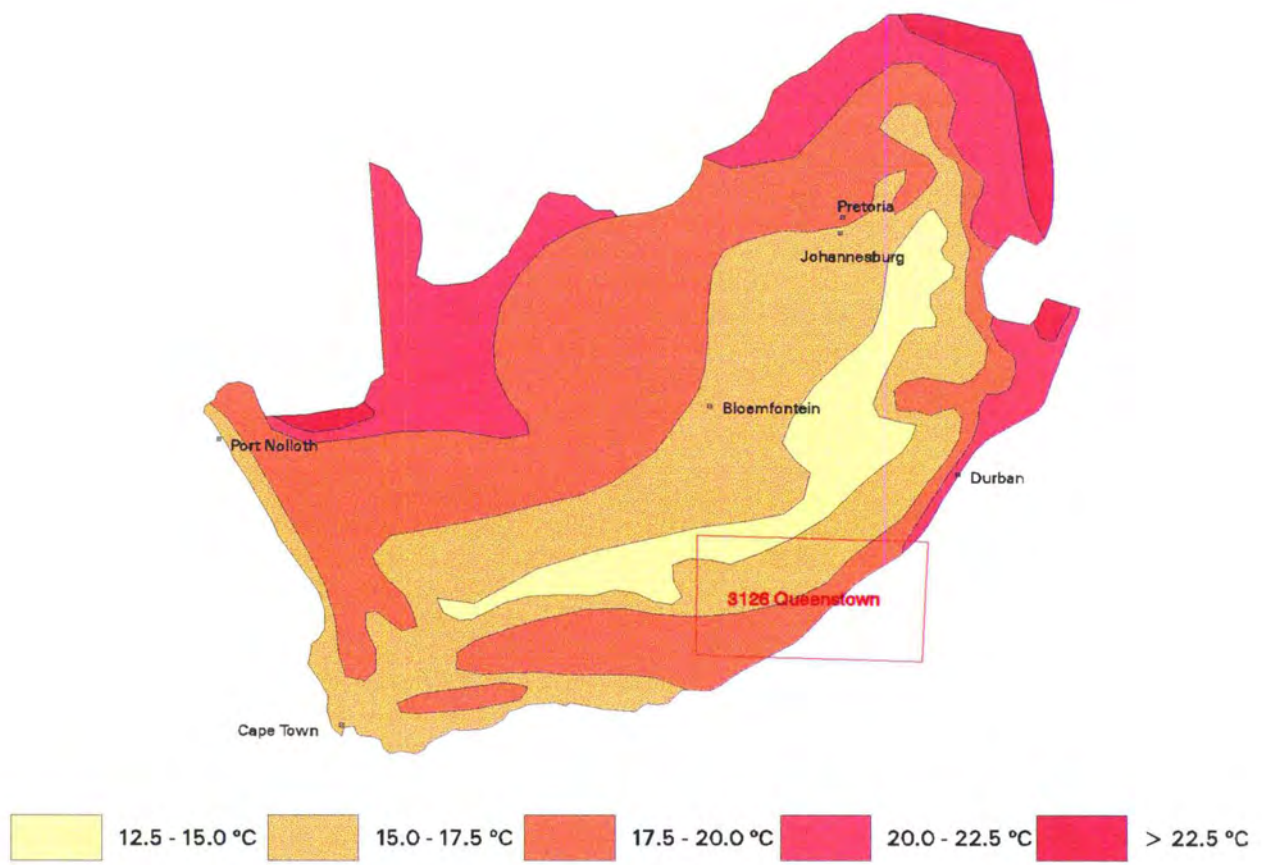


Fig. 5: Mean annual surface temperature for South Africa.
modified after DWAf 1986

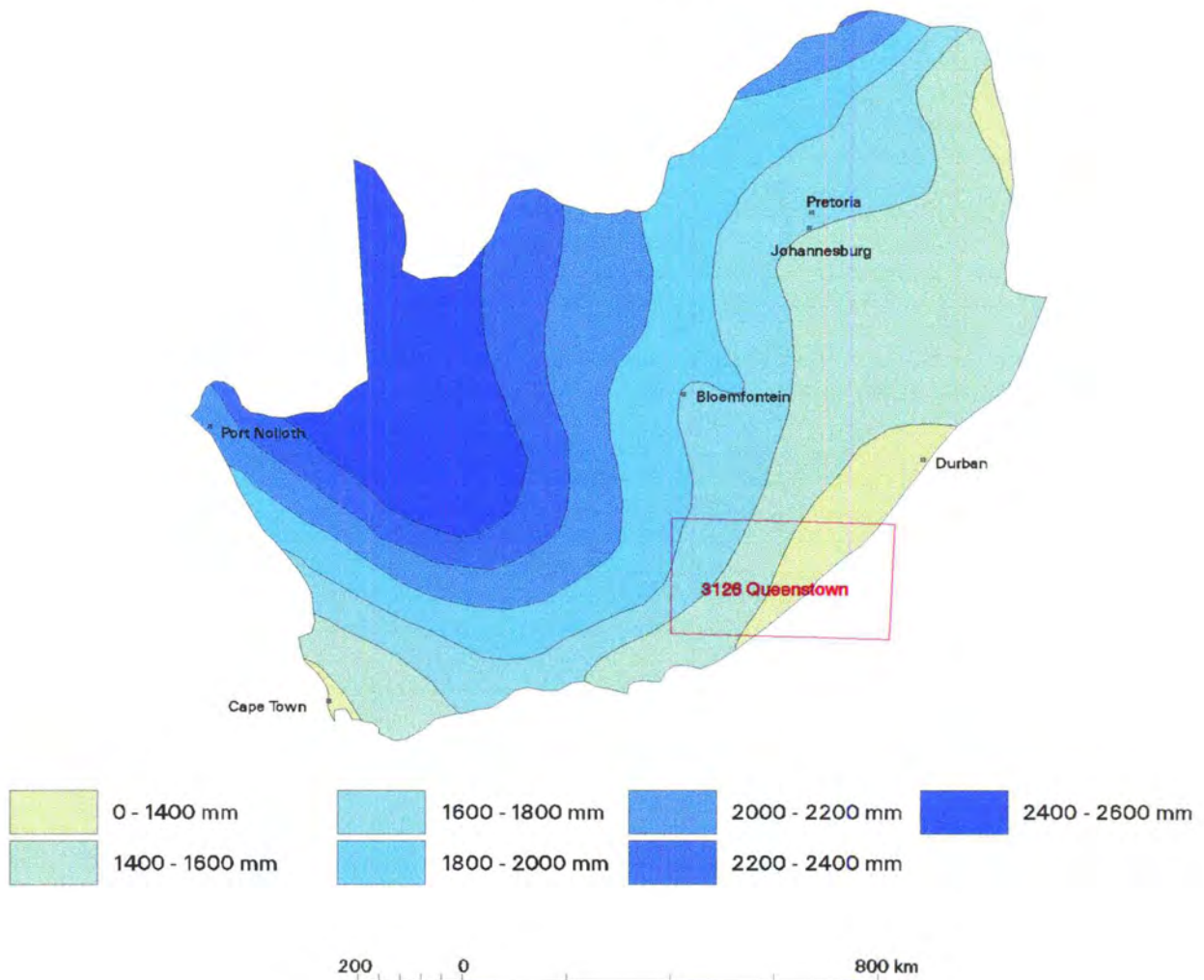


Fig. 6: Mean annual potential evaporation for South Africa.
modified after DWAf 1986

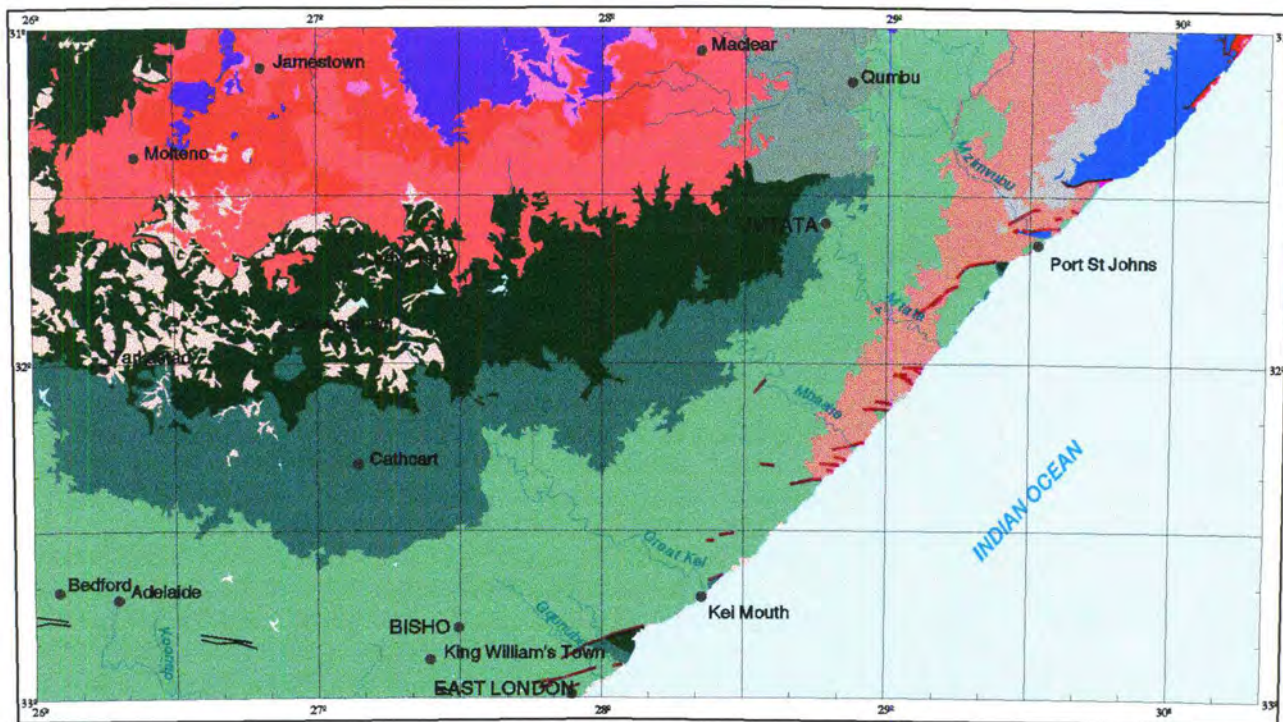
3. GEOLOGY

The lithostratigraphy and structure of the study area are given in Fig. 7. Appendix 2 is a chronostratigraphic column for South Africa as a whole, showing how the geological history of the study area fits into the broader context. The Namibian age Natal Metamorphic Province basement rocks, exposed only along the coast in the north-eastern corner of the map area, comprise mainly granite, gneiss and charnockite. The Ordovician/Silurian Natal Group rocks outcropping in the north-eastern corner of the study area comprise predominantly quartz arenites. This succession lies unconformably on the basement rocks of the Natal Metamorphic province.

The Karoo Supergroup underlies the bulk of the study area, consisting of a thick accumulation of continental and marine Permian to Jurassic mudrock and sandstone, with tillite (diamictite) at the base and a capping of basalt. These lithologies are intensively intruded by dolerite. Two main categories of intrusion are recognised, namely vertical dykes and sheets of varying inclination and curvature. Dolerite sheets, which approximately conform to bedding dip, are termed sills. The most prominent dykes and some of the major sills/sheets are shown in Fig. 8. All the individual intrusions are too intricate/complex to be displayed on maps of this scale and the reader requiring detail on individual intrusions and their relationship to the host rock is referred to the published maps from which Fig. 8 was derived (SA 1:250 000 geological series sheets 3126, 3128, 3226 and 3228).

Quaternary unconsolidated sediments are limited in extent. The bulk of the alluvium/colluvial accumulations occur in the north-western quarter of the study area and there is a narrow discontinuous belt of dunes along the coastline.

The form and interrelationship between the lithological units, facies within these units, intrusive and superimposed structures are best understood by examining their process / history of formation. The geological history of this area is reviewed below with this objective in mind. Firstly, the basement underlying the Cape and Karoo Supergroup is superficially examined with specific reference to its structural influence on the locality of the Cape Basin and the subsequent deposition



40 0 160 km

Fig. 7: Lithostratigraphy and structure.

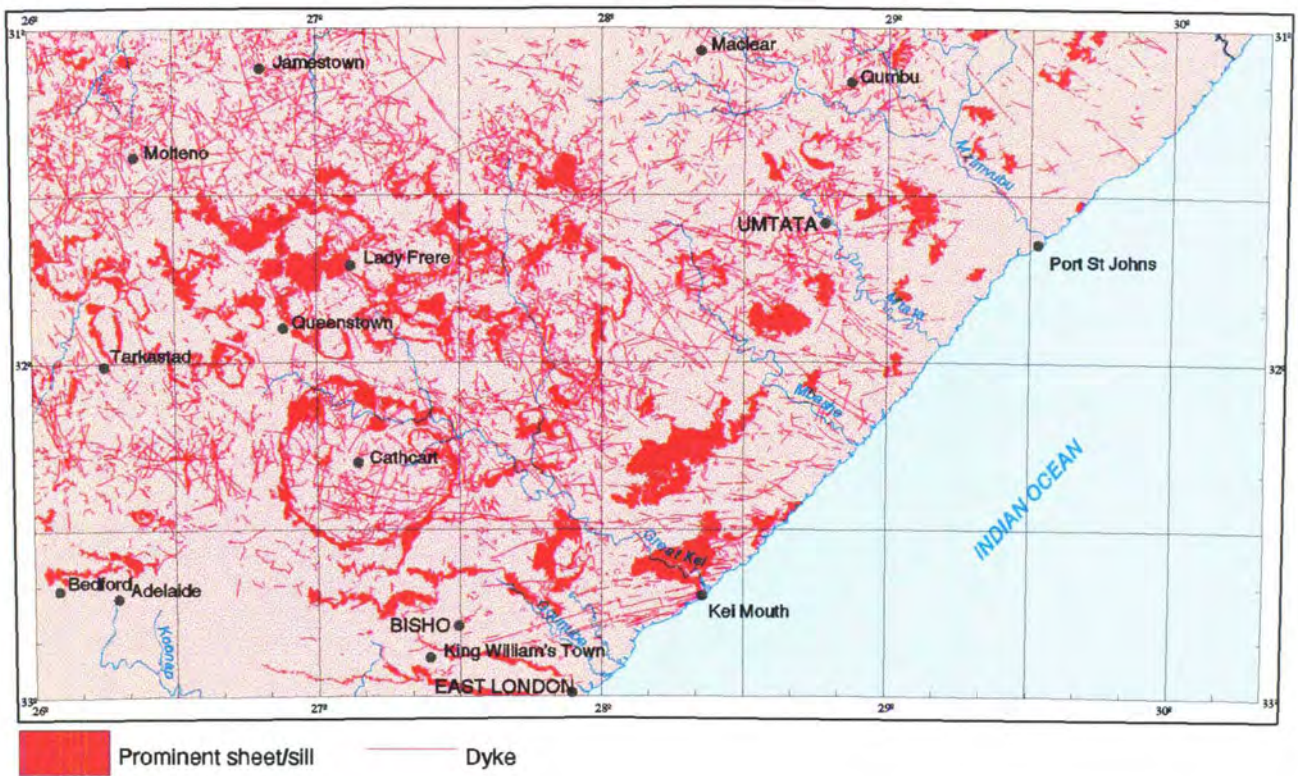


Fig. 8: Dolerite intrusions.

of the Karoo Basin. The orogenic deformation of the Cape Rocks (Cape Orogeny) and their influence on the lithology of the Karoo Supergroup is then discussed together with detailed description of those lithological units cropping out in the study area. The later volcanic outpourings and igneous intrusions into the Karoo Supergroup, the more recent continental tilting and influence on molding the present day landscape as well as neotectonic / present day stress regime are then dealt with.

3.1 Pre-Karoo rocks

3.1.1 The Basement

The history of Africa's basement rocks has been marked by several periods of mountain building during which large areas were folded, metamorphosed and subjected to deep-seated intrusions. These regions ultimately became stable continental blocks (cratons) which were fused together by subsequent orogenic events to form the African shield (Schmitz and Rooyani, 1987).

One such Archaean craton - the > 2.5 Ga. (Barton et al., 1977) Kaapvaal Craton is situated in Southern Africa, underlying the eastern half of South Africa to the north of the study area (north of 30° latitude). To the south of this craton east-west trending metamorphic belts form the basement lithosphere onto which the rocks of the study area were deposited. The 1.0 Ga. Namaqua Natal Belt (Nicolaysen and Burger 1965; Burger and Coertze, 1973) is the northernmost belt and is exposed only along the coast in the north-east corner of the map as the Natal Complex. The 1.0 - 0.5 Ga. Southern Cape Conductive Belt (SCCB) (de Beer et al., 1982 in Veevers et al., 1994) runs to the south of this but is not exposed. The SCCB forms the basement onto which the sediments of the study area were deposited, except along the northern edge of Map. North of approximately 31.5° degrees latitude the Namaqua Natal Belt forms the basement. Extensions and compressions of this basement determined the depositional structural axes of both the Cape and Karoo Basins, the weak crust and preferential subsidence of the SCCB in particular determining the location of the Cape Basin (Veevers et al., 1994).

3.1.2 Natal Group

According to Tankard et al. (1982) - Southern Africa was situated at the heart of Gondwana during the Early Palaeozoic and underwent abortive rifting to form elongate troughs in the Southern Cape and Natal into which continental and marine predominantly quartz arenite successions of the Table Mountain and Natal Groups accumulated. While these groups comprise predominantly quartz arenites, other rock types (conglomerates, coarse-grained sandstones, siltstone, mudstone and diamictite) are also represented. The 900 - 1 300 m thick Natal Group was considered to be the temporal equivalent to the Table Mountain Group until 1992, but on the basis of more recent fossil evidence (Thomas et al., 1992) it is more likely an equivalent of the younger Lower Witteberg Group. The predominantly argillaceous Bokkeveld and Witteberg Groups succeeded the Table Mountain Group in the Southern Cape, the accumulation of sediments continuing until the end of the Devonian (Appendix 2).

3.2 Karoo Supergroup

During the late Carboniferous, sediments started accumulating in sags developing as a result of warping of the cratonic platform (Veevers, 1988). The locality of the less competent crust of the SCCB influenced deformation in the Early Permian when sinking of the relatively dense material in the northern part of the SCCB together with uplift by folding in the south initiated the Karoo Structural Basin (Rust, 1975). The rising Cape Fold Belt caused the shedding of pulses of thick Karoo Supergroup sedimentary material into this basin (Veevers et al., 1994).

Later in the Permian and Triassic the southern part of the SCCB marked the site of intense thrusting and folding (de Beer, 1983, Hälbich, 1983). The changing tectonic framework and migration from polar to tropical latitudes resulted in a broad spectrum of palaeoenvironments being preserved in the Karoo Supergroup, ranging from glacial through coarse bedload and mixed load streams, deltaic and mixed load streams, deltaic beach, proximal terrigenous shelf and distal subsiding basins (Tankard et al., 1982).

The major units of the Karoo Basin are now discussed specifically focussing on the character of the rocks underlying the study area. The units are, stratigraphically, the Dwyka Group, Eccca Group, Beaufort Group, Molteno Formation, Elliot Formation, Clarens Formation and the Drakensberg Group (Fig. 7).

3.2.1 Dwyka Group

The “normally completely massive and structureless” (Johnson, 1976) 500 m thick Dwyka Group outcrops near the coast in the eastern part of the mapped area consists of material of glacial origin and which unconformably overlies the Natal Group. According to Karpeta and Johnson (GSSA, 1979) this diamictite is a glacial till consisting of angular clasts (up to 250 mm diameter) set in a fine to very fine-grained matrix. Thin mudstone lenses occasionally occur within this Group - representing meltwater-lake deposits.

Based on geomorphologic evidence and impressions in glacial pavements, the Dwyka material was derived from several ice sheets converging on the Karoo Basin from the west, north, north-east and east (Tankard et al., 1982). The tillite outcropping in the study area was derived from the south-westward to westward moving Natal ice sheet and contains clasts from the Natal Complex.

The Northern part of the Karoo Basin was deeply incised by ice sheets active during the deposition of the Dwyka tillite (Matthews, 1972; Van Vuuren and Cole, 1979). According to Norman and Partridge (in Brink, 1983), the irregular topography so formed strongly influenced the drainage patterns and the distribution of facies of the overlying Karoo deposits. Differential compaction tended to preserve a subdued version of the originally rugged terrain.

There is evidence that sea level influenced sedimentation, but only in the later stages of the Dwyka deposition. There is firm fossil evidence for marine sedimentation in the upper Dwyka zone (McLachlan and Anderson, 1973) however geochemical research (Visser, 1989) gives positive evidence for marine conditions only in the mudrocks immediately overlying the Dwyka glacial beds. Veevers et al. (1994) suggest marine transgression did indeed influence late Dwyka deposition, being responsible for the interglacial mudrock units found in this part of the succession.

The sea level rise responsible for this marine transgression was probably caused by returning meltwater on disintegration of ice sheets, augmented by subsidence during a Pangean extensional phase (Veevers, 1990). Isostatic rebound is likely to have resulted in the subsequent sea level fall (Veevers et al., 1994).

3.2.2. Eccca Group

The Eccca Group sediments were deposited in the east-west Karoo trough of the southern Karoo Basin, which was established by, continued post-Dwyka downwarping (Ryan, 1967). The Eccca Group is divided into lower and upper sequences but only the upper sequence is represented in the study area, conformably overlying the Dwyka tillite. Plant and reptile fossil evidence point to shallow lacustrine conditions for the lower sequence of the Eccca Group (Tankard et al., 1982), but the upper Eccca Group sediments found in the study area rather represent “the first pulse of thick sediment shed into the foredeep of the rising proto-Cape Fold Belt” (Veevers et al., 1994).

The Eccca Group rocks outcropping in the study area consist of a 1 000 metre thick succession of rhythmically bedded and laminated shales and minor sandstones of the Fort Brown Formation. Limited exposures of the underlying less than 100 metre thick Ripon Formation (interbedded shale and massive generally 10 m thick sandstone) are confined to the area south of Coffee Bay (GSSA, 1979).

As to whether the Eccca sediments were deposited in a marine or freshwater environment, Veevers et al. (1994) are of the opinion that convincing evidence of a Permian sea in Southern Africa is present in the form of marine invertebrates only at the upper Dwyka Group to Eccca Group transition. Subsequent to the transition they believe that the water of the Eccca Basin water was rather brackish to fresh, later becoming entirely non-marine due to basinal shrinking on uplift along the Cape Fold Belt.

3.2.3 Beaufort Group

After the filling of the Ecca basin by prograding deltas, a much greater volume of sediment, derived from the faster rising Cape Fold Belt, prograded northward in rivers. The predominantly fluvial Beaufort Group sediments reached an estimated thickness of 6 km in the south thinning rapidly toward the north due to a combination of a younging of the Ecca/Beaufort boundary and erosion of Upper Beaufort strata before deposition of the Late Triassic Molteno Formation (Veevers et al., 1994).

The Beaufort Group is subdivided into the Adelaide and Tarkastad Subgroups. The Adelaide Subgroup, which consists of greenish gray and greyish red mudstone and sandstone, is overlain by the Tarkastad Subgroup with a larger proportion of sandstone and red mudstone (Kent, 1980). These two subgroups are examined in more detail below.

3.2.3.1 Adelaide Subgroup (Middleton and Balfour Formations)

According to Tankard et al. (1982) the Adelaide Subgroup of the Eastern Cape is a shallow lacustrine and fluvial facies comprising laminated mudstones, siltstones and discontinuous sandstone units. The sandstone units comprise about 25% of the succession consisting of layers “a few metres to a few tens of metres thick” (GSSA, 1974).

The Adelaide Subgroup outcropping in the study area is represented by the upper part of the Middleton Formation and the overlying Balfour Formation but the lithological boundaries between the two are gradational and uncertain. Biozonation boundaries for this area are also uncertain (Rubidge, 1995). The Middleton Formation of the study area forms the lower Cistecephalus assemblage zone while the Balfour Formation forms the upper Cistecephalus, Dicynodon and lower Lystrosaurus zones (Rubidge, 1995).

The approximately 1 900 m thick Middleton Formation comprises mudstone interspersed with multistoried channel sandstones, the sandstone to mudrock ratio being in the order of 1:2 (Rubidge, 1995). The overlying Balfour Formation is approximately 2 000 m thick. Its contact with the underlying Middleton Formation is relatively sandstone rich although mudrock still predominates.

According to Rubidge (1995), these sandstone bodies at the base of the Balfour Formation are multistoried and sheet-like and were deposited in low sinuosity streams. Mudrocks are thought to be floodplain deposits flanking the network of streams. Straightening of the streams through time indicates a combination of differential subsidence of the Karoo trough and increased discharge caused by tectonic pulses in the south. Toward the top of the Balfour Formation the sandstones become sparser and more lenticular, representing deposition in high sinuosity stream channels, whereas the mudstones represent floodplain deposits.

3.2.3.2 Tarkastad Subgroup (Katberg and Burgersdorp Formations)

The Tarkastad Subgroup corresponds to the Early Triassic *Lystrosaurus* and *Cynognathus* tetrapod zones, and is divided into the lower sandstone rich Katberg Formation and an upper mudstone-dominant Burgersdorp Formation. Where the subgroup narrows to the north of Umtata (approximately 31.5° latitude) the difference between these formations becomes obscure and the two formations cannot be clearly distinguished from each other. The Katberg and Burgersdorp Formations are therefore not separated on the published 1: 250 000 geological map for that area (GSSA, 1979).

The origin of the 500 - 1000 m thick proximal Katberg Formation sediments represents a strong pulse of fluvial braided channel sandstone (Hiller and Stavrakis, 1980, 1984). The depositional environment varied from low sinuosity (braided) rivers in the proximal south to high sinuosity (meandering) rivers in the more distal central and northern part (Rubidge, 1995). Fine-grained to medium-grained horizontally laminated, cross-bedded or massive sandstone comprises about 90% of the total thickness with interbeds of massive mudstone constituting up to 30% locally (GSSA, 1984). The depositional environment becomes more distal toward the north with the result that the maximum grain size decreases in that direction together with an increasing argillaceous component. In the vicinity of Queenstown sediments of the Katberg Formation interfinger with the shaly sediments of the lower part of the Burgersdorp Formation.

The Katberg Formation is overlain by the Burgersdorp Formation, a fluvial deposit (Veevers et al., 1994) which reaches a thickness of 600m in the Queenstown-Lady Frere area (Rubidge, 1995). This is a relatively mudstone-rich part of the Tarkastad Subgroup with sandstone comprising 20% - 30 %. Sandstones average 2 to 3 m thick but range up to 10 m in thickness. The sandstones mostly extending over a distance of a few hundred metres to a few kilometres before pinching out. The continuity of these beds led Du Toit (1904) to describe them as displaying a “wonderful lithological uniformity”. The sandstones basal contacts are sharp and they form parts of upward fining sequences grading into mudstone, which dominates the succession.

3.2.4 The Molteno Formation

The upper part of the Karoo Supergroup (Molteno, Elliot and Clarens Formations) was deposited during the Late Triassic being separated from the lower Karoo by a lacuna occupying the Middle Triassic (Veevers et al., 1994). A low angle unconformity exists between the underlying Burgersdorp Formation and the Late Triassic Molteno Formation whereas the upper contact with the Elliot Formation is gradational. According to Turner (1975, 1983) the Molteno Formation was deposited by perennial high energy braided streams draining an extensive alluvial plain. It is characterized by the upward-fining cycles typical of fluvial regimes, with a pebble conglomerate at the base of each cycle succeeded by coarse sandstone which grades into silty shale, shale and occasionally coal. Laterally-migrating low-sinuosity streams were responsible for the erosional surface and pebble conglomerate at the base of each cycle. This is overlain by coarse-grained sandstone interpreted as channel bar deposits grading into bar top deposits. The shales and thin coals at the top of the cycle are backswamp deposits. Mudstone and sandstone are the predominant rock types with sandstone content ranging from 30 - 50 percent. In anomalous instances the sandstone component is significantly higher, for example in an area west of the town of Molteno where the sandstone component reaches 75%. Minor rock types are shale (2 - 10%), coal and conglomerate (each less than 1%). Sandstone lithosomes generally range from a few metres to 20 m in thickness with a maximum of 60 metres. They are generally laterally persistent - often traceable for a few tens of kilometres. The Indwe sandstone member toward the base of the Molteno Formation is persistent throughout the area.

The influx of the Molteno sediments coincided with a period of folding and thrusting of the Cape Fold Belt (Hälbich et al., 1983). Palaeocurrent data indicate transport from the south and south-east. Petrographic evidence suggests the source area in the south was the Cape Supergroup whereas the source from the south-east was probably granitic (Turner, 1975). Of the six fining upward cycles in the Formation the first two prograded northward while the remaining four receded southward (Veevers et al., 1994) influencing the deposition of the overlying Elliot Formation.

3.2.5 Elliot Formation

The Elliot Formation is a downslope facies of the Molteno Formation. As the last four facies of the Molteno Formation receded southward they were followed by this distal facies which finally covered the entire Molteno (Veevers et al., 1994). This Formation is between 300 m and 500 m thick, deposited in a distal fluvial system and consists of interbedded fine grained sandstone (30% of the succession) and mudstone in generally upward fining cycles between 10 and 30 m thick. The lenticular sandstone horizons are between 3 and 15 metres thick and are of limited lateral extent, seldom traced more than a few km (GSSA, 1984).

3.2.6 Clarens Formation

The contact with the underlying Elliot Formation is gradational, the contact being taken “at the point where red and purple mudstones and cross-bedded sandstones become subordinate to lighter “massive” sandstones and shales” (Dingle et al., 1983, p 48). The Formation is fine to very fine grained, predominantly massive and structureless. The thickness varies from 20 m to 300 m and the unit commonly forms sandstone cliffs (Johnson, 1976). The bulk of the Clarens Formation represents aeolian dune deposits indicating an arid environment although lacustrine siltstones are present toward the base. (Tankard et al., 1982).

3.2.7 Drakensberg Group

3.2.7.1 Basalt lavas

The Drakensberg Group is made up of a 1 400 m thick succession of basalt flood lavas fed by a complex of dykes and sills called the Karoo Dolerite that was emplaced/intruded during the Early and Middle Jurassic. The thickness of the lava flows varies from 0.5 m to 50 m (Eales et al., 1984). In the basal one third of the sequence, the lavas are interlayered with pyroclastics and thin lacustrine sandstone, mostly less than 10 m thick.

3.2.7.2 Dolerite intrusions

The highly interconnected network of dolerite intrusions of the Queenstown 3126 map region appears similar to that investigated in detail by Chevallier and Woodford, (*in press*) in the Western Karoo basin. Despite intensive investigation, these researchers found it impossible to single out any particular intrusive or tectonic event responsible for the formation of these intrusives, rather concluding that a very large number of fractures were either simultaneously infilled by magma, or that the intrusive network acted like a stockwork-like magma reservoir. Considering the similar complexity of the dolerite intrusives in the study area it is probable that a similar conclusion would be reached for the Queenstown 3126 map region if studied in detail.

Dolerite dykes. According to the Geological Survey of South Africa 1:250 000 map sheets 3126 (GSSA, 1984), 3128 (GSSA, 1979), 3226 (GSSA, 1974), 3228 (GSSA, 1979) and accompanying explanations, dolerite dykes (Plate 2) of the study area are usually between 1 m and 10 m thick and can be tens of kilometres long. Their orientations are variable but with a north-westerly strike prominent over much of the area. In the Kei Mouth area, where dykes strike almost exclusively east-west, two prominent dykes are up to 300 m wide and traceable for over 100 km. Many of these east-west trending dykes curve progressively to NNW inland. Chevallier and Woodford (*in press*) postulate the main magma source for the Karoo igneous rocks to be a triple junction (Fig. 9) and therefore a palaeo-plume situated off the coast north-east of East London. These major dyke swarms are postulated to be the feeder dykes along which the magma was laterally propagated.



Plate 2: A dolerite dyke (light yellowish brown in foreground) forms a topographic ridge extending into the distance.

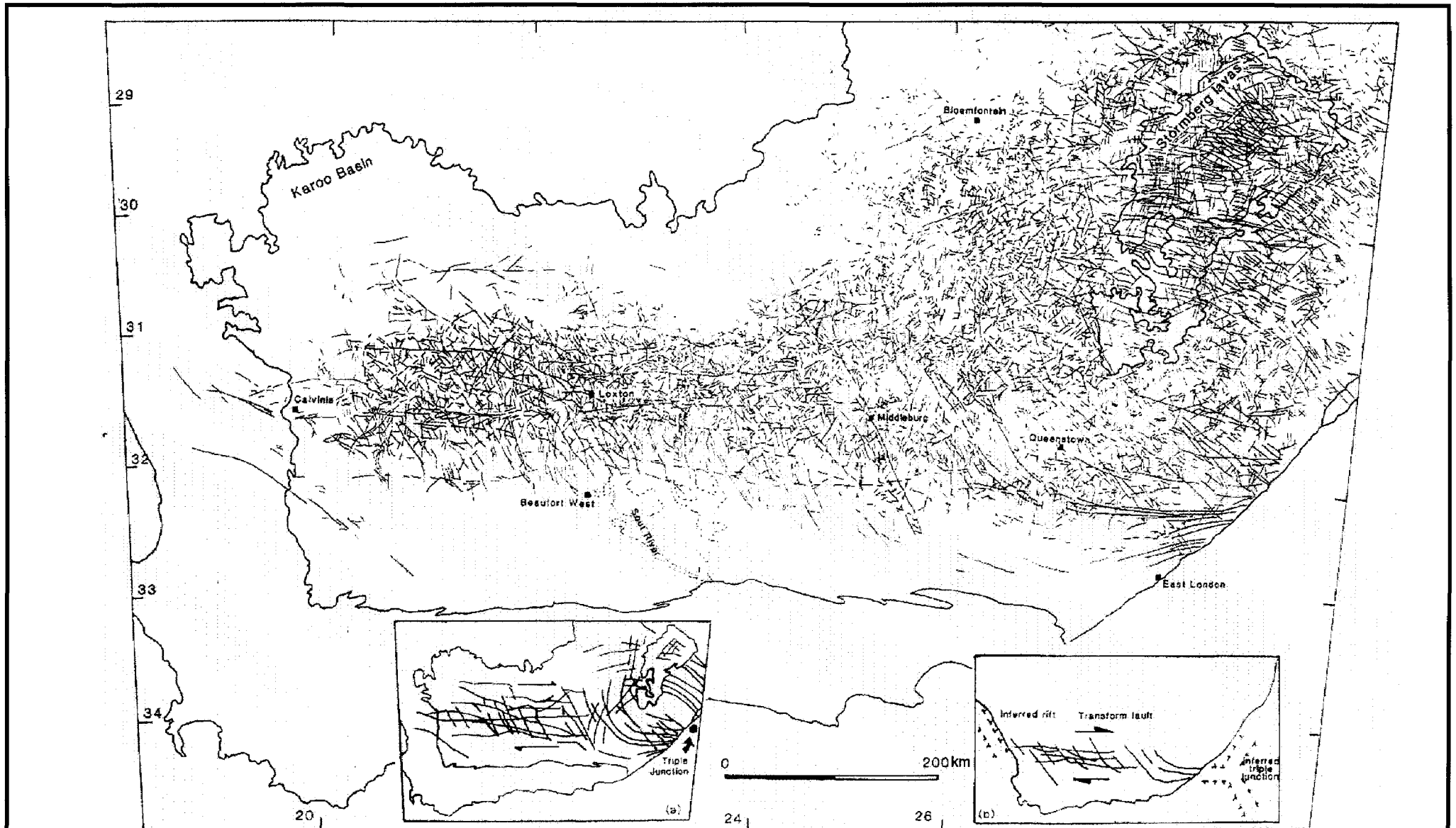


Fig. 9: Dolerite dykes of the main Karoo Basin and geodynamic interpretation. Inset a: simplified structural map showing the relation between the E-W right lateral shear zone and the NNW dykes and the position of a postulate triple junction offshore the East coast. Inset b: geodynamic interpretation of the Karoo dolerite structural set-up (After Chevallier and Woodford (1998)).

Dolerite sills, sheets and ring-sheets. The sills and sheets of varying inclination and curvature occurring in the study area are usually between a few metres and 100 metres thick but can be well in excess of this in some instances (e.g. the Andriesberg north of Queenstown (300 m), and Tabankulu north-west of Flagstaff (500 m)). Ring-shaped 60 to 100 m thick (Chevallier, L., 1998, *pers. comm.*) dolerite intrusions are a prominent feature in the western part of the study area, particularly in the vicinity of Queenstown, whereas further to the east interconnected dolerite sills forming stacks is the dominant feature.

Mode of dolerite emplacement. There is much evidence that the style and abundance of dolerite intrusions changes with stratigraphic level. For example Winter and Venter (1970) observed that dolerite sheets “seem to terminate at a critical distance of a few thousand feet below the basalts”. Dingle et al. (1983) also recognise that changes in style of dolerite intrusion depends on stratigraphic level (Fig. 10). This apparent stratigraphic control on dolerite intrusion is therefore probably responsible for much of the regional variation in intrusive style observed across the study area (Fig. 11). Sills appear to dilate only at a critically lower pressure related to the thickness of the overburden. This results in dolerite being rare in the lower lithologies (e.g. in the Middleton Formation in the south west, where strata are folded by the Cape Orogeny as well in as the Natal sandstone in the east) but higher in the succession (north of the folded strata) is a zone of massive sheets corresponding to the Balfour Formation. From this stratigraphic level up to and including the basal parts of the Molteno Formation a combination of dykes sheets and sills occur with the ring-shaped intrusions being most common in the upper parts (concentrated mainly in the Burgersdorp Formation and lower Molteno Formation). Above this stratigraphic level dykes are most common, sheets become rare and volcanic vents/diatremes appear.

Dingle et al. (1983), explain the stratigraphic-related variations in intrusive style as resulting from a progression of events. Firstly, upward movement of magma resulted in emplacement of large sill like magma chambers at 1 000 - 2 000 m beneath the surface in Elliot/Clarens times. This was followed by degassing of the magma and contact with ground water producing explosive action and the creation of diatremes at and above the level of the sills. They postulate that the sills were magma chambers, which later fed magma into extensive fissures from which there was massive quiet effusion of lava at the surface to form the Drakensberg basalt succession. Extensive dolerite dykes resulted from cooling and solidification of the magmas in these feeder fissures.

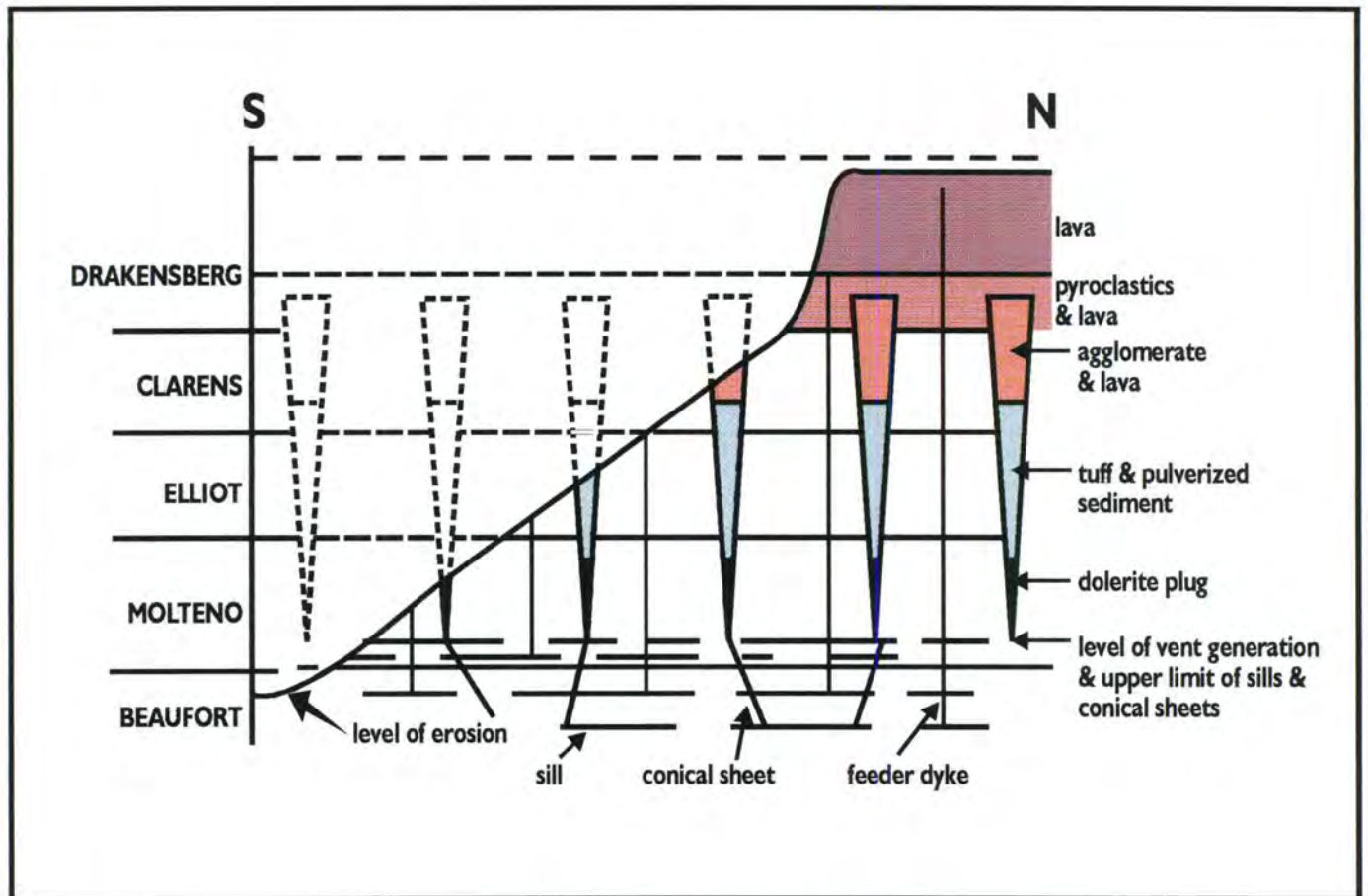


Fig 10: Idealized S-N section showing stratigraphic relationships of Drakensberg intrusive and extrusive rocks in the main Karoo Basin.

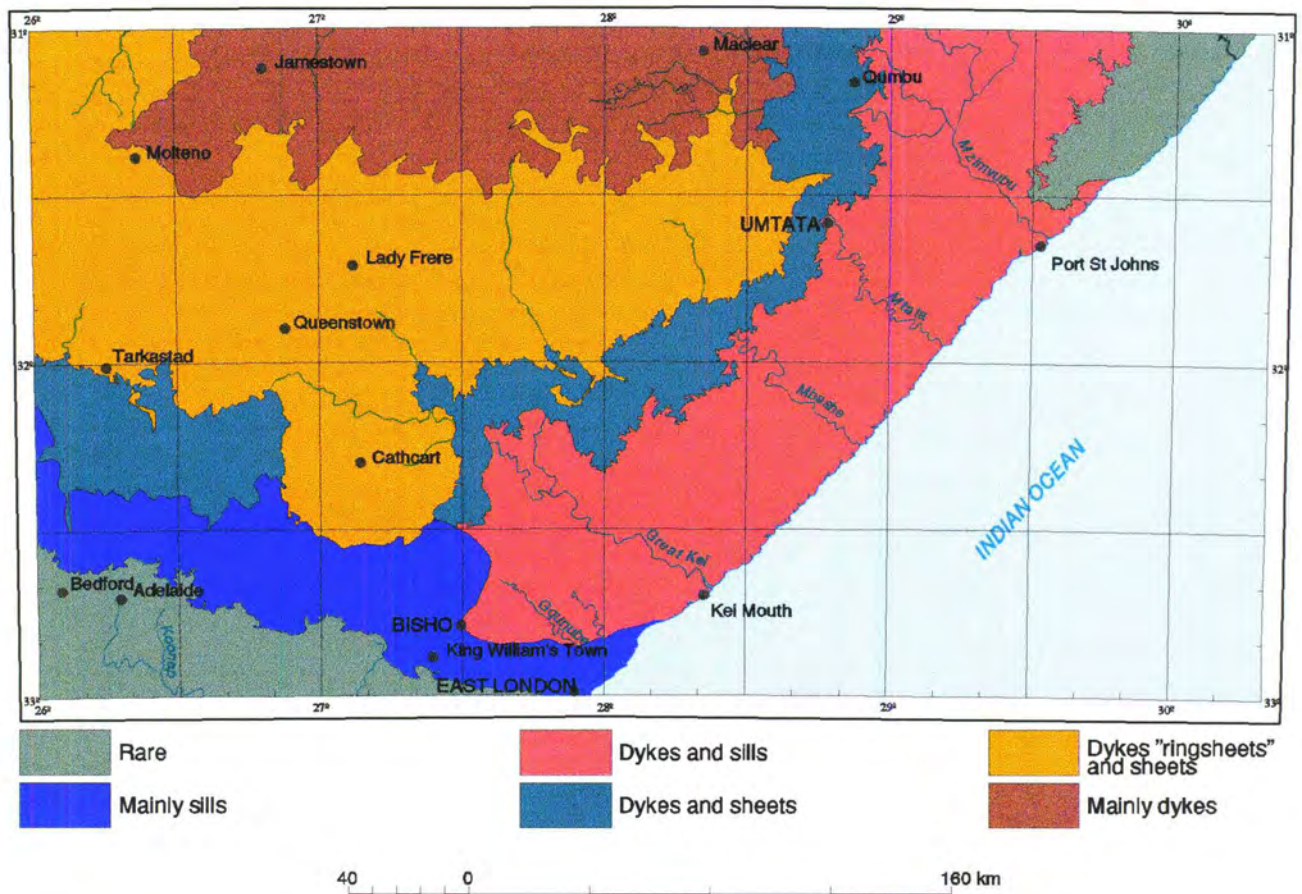


Fig. 11: Abundance and predominant style of dolerite intrusions.

Bedding also seems to have influenced the emplacement of intrusions as implied by the tendency for sheets of dolerite to immediately overlie Indwe sandstone (Du Toit, 1904). Broadly stepped sheets in former Transkei are described by Du Toit (1920) who noted that they tend to follow those bedding planes that possess lesser cohesion, but break abruptly across the stronger layers at intervals hence the sills become an inclined sheet in parts of their courses.

Ring-shape dolerite intrusions of the study area are similar to those in the western Karoo which have recently been investigated in detail by Chevallier and Woodford (*in press*). They describe the shape as "saucer like with an inner sill at the bottom, an arcuate inclined sheet (the ring) on the periphery and an outer sill on the rim (Fig.12). Many arcuate dykes are seen branching onto the ring structures Meyerboom and Wallace (1978) investigated the ring-shaped dolerite intrusions occurring within the Queenstown study area. The usually 10 - 18 km diameter rings are described as saucer shaped with inward dipping rims. In the Katberg Formation the dips are in the 2-11 degree range, steepening to 10 - 35 degrees in the Queenstown area. Undeformed sediments are usually exposed in the centre of the annular structures but dolerite has been intersected at shallow depth in boreholes drilled through these sediments indicating dolerite continuity beneath the floor.

Various theories regarding the emplacement mechanism of these ring dolerites have been proposed, none of which satisfactorily explain *all* the associated features (Chevallier and Woodford, *in press*). Some of the theories are briefly outlined below, but the merits and weaknesses of these theories are not entered into. Fracturing associated with these intrusions are of most hydrogeological relevance, and dealt with in the section on structure.

A number of researchers have proposed that an undulating sheet forming domes and basins is responsible for the appearance of the ring shaped intrusions (Du Toit, (1905), Rogers and Du Toit (1903), and Meyerboom and Wallace (1978). The latter postulate that variations in the topography existing at time of intrusion caused subsurface variations in lithostatic pressure. An intruding sheet - guided by a bedding plane - would tend to follow the pressure surface at which magma pressure equals that resulting from lithostatic load. A topographic high at surface causes this pressure surface to be depressed - resulting in the sheet taking on a saucer shape. Conversely a topographic low at surface results in an updoming of the pressure surface and a dome shaped intrusion. In this way they propose that saucers formed under topographic highs and domes under topographic lows.

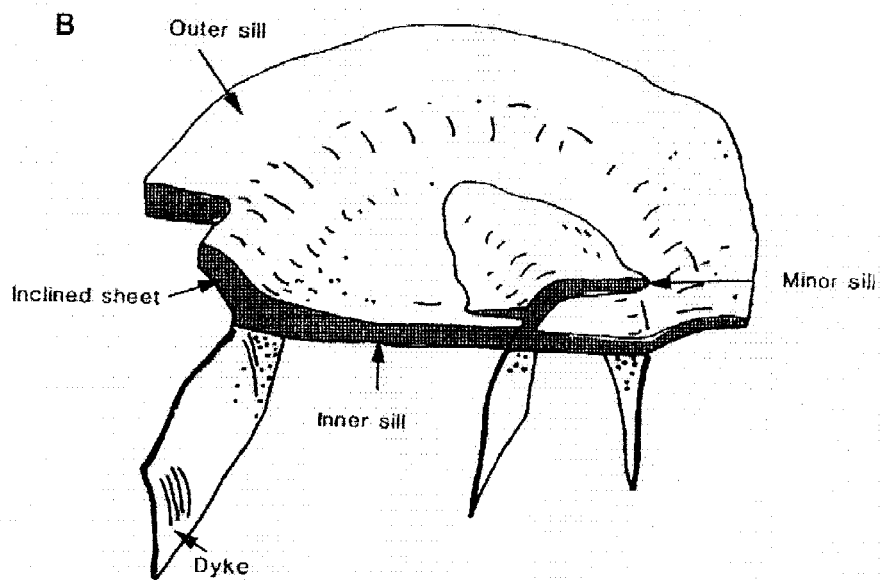
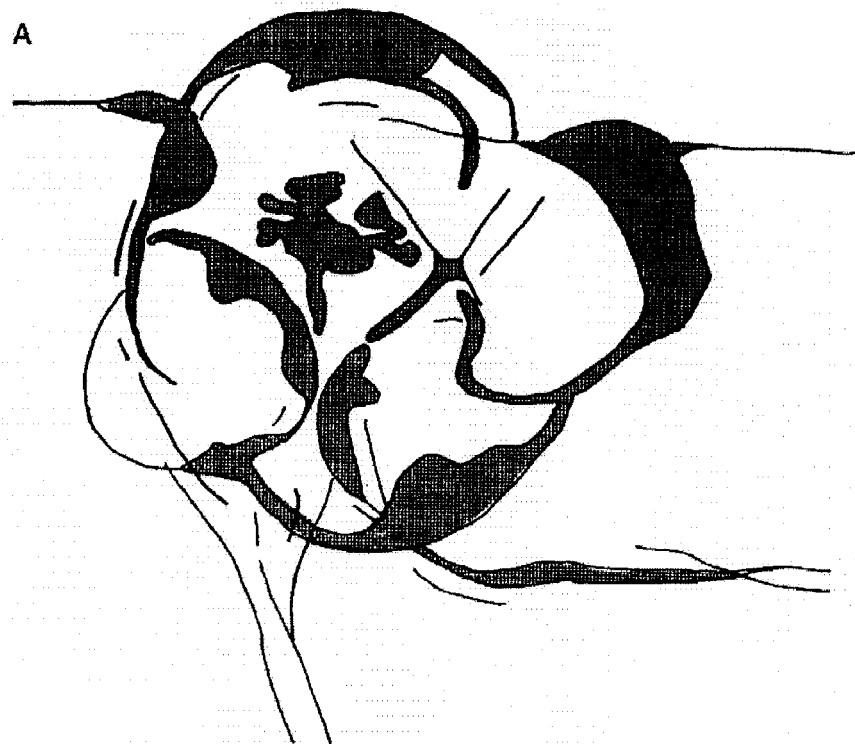


Fig. 12: Morpho-tectonic model of Karoo dolerite sill and ring systems. A) Schematic map, B) 3-D model.

Lombard (1952) proposed a cone sheet model, Burger et al. (1981) and Vivier et al. (1995) a lacolith emplacement model for complexes found in the Free State. Chevallier and Woodford (*in press*) prefer a model where “ring dykes” exhibit a double curvature along strike and vertical section leading to a “trumpet” shaped intrusion (Fig. 13). The mode of emplacement proposed by them is one whereby dolerite dykes feed into the inclined sheets, which then propagate into an outer sill and then into an inner sill”. A characteristic feature noted by Chevallier and Woodford (*in press*) is that the largest ring structures occur toward the base of the sequence, becoming smaller toward the upper parts. A similar pattern is observed in the study area with the largest 60 km in diameter occurring in the lower part Beaufort group centered on Cathcart (Fig. 8) diminishing to less than 3 km diameter in the Molteno Formation in the upper parts of the succession.

3.3 Post-Karoo lithologies

Incipient breakup of Gondwana commenced in the Mid Jurassic with horst and graben development at the newly forming continental margins. This resulted in the sites for deposition shifting from a mid continental location to the future continental margins (Veevers et al., 1994). The break up process lasted from the Mid Jurassic to Lower Cretaceous times when the Gondwana was finally disrupted.

Post Gondwana history is one of continental erosion as opposed to the predominant build up discussed up to this point. Scarp retreat therefore affected the Karoo Basin in the later Jurassic to Cretaceous. Partridge and Maud (1987) believe that a single cycle of erosion (and offshore sedimentation) prevailed from the time of rifting to the Early Miocene resulting in the formation of the African Surface - a gentle pediplain at 500 m - 600 m, extending across most of Southern Africa. Slight uplift in the Miocene tilted the continent to the west initiating renewed erosion between 100 m and 300 m below the African surface. A further major uplift of up to 900 m in the end-Pliocene affected Southern Africa, and the south-eastern portion (including the study area) in particular. This uplift initiated renewed erosion causing deep incision along the major rivers and steep topography in the eastern part of the study area in particular.

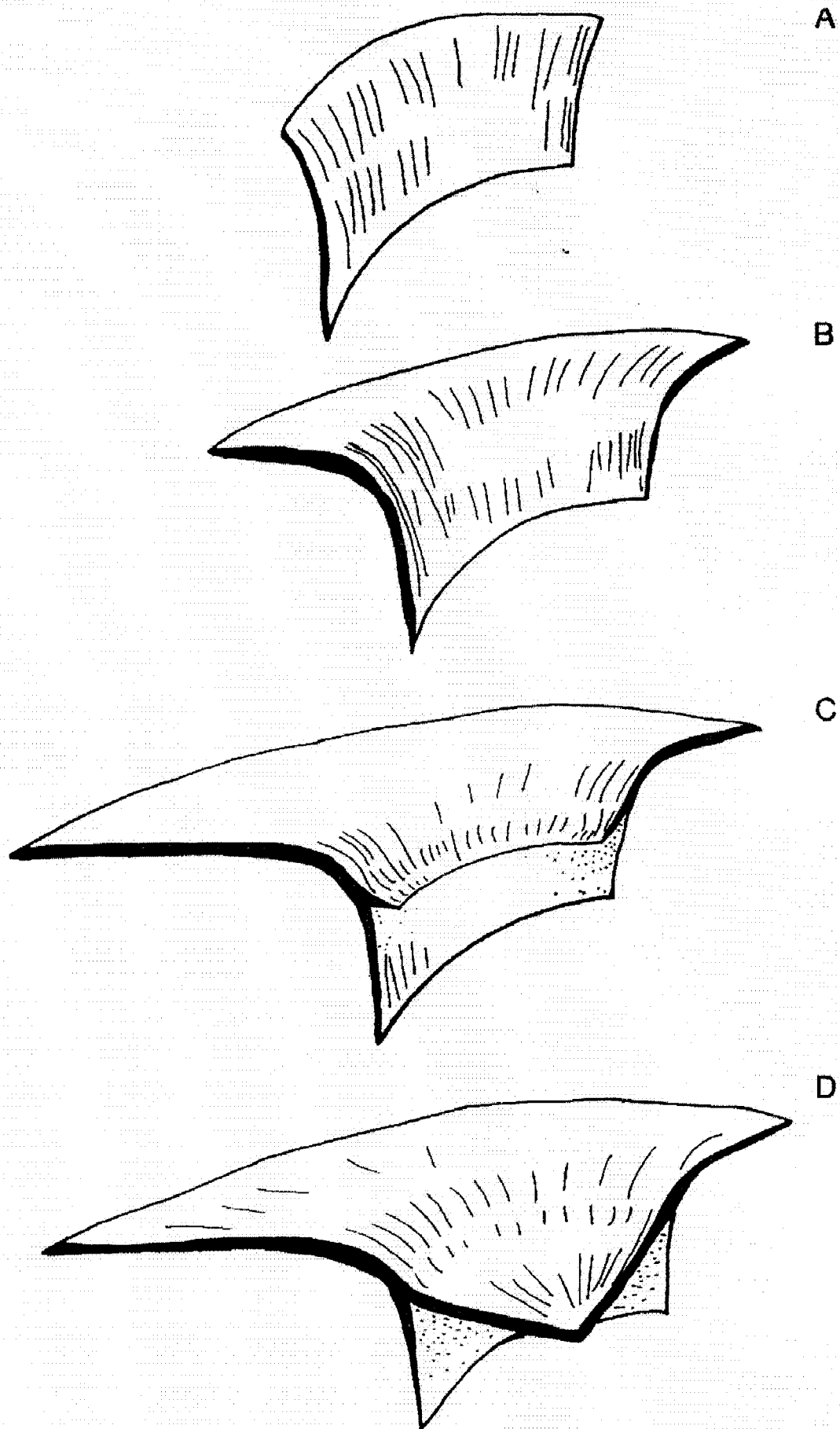


Fig. 13: The different steps of dolerite ring emplacement (After Chevallier and Woodford, 1998): A) curvature along strike and dip of a regional dyke adopting a "trumpet-like shape", B) flattening and thickening of inclined sheet and propagation of outer sill, C) gap opening at the base of the inclined sheet as a result of sediment up-drag, D) propagation of inner sill.

3.3.1 Cretaceous rocks

A 300 m thickness of Mbotyi Formation is present in a down-faulted area on the coast 30 km north of Port St. Johns. It consists of conglomerate and subordinate coarse sandstone, resting unconformably on Karoo Supergroup rocks.

3.3.2 Quaternary unconsolidated deposits

Because erosion is the predominant geomorphic process in the study area, unconsolidated deposits are limited with alluvium only occurring in some river valleys (up to a few metres thick) and as hillwash on slopes (a thin veneer to about 2 m thick). Alluvium is most extensive in the north-western quarter of the study area, and in particular in the area underlain by Burgersdorp Formation rocks (Fig 7).

3.4 Structure

3.4.1 Faulting

Tensional stress over Southern Africa resulted in upward movement of magma from the mantle to form the Karoo dolerite and lava (GSSA, 1970). Simultaneously and subsequently numerous predominantly east-west striking normal faults developed, the largest movements taking place in the Lower Cretaceous times.

According to the 1: 250 000 published Geological Maps and accompanying Explanations major faults occur only along the coast of the study area (GSSA 1974, 1979). There are several of these east-west striking faults, the downthrows (as much as 3 000 m) being mainly to the south. They are hinge faults with downthrows diminishing inland - for example - a fault immediately to the south of Port St Johns has a displacement of about 3 000 m at the coast but dies out within 16 km inland. Although movement on these faults predominated in the Cretaceous, seismic evidence indicates some recent movement. Neogene and Neotectonic activity along W-E and WNW trending faults is documented in the Southern and South Eastern Cape by Andreoli et al. (1989) Hill (1988) and

Hattingh and Goedhart (1997). An example this activity within the study area is the earthquake near the coast north of Port St. Johns on 1 November 1942 registered 6 on the Mercalli scale (Krige and Maree, 1951).

3.4.2 Folding

The southern edge of the study area is close to the northern limit of the Cape Fold Belt and very localized dips up to 30 degrees (a result of folding) are encountered for example in the vicinity of Bedford. Dip angles decrease progressively northwards with most of the map area being 1 - 5 degrees northward. Variations in dip and direction occur locally next to some intrusions. Dips also steepen in the faulted areas at the coast where eastward dips up to 20 degrees occur.

3.4.3 Fracturing

Localised fracturing associated with dolerite intrusions occurs in both the host rock and the dolerite itself. Joints not necessarily associated with dolerite, also form as a result of tectonic forces, weathering and stress release on unloading by denudation. They usually keep a constant direction over a large regional area (Chevallier, L., 1998, *pers. comm.*) Lithological boundaries often represent zones for development of openings when there is local flexure and rock competence contrast, for example at sandstone mudrock contacts (Hill, Kaplan and Scott (HKS), 1991).

Dolerite dykes develop by rapid hydraulic fracturing and propagation of fissures under magma pressure. The intruding dyke tip causes the formation of closely spaced dyke-parallel joints in the host rock (Delaney et al., 1986). These joints are typically restricted to a zone between 5 and 15 m from the dyke margin (Woodford et al., *in press*). Except for the tip region, deformation of the host rock may be largely elastic (Rubin, 1995). Owing to their mode of intrusion and rapid cooling, dolerite bodies are normally highly jointed and often display a typical hexagonal pattern of shrinkage joints (Brink, 1983). This columnar jointing forms perpendicular to dyke margins within the dolerite and, in the case of dykes/sheets in excess of 10 m thickness, in the baked host rock (Chevallier, L., 1998, *pers. comm.*). The joints are approximately 120° apart (GSSA, 1963). In addition a set of sub horizontal stress relief joints are commonly formed (Brink, 1983). Vandoolaeghe (1980) found that open fractures often transgress dolerite dykes and typically extend up to 15 m into the country rock.

Woodford et al. (*in press*) identify three major types of fracturing within a dolerite sill and ring complex (Fig. 14):

- Vertical thermal columnar jointing (F1) in the inner and outer flat lying sills,
- Fractures parallel to the contact of the inclined sheet (F2). Fracturing in this portion of the complex is most pronounced,

Well-developed, oblique or sub-horizontal open fractures developing in the curved portions of the sill (F3) similar to those identified by Vandoolaeghe (1980) as being of major hydrogeological significance in the vicinity of Queenstown.

Metamorphic effects along dolerite contacts result in the formation of competent but brittle meta-sediments. The magma forming the sills has only a limited baking effect on the surrounding sediments compared to metamorphism associated with dykes (Brink, 1983). The changes are most pronounced in mudrocks, which in extreme cases may change to lydianite. As a rule of thumb Brink (1983) suggests that the zone affected by a dyke be taken as a thickness on either side of the dyke corresponding approximately to the dyke thickness. This is in line with the findings of Stockley (1947) who observed that the width of hornstone is almost directly proportional to dyke width. Schmitz and Rooyani (1987) note too that in the immediate contact with a dyke and up to 1 dyke width away sandstones fuse to quartzites and mudstones bake to hornstones. In addition they note that quartzites may be fractured or massive but hornstones are usually fractured. In the case of sills (Maske, 1966) also notes width of contact aureole degree varies with intrusion thickness, the upper aureole being wider.

The frequency of open fractures is in general much higher in the near land surface zone as evidenced by the higher rate of groundwater interceptions in boreholes near the surface. There is a steady decline in the frequency of groundwater interceptions / open fractures with increasing depth. This phenomenon is likely to be as a result of stress readjustments caused by erosional unloading.

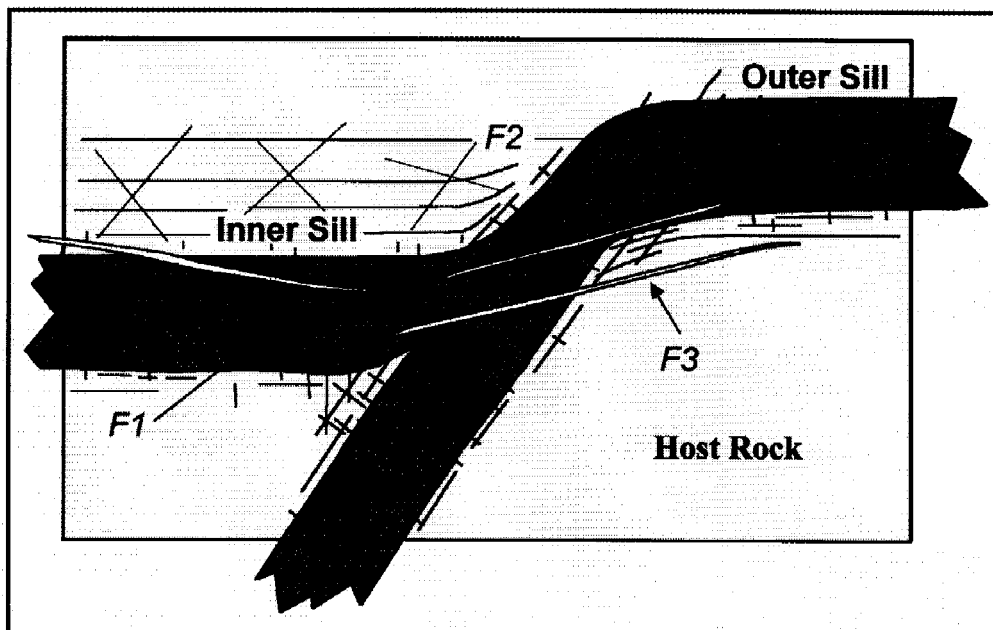


Fig. 14: Different types of fractures associated with sill and ring complexes (After Woodford et al., *in press*).

Botha et. al., (1998) single out fracturing along bedding planes as being a common occurrence in Karoo sediments in episodes of isostatic rebound and erosional unloading as a result of differences in elasticity between the different formations. This process is confirmed by observations made in Brink et al. (1983) where the formation of stress relief phenomena in Karoo sedimentary rocks occurred during excavation of weathered overburden material – continuous sheets of rock separating by as much as 200mm from the underlying layers.

3.4.4 Stress regime

The prevailing stress regime is important for the mode of occurrence of groundwater because it will determine whether fractures are in tension (open) or compression (closed). Andreoli et al. (1996) conclude from research into neotectonic activity in Southern Africa that there is a NW-SE trending maximum horizontal compression from Southern Angola to the offshore Transkei basin. Because the study area falls within this zone the same palaeostress direction can be expected. Andreoli et al. (1996) state that the orientation of major Jurassic dyke swarms in South Africa indicate that a similar field has existed since before the break-up of Gondwana. In this stress regime NW-SE trending structures are likely to be in tension and those at right angles to this in compression.

A comparison of vertical to horizontal in-situ stresses across South Africa was made by Gay (1975) who concluded that at least one of the measured horizontal stresses tend to be larger than vertical at shallow depths (100 – 200 m below surface) but at greater depths the vertical stresses are nearly twice those acting horizontally. Under these circumstances fractures in the horizontal plane are likely to be tensional and therefore open at shallow depths but under compression and therefore closed deeper down due to increasing load pressure. Gay (1980) found that topographic effects influence the orientations of the maximum and minimum principal stresses, but at sites not influenced by topography stresses, the maximum horizontal stress tends to be orientated NW. Assuming this stress regime is generally prevalent in the study area, the NW-SE trending fractures are most likely to be open at depth.

4 HYDROGEOLOGY

4.1 Conceptual model of groundwater occurrence

For the bulk of this area groundwater occurs in dual porosity aquifers, comprising large but infrequent principal transmissive fractures with relatively low storage capacity, and secondary but numerous microfissures in the host rock with higher storativity but lower transmissivity. The microfissures are mainly concentrated in a near surface upper zone, usually less than 30 m thick, which possesses a higher storage capacity than the rocks encountered at deeper levels. However, the upper and lower zones are hydraulically linked. The groundwater stored in the shallower section replenishes by downward leakage of groundwater abstracted from deeper fractures via boreholes, or groundwater issuing from springs and seepages. The deeper fractures often have a higher transmissivity but lower storativity than the shallow zone fractures due to less weathering byproducts.

4.2 The influence of local geology on borehole yield

4.2.1 Aquifers associated with dolerite intrusions

4.2.1.1 Introduction

An understanding of the relation of groundwater to the pattern of dolerite intrusions is the key to successful groundwater exploitation over much of the mapped area. The conceptual illustration beneath the main map illustrates styles of dolerite intrusion and associated fracturing. Associated with these intrusions are fractured or fractured and intergranular aquifers. The fractures occur within the dolerite as well as in the host rock, and are often concentrated toward the margins of the dolerite intrusion (Plate 3). Weathering generates the intergranular property of these aquifers. The dolerite is commonly weathered as a combined result of the fractures providing weathering agents access to the rock as well as the susceptibility of the dolerite minerals to weathering.



Plate 3: A borehole targeting a highly fractured sandstone aquifer at the margin of a dolerite dyke (weathered light yellowish brown).

4.2.1.2 General Trends

The following general trends were revealed on analysis of the groundwater related data from the Queenstown sheet:

- Yields associated with dolerite intrusions are higher than those associated with undeformed sedimentary rocks only.
- Yields associated with dyke and sheet contact zones are broadly similar.
- Yields associated with dolerite intrusions are highly variable at both the local and regional scale.
- Regions that have higher yields than average in the sedimentary rocks will also have correspondingly higher than average yields in the dolerite associated aquifers.

Regional-scale fracturing affects all the rock types in a particular structural domain (i.e. affects both the dolerite and as well as the sedimentary host rocks remote from the intrusion). But at the local-scale dolerite contact zones provide competent rock in which these fractures are likely to remain sufficiently open to be highest yielding. This relationship/phenomenon is clearly illustrated in the area underlain by the Burgersdorp Formation where higher than average yields are obtained in the Burgersdorp Formation sedimentary rocks well away from the direct influence of the dolerite intrusion, but the fractures associated with dolerite are still the highest yielding.

4.2.1.3 Type areas

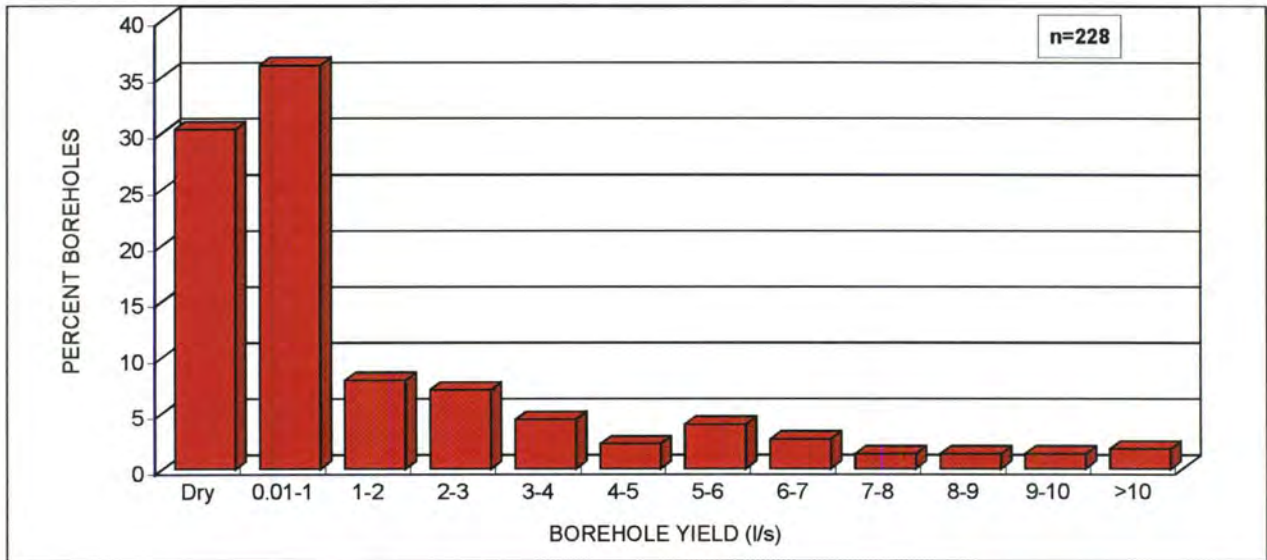
Yield frequency histograms for dolerite versus non-dolerite related drilling targets for the region as a whole are given in Fig. 15 for comparison. A Kolomogorov-Smirnov (K-S) test was carried out to determine whether the two yield frequency distributions shown in Fig 15 are significantly different. The K-S statistic is the maximum absolute difference between two observed cumulative probability distributions written as D. If the observed value of D is greater than a critical value at a specified significance level, which represents the variability due to chance, the null hypothesis can be rejected at that level. The observed D is 0.1019. The critical D values for the K-S test at various significance levels are presented in Table 3 for comparison with the observed D:

Table 3: Results of the Kolmogorov-Smirnov goodness of fit test on borehole yield frequency distributions for dolerite versus non-dolerite targets for the study area as a whole.

Significance level (%)	Critical D values for the K-S test. Dolerite (n= 228) versus non-dolerite (n=117) targets.	Reject hypothesis of no difference between data sets?
1	0.185369	N
5	0.154664	N
10	0.138742	N
15	0.129644	N
20	0.121684	N

The critical D value for the K-S test is in all cases less than calculated D values for the observed frequency distributions. The hypothesis that there is no difference between the data sets can in all cases be accepted. The frequency distributions therefore are not statistically significantly different even at the 20% level (i.e. we are less than 80% confident that there is a real difference). Despite the close similarity between the two frequency distributions a visual comparison reveals an important albeit small difference particularly for yields in excess of 4 ℓ/sec . Fourteen percent of boreholes targeting dolerite yield higher than 4 ℓ/s as opposed to only four percent yielding in excess of 4 ℓ/s when dolerite is not targeted. The results suggest that targeting dolerite enhances prospects for high borehole yields. This may not necessarily be true for all parts of the study area though, and to illustrate and explain the variations in groundwater occurrence associated with dolerite some “type areas” (Fig. 16) were selected. These areas were somewhat loosely selected taking into account the distribution of available information as well as intrusive style and relative abundance of dykes, sheets and sills.

BOREHOLES TARGETING DOLERITE
 QUEENSTOWN 1:500 000 MAP



BOREHOLES NOT TARGETING DOLERITE
 QUEENSTOWN 1:500 000 MAP

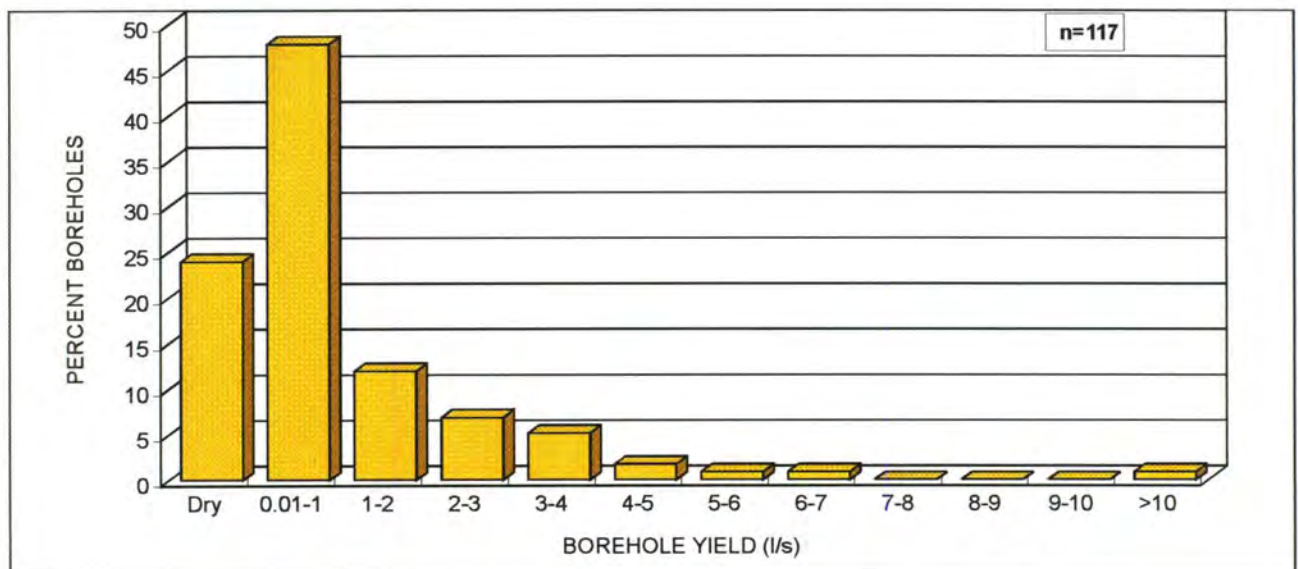


Fig. 15: Comparison of borehole yield for the Queenstown (3126) map region dolerite versus non-dolerite targets.

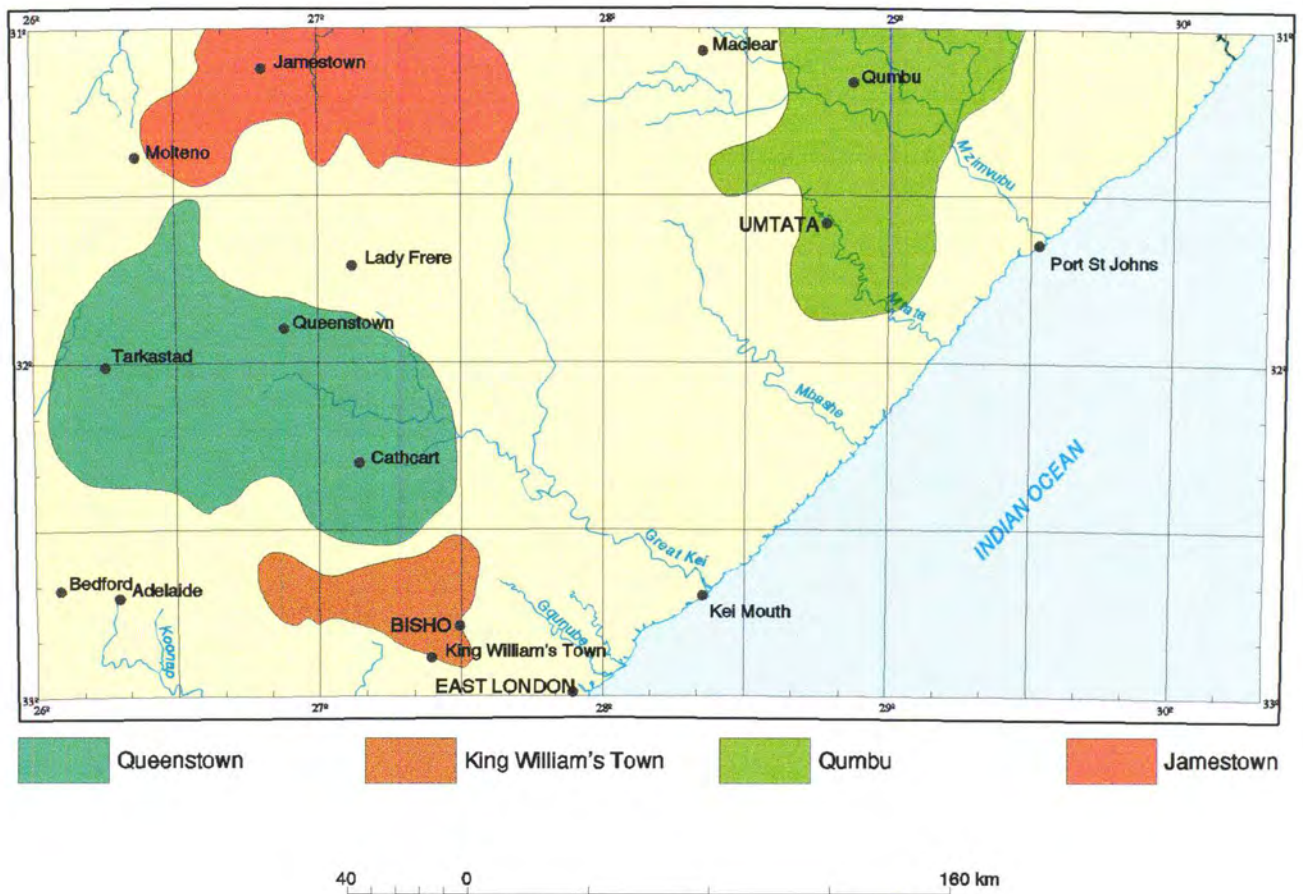


Fig. 16: Type areas.

The type areas are:

- Queenstown – predominantly dykes, “ringsheets” and sheets
- King William’s Town – mainly sills
- Jamestown – mainly dykes
- Qumbu - “dykes and sills” and “dykes and sheets”

K-S two-sample tests were carried out on lumped borehole yield data for the four type areas to determine whether the yield frequency distribution of the dolerite versus non-dolerite as well as dolerite sheet versus dyke targets are significantly different. The observed D is as follows:

- Dolerite sheet versus dolerite dyke targets - 0.1196
- Dolerite versus non-dolerite targets - 0.1169

The critical D values for the K-S test at various significance levels are presented in Table 4 for comparison with the observed D:

Table 4: Results of Kolmogorov-Smirnov goodness of fit test on lumped borehole yield frequency distributions for the four type areas.

Significance level (%)	Critical D values for the K-S test, dolerite (n=188) versus non-dolerite (n=80) targets.	Critical D values for the K-S test, dolerite sheet (n=77) versus dolerite dyke (n=101) targets.	Reject hypothesis of no difference between data sets?
1	0.217586	0.246599	N
5	0.181554	0.205751	N
10	0.162856	0.184571	N
15	0.152177	0.172468	N
20	0.142833	0.16178	N

Again the critical D value for the K-S test is in all cases less than calculated D values for the observed frequency distributions. The lumped frequency distributions therefore are not statistically significantly different even at the 20% level. As with the K-S test conducted on the yield frequency distributions in Fig 15, it is possible that the K-S two sample test again does not detect the subtle but important differences in borehole yield distributions. The K-S test does not pick up the differences as it compares the entire yield distribution. However it appears dolerite only affects the probability of encountering high yielding boreholes and does not greatly affect the probability of dry or low yielding boreholes (which are the majority). Consequently the difference is only reflected in the upper portion of the cumulative distribution curves and does not appear statistically different when whole distributions are compared. Although the lumped frequency distributions are not statistically significantly different, an examination of borehole yield frequency histograms *for each type area* allows for observation of some *apparent* differences *between* type areas. Borehole yield frequency histograms for these type areas are given in Figs. 17 and 18.

4.2.1.4 Queenstown type area

The dolerite-related aquifers typifying this type area are more productive than in all the other type areas (although yields are still lower than in the folded sedimentary aquifers near Bedford where dolerite is rare to absent). The presence of abundant dykes and sheets indicates that significant regional structural disturbance must have taken place during intrusion. What makes this area stand out as being different from the other areas is the presence of ring-shaped dolerite intrusions (Plate 4) as well as the abundance of irregular intrusions displaying sharp variations in thickness and dip along their length. (Note that the colours in Plate 4 are unnatural because the reflective-infrared portion of the spectrum was used. The colour variation therefore is rather an indicator of plant health/density).

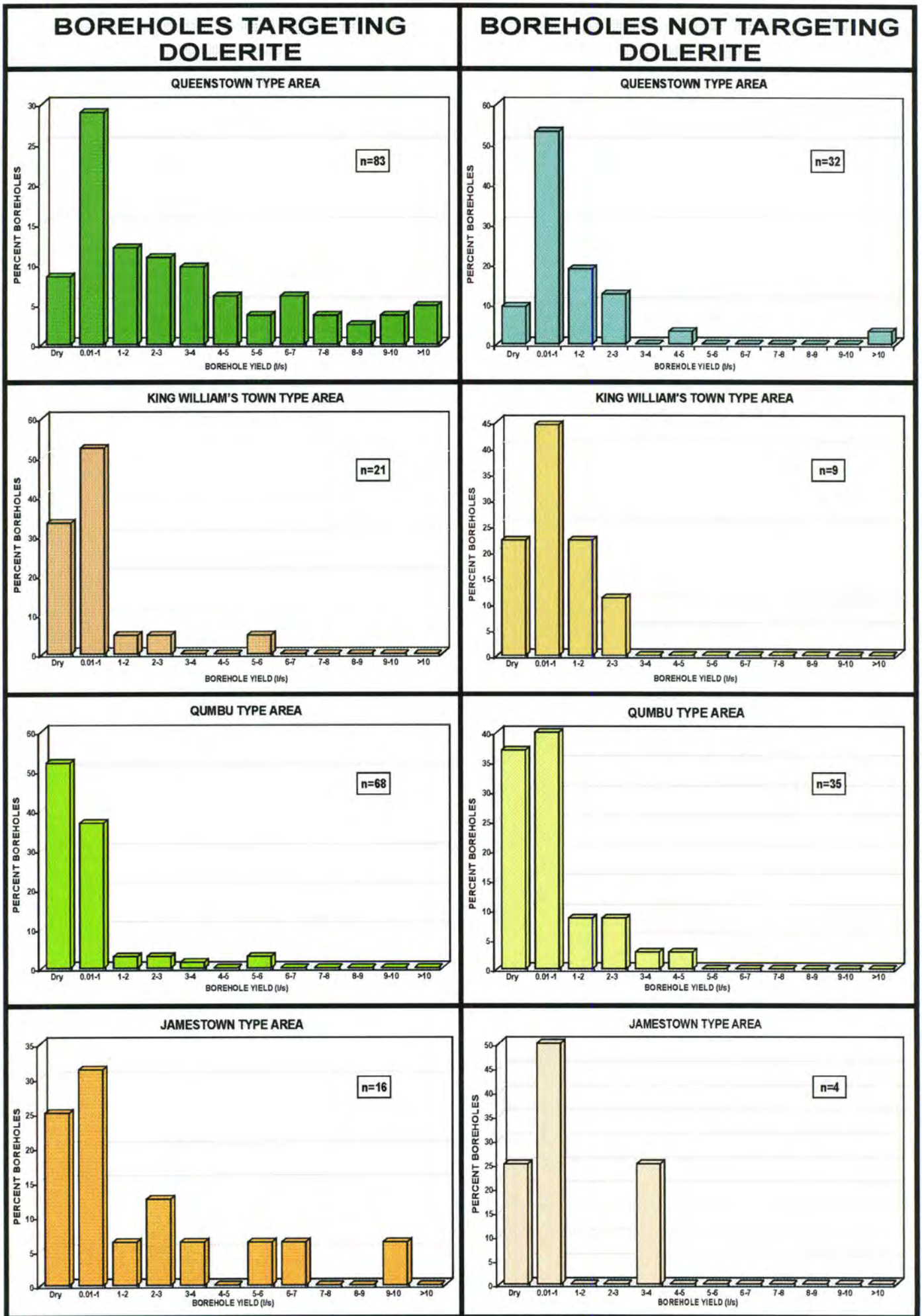


Fig. 17: Comparison of borehole yield per type area, dolerite versus non-dolerite targets.

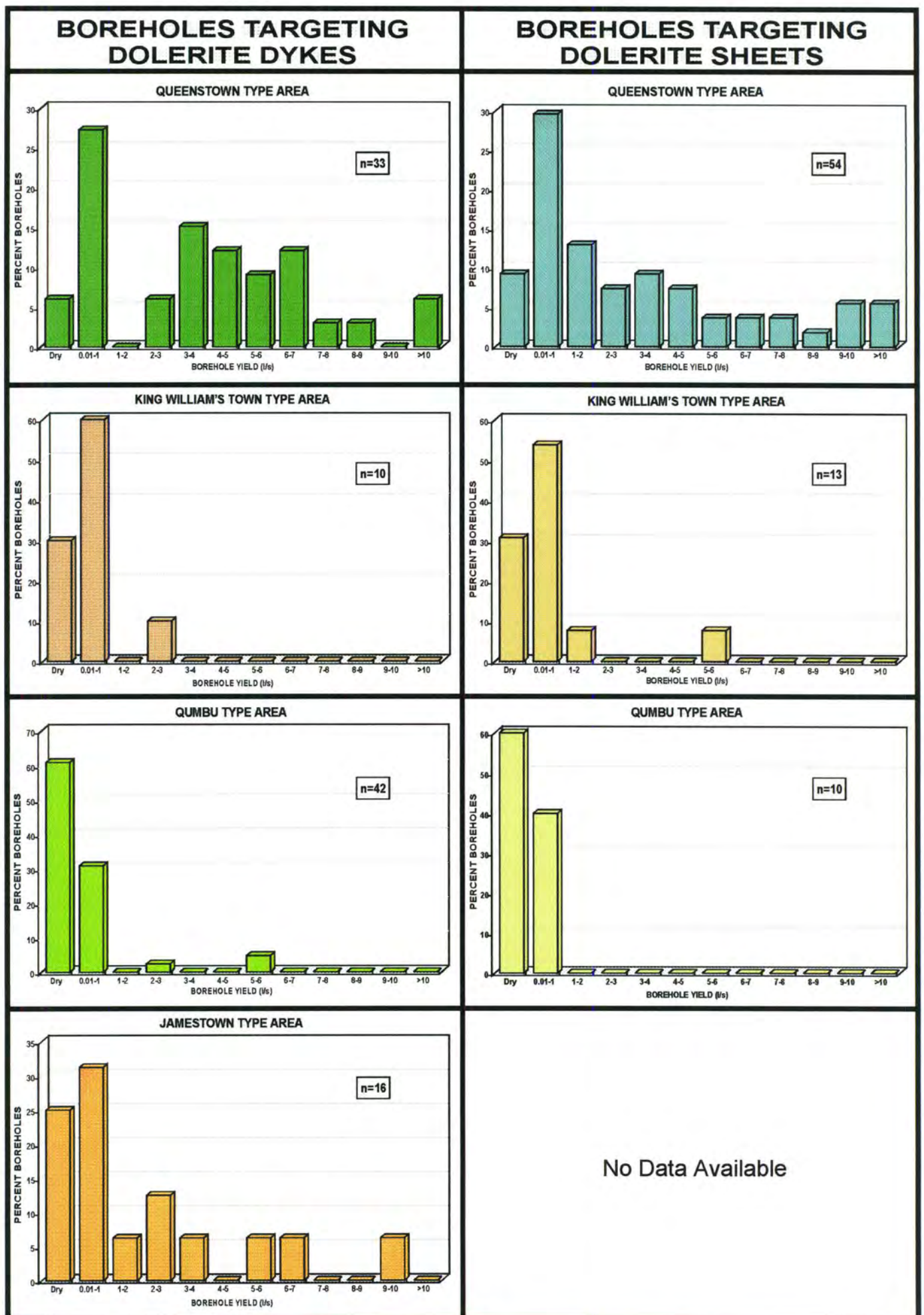


Fig. 18: Comparison of borehole yield per type area, dolerite sheets versus dykes.



Plate 4: A satellite image of the Queenstown area.

(Landsat - 5 TM Bend 745)

The intrusion of the ring structures is likely to cause extension and fracturing of the overlying host rock, and could be responsible for a generally higher incidence of fracturing than the other areas. The irregularity of the dolerite sheet intrusions of this area provide an abundance of curved sheets which Vandoolaeghe (1980) found to be the most productive drilling targets. He concluded that horizontal and oblique fractures within the dolerite sheets and extending tens of metres into the adjacent sediments are the dominant water bearing structures in the Queenstown area (Fig. 19). Fractures transgressing dolerite dykes and continuing into the adjacent sediments were also found to be high yielding. Another factor which could be responsible for the relatively high yields in the vicinity of Queenstown is the abundance of dolerite intrusions, which provide plentiful potential drilling sites. In addition the relatively flat terrain - particularly to the west of Queenstown - makes drilling access easier than the other areas, allowing more leeway in the optimal positioning of a drill rig.

4.2.1.5 King William's Town type area

The King William's Town type area is characterised by massive, shallow dipping, dolerite sheets, while dolerite dykes are rare. The contact zones of the massive sheets are notoriously unproductive, with more dry boreholes than in unaltered sedimentary rock. Dolerite-related yields of more than 3 ℓ/s are extremely rare. The dolerite sheet contact zone normally only yields water if a structural feature is present.

Best results are obtained for boreholes drilled away from the influence of dolerite, the prospects for success seemingly greater in topographic lows away from the rigid sheets. The reason for the poor results on these sheets is uncertain, but may be related to lack of tectonic activity and associated fracturing, and rarity of dykes along which structural movements/adjustments could have occurred.

It is speculated that little tectonic related fracturing has occurred due to rigidity of the thick sheets and rarity of dykes along which structural movements/adjustments could have occurred. Even in the Queenstown area Vandoolaeghe (1985) found the thickest sheets (>50 m) to be less productive. Poor results at dolerite contacts prompted Meyer (1972) to investigate potential a little distance away from the intrusions. Best results were obtained some metres from the contact but still within the "zone of influence" of the intrusion, but the reason for this is unclear. It would appear that the contacts are frozen and the adjoining country rocks in the immediate vicinity of the intrusion are baked solid.

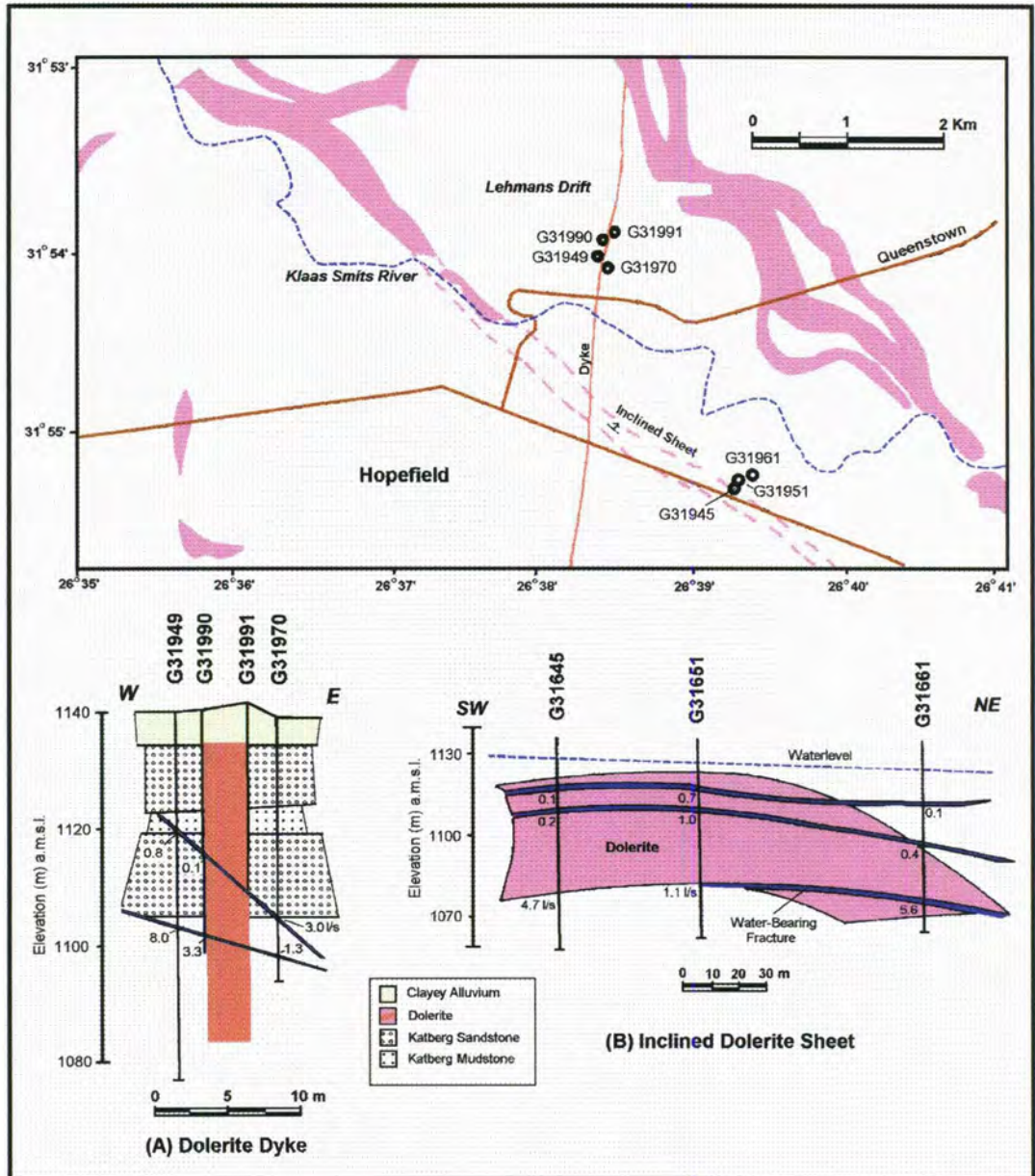


Fig. 19: Geohydrology of the Lehman's Drift (a) Dyke and (b) Inclined sheet, Queenstown.

Numerous borehole siting reports dating as far back as 1948 (Du Plessis, 1948) emphasize the overriding influence of topographic setting on drilling success in this area in particular. Siting in topographic lows is therefore critical. The probability of obtaining high yields in this area is greatest where fracture zones coincide with sandstone rich lithologies (SRK, 1990).

4.2.1.6 Qumbu type area

The style of intrusion, especially in the Burgersdorp Formation in the Qumbu type area, is very similar to that of the Queenstown type area, with dykes and sheets both abundant. However drilling associated with dolerite intrusions is far less successful than in the Queenstown type area, with yields seldom exceeding 3 ℓ/s.

The reason for this low success rate has probably more to do with economics than hydrogeology. The terrain is more hilly than the Queenstown type area and limited financial resources have often precluded the optimal siting of boreholes. Historically, drilling has taken place in or very close to the villages - generally situated on hilltops, which is not ideal from topographic considerations, and gives no choice in selecting the best site from geological considerations.

There is no apparent reason why similar yields to the Queenstown type area cannot be obtained, given optimal borehole siting. Clay products from the more intense weathering in the more humid eastern parts of the study area could result in reduced fracture transmissivities, but only at shallow depths.

From the yield frequency histograms (Fig. 18) dykes appear to be more productive than dolerite sheets. The potential of the sheets in this area may not have been adequately tested and should therefore not be written off on the basis of these poor results. Judging from the successes obtained in dolerite sheets of similar style elsewhere (Queenstown for example), it is probable that their true potential has not been adequately explored.

Yields from boreholes drilled by the Transkei Department of Agriculture and Forestry targeting various features in the Northern Transkei are given in Table 5. Dolerite related targets are included for comparison purposes.

Table 5: Yield statistics for boreholes targeting various features in Northern Transkei (After Smart and Nomquphu, 1995).

Target	No. of Boreholes	Percent boreholes per yield (ℓ/s) range							
		Dry	<0.5	0.5-1.0	1-2	2-3	3-4	4-5	5-6
Topographic low	27	44	19	15	7	11	0	0	4
Lineament	23	56	30	9	0	0	0	4	0
Fault	4	100	0	0	0	0	0	0	0
Total dolerite*	81	49	28	12	3	7	1	0	3

* Total targeting dolerite related fracturing.

The importance of siting boreholes in topographic lows is highlighted by the above statistics with 22 % yielding in excess of 1 ℓ/s , and up to 6 ℓ/s in exceptional cases. Possible explanations for the higher productivity of boreholes sited in topographic lows include:

- topographic lows often coincide with more easily erodible fractured zones,
- weathering is often more pronounced here,
- some boreholes drilled in the topographic lows did intersect dolerite, although not specifically targeted.

Boreholes specifically targeting dolerite fared next best. The chances of obtaining high yields can therefore be maximized by selecting dolerite-related targets in topographic lows. Poor results are obtained from lineaments with yields rarely exceeding 1 ℓ/s . These lineaments observed on aerial photographs probably represent joints or faults not identifiable in the field. Worst results were obtained for structures positively identified as faults - all the boreholes being dry.

4.2.1.7 Jamestown type area

Dolerite dykes are common in this area and sheets/sills are rare. In the Dordrecht area, Meyer (1984) found the topographically up-gradient sides of dykes to be most productive. Yields in excess of 2 ℓ/s are relatively common for boreholes targeting dolerite dykes (37%) but up to 9 ℓ/s are obtained in some instances. These results are much higher than the yields obtained adjacent to dykes in the King William's Town type area (only 10% of yields greater than 2 ℓ/s) and Qumbu type area (7 % greater than 2 ℓ/s). The yields in the Jamestown type area are however not as high as the Queenstown type area where approximately 65% of boreholes targeting dolerite dykes yield in excess of 2 ℓ/s and approximately 5% yield in excess of 10 ℓ/s.

4.2.1.8 Discussion

Dykes are generally longer and more abundant in the higher yielding Queenstown and Jamestown type areas than the other two regions. This correlation could indicate that the abundance and length of dyke intrusions reflect the degree of associated structural disturbance / fracturing resulting in higher yields. Assuming the study area is subject to regional compression from the south-east, dykes with a north-west trend will be in tension and associated fractures more open as a result. This could also partly explain the better results obtained in the Queenstown and Jamestown type areas where this trend is more prominent (Fig. 8).

However, with the current level of information it is only possible to speculate as to the reasons for the borehole yield variations associated with dolerite. Detailed research-orientated drilling investigations in the individual type areas are required to better explain such variations. Such a drilling programme would entail drilling traverses through typical dolerite intrusions to determine their structure, obtain detail on the distribution of associated fractures, including their orientation and yield. Definitive statements cannot be made about the relationship between dolerite intrusions and groundwater occurrence until the results of such research are obtained. This is especially important in areas that appear to have little groundwater potential associated with dolerite. The poor results could well be due to the lack of scientifically sited boreholes, rather than any lack of potential associated with the dolerite.

4.2.2 Aquifers associated with fracturing unrelated to dolerite

In general, fractured sedimentary rock (not influenced by dolerite intrusion) yields less than 1 ℓ/s . Higher yields are obtainable up to 3 ℓ/s but can be as high as 5 ℓ/s in exceptional cases (Fig. 15). Statistics (Smart, 1993) for sixteen boreholes drilled in sedimentary rock near Queenstown (away from the influence of known dolerite but possibly influenced by undetected dolerite at depth) are given in Table 6.

Table 6: Borehole yield ranges for sedimentary rock in the Queenstown type area (After Smart in KBCE, 1993).

Percentage boreholes per yield (ℓ/s) range (16 boreholes total)					
Dry	<1.5	1.5-3	3-4	4 -5.5	>5.5
12	34	24	24	6	0

All these boreholes yield less than 6 ℓ/s whereas approximately 25% of yields exceed 6 ℓ/s in boreholes targeting dolerites in the same area.

Tectonically induced fracturing of sedimentary rock is particularly important in the dolerite scarce folded terrain in the Bedford vicinity in the south-western corner of the study area. High yields, mostly less than 4 ℓ/s but up to 20 ℓ/s are obtained and there are relatively few dry boreholes (only 17% of boreholes are dry in this area whereas elsewhere in undeformed dolerite rich areas between 23 and 45 % of boreholes are dry). This region was influenced by directional and compressional stresses from the south during the Cape Orogeny resulting in folding. Enhanced fracturing of the affected sedimentary rocks is noted in association with the more intensely folded portions, in particular at anticline hinges (Simonis, 1987).

Tectonic structures (folds, flexure, joint zones) coinciding with sandstone horizons are favored targets (Sami, 1996). Significantly higher yields are noted adjacent to the rare dolerite intrusions or in the vicinity of flexured sedimentary rocks but no statistical evidence for improved borehole yields along faults or fold axes was reported.

Lithological boundaries represent favourable zones for development of openings where there is local flexure and rock competence contrast e.g. mudrock/sandstone contacts (HKS, 1991). Unconformities at lithological contacts are likely to be more productive due to weathering effects at the contact. For example two boreholes drilled to test the lithological unconformable boundary between the Natal Sandstone and Dwyka Tillite Group (SRK, 1993) yield approximately 6 ℓ/s, which are abnormally high yields for these two lithological units.

Another lithological boundary which can be singled out as a potential target is the contact between the Drakensberg Group basalt and the underlying Clarens Formation sandstone (in the north of the mapped area). High yields (as high as 10 ℓ/s) are reported at this contact, which is also a relatively common site for spring emanations.

Faults Very limited borehole yield data are available for faults but indications are that these structures represent poor targets for groundwater (all 7 boreholes known to have targeted faults are dry). By way of illustration a 116 m deep borehole sited by the author drilled into a major (3 000 m throw) east-west trending fault situated to the south of the study area. Although outside the study area it is typical of the major faults along the coast within the study area. The rock material was very soft and highly friable, and the borehole produced only seepage, although it became weakly artesian a few hours after borehole completion.

Based on this experience it is speculated that the material filling fault planes in the study area has a low permeability. A number of factors could jointly be responsible for this low permeability. The generally incompetent nature of the sedimentary rocks and the large-scale movement could result in formation of rock flour as opposed to a highly transmissive breccia with angular rotated fragments. In addition, intense weathering (decomposition) associated with the high rainfall areas where major faults are concentrated could further limit breccia fragment size and transmissivity.

4.2.3 Intergranular aquifers

These aquifers are unconsolidated sedimentary deposits where groundwater occupies interconnected pore spaces. Consolidated rocks with a significant intergranular porosity or transmissivity are not found in the study area. Boreholes drilled into alluvial aquifers in general yield less than 1,5 ℓ/s. Isolated coarser and thicker occurrences yield in excess of 5 ℓ/s.

Extensive unconsolidated colluvial and fluvial deposits are found only in the north-west quarter of the map in the vicinity of Queenstown. For the remainder of the area uplift resulted in a relatively young, deeply incised, eroding landscape with little scope for deposition, hence isolated unconsolidated fluvial deposits are found only in some sections of river channels.

The alluvial and colluvial inland deposits investigated by DWA (Vandoolaeghe, 1980) in the Queenstown vicinity were found to have much lower yields than the underlying fractured rock aquifers. The explanation for the low yields is that the grain size is very fine resulting in very low permeability.

In general, these aquifers are considered to have a relatively low storage capacity because the deposits are relatively thin with a limited saturated thickness (usually less than 5m). During dry periods bedrock is commonly exposed in river channels. Under these circumstances groundwater will drain into the river channels and as a result the alluvial deposits will not be permanently saturated.

Coastal deposits also provide aquifers of only local importance due to their limited extent. Sporadically developed coastal dunes are restricted to a very narrow zone within 2 km of the coast. An investigation at Bonza Bay (Boehmer, 1969) showed the underlying fractured rock to be more productive than the dunes, while the dunes do have some value as a storage medium, a similar situation to the inland alluvial deposits.

4.3 Regional variation in borehole yields

Hydrogeologically distinct regions were identified to allow borehole yields from areas of differing character to be compared. The hydrogeological regions identified for this study are given in Fig. 20 and their characteristics are given in Table 7. Factors taken into account when delineating these areas included:

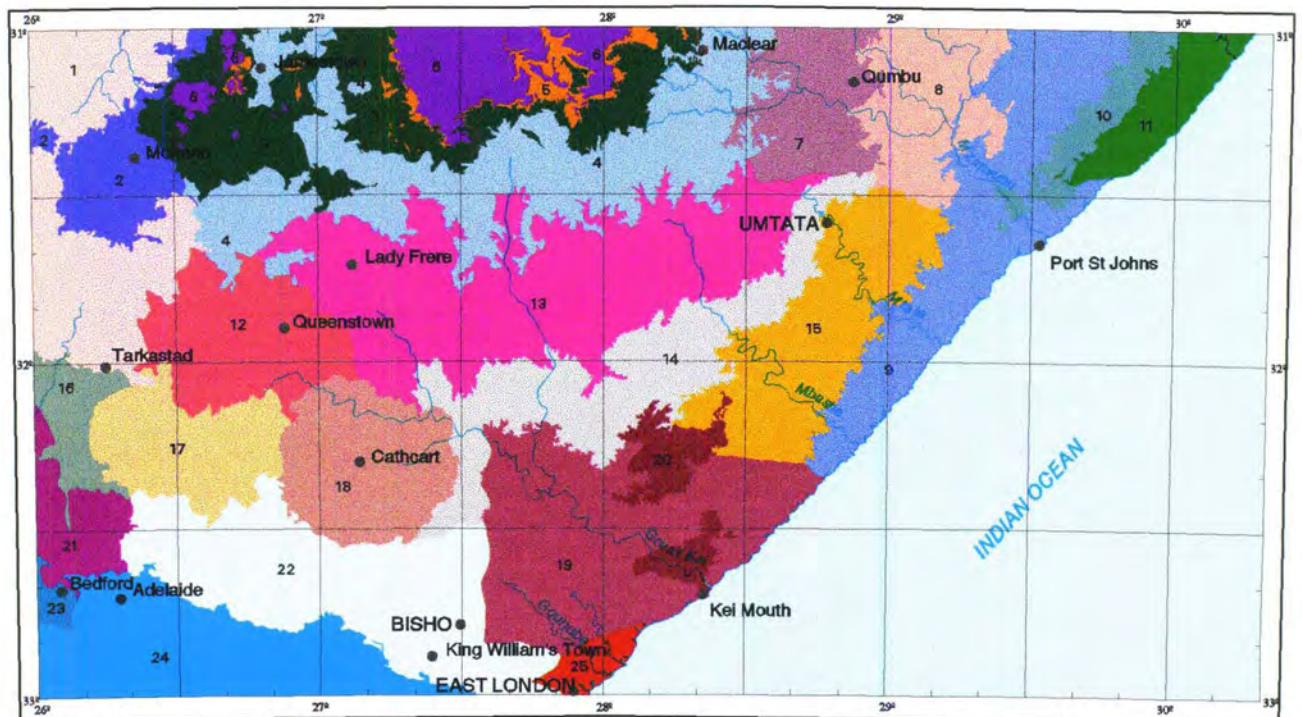


Fig. 20: Hydrogeological regions.

Table 7: Characteristics of the hydrogeological regions.

Hydrogeological region	Dolerite		Host rock (in order of abundance). Mdst = Mudstone Sst = sandstone	Dominant structure and trend	Fractured (F) or Fractured and intergranular (F+I)	Statistics of borehole yield l/s*						Total boreholes	
	Dyke	Sheets and sills				Median	75%tile	25%tile	Mean	Standard deviation	Upper standard deviation		Lower standard deviation
1	Common	Common	Mdst, Sst	NNW dykes	F	1.06	2.52	0.40	0.9	0.64	3.92	0.21	267
2	Common	Common	Sst, Mdst	NNW+EW dykes	F	1.06	5.80	0.25	0.86	0.78	5.13	0.15	86
3	Common	Rare	Mdst, Sst	NW+NE dykes	F+I	0.60	1.28	0.18	0.45	0.71	2.23	0.38	177
4	Common	Common	Mdst,Sst	NW+NE dykes	F+I	0.63	1.58	0.23	0.59	0.63	2.52	0.14	474
5	Common	Rare	Sst	WNW+NNE dykes	F+I	1.22	2.56	0.68	0.95	0.57	4.83	0.35	19
6	Common	Rare	Basalt	WNW dykes	F+I	0.64	1.83	0.14	0.5	0.75	2.83	0.09	147
7	Common	Common	Sst, Mdst	NNW+NNE dykes	F+I	1.23	2.25	0.45	1	0.45	2.85	0.35	94
8	Common	Common	Mdst, Sst	NW+NE dykes	F+I	0.62	1.00	0.3	0.62	0.38	1.5	0.57	52
9	Rare	Common	Shale	NW dykes	F+I	1.17	1.78	0.55	0.16	0.35	0.36	0.07	80
10	Rare	Rare	Tillite	NW dykes	F+I	0.30	0.65	0.14	0.02	0.53	0.07	0.01	55
11	Rare	Rare	Sst	NW dykes	F+I	0.50	1.04	0.18	0.47	0.4	1.22	0.19	28
12	Common	Common	Mdst, Sst	NNW dykes	F+I	1.88	4.43	0.75	1.74	0.6	6.91	0.44	709
13	Common	Common	Mdst, Sst	NW dykes	F+I	1.80	3.00	0.65	1.3	0.45	2.9	0.36	310
14	Common	Common	Sst, Mdst	NW+ENE dykes	F+I	1.01	2.50	0.32	0.84	0.52	2.76	0.25	248
15	Common	Common	Mdst, Sst	NW +ENE dykes	F+I	0.50	1.26	0.3	0.58	0.42	1.53	0.22	61
16	Common	Common	Sst, Mdst	NW dykes	F	0.61	2.54	0.1	0.49	0.82	3.3	0.07	98
17	Common	Common	Sst, Mdst	NW+EW dykes	F+I	0.85	2.50	0.33	0.77	0.59	2.99	0.2	249
18	Common	Common	Sst, Mdst	NW+NNE dykes	F+I	0.89	2.15	0.28	0.65	0.65	3.41	0.17	268
19	Common	Common	Mdst, Sst	NW+NS dykes	F+I	0.49	1.36	0.11	0.53	0.73	2.84	0.1	389
20	Rare	Common	Mdst, Sst	-----	F+I	0.70	1.55	0.1	0.48	0.75	2.76	0.08	122
21	Rare	Common	Mdst, Sst	-----	F	0.59	1.55	0.07	0.4	0.82	2.69	0.06	85
22	Rare	Common	Mdst, Sst	-----	F+I	0.60	1.83	0.21	0.57	0.67	2.68	0.12	676
23	Rare	Rare	Mdst, Sst	Folding (EW)	F	5.00	8.00	1.4	3.62	0.53	12.03	1.09	81
24	Rare	Rare	Mdst, Sst	Folding (EW)	F+I	0.63	1.98	0.28	0.66	0.61	2.7	0.16	379
25	Rare	Common	Mdst, Sst	Faults (ENE)	F+I	0.25	1.51	0.06	0.29	0.79	1.79	0.05	35
													5 189

* Excludes dry boreholes

- Dolerite abundance and style of intrusion,
- Lithology,
- Geological structure (faults, folding, dyke orientations),
- Intensity and mode of weathering,
- Catchment boundaries.

Instances occurred where groups of higher yielding boreholes were identified without there being an obvious geohydrological explanation for that area being superior. Despite this these areas were assigned to separate hydrogeological regions for statistical analysis e.g. the higher yielding boreholes around Queenstown were analysed separately from those in the hydrogeologically similar Burgersdorp Formation further to the east. This was done to avoid extrapolating unrealistically high borehole yields to the eastern area. The results of the statistical analyses for each region are included in Table 7.

The following examples demonstrate that what one sees on a regional map can depend on how the data are analysed and presented. It is important to note that the one method is not necessarily better than another, but rather the use of a variety of methods can be instrumental in highlighting aspects which otherwise go unnoticed.

Example 1 (Fig. 21)

The yield ranges adopted for the standard legend for the General Hydrogeological Map are not sensitive enough to adequately distinguish yield variation across the study area, because virtually the whole study area falls in a single yield range category (0.5 - 2 *l/s*). A better indication of yield ranges for this area can be obtained from Fig. 21, compiled using smaller yield ranges for the legend.

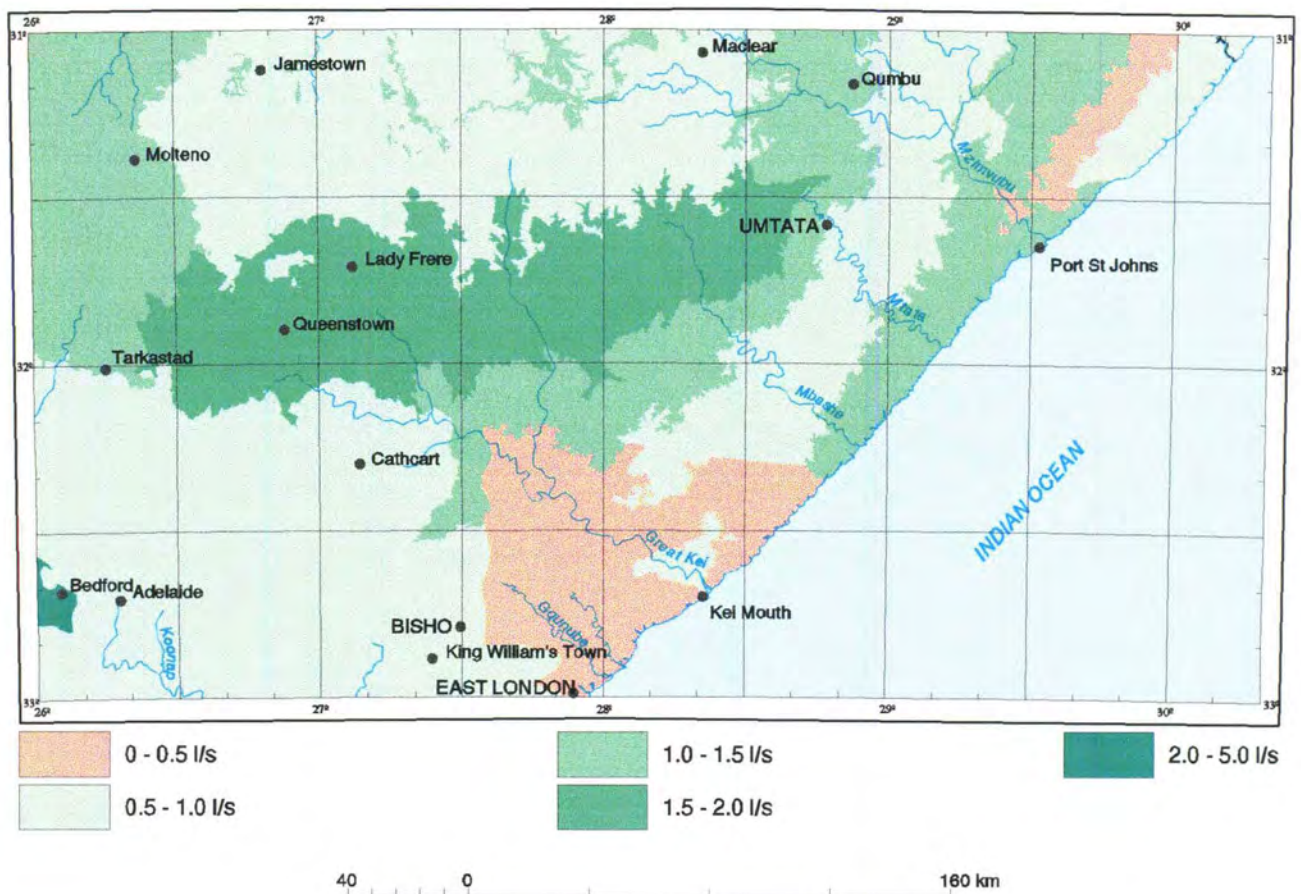


Fig. 21: Hydrogeological map using alternative yield classes

Example 2 (Fig. 22)

Focusing on the incidence of dry boreholes reveals a lowest incidence of dry boreholes in the west and south-west of the region (with the latter being affected by the Cape Orogeny) as well as the Natal Group sandstone in the extreme north-east (Fig. 22). This Figure was compiled by determining the percentage dry boreholes within each of the 25 hydrogeological regions. Those regions with less than 15% dry boreholes were assigned a “low” incidence and those exceeding 15% dry boreholes a “high” incidence. The median percentage dry boreholes for the hydrogeological regions comprising the area of “low” incidence is 12% whereas the median percentage of dry boreholes for the area of “high” incidence of dry boreholes is 38% but can reach 60 %.

Example 3 (Fig. 23)

An examination of the areal distribution of higher yielding boreholes (in the 3 - 10 ℓ/s range) reveals the pattern highlighted in Fig 23. The area with higher yielding boreholes is affected by folding in the extreme south-west (Bedford area) as well as in a centrally situated east-west trending zone in the Queenstown area coinciding with ring shaped dolerite intrusions into the Burgersdorp Formation.

A discussion of the observed borehole yield variations in the study area follows:

4.3.1 Low incidence of dry boreholes in the west (Regions 1, 12, 16,17,21,22,23,24).

The relatively low incidence of dry boreholes in the western portion of the study area indicates a generally higher degree of fracturing in the rock matrix in this region. This could possibly be related to a higher degree of tectonism affecting the western part of this area, the intensity dissipating in the east. This could well be the case if the abundance of dolerite dykes is taken as a reflection of the intensity of tectonism affecting the study area. Dolerite dykes are abundant in the western parts becoming progressively less frequent toward the east (Fig. 8).

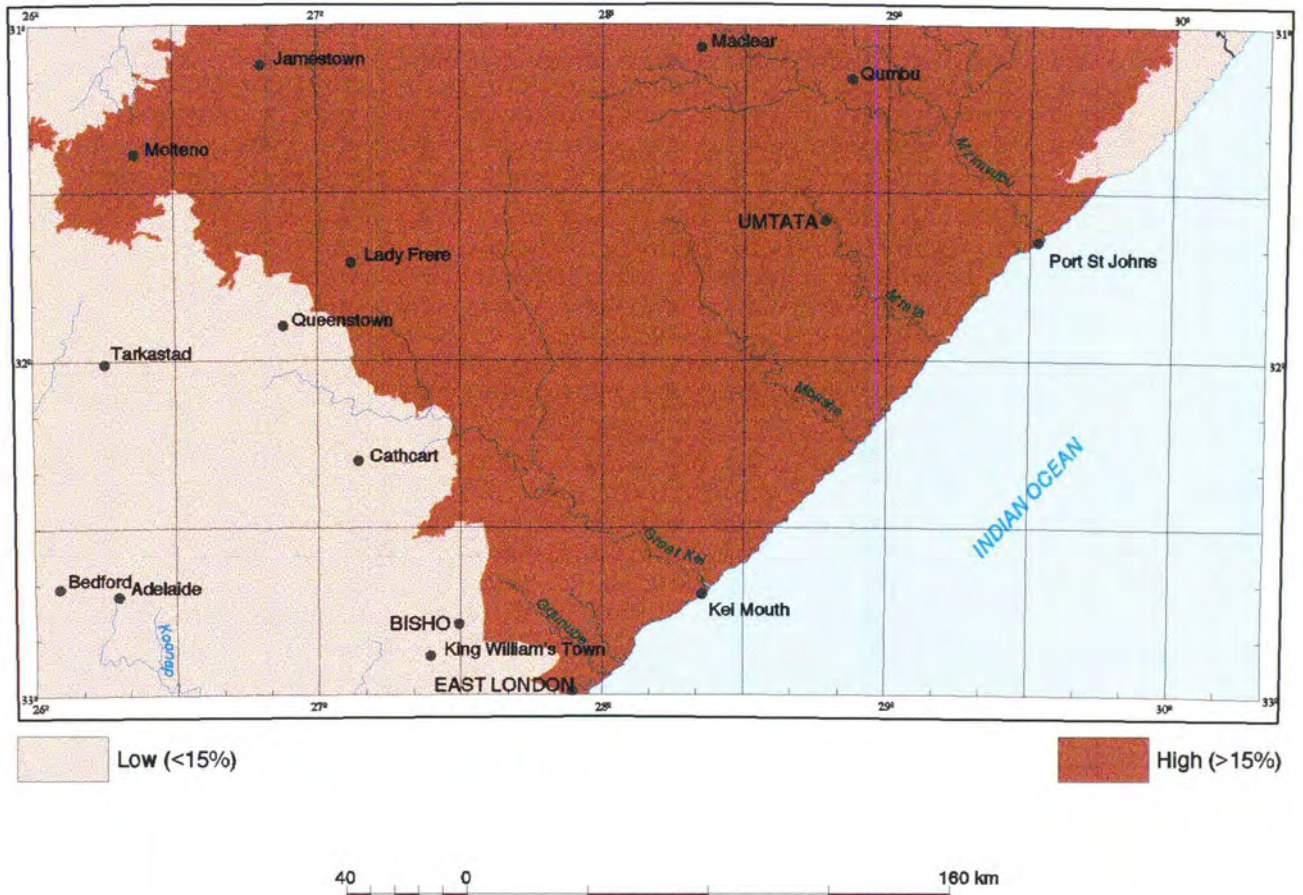


Fig. 22: Relative incidence of dry boreholes.

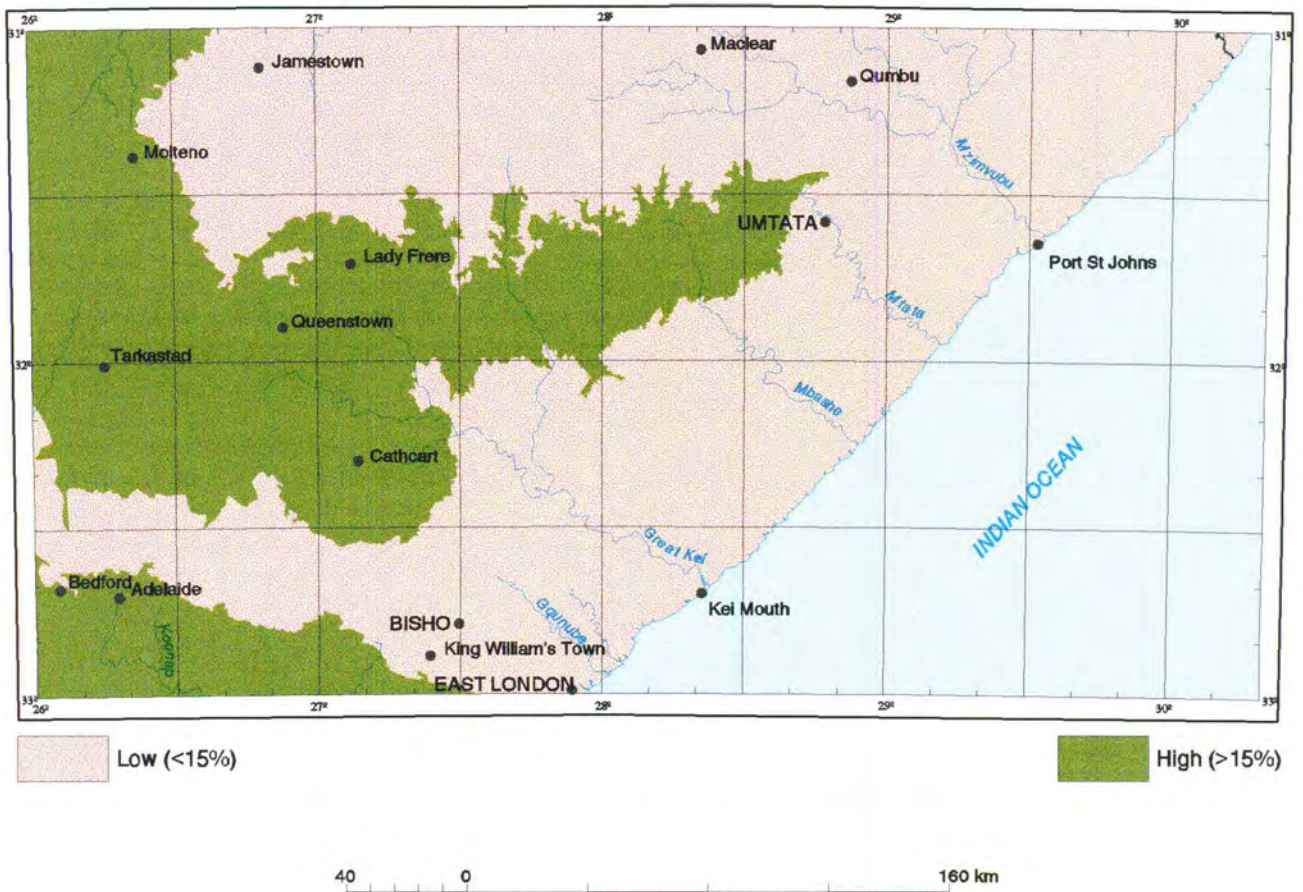


Fig. 23: Relative incidence of high yielding boreholes in the 3-10 l/sec range.

Mode of weathering could play a role in the observed change in incidence of dry boreholes across the study area from east to west. Clay minerals generated by chemical weathering in the eastern parts may result in lower transmissivities of near surface fractures (and a higher incidence of “dry” boreholes) than in the west where weathering by physical disintegration will not generate clay minerals. A higher density of fractures associated with folding in the south-western part of the area could explain the low incidence of dry boreholes in regions 23 and 24.

4.3.2 High yields in Bedford vicinity (regions 23 and 24)

These result from fracturing associated with folding related to the Cape Orogeny. The fact that the lithology is relatively competent (sandstone rich) probably results in fractures being more open than if it were mudrock rich (fractures tend to squeeze closed under load pressure in the softer, more mudrock rich lithologies).

4.3.3 High yields in the Queenstown vicinity (regions 1, 2, 12, 13, 16, 17 and 18)

Ring-shaped dolerite intrusions and irregular sheets are concentrated within these regions indicating that deformation related to their emplacement may have resulted in more intense fracturing than surrounding areas. It could be argued that the high yields obtained for region 12 results from this area being the focus of an intensive scientific drilling programme (Vandoolaeghe, 1980). This argument does not hold however because the median yield is virtually identical to that obtained for the adjacent region 13, where no such scientific drilling investigation was undertaken.

4.3.4 Low yields in the East London - Kei Mouth area (regions 19 and 25).

Dolerite dyke orientation in this area differs markedly from the other areas, as here the predominant dyke trends are east-west and west-south-west. Assuming that the regional maximum compressive stress is indeed directed from the south-east, structures of this orientation will be under compression. Generally low yields could therefore be expected because the major fractures may be closed.

4.3.5 Low yields in the Dwyka Group (region 10)

The following possibly contribute to the lower yield: -

- The rarity of dolerite intrusives and therefore related targets.
- This rock type is predominantly massive and as a result fracturing on bedding planes will not be as prevalent as in interbedded lithologies. Bedding related fractures in tillite will probably be discreet/discontinuous as a result.
- The steepness of the terrain limits ready access of drilling rigs to optimal drilling targets. In many instances therefore it is necessary to construct roads to the required drilling position.

4.3.6 High yields in the Eccca Formation (region 9)

Fissility of this shaley lithology may result in a generally higher bedding-related fracture frequency than sedimentary sequences where massive mudrocks predominate. The higher borehole yields in the Eccca can possibly therefore be a function of the higher fracture frequency expected in the more fractured shale.

4.4 Variations in borehole yield with depth

Two aspects are considered in relation to depth of borehole: the probability of striking water, and the average yield. To ascertain water strike probability with depth, the total number of groundwater interceptions obtained in each 5 m depth interval was determined. The number of interceptions in each 5 m depth interval expressed as a proportion of the total number of interceptions for the entire depth range of all boreholes was taken as the probability of striking water within that depth range.

As far as the probability of striking water is concerned, the general trend (Fig. 24) is a decrease in the chances of striking groundwater with depth below the land surface (average rest water-level for the region was 17m below surface). An inflection point in this trend occurs at approximately 55m below surface, the probability of striking groundwater decreasing more sharply in the zone between groundwater level and 55m below surface than between 55 and 135m. This inflection point marks the bottom limit of a more intensely fractured zone. The *mean yield* obtained at water strikes in relation to depth below surface (Fig. 25) shows little significant variation with depth.

**PROBABILITY OF STRIKING WATER
QUEENSTOWN 1:500 000 MAP**

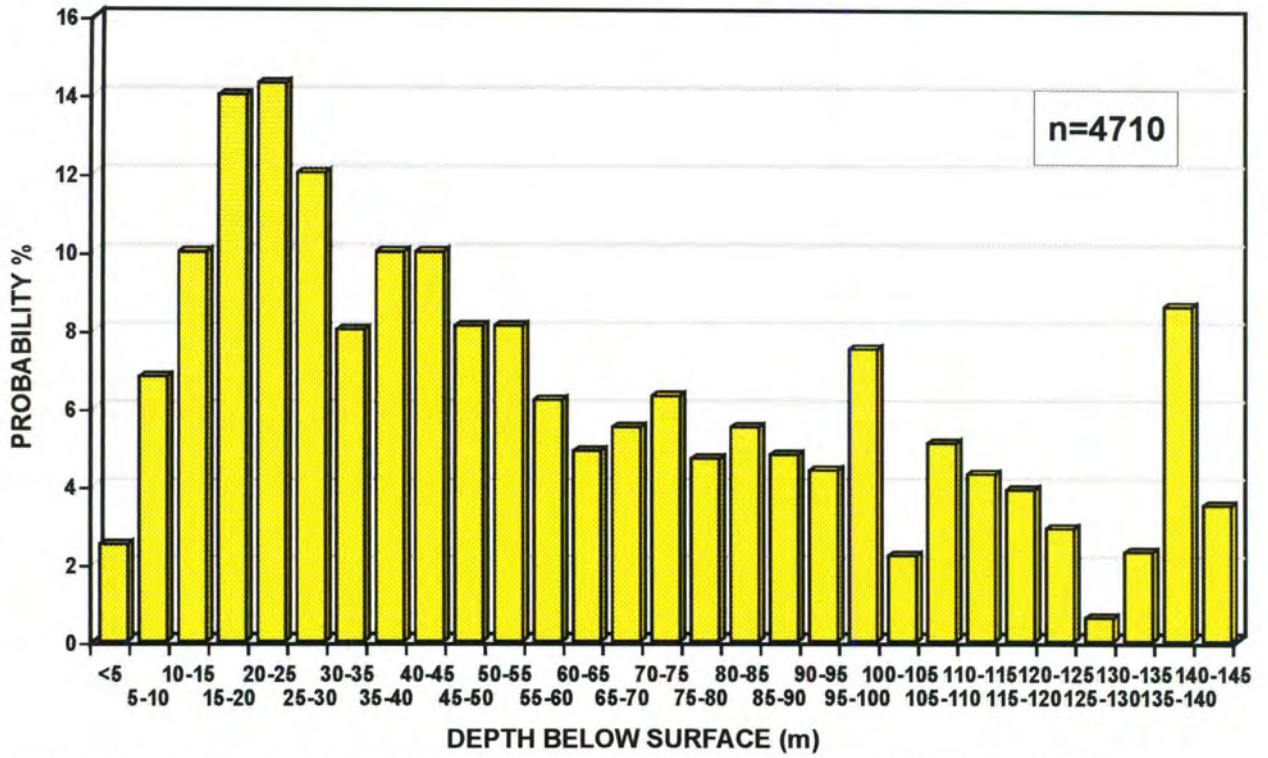


Fig. 24: Probability of striking groundwater with depth from surface.

**WATER STRIKE DEPTH VS YIELD
QUEENSTOWN 1:500 000 MAP**

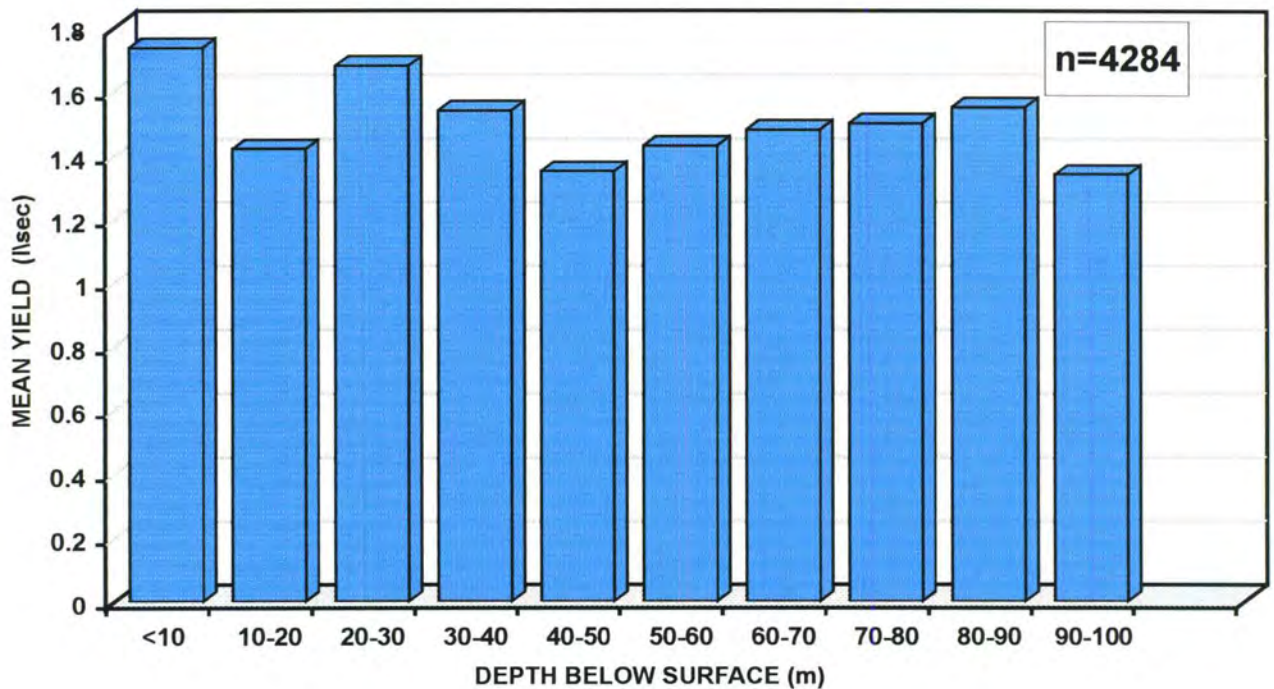


Fig. 25: Yield obtained at water strikes in relation to depth from surface.

As far as optimum drilling depths are concerned, these statistics can be looked at in two ways. If a large number of boreholes were to be drilled, then 50m would appear to be the optimum maximum drilling depth. The overall average water yield per metre drilled is certainly not going to increase by drilling boreholes deeper than this. On the other hand, if drilling sites are limited, for example by difficult terrain, it would be unwise to give up at 50m and turn to more expensive alternatives like surface water - higher yields may be intercepted at much greater depths than this.

4.5 Springs

Springs are important groundwater sources in the high rainfall areas (mainly in the east of the area as well as in the mountainous areas). Snowfalls in the Drakensberg enhance recharge to the springs - the slow melting process allowing more time for percolation of the melt to groundwater as opposed to rapid runoff resulting from rainfall.

Springs emanate wherever the water /piezometric surface coincides with the land surface. Common spring sites include:

- dykes intersecting drainage features,
- contacts of dolerite sills/sheets,
- basal contact of a fractured sandstone with an underlying less permeable mudrock horizon,
- weathered basins (usually weathered dolerite sheets) also known as “sponges”.

The yield and sustainability of spring flow depends on an interplay between the recharge rate, the size of the groundwater reservoir, permeability of the aquifer feeding the spring and the hydraulic head above the spring outlet. A perennial high flow rate indicates both large reservoir capacity plus high transmissivity. Flows of short duration after recharge events indicate a low reservoir capacity relative to the transmissivity. In the latter case, the relatively high flow rate results in rapid dewatering of the source aquifer. Obviously flow from springs which are more regularly replenished will also be more sustained but storage capacity remains the overriding factor.

4.6 Groundwater quality and chemical characteristics

The chemical quality of groundwater in an area is influenced by several factors, which may include the geology, topography and climate (Tordiffe et al., 1985). According to Cheboratev (1955) the proportion of soluble matter taken up by groundwater from rock material will depend on:

- lithology,
- structural features of the area,
- water temperature,
- chemical composition of the rock and water,
- abundance of particular ions and compounds in the water,
- the amount of water moving through the rock,
- type of flow (e.g. fracture or intergranular),
- velocity of flow.

In some instances groundwater quality restricts the variety of potential uses of a groundwater resource, for example excessive concentrations of specific ions can be harmful to health, cause either scaling in or corrosion of pipes, reduce crop yields and degrade soils. Results of 606 sample analyses are available in the DWAF National Groundwater Data Bank. The distribution of the sampling points is shown in Fig. 26. Most samples were analysed for the following elements: Na, Mg, Ca, Cl, SO₄, N, F, PO₄, Si, NH₄ and alkalinity. In addition groundwater electrical conductivities are available for 1 573 boreholes.

4.6.1 Regional water quality trends

The electrical conductivity (EC) of groundwater can be used as a first approximation of its quality. Regional quality trends are given in Fig.26. The contour map is based on a relatively sparse distribution of sample points and therefore only depicts general trends. Local quality variations will occur with the result that trends depicted on the map can differ significantly from that found at a point in the field.

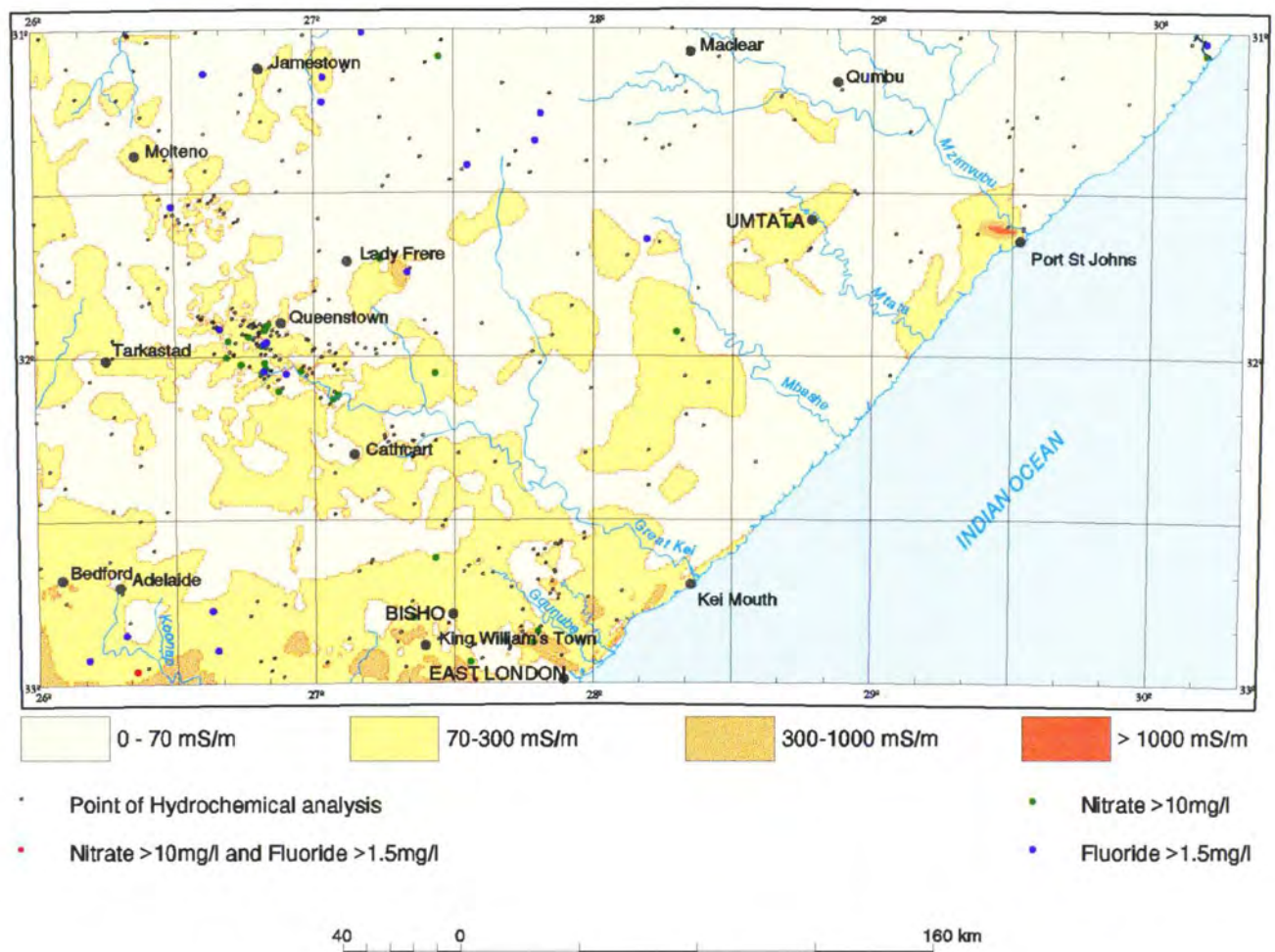


Fig. 26: Groundwater quality and some hydrochemical details.

In the study area electrical conductivities (ECs) rarely exceed the 300 (mS/m) maximum acceptable limit for human consumption (South African Bureau of Standards (SABS), 1984). The areas where the 300 mS/m limit is exceeded include the extreme south as well as in localised areas such as faulted terrain near Port St Johns. In the latter case it exceeds 1 000mS/m.

While the water quality for sampled springs and boreholes obtained from the Dwyka Group diamictite (in the north-east of the study area) is generally less than 300 mS/m, there are indications that deep saline water exists in this rock type. Evidence for this is the saline springs (EC = 1 400 mS/m) emanating at the bottom of deep gorges in the Bizana area, 300 m below the surrounding plateau (Bond, 1946). Anomalously high individual conductivities are obtained near Umtata and Lady Frere. The reason for these high ECs is not known.

In general the lowest ECs are found where the precipitation is highest. Lower ECs are therefore found in the north-eastern half of the map where precipitation usually exceeds 600mm p.a. and along mountain ranges (e.g. Amatola, Elandsberg, Didima ranges – Fig. 3). The poorer quality water occurs in the topographic depressions where the precipitation is lower.

Tordiffe and Botha (1981) carried out a study of the regional distribution of dissolved salts in the Great Fish river catchment bordering the study area in the west. The research revealed that macro-topography influences groundwater flow direction and rates, which in turn affects dissolved salt distributions in the area. The higher salinity in the lower lying areas was in part attributed to a gradual buildup of dissolved substances as the groundwater progressed along its course down the basin. Although it was found that geological composition did play a role in controlling water quality of the area, the influence of rock type remains subordinate to topography.

Comparison of lithology (Fig. 7) with precipitation (Fig 4), elevation (Fig 3) and quality (Fig 26) shows that the more resistant sandstone-rich formations tend to form topographic highs or escarpment faces which receive higher precipitation and display better quality groundwater. The less resistant mudrock rich lithologies tend to occupy topographic lows. It is evident therefore that lithology influences groundwater quality trends, if only by virtue of its influence on topography and hence precipitation.

The regional distribution of dissolved salts occurring in the study area can be explained as follows (assuming a similar process to that postulated by Tordiffe and Botha, 1981):

- Fresh groundwater is found in the elevated often more sandstone-rich high rainfall areas where recharge predominates.
- Groundwater travels along the regional flow path from these recharge areas toward the topographically low discharge areas that receive less precipitation, accumulating salts during the flow process.
- A trend of increasing ECs can therefore be expected as salts accumulate along the flow path from the topographic highs to the low-lying areas.
- Evaporation and evapotranspiration by phreatophytes growing in topographic lows can result in further concentration of ions in these topographic lows.

4.6.1.1 Local cases of high nitrate and fluoride levels.

It is not possible to produce contour maps of nitrate and fluoride concentration for the study area, as sampling points are too widely scattered across the region. It must be emphasised therefore that the points highlighted in Fig 26. do not represent the only places where high nitrate or fluoride occurs in the area. In addition there may be other potentially harmful constituents present that have not been highlighted on the map.

Nitrate

High nitrate content of groundwater can be a health risk - particularly for infants as they are susceptible to methaemoglobinaemia commonly known as “blue baby syndrome”. Excessive nitrate in this instance causes a reduction in the oxygen carrying capacity of the blood and can lead to death. Fig. 27 is a frequency histogram for nitrate analyses available on the National Groundwater Data Bank (NGDB).

Eight percent of analyses available for the study area exceed the 10 mg/l maximum limit for insignificant risk (SABS, 1984). The localities of these elevated nitrates are shown in Fig. 27. An investigation by the author into the incidence of high nitrates in groundwater to the north of East London revealed that inadequate precautions in the design of cattle watering points were the likely cause - resulting in fecal pollution of the water (Plate 5). It is likely that similar point pollution sources are responsible for the scattered high nitrates across the area.

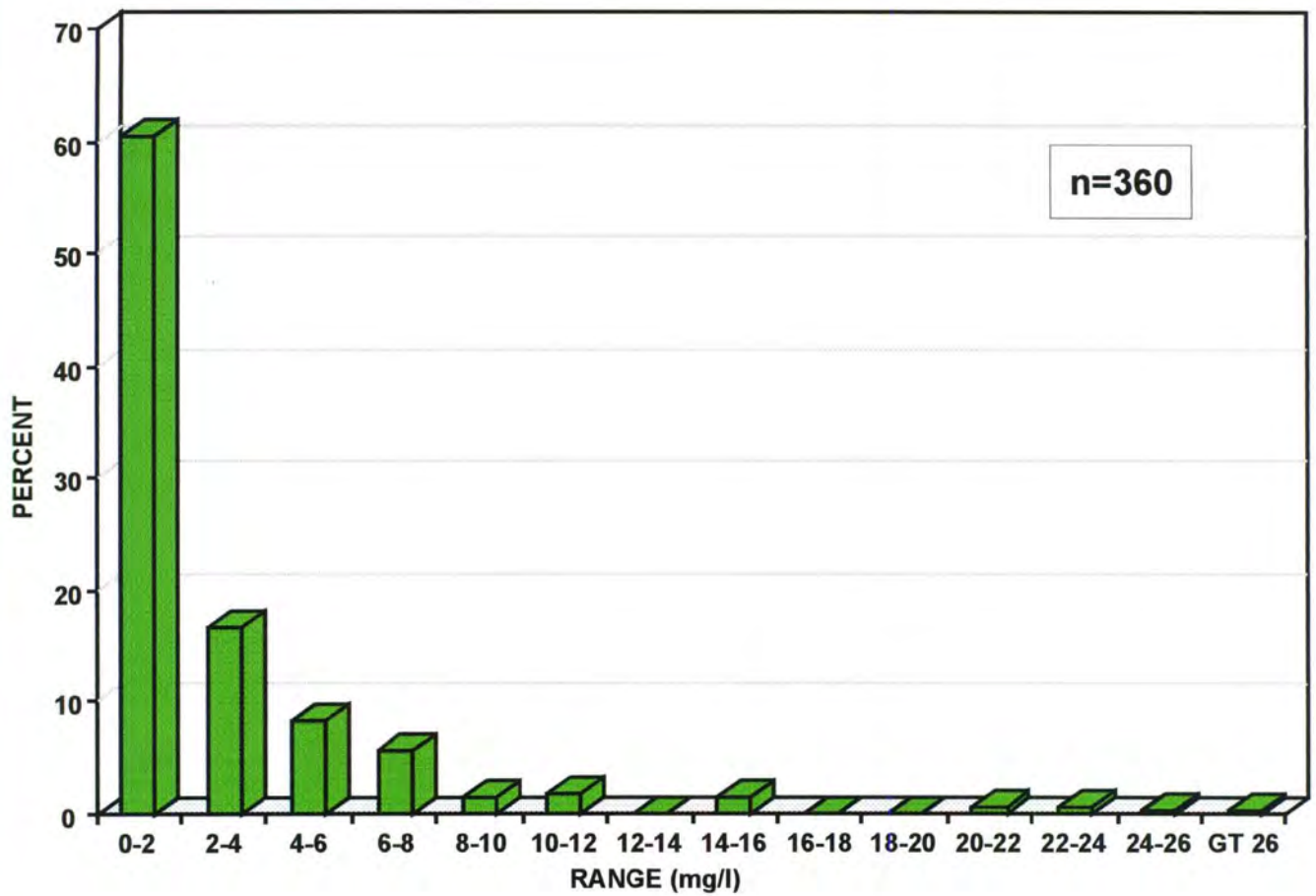


Fig. 27: Frequency distribution histogram of nitrate concentrations.

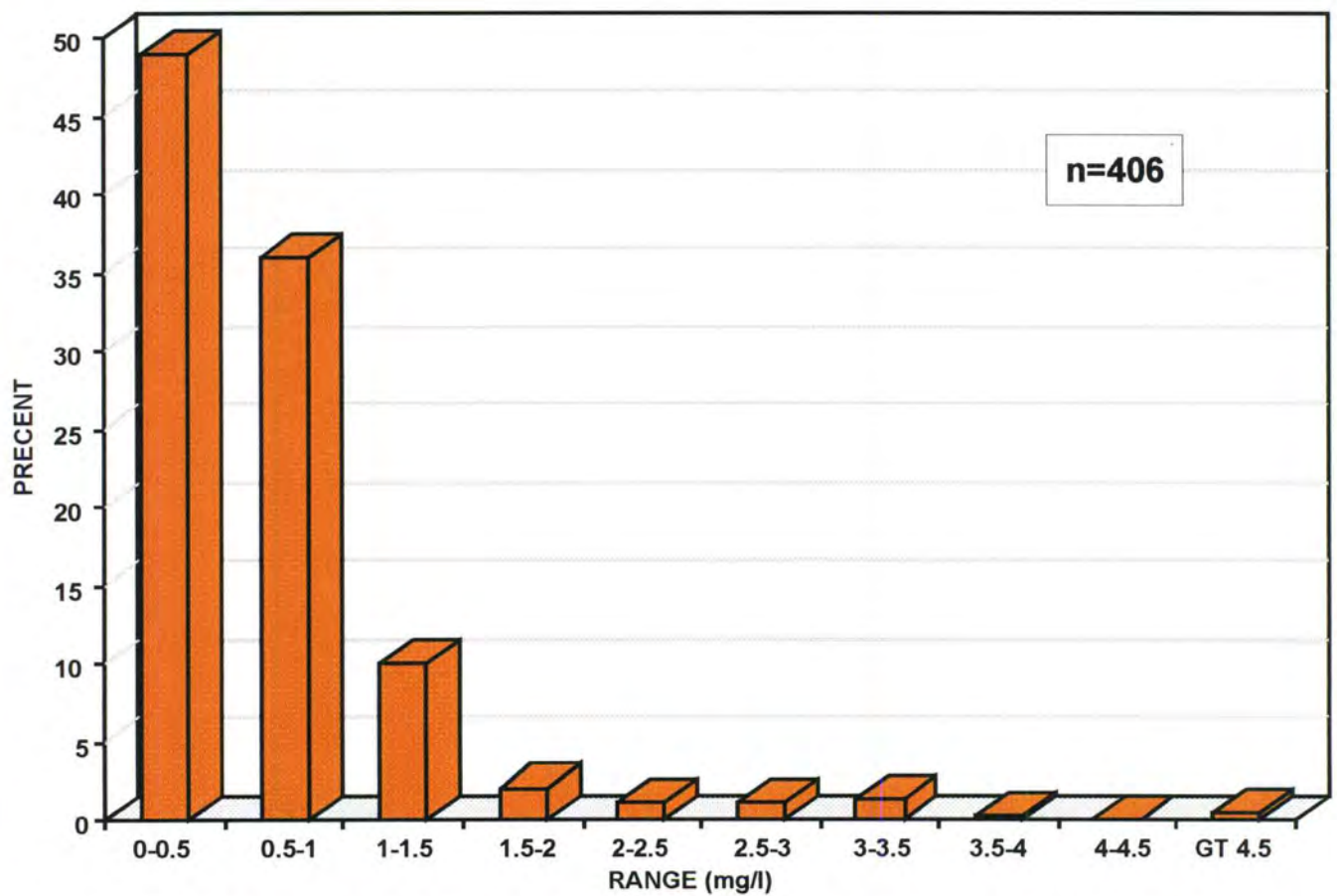


Fig. 28: Frequency distribution histogram of fluoride concentrations.



Plate 5: A borehole which had to be abandoned due to nitrate pollution from cattle excrement (the cattle drinking trough is situated too close to the borehole and the borehole itself is inadequately sealed at surface by the too small concrete block).

Downward leaching of nitrogenous fertilizer is another likely nitrate contributor, especially where intensive crop farming is practiced to the south west of Queenstown. An additional nitrate source in that vicinity is the treated municipal sewage water, which is used for irrigation.

Fluoride

Fig. 28 is a frequency distribution plot of fluoride concentration for analyses available in the NGDB, the highest recorded fluoride content being 5.6 mg/l.

Fluoride is utilized by higher life forms in the structure of bones and teeth (Hem, 1970). Although fluoride in drinking water protects against dental caries (Underwood, 1971), higher concentrations induce dental and skeletal fluorosis, goitre and increased vertebral bone density (Mc Cafferey, 1995). Fluoride content exceeds the 1.5 mg/l SABS (1984) maximum limit for insignificant risk in seven percent of the available analyses boreholes, the localities of which are given in Fig. 26. The fluoride highs are most common in boreholes drilled into the Molteno Formation in the northern part of the study area. Fluoride is usually associated with acidic igneous rocks, and the probable granitic origin of the material which comprises the Molteno Formation sediments (Turner, 1975) could be a source of the elevated fluoride, which possibly accumulates in groundwater circulating in this Formation.

Gases associated with volcanism are an important source for fluoride in natural water (Hem, 1970) and therefore another possible explanation for the fluoride anomalies is the volcanic plugs which are relatively common at the Molteno Formation's stratigraphic level. A comparison of the distribution of high fluoride values in the Molteno Formation with the 1:250 000 published geological maps of the area reveals that although the anomalies do not co-incide with mapped volcanic plugs, they do indeed occur in their general vicinity. Fluoride highs are more likely to be expected in association with acidic volcanic plugs rather than the basic ones of the study area though. Additional work will be required to positively link fluoride occurrence with these volcanic plugs.

In the south-western part of the study area fluoride in excess of the 1.5 mg/l occurs in the Middelton Formation in the area folded during the Cape Orogeny. The literature reports that fluorine is a common constituent in thermal waters (Kent, 1969) and it is possible that these concentrations are related to deep-seated thermal water sources transported to shallow levels by upwelling

groundwater. The thermal spring associated with a prominent fold structure to the south of Fort Beaufort provides evidence that such upwelling is indeed taking place in this area. The fluoride concentration of this spring water is 13.2 mg/l (Kent, 1949) and the groundwater temperature 27⁰ C. Further evidence for deep groundwater circulation in the southern part of the study area is the presence of a remnant hot spring coinciding with fractures caused by folding 14 km west of East London (Nichols, 1990). This is indicative of historical upward migration of deeper groundwater.

4.6.1.2 Suitability for agricultural irrigation and animals

The structure of soils can be damaged if the hydrochemistry of the groundwater used for irrigation is unsuitable. If sodium in groundwater is excessive it will dominate ion exchange sites of clays, and can replace adsorbed calcium and magnesium nutrients in the soil. This exchange results in a soil structure breakdown, reducing soil permeability and infiltration rates. A measure of the hazard of damaging the soil structure can be obtained by calculating the sodium adsorption ratio (SAR) of the groundwater. This ratio for groundwater in the various lithologies is given on the Wilcox diagrams in Appendix 3a. The hazard in most lithologies is low but caution must be exercised toward the southern edge of the study area in the Adelaide Group - particularly with groundwater from the Middleton Formation (south of the Bedford - Fort Beaufort road) where the hazard is medium to high. A few samples exhibiting anomalously high SAR's occur in the Molteno Formation.

Salts dissolved in irrigation water can also accumulate in the soil over time causing salinization of the soil and declining crop yield. The potential for this to occur is greatest in areas where the dissolved salt concentration in the groundwater is highest – again the area at the southern edge of the Map. Problems associated with salinization can be managed by selecting salt tolerant crops and / or using specialised irrigation techniques such as drip irrigation.

Water from throughout the area can in general be used safely for stockwater. Poultry are at risk where ECs locally exceed the 460 mS/m limit (DWAF, 1993) at the southern edge of the study area.

4.6.2 Groundwater hydrochemical classification.

Water type can be classified using the Piper (1944) graphical technique. The water type is determined by the position a particular sample occupies on the diagram - a function of the relative proportions of the elements. The hydrochemical character of groundwater from the various lithologies is summarised using the Piper technique in Fig. 29. The graphs from which this diagram was derived are given in Appendix 3b.

Based on the Piper (1944) classification two main water types are present:

A Sodium Chloride / Sodium Bicarbonate type - occurring in the lower Beaufort Group (Middelton Formation) at the southern margin and at the along the coast in the east of the study area.

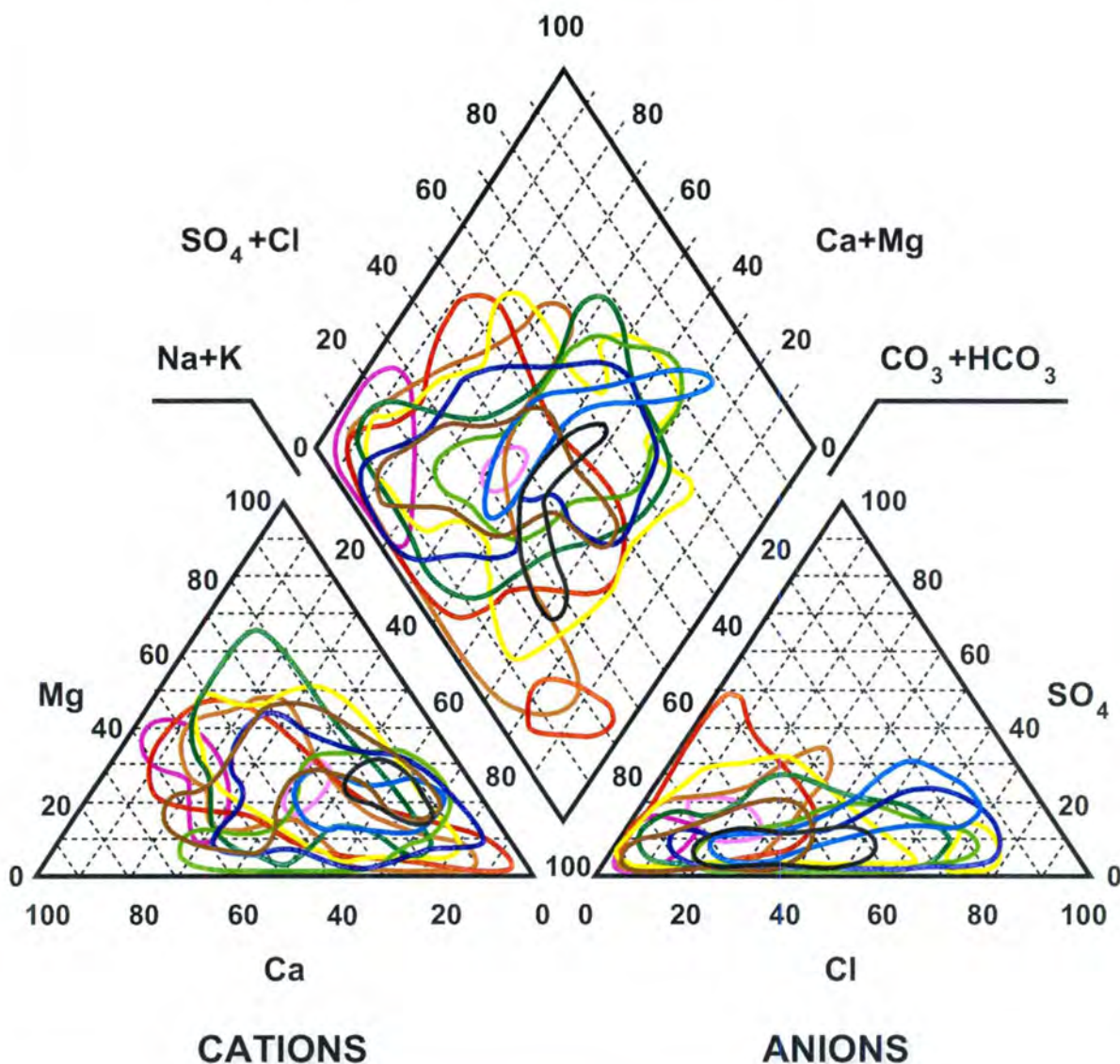
Calcium Magnesium Bicarbonate groundwater predominates for the remainder of the study area.

4.6.2.1 Sodium Chloride / Sodium Bicarbonate

Elevated sodium and chloride ionic concentrations occur along the coast and in the lower Beaufort Group along the southern margin of the study area. Tordiffe (1978 and 1981) suggested that a process of upward filtration of connate marine water originating in the Ecca Group shales contributes to the groundwater salinity in lower formations of the Beaufort Group but no study was done at that stage to verify this hypothesis.

A later investigation of chloride and isotopic relationships (Sami, 1992) in the Bedford vicinity however revealed that the chloride ions are of meteoric origin, and that the process was one of a period of evaporative enrichment of meteoric salts at or near the soil surface followed by periodic leaching of these accumulations into the groundwater during infrequent storm/recharge events. Sodium chloride (NaCl) is preferentially leached because of its high solubility, resulting in the NaCl type groundwater. It was found that meteoric sodium chloride contributes more than 90% of the dissolved sodium, except at low salinities where cation exchange process yield additional sodium in exchange for dissolved calcium and magnesium. At high salinity the process reverses with bound calcium and magnesium increasingly exchanged for sodium.

Piper Diagram



	<u>GROUP</u>	<u>SUBGROUP</u>	<u>FORMATION</u>	<u>LITHOLOGY*</u>	
KAROO SUPERGROUP	DRAKENSBERG		Clarens	basaltic lava	—
			Elliot	sandstone	—
			Molteno	mudstone, sandstone	—
	BEAUFORT	Tarkastad	Burgersdorp	mudstone/sandstone	—
			Katberg	mudstone, sandstone	—
		Adelaide	Middleton	sandstone, mudstone	—
			Balfour	mudstone, sandstone	—
	ECCA		Dwyka	mudstone, sandstone	—
				shale, mudstone, sandstone	—
				tillite	—
NATAL			quartzitic sandstone	—	

* Rock type in order of abundance

Figure 29: Composite piper diagram

The bicarbonate/chloride character of the groundwater near the east coast of the study area is typical of a coastal margin where the precipitation takes on some sea water character. Gorham (1955) showed that seawater and rainfall can display similar ratios of sodium to chloride and magnesium in coastal areas such as this. It is concluded therefore that proximity to the coast with accompanying atmospheric fall out is most likely responsible for the bicarbonate/chloride groundwater in the coastal margin study area.

4.6.2.2 Calcium Magnesium bicarbonate waters.

With the exception of the Middelton Formation and the north eastern coastal margin, groundwater of the study area is predominantly calcium, magnesium bicarbonate type with some sodium and chloride enrichment. This enrichment is most prevalent in the Burgersdorp, Katberg and Balfour Formations. These bicarbonate waters are indicative of active groundwater circulation (Johnson, 1974) with the sodium and chloride enrichment occurring through ionic exchange in the flow path.

5 GROUNDWATER DEVELOPMENT

5.1 Existing utilization

The General Hydrogeological Map shows areas of major groundwater abstraction using a circular symbol to denote total abstraction for a given quaternary catchment. Major abstraction includes agricultural irrigation (mainly in the Queenstown area - Plate 6), and municipal supplies (e.g. Tarkastad, Sterkstroom, Jamestown, Bedford, Komga). Symbols denoting abstraction on the map do not represent the actual point of abstraction, but rather the total annual abstraction of the quaternary catchment.

Groundwater is also used for domestic supplies and stockwatering in the rural areas. The use of groundwater by rural communities is relatively low per unit area as a result of the widely scattered population and low per capita consumption necessitated by distances from dwelling to water source. No attempt has therefore been made to estimate groundwater abstraction rates for rural use in this thesis.

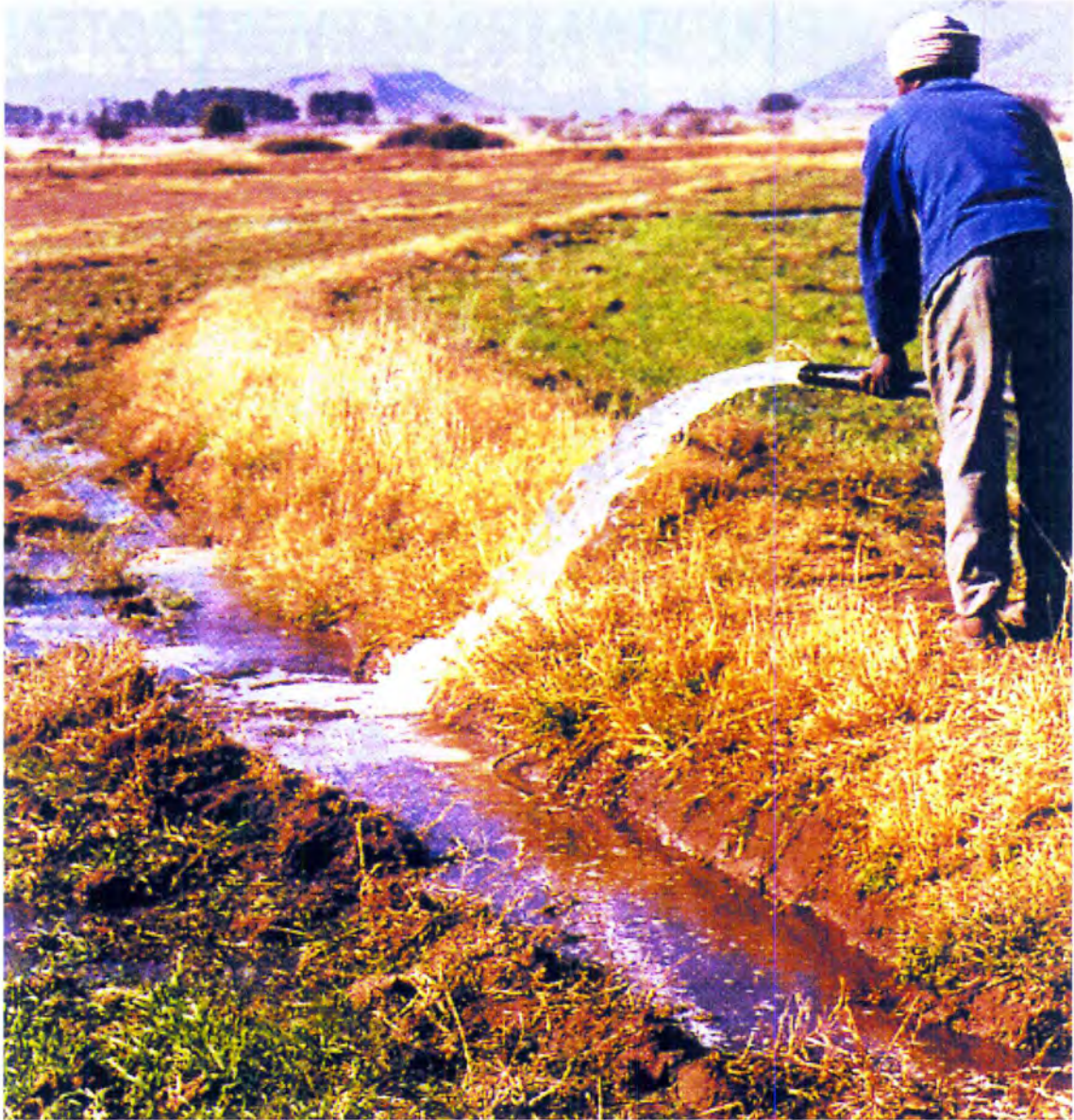


Plate 6: Flood irrigation from boreholes in the Queenstown area,

5.2 Groundwater potential

Two aspects concerning potential for exploiting the groundwater resources of study area are examined. Firstly the Harvest Potential which is defined as *the maximum volume of water which is available for abstraction on a long term basis without exhausting the resource*, and secondly the groundwater Development Potential which deals with factors affecting the volume practically abstractable.

5.2.1 Groundwater Harvest Potential

For the purposes of this study Harvest Potential is taken as the maximum sustainable abstraction rate *if only recharge and storage are the limiting factors* on exploitation. Determination of both these parameters is problematic and the subject of much current research. It should therefore be borne in mind that all volumes presented are estimates rather than precise calculations. The Harvest Potential for the bulk of the area is between 2 000 m³/km²/a and 80 000 m³/km²/a as shown in Fig. 30.

5.2.1.1 Recharge estimate

Recharge potential for the study area is given in Fig.31. In producing this map cognizance was taken of a guideline for recharge estimation in South Africa using chloride profiles (Bredenkamp et al., 1995) and recharge estimates by Sami and Hughes (1996).

Fig. 32 is a composite graph of rainfall versus recharge for various sites by the chloride profile method. A provisional estimate of recharge can be made from this relationship provided the mean annual precipitation is known (Bredenkamp et al., 1995). None of the research sites used to compile the graph are within the Queenstown map area, although Sami and Hughes (1996) used the chloride mass balance to estimate recharge near Bedford, which is within the study area. The result is therefore incorporated in Fig. 32 and the rainfall recharge relationship modified accordingly as shown

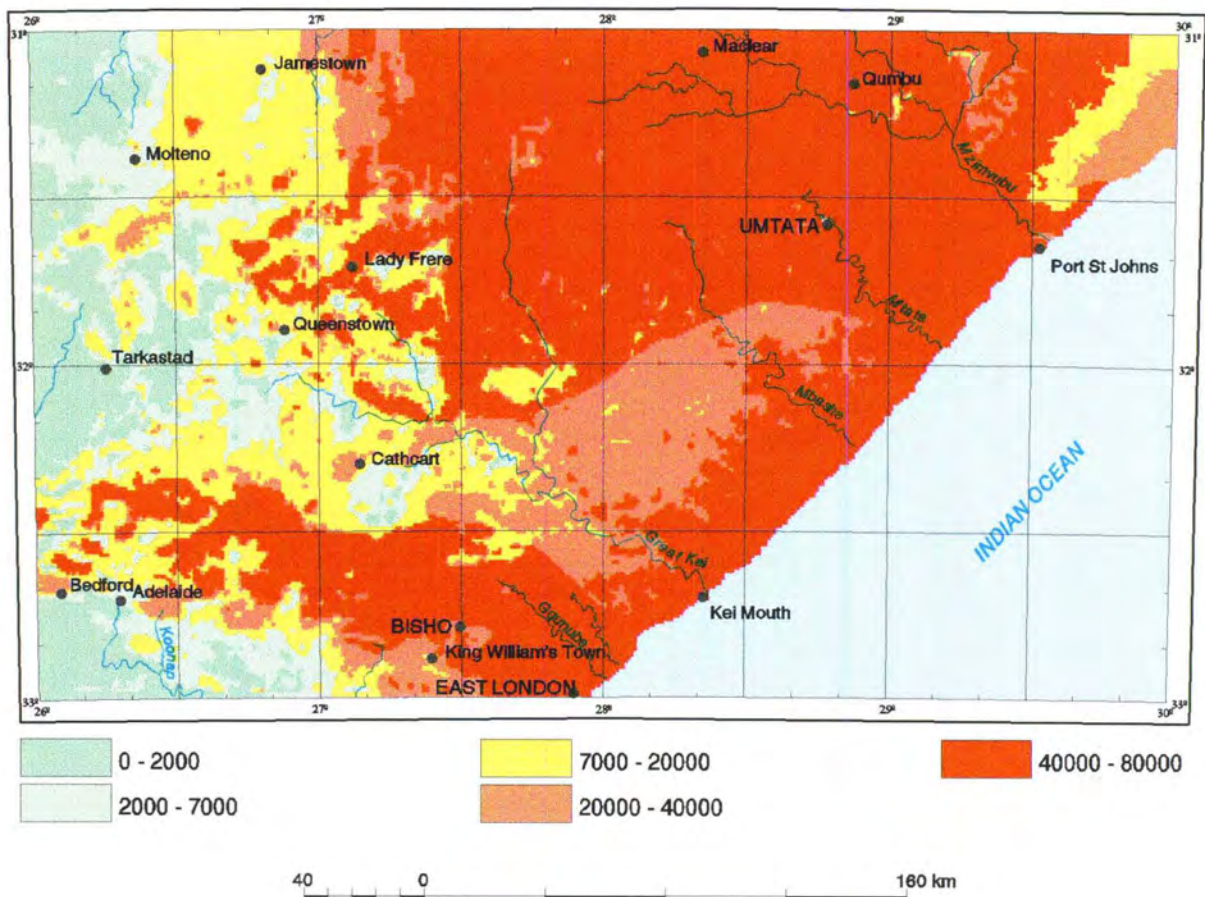


Fig. 30: Groundwater harvest potential ($m^3/km^2/annum$).

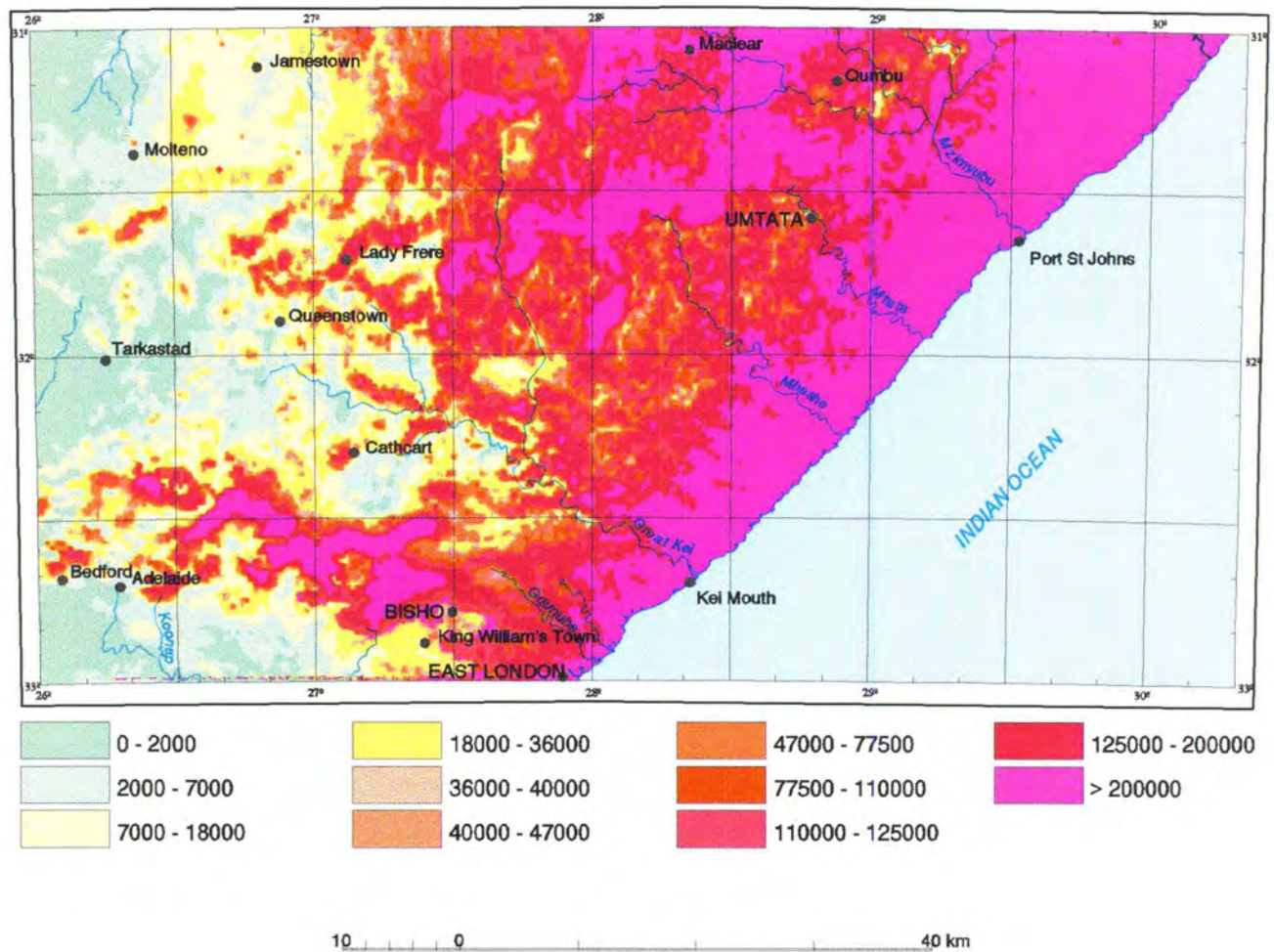


Fig. 31: Mean Annual Recharge Potential (m³/km²).

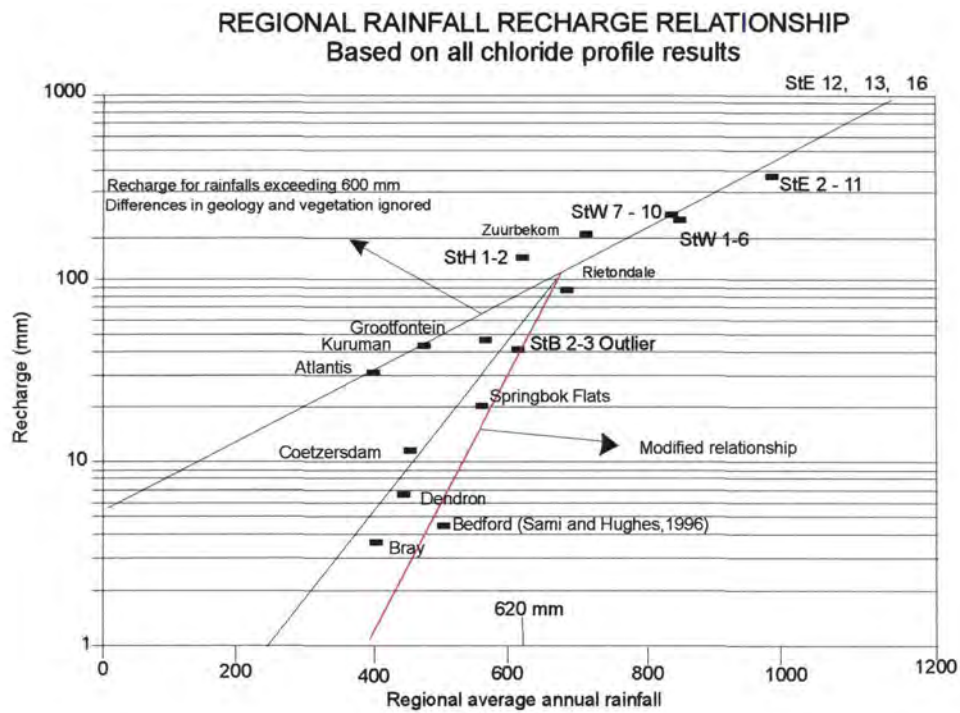


Figure 32: Composite graph portraying relationship between average rainfall and recharge from chloride profile results (modified after Bredenkamp et al., 1995).

The modified relationship was used to estimate recharge for the Queenstown (3126) map region by reading off the graph the expected recharge for particular rainfall ranges. The recharge map was compiled by applying the ranges so obtained to the precipitation map. Use of the unmodified Bredenkamp et al. (1995) rainfall-recharge relationship would have resulted in higher recharge estimates, particularly in the drier parts the area.

5.2.1.2 Storage estimate

Groundwater storage per km² is given in Fig. 33. This volume was calculated as follows:

$$\text{Storage} = S \times T \times A$$

Where:

S = storativity

T = aquifer thickness

A = area

According to Vegter (1995) storage coefficients for fractured and decomposed to partially decomposed sedimentary hard rock and igneous rock range from 0.001 to 0.01. Typical storativity values obtained for Karoo aquifers are given in Table 8.

Table 8: Typical storativity values for Karoo aquifers (after Sami and Muray,1997).

Locality	Storativity	Method	Reference
Dewetsdorp	0.004	Water balance	Bredenkamp et al., 1995
De Aar	0.004	Water balance	Bredenkamp et al., 1995
Beaufort West	0.001 - 0.007	Pumping test	Bredenkamp et al., 1995
Oviston	0.0014 - 0.0049	-	Geological Society S.A.(1993)
Kestell	0.000011-0.0047	-	Geological Society S.A.(1993)
Queenstown	0.000033-0.0048	Pumping test	Vandoolaeghe (1980)

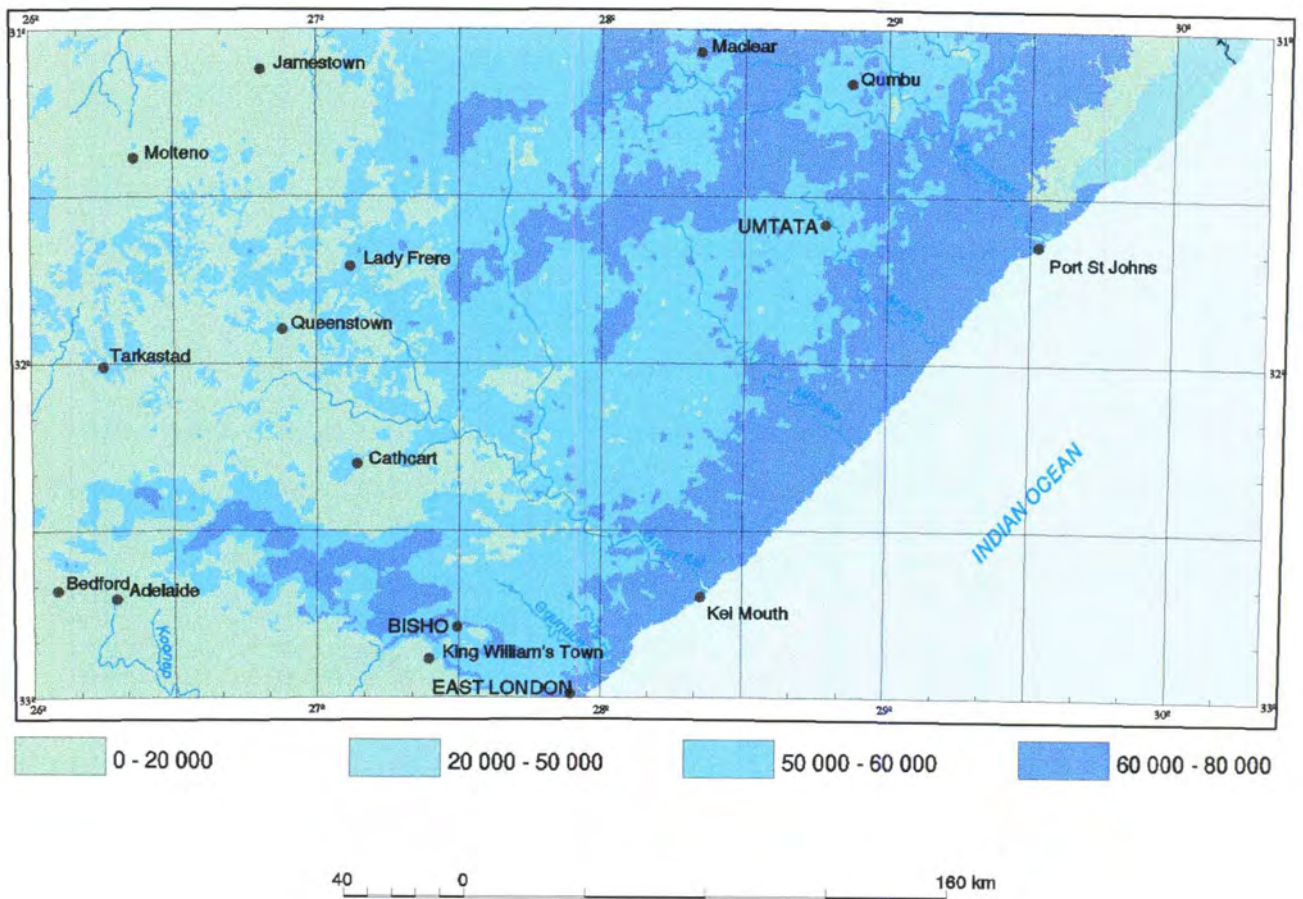


Fig. 33: Groundwater storage (m^3/km^2).

Storativities can in general be expected to be higher in the more intensely-weathered / decomposed rocks in the eastern part of the study. Cognizance is taken of this storage variation by applying a sliding storativity range to the area as follows:

- 0.001 to Karoo aquifers to the west of the 600 mm p.a. precipitation contour but 0.003 where alluvium covered,
- 0.003 to Karoo aquifers receiving 600 to 800 mm precipitation per annum,
- 0.004 to Karoo aquifers receiving > 800 mm precipitation per annum,
- 0.001 to all Karoo aquifers where dolerite is absent/rare, irrespective of precipitation.

The aquifer thickness is estimated from water strike information for the study area as well as approximations made in the literature. Aquifer thickness (T) is taken as 20m based on analysis of depths to water strike (section 4.4), the fractures (water strikes) to this depth generally being more frequent and permeable than deeper subsurface. A large proportion of the groundwater will therefore be stored in this upper 20 metre thick zone.

This thickness roughly concurs with estimates made by other researchers. Vegter (1995) on the National groundwater map recommends drilling 20 - 30 m below groundwater level in the study area. In addition Kirchner et al. (1991) maintain that Karoo aquifers are generally in the order of 20 - 25 m thick.

Insufficient data are available for an analysis of the optimum drilling depth for the Natal Group sandstone. A storativity of 0.001 and aquifer thickness of 50 m is assigned to this lithology based on information from the National Saturated Interstices map (Vegter, 1995).

The storage volume per km² is required - the area (A) is therefore taken as 1 km².

5.2.1.3 Available storage to cope with drought periods

Aquifer storage must be sufficient to tide across drought cycles. As a safety factor the estimated storage (Fig. 33) is divided by drought length to obtain an available storage per annum to account for drought years (Fig. 34). For the purpose of this study a drought year is defined as occurring when a year (Jan-Dec) receives less than one standard deviation from the mean long term rainfall based on a minimum rainfall record of 30 years (Louw, E., 1998, *pers. comm.*).

5.2.1.4 "Available" storage plus drought recharge

During drought it is not necessary to totally rely on storage because the precipitation during drought will provide at least some recharge. The recharge during drought is therefore added to the "available storage" (Fig. 35). The precipitation per annum during drought was determined by dividing the total precipitation during drought by drought length in years. Drought recharge was then determined for this precipitation using the rainfall recharge relationship in Fig. 32 in a similar manner to the recharge as outlined the above section entitled "recharge estimate". In this instance however the rainfall during drought was used instead of the mean annual precipitation.

The lesser of the calculated recharge (Fig. 31) and available storage plus drought recharge (Fig. 35) is taken as the Harvest Potential. (Fig. 30).

5.2.2 Groundwater development potential

5.2.2.1 Factors restricting development

In most instances it is unlikely that the full Harvest Potential will be abstractable. The potential to fully develop the resource is restricted by a complex interplay of local factors including:

- Transmissivity/interconnectivity of fractures. The extent to which a resource can be developed depends on the rate at which boreholes can extract the groundwater on a long-term basis. This volume is limited by the rate at which groundwater can flow toward points of abstraction, and is proportional to the interconnectivity of fractures or extent to which fractures are supplemented from the porous matrix of microfissures.

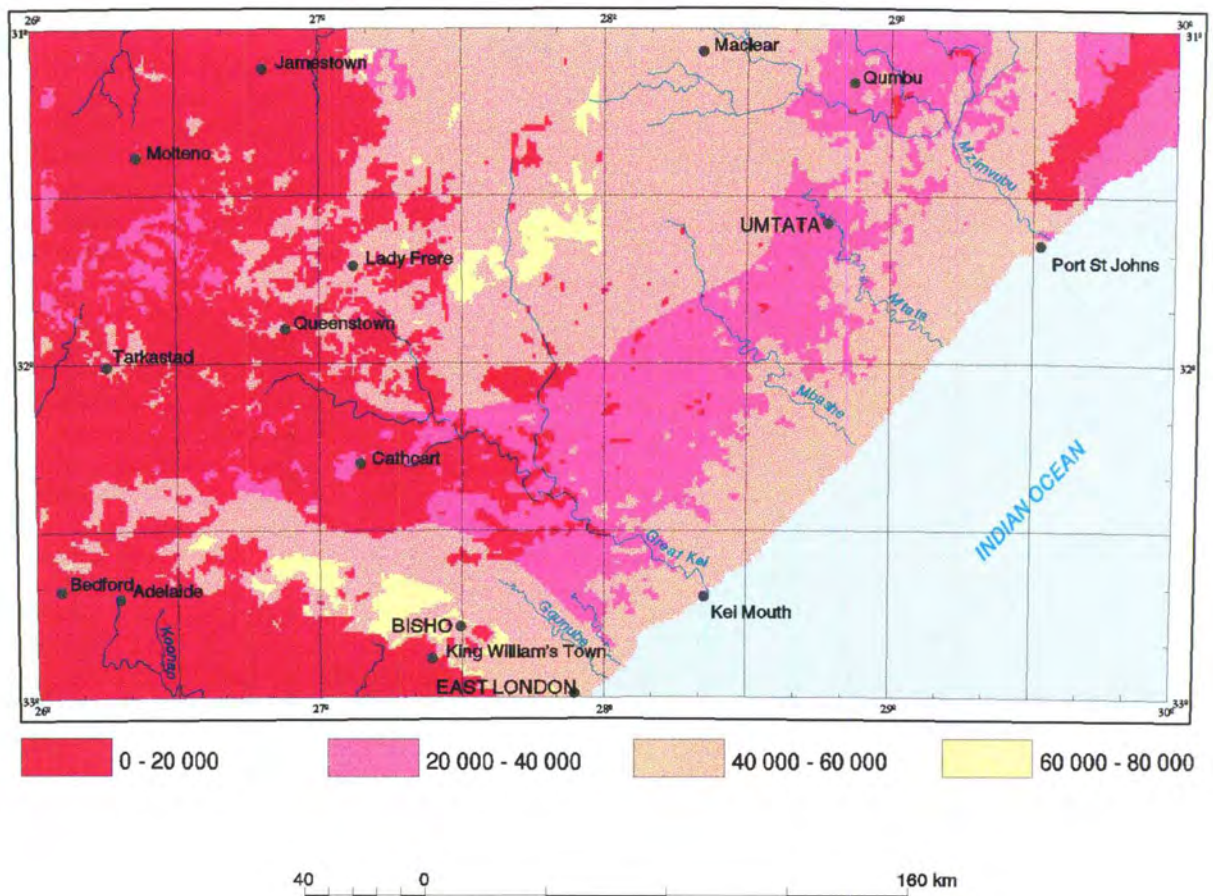


Fig. 34: Available storage ($\text{m}^3/\text{km}^2/\text{annum}$).

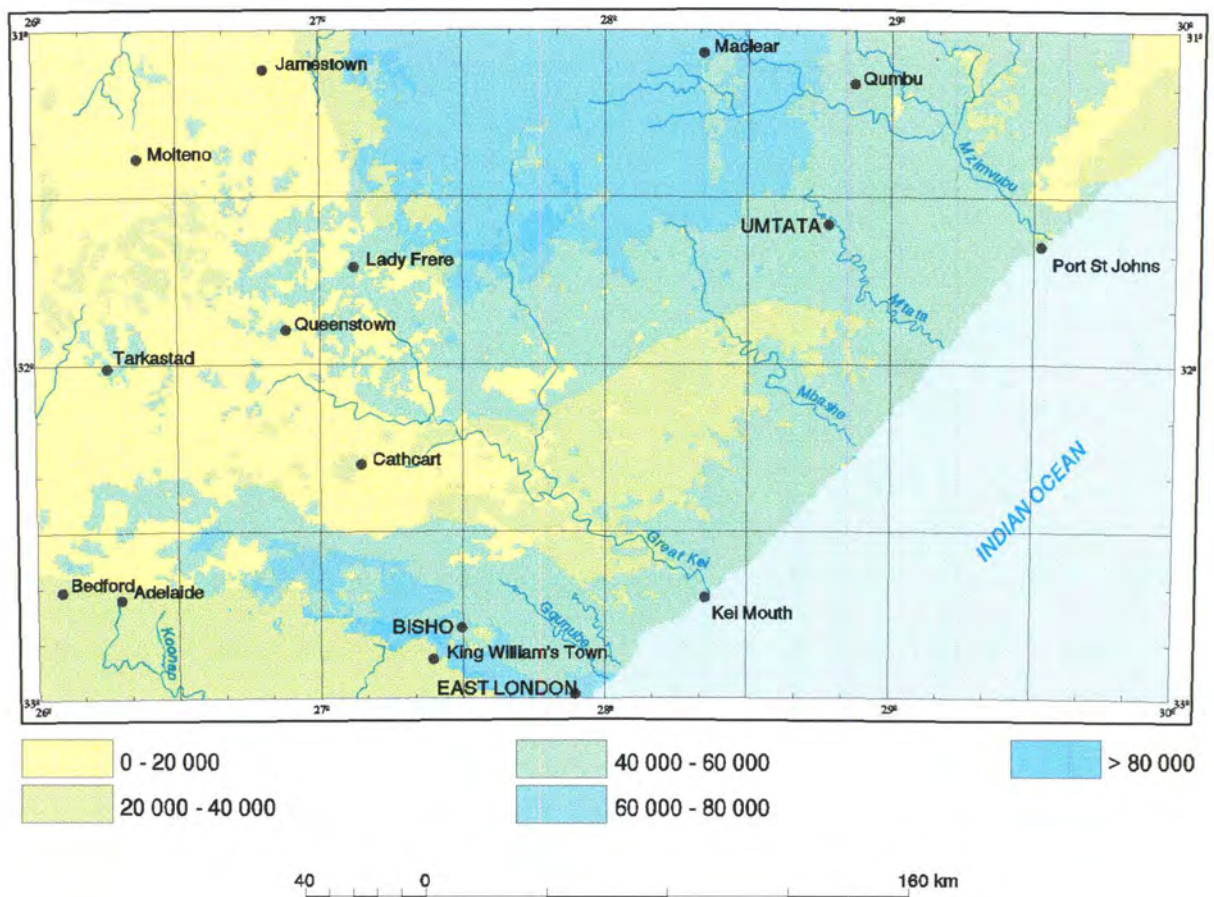


Fig. 35: Available storage plus drought recharge ($\text{m}^3/\text{km}^2/\text{annum}$).

- Borehole density. For a given transmissivity, low-yielding, closely spaced boreholes permit a higher recovery than high yielding, widely spaced boreholes (Seward et al., 1996). The lower recovery in the latter instance results from local dewatering in the vicinity of the borehole (causing the borehole to “dry up”) while there is little drawdown in the aquifer at some distance from the borehole. In this way only part of the groundwater available for abstraction can be recovered. Closely spaced low yielding boreholes on the other hand result in a more even lowering of the water table throughout the aquifer and a higher groundwater recovery.
- Density of drilling targets available in the area. An abundance of targets evenly distributed across an area will represent a favorable situation for full development of the resource because the possibilities for capturing the resource are greater. Lower recovery is expected if there are a limited number of targets or if they are closely concentrated within a small portion of the area.
- Accessibility for drilling equipment. As a rule the more rugged the terrain the lower the development potential due to the smaller the proportion of the area which can be practically accessed for drilling. This can be offset by the greater number of springs expected in rugged terrain receiving high precipitation.
- Economic factors. The cost associated with developing a groundwater scheme involves both fixed and recurrent costs. Fixed costs relate to the initial exploration, data collection and analysis, drilling, construction, test pumping, equipping and pump installation. The cost of the pumping device to raise the groundwater to surface for distribution depends on the required discharge and pumping head. These costs depend on the geology, type of drilling equipment required, well diameter, aquifer depth formation productivity, rest water level, discharge required, and energy sources. Each system must be individually examined because costs will vary according to local physical and socio-economic conditions (Sami and Murray, 1997). The cost of providing a borehole of specified yield depends on the number of boreholes that must be drilled to supply groundwater at that delivery rate. This depends on the local drilling success rate, for example costs will be much lower if at a particular locality there is good potential for strong boreholes requiring only shallow drilling.

- The recovery of all the available water on a regional scale is dependent on financial resources to establish the required number of boreholes. The more profitably groundwater can be used the more finance is likely to be available for establishing greater number of abstraction points - thereby permitting higher recovery. For example an abundance of arable land will permit crop production and a return on the capital outlay - this can then be invested in further development of the resource. Low financial returns on supply established for purely subsistence purposes will on the other hand limit further development.
- Water quality. This can restrict the use to which groundwater can be used. Hydrochemical analysis should be carried out on all groundwater to establish whether concentrations of the various elements comply with SA Water Quality Guidelines (DWAF, 1993) for the intended use.

From the above it can be seen that development potential depends on local hydrogeological conditions as well as available finance. This kind of detail is not entered into in this study although a crude estimate of the development potential at a regional level is made using a combination of typical borehole yield and Harvest Potential.

5.2.2.2 Possibilities for additional development

The Abstraction Potential (Fig. 36) for the various hydrogeological regions is calculated by assuming that it is possible to establish a borehole yielding the median yield every km² pumping for 12 hours per day. This abstraction will not be sustainable though if the Harvest Potential is exceeded. The lesser of the Abstraction Potential and Harvest Potential is therefore taken as the Development Potential (Fig. 37).

The population support capacity (a term used by planners for the number of people that can be supplied by water per km² assuming a particular consumption rate) for rural and urban supply situations are given in Figs. 38 and 39 respectively. For the rural situation a water requirement of 25 l/person/day is assumed and 200 l/person/day is assumed for urban populations.

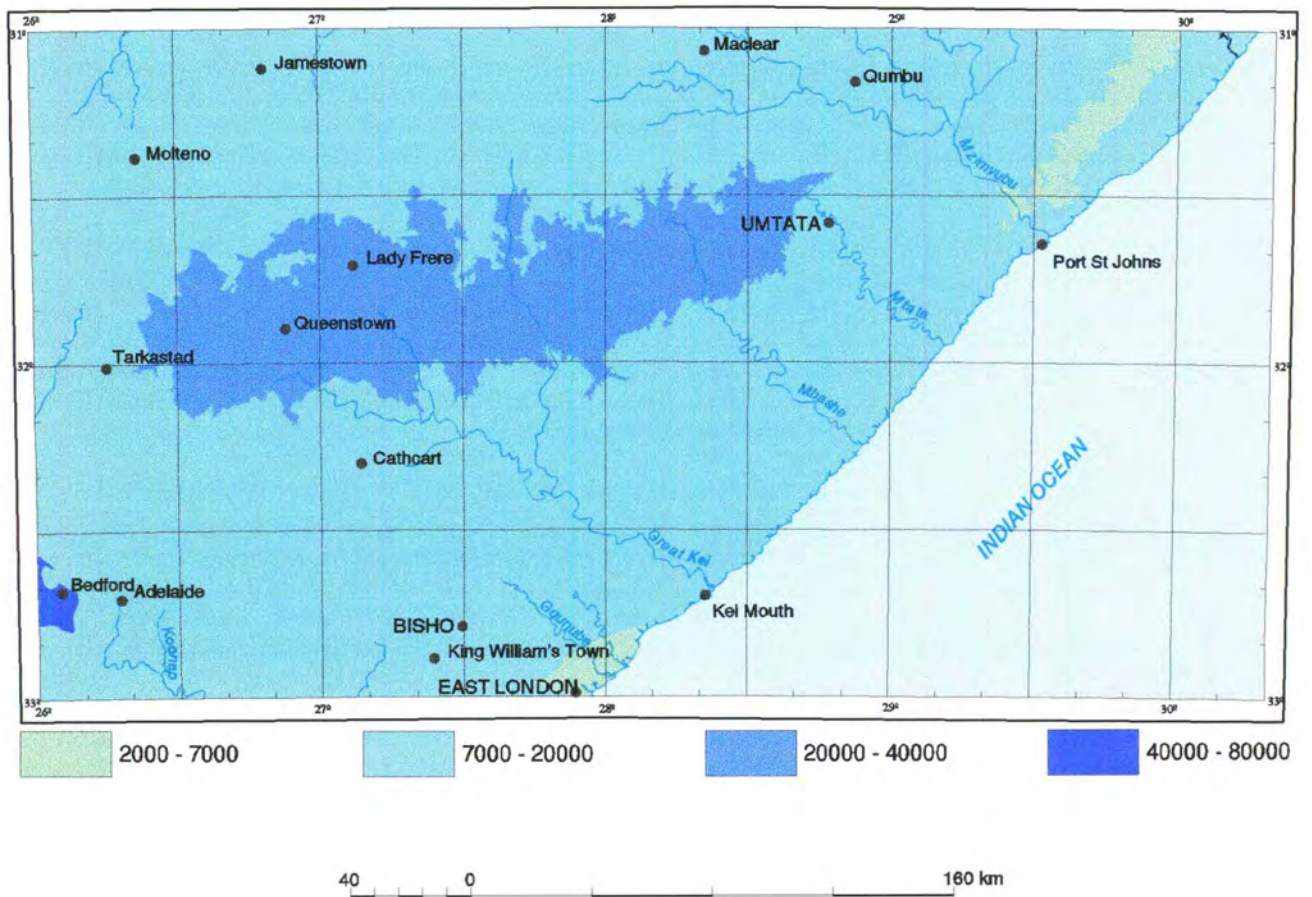


Fig. 36: Groundwater abstraction potential ($\text{m}^3/\text{km}^2/\text{annum}$).

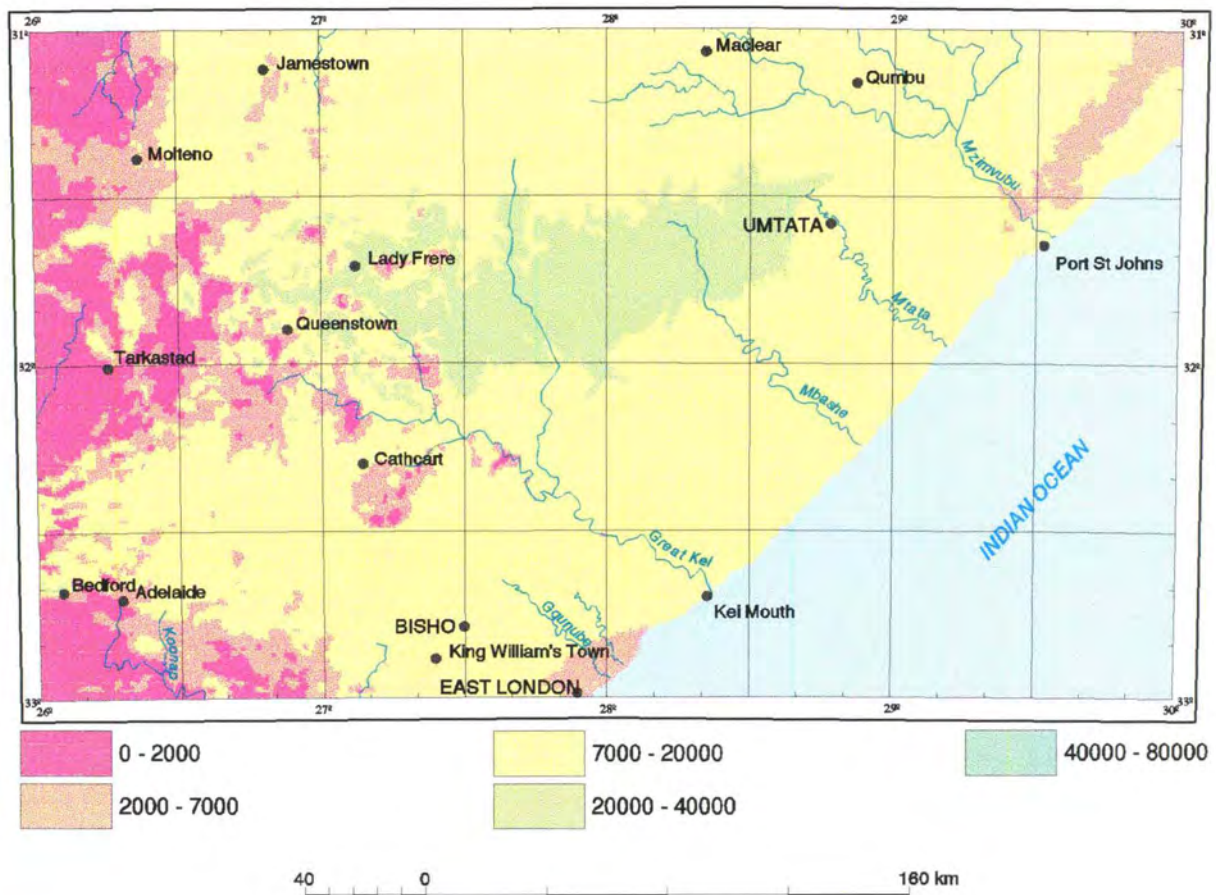


Fig. 37: Groundwater development potential ($\text{m}^3/\text{km}^2/\text{annum}$).

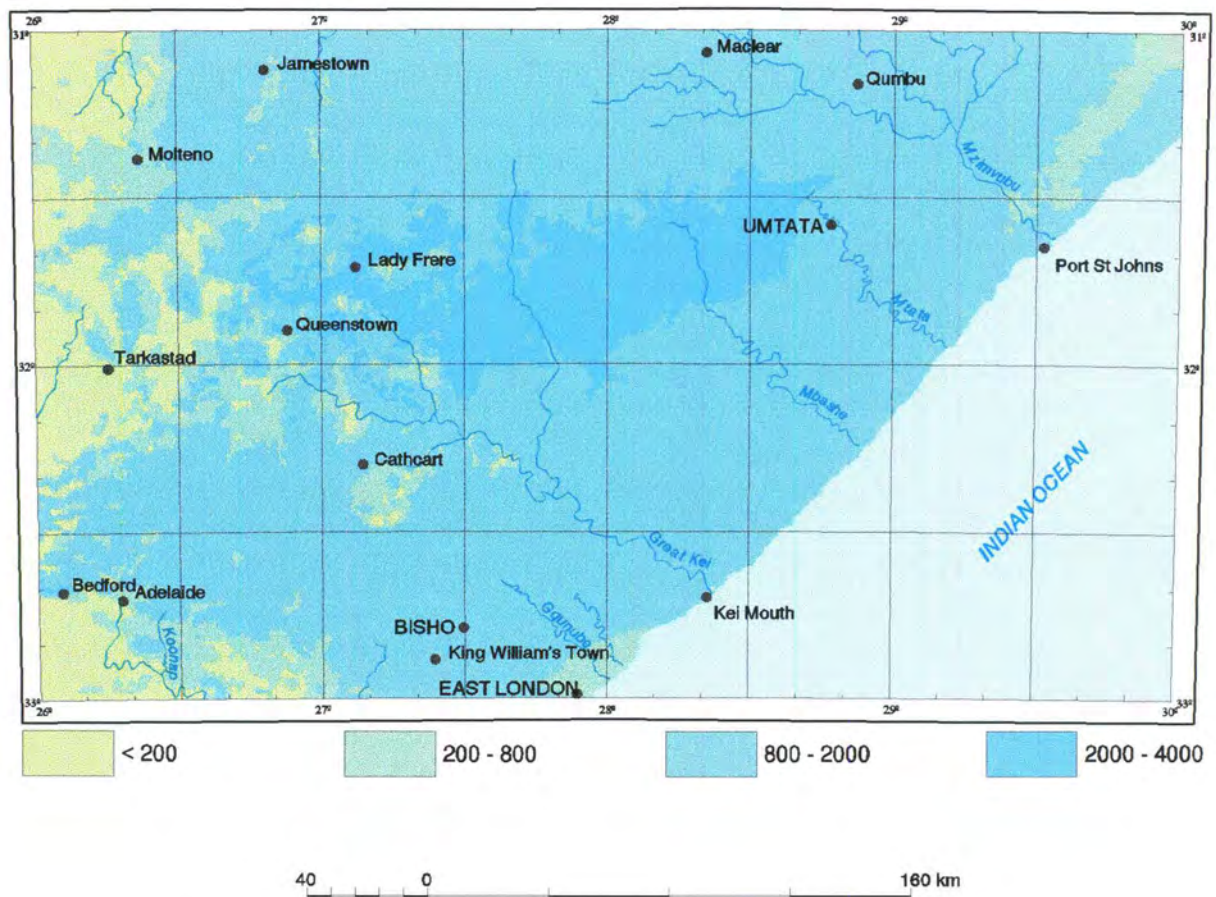


Fig. 38: Rural population support capacity (persons/km²).
 assumes 25 l/person/day required

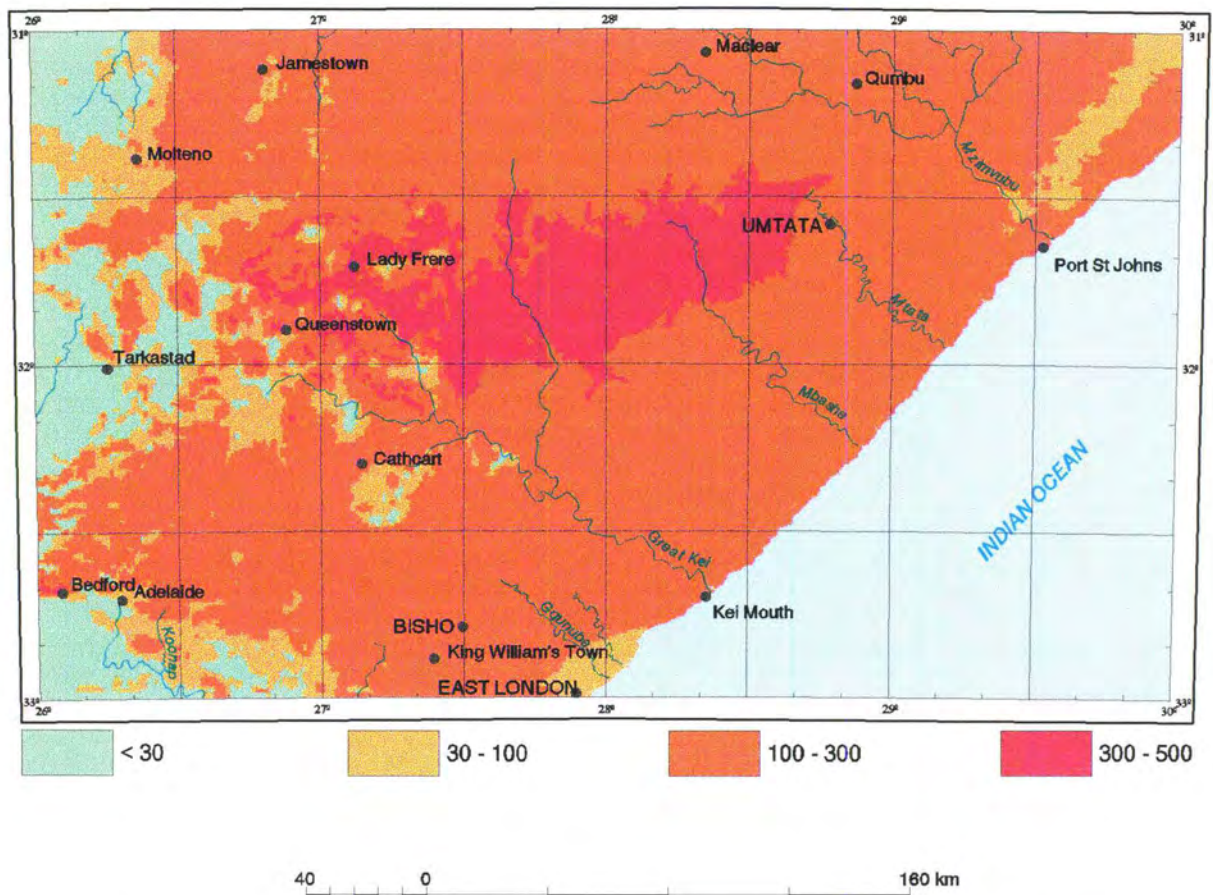


Fig. 39: Urban population support capacity (persons/km²).
 assumes 200 l/person/day required

5.2.2.3 Risk of over-exploitation

Although as a general rule over-exploitation is possible in any area where potential demand exceeds supply, most caution must be exercised in areas where Development Potential (what can be abstracted practically or economically) exceeds the Exploitation Potential (what may be abstracted sustainably). Areas where this situation is most likely to arise are shown in Fig.40.

The south-western part of the map (Bedford area) is such an example. Here the boreholes yields are among the highest for the mapped area, with a median of 5 ℓ/s (or 79 000 $m^3/km^2/a$ assuming one borehole is established per km^2 pumping 12 hours per day) but the harvest potential for this same area is the lowest for the study area (2 000 $m^3/km^2/a$).

Most irrigation from groundwater is carried out in the Klaas Smits catchment located roughly in the area between Tarkastad, Molteno and Queenstown. Given the high Abstraction Potential of this area there is a risk of over-exploitation and steps need to be taken to ensure that the groundwater resources of this area are adequately managed. Based on figures for this catchment obtained from the Upper Kei Basin study (KBCE, 1993) the average groundwater abstraction is 3 200 $m^3/km^2/a$ whereas the Harvest Potential (Fig. 30) for this same area varies from less than 2 000 $m^3/km^2/a$ in the south-western parts to 40 000 $m^3/km^2/a$ in the north-east, but on the whole ranges from 2 000 $m^3/km^2/a$ to 20 000 $m^3/km^2/a$. Based on the average groundwater abstraction this catchment (3 200 $m^3/km^2/a$) it is unlikely that the groundwater resources are currently being over-exploited at the catchment scale. However groundwater use is not evenly distributed in this catchment and there is a possibility that in specific portions exploitation rates exceed the sustainable yield. More detailed study will be required to determine whether local scale dewatering is indeed occurring.

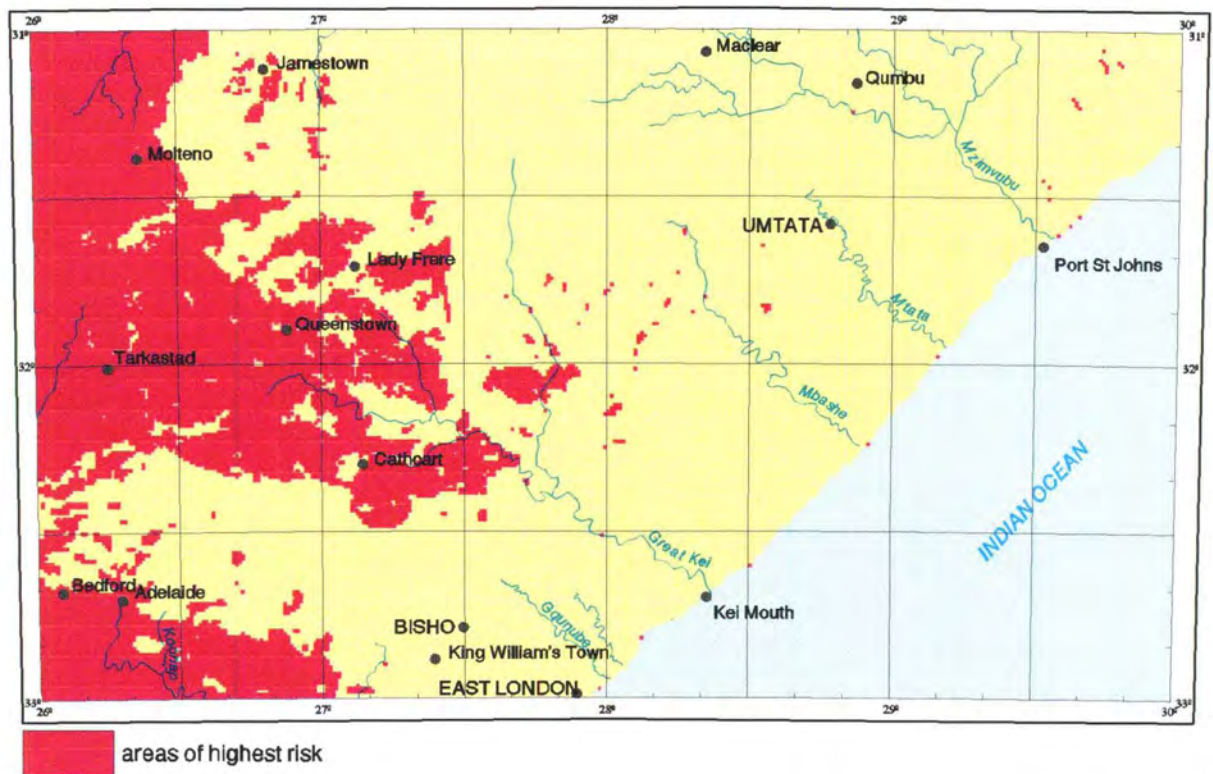


Fig. 40: Groundwater over-exploitation hazard.

5.3 Borehole siting techniques

5.3.1 Recommended approach

Borehole siting should involve firstly a desk study where available geological maps, aerial photographs and satellite images are examined to ascertain the hydrogeological setting and to home in on the most promising drilling sites. This is followed by field proofing of features identified on aerial photographs and satellite images and hydrocensus during which historical degree of success on geohydrological features in the area is ascertained. This information, plus examination of the geology at the most promising sites will allow prioritization of possible drilling sites. If necessary additional information can then be obtained using geophysical techniques.

5.3.2 Geophysics

Geophysical techniques measure variation in space of natural (magnetic) and induced physical (electromagnetic) fields. These variations result from the varying nature of the physical properties of the rocks, which can indicate the presence of water. In the study area the magnetic susceptibility and electrical conductivity are the most commonly measured geophysical properties.

5.3.2.1 Geophysical methods

Although a wide variety of geophysical techniques exist, only field methods applicable to, and in common use in the Queenstown (3126) Map region, are introduced below:

Magnetic method

The magnetic geophysical method measures the strength of the Earth's magnetic field and is the most commonly used in the study area. The magnetization of rocks is due partly to induction (induced magnetization) in the earth's field and partly to their permanent (remnant) magnetization. The induced intensity depends primarily upon the magnetic susceptibility of the rocks and magnetizing field, and the permanent intensity depends on the geological history of the rock (Parasnis, 1972). The susceptibility of rocks is almost entirely controlled by the amount of ferromagnetic minerals, their grain size, mode of distribution etc, and is extremely variable.

Although there is great variation in susceptibility values, even for a particular rock, and wide overlap between the types, sedimentary rocks have the lowest average susceptibility (0 - 1660 emu) and basic igneous rocks the highest (100 – 3 000 emu) (Telford et al., 1976). Both igneous and sedimentary rocks possess permanent magnetization to varying degrees. This magnetization is acquired on cooling of the ferromagnetic constituents from high temperatures and orientation reflects that of the geomagnetic field present at the time. As a result the induced magnetism is the same direction as the earth's magnetic field whereas remnant magnetism need not be and can even be opposite.

Electrical resistivity method

The electrical resistivity method makes use of the inverse of electrical conductance of rocks. In most rocks conduction by minerals is insignificant, with current flow being electrolytic (i.e. by ions), hence less resistive zones are indicative of water saturated formations. This method is useful in groundwater investigations because conductivity of the underlying rocks is usually a function of the pore / fracture volume and of the conductivity and amount of water filling the fractures. In the electrical resistivity method four electrodes are inserted at points along a profile on the surface of the ground. Electrical current is forced into the ground through the outer two electrodes, and the potential difference caused by the current is measured between the inner two electrodes. By altering the electrode spacing (depth sounding) it is possible to measure variations in rock conductivity (or effective resistivity) with depth. A vertical structure can be located by systematically shifting the electrodes along a traverse line but maintaining a constant spacing (horizontal profiling).

Electromagnetic method

The electromagnetic method is becoming an important alternative to resistivity methods in recent years due to the greater mobility, deeper penetration and higher resolution (Botha, 1992). It is used for location of major fractures, and for locating and detecting saline water. It is a combination of electrical and magnetic techniques and is usually used for profiling. The method entails generating an alternating current in a transmitter coil, which produces a magnetic field. This field induces small electric currents in the earth in turn generating a secondary magnetic field, which is measured by a receiver coil. The induced field is a function of coil spacing, instrument operating frequency and ground conductivity. The ratio of the secondary to the primary magnetic field is linearly proportional to the ground conductivity. Hydrogeological variations can be inferred from the conductivity changes.

There are two categories of electromagnetic technique (Botha, 1992) namely:

- the frequency domain (FDEM),
- time domain (TDEM).

In the case of the FDEM technique a sinusoidal current is transmitted through the source loop inducing a secondary current flow in the subsurface. In the TDEM method instead of a sinusoidal source current, a step function is used. During half of the step function cycle no current flows in the source loop. In the absence of the source current, induction currents decay back to zero. The rate of decay is a function of geo-electric parameters of the rock material. It is the decay rate, which is measured in the TDEM method. The major difference between the FDEM and the TDEM methods is the penetration depth that can be achieved, with the TDEM method penetrating much deeper (Botha, 1992).

5.3.2.2 Applications of geophysical techniques

No one geophysical technique is applicable to all modes of groundwater occurrence. A particular technique is usually most suited to exploring a specific aquifer type and will therefore mainly be used for that particular target. (e.g. magnetic techniques are most suited to exploration for groundwater occurrence associated with magnetic dolerite, and therefore almost exclusively used for that purpose). Because the techniques are target specific, comparison of the success rates for siting high yielding boreholes using various geophysical cannot be made for a particular target type. (For example the magnetic technique cannot be compared to the resistivity technique in locating groundwater associated with dolerite, because the latter method is rarely used in this case). An overview of the variety of techniques applicable to siting boreholes in the various aquifer types found in the study area is given below:

Alluvium

The aquifer geometry is required in order to assess the volume of stored groundwater. Palaeochannels incised in the bedrock are targets. In some cases these can be inferred from vegetation changes on air photographs and satellite images. To define the bedrock profile, depth sounding using the resistivity geophysical technique can be employed.

Dolerite intrusions / contact zones

In the study area groundwater is most often associated with the contact zone between the dolerite and the sedimentary host rock and the magnetic geophysical technique is most appropriate. This method is successful in delineation of dolerite intrusions because of the marked difference in magnetisation between the dolerite and the sedimentary host. The low magnetic susceptibility of sedimentary rocks versus the generally high susceptibility of dolerite due to the higher magnetite content causes local variation in the magnetic field strength of the earth.

Over the past 50 years magnetic surveys have proven to be the most efficient way to trace dolerite intrusions in South Africa (Woodford et al., *in press*). Enslin (1950) carried some of the earliest magnetic geophysical work in the Karoo rocks, using magnetometers measuring the vertical component of the field. Proton magnetometers are currently in most common use, recording total magnetic field. The equipment is portable and easy to operate and target features usually traversed at right angles to the expected orientation. Graphical plots of the data obtained can be used to interpret orientation, angle of dip and width of dykes.

Exploratory investigations in the Queenstown vicinity (Vandoolaeghe, 1980) successfully employed a combination of air photo and satellite image interpretation, field mapping, magnetic profiling and exploratory drilling in the location of target features. Magnetic profiling proved to be the most suitable for mapping dolerite structures. The dip direction on dykes can often be predicted from the shape of the anomaly but the complications arising from variation in magnetic mineral content, depth of burial and dyke orientation in relation to the earth's magnetic field can lead to incorrect interpretations (Woodford et al., *in press*). A typical magnetic anomaly associated with a north-westerly dipping dolerite dyke in the King William's Town type area is shown in Fig. 41.

Recent investigations carried out by DWAF in similar geological terrain to the study area - (e.g. Calvinia, Woodford, A. C., 1995, *pers. comm.*) indicate that inclined joint zones within dolerite may be located using electromagnetic methods. This option should therefore be considered in future investigations. Vandoolaeghe (1980) tested resistivity techniques in the location of fracturing associated with dolerite intrusions west of Queenstown, concluding that this method "can be buried once and forever" as a tool due to the clear superiority of magnetic techniques in elucidating the dolerite structure.

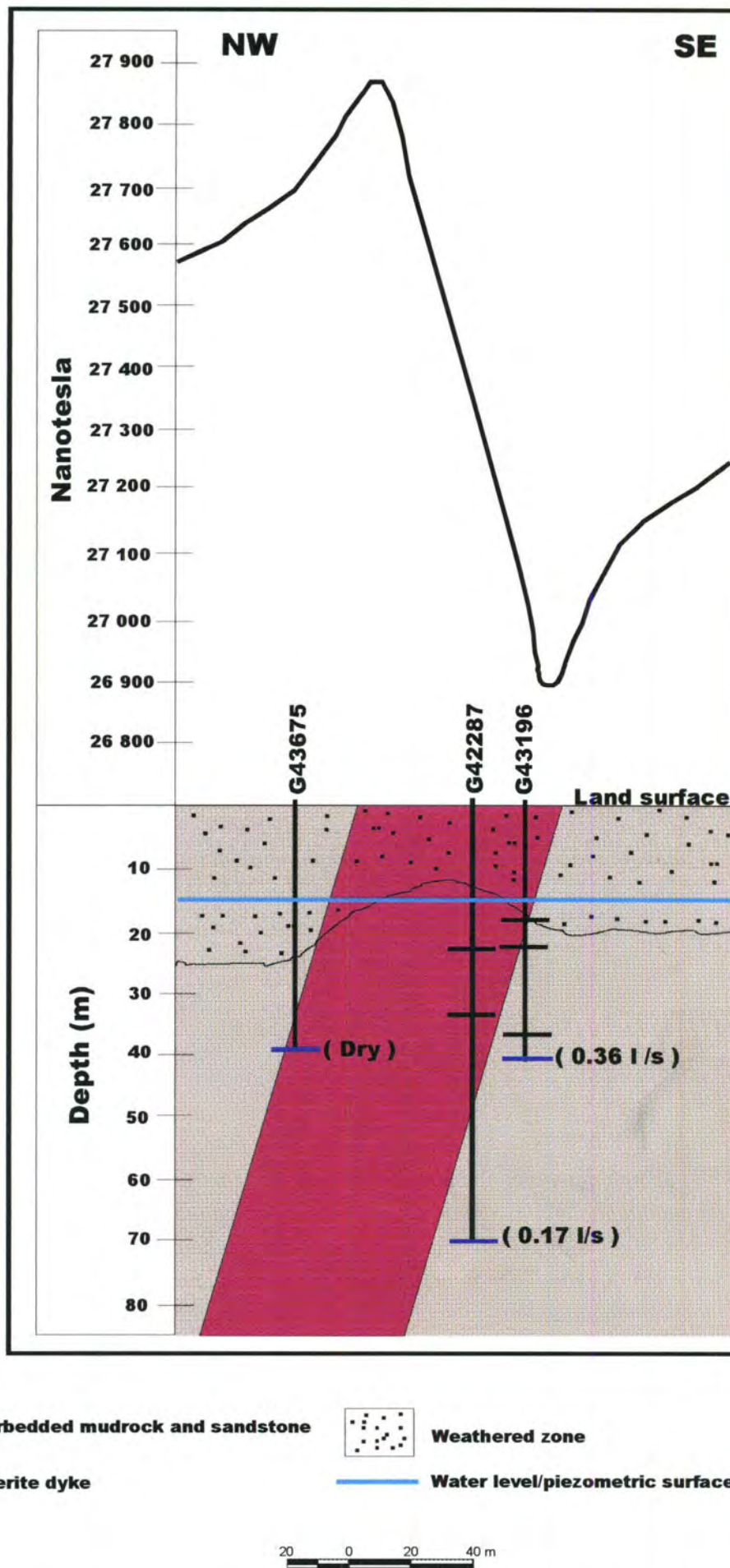


Fig. 41: Total field magnetic anomaly caused by a dyke in the King William's Town type area (After Calitz, 1995).

Fractured sedimentary rocks

Delineation of vertical fault and joint zones is relatively straightforward employing a combination of satellite imagery, air photo interpretation and field mapping. A combination of remote sensing and electromagnetic/resistivity geophysical methods is probably a good approach as indicated by relatively high yields obtained in the King William's Town vicinity using this technique (GCS, 1994). Constant depth profiling geophysical techniques can be used to trace lateral variations caused by faults, fracture zones and degree of associated weathering. The FDEM method is likely to be the most suitable for the study area as it is "particularly suitable for locating narrow conductive zones such as fractures and faults which constitute secondary aquifers" (Botha, 1992).

Depth soundings may be used to determine the depth of the weathered zone or thickness of layers, and therefore assist in making groundwater storage estimates if the water level is known. Potential for weathered zone aquifers is highest in the eastern parts of the study area and in particular where the rocks are significantly jointed.

Detection of fractures confined to particular lithological units (e.g. sandstone horizons / contacts) is difficult. Because strata are horizontal the fractures do not extend to surface and cannot be predicted - successful boreholes being largely drilled by chance. In general bedding plane jointing is not likely to be intense and cannot therefore be considered prime targets. The use of both resistivity and electromagnetic methods may be applicable in their detection.

5.4 Drilling methods

Because the aquifers in this area are mainly in hard rock it is necessary to mechanically drill boreholes to access the groundwater. Historically (prior to 1970) these were usually drilled with the cable-tool method but more recently the faster rotary percussion method is most commonly utilized. The cable tool method is cheaper and less labor intensive, involving lifting and dropping a heavy string of tools into the borehole as a series of strokes, and can be used to depths of 300 m. The bit breaks or crushes rock into fragments, which are mixed with water to form sludge and removed periodically by bailer. This method can be used to drill a variety of formations (boulders, unconsolidated and consolidated fractured rock).

The rotary percussion method uses a “down the hole” hammer which strikes the rock while the drill rods turn, giving a percussion effect. Rock fragments are blown out of the borehole by the compressed air used to drive the hammer. The main advantage of the method is its speed, making it possible to drill 100 m deep boreholes in 1-2 days.

5.5 Aquifer management

It is necessary to estimate the sustainable yield of the groundwater unit in which the borehole is situated in order to ensure that the borehole can be used without depleting the resource in the long term. This is a specialized task requiring the expertise of a geohydrologist, entailing test pumping of the borehole, evaluation of the local hydrogeology, topographic setting and recharge. The storage capacity of the unit needs to be estimated, as well as all the water inputs and outputs from the unit. Commissioning of another borehole means that some of the losses from the system will be diverted to this borehole. Some of the losses include base-flow, evapotranspiration and other boreholes. In accordance with the National Water Act, (Government Gazette, 1998) it is also necessary to ensure that the “reserve” required for maintenance of the environment and basic human needs is not impacted by the establishment of the borehole.

On the basis of these information / considerations the hydrogeologist makes, recommendations on the pumping rate and duration. It is important that these recommendations are made prior to equipping the borehole so as to ensure that the correct size pump is installed and a reasonable pump rate selected.

It is important to manage the aquifer to ensure that groundwater abstraction is balanced by groundwater recharge in the long-term. Once abstraction commences therefore it is critical to keep a record of volumes pumped and water level in the borehole/s. Armed with this information it is possible to adjust pumping rates to sustainable levels (reduce the rate if continuous declining trend in water levels is detected, or even increase abstraction rates if trends indicate impact is limited).

Due to the highly heterogeneous nature of the fractured rock aquifers characteristic of the study area, it is very difficult to make accurate estimates of the sustainable yield. For this reason it is crucial to implement long term monitoring of the aquifer behavior so that the initial estimates can be refined.

6 STUDY LIMITATIONS

Some of the major limitations which came to light during the course of this investigation are given below:

- 1:500 000 map scale is too coarse to show hydrogeological variation at the local scale (topographic influences, dykes etc).
- The borehole yield ranges adopted for the standard legend are too “coarse” to adequately portray the small regional yield variations found on the Queenstown map – virtually the whole area being in the 0.5 – 2 *ℓ/s* category. The colours permitted by the standard legend would have been put to better use depicting smaller yield intervals than making the distinction between fractured and “fractured and intergranular aquifers”.
- The prescribed exclusion of dry boreholes from the data set used to assign the yield class for a particular region can, in some instances, result in unrealistically high median yields. This is particularly true for those regions with a relatively high incidence of dry boreholes (Fig 22).
- Poor borehole coordinate accuracy coupled with geological map coverages of inadequate accuracy precludes use of GIS techniques to overlay borehole information onto linear features (for comparison of borehole yields on dolerite dykes versus those drilled away from dykes for example).
- Numerous Departmental borehole-siting reports contain geological descriptions of the drilling targets and a corresponding borehole site “G” number. Upon drilling the site different “boring branch” number was recorded for the site but rarely the original borehole site “G” number. As a result numerous drilling results could not be correlated with target descriptions, and detailed comparisons between local geology and geohydrology were scarcely possible.

7 CONCLUDING SUMMARY

The main conclusions are as follows:

- For the bulk of the area borehole yields are in the 0.5 - 2.0 ℓ/s range. Higher yields (in the 2.0 - 5.0 ℓ/s range) are common only in a small area in the south-west of the map. Lowest yields (0.1 - 0.5 ℓ/s) are obtained in an area immediately north of East London and in the Dwyka Group near the NE coast.
- Boreholes in the higher yield ranges (3 - 10 ℓ/s) are more common in the south-western part of the study area than in the north-east.
- The incidence of dry boreholes is less common in the south-western part of the study area than in the north-east.
- The groundwater quality is good, ECs rarely exceeding the 300 mS/m maximum recommended limit for insignificant risk for human consumption. Quality is best in the higher rainfall north-eastern half of the study area - usually within the 70 mS/m limit for no risk. Water quality is worst along the southern edge of the mapped area where it exceeds 300 mS/m recommended limit for human consumption
- Groundwater occurrence is mainly in “fractured and intergranular” and fractured aquifers. The “fractured and intergranular” type predominates in the more humid eastern part of the study area where the lithologies are more highly weathered whereas the fractured type predominates in the drier west.
- Highest borehole yields are obtained in folded areas (restricted to the southern edge of the study area) followed by rocks with dolerite intrusions (common over the bulk of the study area). Other targets include fractured sedimentary and volcanic rock and unconsolidated deposits.

- Yields obtained from dolerite contact zones vary across the area; differences correspond to spatial variations in style of intrusion. Highest success rates are obtained in areas intruded by a combination of dykes, ring-shaped sheets and irregular sheets while poor results are obtained in thick massive sills.
- A better understanding of the relationship between groundwater occurrence and the structure of dolerite intrusions is required for thorough hydrogeological assessment of groundwater occurrence.
- Improved drilling success rates can be obtained by locating drilling targets in topographic lows.
- Target features can be located by a combination of air photo and satellite image interpretation, hydrogeological mapping, and geophysical methods. The magnetic, resistivity and possibly electromagnetic geophysical methods are most appropriate to employ in the study area.
- The groundwater Harvest Potential is lowest in the west becoming higher to the east of the study area. It ranges from 2 000 m³/km²/annum to 80 000 m³/km²/annum.
- Over much of the area, particularly the eastern parts, it is unlikely that the full Harvest Potential will be practically abstractable due to a combination localized fracture zones, low matrix transmissivity and accessibility problems in steep terrain.
- Risk of over-exploitation is highest where high transmissivity coincides with low recharge. The areas of highest risk are the area of high yielding boreholes near Bedford and the area to the west of Queenstown.

8 RECOMMENDATIONS FOR FURTHER WORK

8.1 Research into groundwater occurrence

Despite the large number of boreholes drilled in this area, inadequate coordinate accuracy and paucity of correlatable drilling results have left a groundwater occurrence knowledge gap. To rectify this situation it is recommended that an intensive exploratory drilling programme be implemented in this area.

A host of potential drilling targets exist throughout the study area, such as: - dykes of various orientation and thickness, sheets of varying structure, diatremes, weathered zone, faults, lineaments. The target features chosen for exploration/testing should be selected in areas requiring establishment of groundwater supplies, and specifically where larger scale supplies are an urgent requirement. For this reason priority drilling targets must be identified in liaison with the Water Services Directorate, which is responsible for the development of the water resources for the rural areas. Using this approach the exploratory drilling will have immediate application and suitably located boreholes with adequate yield could even be incorporated into the supply system. Monitoring of exploratory boreholes incorporated into the supply system will provide valuable additional information concerning the long-term performance of these aquifers.

A well planned drilling programme aimed at elucidating hydrogeological detail at suitable sites representative of the target features of the area will be more informative than launching a time consuming search for existing boreholes with poor-coordinate accuracy. The scattered distribution of these historical boreholes coupled in some cases unreliable hydrogeological records will not provide sufficient detail for adequate target assessment. It is important that research into the most appropriate geophysical methods, or combination of methods, for borehole siting be coupled with this research into groundwater occurrence.

In addition all boreholes drilled in this area must be properly documented and entered onto the National Groundwater Data Base. A GIS - linked hydrogeological data bank for these boreholes must be maintained. Regular analysis of the drilling results will assist in the identification of the best drilling targets and siting techniques for particular parts of the area.

8.2 Calibration of exploitation potential

Research sites should be established to calibrate the groundwater Exploitation Potential. Suitable sites covering wide precipitation range must be identified to allow for extrapolation of the results to the Region as a whole. The following are recommended:

Low rainfall area (< 500 mm p.a.)

Bedford area in the south-western corner of the map. Low rainfall coupled with high borehole yields (transmissivity) increase the risk for over-exploitation because groundwater is readily extractable but recharge is low. The extensive hydrological and geohydrological information already available for this area from research by Rhodes University (Hughes et al., 1992 and Sami, 1996) will provide a suitable foundation for this research.

Moderate rainfall area (500 - 600 mm p.a.)

Area between Tarkastad and Queenstown. Ideal research sites are present with defined groundwater units - including "dolerite ring structures". Springs emanating from these units facilitate measurement of outflow. Quantification of the resource is necessary because groundwater in that area is extensively used for irrigation; the possibility of over-exploitation therefore exists.

High rainfall area. (600 - 800 mm p.a.)

The Amatola mountain range receives rainfall of this magnitude and its location between the above two proposed research sites would reduce logistical costs. Additional work is required to identify the exact locality of such a site that ideally must comprise a well-defined aquifer unit where groundwater is exploited.

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MAP REFERENCES

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Appendices

Appendix 1: Mapping standards

- 1a Mapping standards and specifications**
- 1b Dolerite depiction**

Appendix 2: Chronostratigraphic column

Appendix 3: Hydrochemistry

- 3a Wilcox diagrams per lithology**
- 3b Piper diagrams per lithology**

1a Mapping standards and specifications

WORKING DOCUMENT

STANDARDS
and
SPECIFICATIONS
for
the
MAPPING PROGRAMME
of
the

1:500 000
HYDROGEOLOGICAL
MAP SERIES
OF
THE
REPUBLIC OF SOUTH AFRICA

compiled
by
Mapping Management Team

1996

INTRODUCTION

Hydrogeological maps are internationally accepted as important tools for a wide variety of planning and educational purposes. The importance of groundwater in the RDP (Reconstruction and Development Programme) of South Africa has added extra urgency to the need for a synoptic overview of groundwater conditions that hydrogeological maps provide.

The recommendations of the IAH (International Association of Hydrogeologists) is to begin with small scale national maps, proceed to medium scale regional maps, and then to large scale local maps. South Africa has adopted this approach with a national map with a scale of 1:2,5 million being published first. Regional 1:500 000 scale maps are now being compiled.

The purpose of this document is to provide the standard legends to be used for the 1:500 000 maps, and to provide guidelines on the methodologies to be used.

The guiding philosophy of the Mapping Management Team is contained in the following quote from Struckmeier and Margat:

“the most important thing about a map is that it is prepared, if possible in time, **and that it is completed!**”

Paul Seward
Project Manager

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SPECIFICATIONS:

1. MAIN MAP:

1.1. HYDROGEOLOGICAL METHODOLOGY

Regional variations in hydrogeological conditions, knowledge, and data, prevent a standardized and/or automated delineation of hydrogeology. The Hydrogeological Manager is responsible for ensuring uniformity in interpretation and representation throughout the RSA. The Map Author should not proceed until an appropriate and acceptable methodology has been negotiated with the Hydrogeological Manager.

Each 1:500 000 map sheet must be assigned to a single Map Author. It is the Map Author's responsibility to ensure uniformity within the map sheet. It is the Hydrogeological Manager's responsibility to ensure uniformity across map sheet boundaries within the RSA.

All parties should be familiar with the 1995 IAH publication:

Hydrogeological Maps, A Guide and a Standard Legend. Wherever possible, the strategies contained in this document should be used to resolve arbitrary disputes, that are not of a purely South African character.

The hydrogeological maps are required to depict the type of aquifers and their (expected) immediate borehole yields - i.e. governed by transmissivity, but ignoring storage and recharge. The classification by mode of occurrence of groundwater is based on groundwater flow only.

The divisions to be used are as follows:

- i. Intergranular
- ii. Fractured
- iii. Karst; and
- iv. Intergranular and fractured;

Map Authors may include a detailed discussion on the groundwater occurrence in the area in the brochure of the map. Should any of the maps not fit together correctly when they are joined, the Hydrogeological Manager will be responsible for clarifying this issue with the Map Authors.

Examples of when intergranular, fractured and fractured and intergranular would be used:

intergranular

When flow is only in the intergranular zone, i.e. in the pores between unconsolidated grains or weathered crystals.

Examples are:

1. sands and gravels

2. weathered crystalline rock where the principal water strike is in the weathered intergranular part

fractured

Where the principal water strike is in a fracture (including joints, faults, fissures etc.) or in the contact between two different rock types.

Examples are:

1. fractured sandstone (or most brittle rocks)
2. fractured Dwyka tillite

intergranular and fractured

Where the yield of the borehole is being supplied by both intergranular and fracture flow. Groundwater occurrence should be classed as intergranular and fractured provided the intergranular zone has a marked effect on the borehole yield.

Examples are:

1. Where dolerite has weathered near its contact with the host rock and therefore this intergranular zone contributes water to the fissured zones in which groundwater is struck
2. Weathered granite contributes to the yield of the borehole by intergranular flow to areas of higher hydraulic conductivity, such as the contact between weathered and solid granite, or fractures within the fresh granite

1.2. LITHOLOGY METHODOLOGY

The Map Author is responsible for compiling the lithology. The methodology for compiling the lithology is to be negotiated between the Map Author and the Hydrogeological Manager.

When a geological coverage has been obtained, each formation needs to be given a id number and symbol. The id number (24 - 49) is obtained from the numbers on the lithology legend.

The symbol (Nk, Mle, etc.) placed in the polygon depicts the chronostratigraphic identity. The Map Authors must go to formation level and group their rocks into one of the groups which appear on the chronostratigraphic column. The first letter in capitals will reflect the age and the following letter reflects the name of the group from which the formation is from.

Chronostratigraphy

1	2	3	4	5	6
65 140 195 230 345 395 435 500 570	PHANEROZOIC	Cainozoic	Quaternary	Q	Fluvial deposits (Q)
			Tertiary	T	Whitesand Formation (T-Qw); Langebaan Formation (T-Q1); Velddrif Formation (T-Qv); Kalahari Group (T-Qk); Bredasdorp Group (T-Qb); Algoa Group (T-Qa); Berea Formation (T-Qbe); Bluff Formation (T-Qb1)
		Mesozoic	Crataceous	K	Zululand Group (Kz); Uitenhage Group (J-ku); Bumbeni Complex (Jb); Dolorite (Jd); Drakensberg Group (Jdr); Lebombo Group (Jl)
			Jurassic	J	
			Triassic	Tr	Clarens Formation (Trc); Elliot Formation (Tre); Molteno Formation (Trm); Beaufort Group (P-Trb); Ecca Group (Pe)
		Paleozoic	Permian	P	Dwyka Group (C-Pd)
			Carboniferous	C	
			Devonian	D	Witteberg Group (Dw); Sokkeveld Group (Db)
			Silurian	S	
			Ordovician	O	Natal Group (O-Sn); Table Mountain Group (O-St)
		Cambrian	E	Klipheuwel Group (Ek) Cape Granite Suite (N-E)	
1180 2070	PROTEROZOIC	Namibian	N	Kango Group (Nk); Gamtoos Group (Nga); Kaaimans Group (Nka); Malmesbury Group (Nm); Gariep Complex (Ng); Nama Group (Nn); Vanrhynsdorp Group (Nv); Hlobane Complex (Nh); Macala Complex (Nma); Mambula Complex (Nmb); Mialad Complex (Nml); Sithilo Complex (Ns); Tugela Rand Complex (Nt); Tugela Group (Ntu); Mfongosi Group (Nmf); Ningwa Group (Nnt); Mapumulo Group (Nmp)	
		Mokolian	M	Okiep Group (Mok); Bushmanland Group (Mb); Korannaland Sequence (Mk); Waterberg Group (Mwa); Wilgenhoutsdrif Group (Mw); Volop Group (Mv); Ultraal Formation (Mu); Blouberg Formation (Mbl); Kafferskroal Complex (Mka); Koringkoppies Complex (Mki); Orange River Group (Mo); Soutpansberg Group (Ms); Little Namaqualand Suite (Mli); Hangoor Suite (Mha); Keimoes Suite (Mk); Granite-gneiss (MB); Vlootsdrif Uite (Mv); Lebowa Granite Suite (Mle); Hartley Formation (V-Mha); Lucknow Formation V-Mlu)	
	Vaalian	V	Rooiberg Group (Vr); Pretoria Group (Vp); Chuniespoort Group (Vc); Black Reef Formation (Vb); Groblersdal Group (Vg); Wolkberg Group (Vw); Griquatown Group (Vq); Campbell Group (Vca); Vryburg Formation (Vv); Rustenburg Suite (Vru); Meinhardskraal Granite (Vmo); Schiel Alkaline Complex (Vsa); Mpageni Granite (Vmpg); Diabase (Vd); Mashashane Suite (R-Vmh); Mashishimale Suite (R-Vms); Hartewater Group (R-Vha)		
2620 3090	ACHAEZOZOIC	Randian	R	Amalia Group (R-Va); Zoetlief Group (R-Vz); Kipriviersberg Group (R-Vk); Platberg Group (R-Vp); Central Rand Group (Rc); West Rand Group (Rwr); Dominion Group (Rd); Salisbury Kap Granite (Rsa); Harmony Granite (Rha); Hour River Gneiss (Rho); Sulai Gneiss (Rbu); Rookwater Complex (Rro); Marydale Group (Z-Rm); Mozaan Group (Z-Rma)	
		Swazian	Z	Messina Suite (Zme); Nsuzi Group (Zns); Halfway House Granite (Zht); Eastern Mpumalanga granite areas (ZB); Basement Complex (Z); Baif Bridge Complex (Zbb); Bandellerkop Complex (Zb); Pietersburg Group (Zp); Glyani Group (Zg); Gravelotte Group (Zg); Moodies Group (Zm); Fig Tree Group (Zf); Onverwacht Group (Zo); Nondweni Greenstones (Zn); Kaap Valley Granite (Zka); Kraaipan Group (Zk); Sand River Gneiss (Zs); Unnamed gneissic rocks (ZC)	

1 = Million Years B.P. (B.P. = Before Period)
2 = Eonotham (Eon)
3 = Erathem (Era)

4 = System (Period)
5 = Symbol
6 = Complex, Suite, Group, Formation (with symbol)

The Hydrogeological Manager has the responsibility for ensuring a uniform approach to depicting lithology throughout RSA.

Basic intrusions (dolerite, diabase, etc.) depiction:
Two forms of portrayal are necessary to adequately depict the basic intrusions:

- i. "Large" basic intrusions should be individually depicted with the basic / ultra basic intrusive rocks ornament only.
- ii. Where basic intrusions intricately intrudes the host, a mixture of both the basic intrusions and the host ornaments should be used.

The percentage basic intrusions coverage at surface that does not warrant recognition in the lithology ornament is to be decided in consultation with the Hydrogeological Manager so that consistency is ensured across map boundaries.

1.3. DEPTH TO GROUNDWATER LEVEL

Shown in contour lines on the map face where data are available.
Methodology from the GIS Manager.
The Map Author is responsible for compiling the contour lines.

1.4. HYDROLOGICAL FEATURES

a. Groundwater Abstraction:

i. Main groundwater abstraction concentrations:

- < 1 million cubic metres/a
- 1 - 2 million cubic metres/a
- 2 - 5 million cubic metres/a
- 5 - 10 million cubic metres/a
- > 10 million cubic metres/a

ii. Usage of water

- Mining and industrial
- Domestic
- Irrigation

iii. Areas where groundwater is intensively being utilised
- irrigation areas

b. Spring, warm, cold (known and /or important)

c. Artesian borehole (known and /or important)

d. Subterranean Government Water Control Area

It is the Map Author's responsibility to obtain the above mentioned information.

1.5. DRAINAGE

- i. Primary rivers
- ii. Secondary rivers
- iii. Non perennial and perennial of the above mentioned rivers.
- iv. Dams
- v. Pans connected to drainage patterns
- vi. Surface device - Responsibility of GIS Manager
- vii. Catchment area

The Directorate: Strategic Planning is busy compiling a data base(DB5) by using existing digital data from the Chief Directorate of Survey and Land Information. The 1:500 000 Topographical map series is used to populate the data base.

1.6. INFRASTRUCTURE

Only to be used as reference points

- a. Urban areas:
 - i. Cities/metropol
 - ii. Large towns
 - iii. Small towns
- b. Roads:
 - i. National route
 - ii. Main route
- c. Boundaries:
 - i. Provincial boundaries
 - ii. International boundaries.

This information is available from Strategic Planning in digital format. The provincial boundaries and provincial names will be available in an additional index map on the map face. The location of each map sheet will be indicated in the 'Index to maps' map.

The location of the Republic of South Africa will be indicated on a map of Africa.

This information has already been finalised and has been incorporated into the standard layout aml(program) for this series.

2. INSET MAPS:

2.1. DISTRIBUTION OF BOREHOLE DATA

Index:

- No borehole information
- 1 borehole
- 2 - 10 boreholes
- 11 - 20 boreholes
- > 20 boreholes

Borehole data points per one minute grid

Methodology from the GIS Manager.

1:2 000 000 scale

2.2. ELEVATION ABOVE MEAN SEA LEVEL

Index:

- sea level - 200m
- 200 - 400m
- 400 - 800m
- 800 - 1 200m
- 1 200 - 1 600m
- 1 600 - 2 000m
- 2 000 - 2 500m
- > 2 500m

This data was obtained from the Computing Centre for Water Research, at the University of Natal, Pietermaritzburg, and was compiled by H Mullin, Department of Water Affairs and Forestry. It is part of the layout aml(program) for this series.

1:2 000 000 scale

2.3. MEAN ANNUAL PRECIPITATION

Index:

- < 100mm
- 100 - 200mm
- 200 - 300mm
- 300 - 400mm
- 400 - 600mm
- 600 - 800mm
- 800 - 1 000mm
- > 1 000mm

This data was obtained from the Computing Centre for Water Research, at the University of Natal, Pietermaritzburg, and was compiled by H Mullin, Department of Water Affairs and Forestry. It is part of the layout aml(program) for this series.

1:2 000 000 scale

2.4. GROUNDWATER QUALITY

Electrical conductivity:

- < 70mS/m
- 71 - 300mS/m
- 301 - 1 000mS/m
- > 1 000mS/m

Chemistry:

- NO₃ + NO₂(N) > 10mg/l
- F > 1.5mg/l
- NO₃ + NO₂(N) > 10mg/l & F > 1.5mg/l

Methodology from GIS Manager

1:1 500 000 scale

3. HYDROGEOLOGICAL DIAGRAM

Hydrogeological diagrams are required to explain the 3D dimension in areas where different aquifer types overlay each other. A typical complex section should be selected and shown. Vertical and horizontal exaggerations may be used to best depict the situation.

4. LANGUAGE POLICY

The following language policy was approved in 1994, by Management of the Department of Water Affairs and Forestry, for use on the Hydrogeological map series:

“.....op die kaarte verskyn twee tale, naamlik Engels en Afrikaans;

..... die meegaande verklarende notas word rug aan rug in Engels en die eerste Afrikataal van die spesifieke gebied gedruk, bv. Afrikaans vir die Kaapstadvel en Zoeloe vir die Durbanvel. Waar nodig sal uitsluitel oor hierdie keuses van die verantwoordelike owerheid verkry word.”

5. EXPLANATORY BROCHURE

An explanatory brochure is needed to accompany each map sheet. This will contain additional information which cannot be portrayed on the map sheet without cluttering it. This information will be available as hard copy or on diskette in the form of Arc View.

The format and content of the brochure will be specified in a separate brochure standards document.

6. MAP LAYOUT

6.1 ARC/INFO PROGRAMMES

The following sets out the procedures for creating a 1:500 000 hydrogeology map by running a series of Arc/Info programmes (amls). Any problems encountered or help needed in running these programs can be reported to the Cartographic Manager.

There are eleven basic amls to be used, some are already set and should be used as is and others must be adjusted according to the specified sheet.

a. Setup.aml

This aml specifies a few standard settings, such as

- page size
- variables for directory structure
- shadeset, lineset and markerset

This aml must never be changed unless authorised by the Cartographic Manager.

b. Layout.aml

This specifies the placement of standard index maps and the chronostratigraphy column. Should not be changed unless authorised by Cartographic Manager.

c. Main.aml

This aml is a basic aml to help the user when creating a map and thus may be changed. All other amls run within this aml. This aml is the one to use to run your map composition.

There are however a few basic rules to follow.

- Stick to the coverage name given (see a list under point 6.2.).
- Only change map position when authorised by the Cartographic Manager.

d. Infra.aml

This aml is run within main.aml and basic topographic and cadastral data are specified within. Not to be changed unless authorised by Cartographic Manager. If other selections are needed add this to the main.aml or consult Cartographic Manager on changing infra.aml or adding another aml.

e. Infracl.aml

The same as infra.aml with exception of coverage names for inset maps

f. Legend.aml

This contains the legend for the main map and are to be used as a guideline. Consult Cartographic Manager on placement of legend.

g. Snit.aml

This will be for the hydrogeological diagram and will be written as soon as there are useful examples.

h. Dis.aml

This is for the borehole distribution map and is to be used as a guideline. Legend for map within this aml.

i. Rain.aml

This is for the rainfall map and is to be used as a guideline. Legend for map within this aml.

j. Elev.aml

This is for the elevation map and is to be used as a guideline. Legend for map within this aml.

k. Qual.aml

This is for the groundwater quality map and is to be used as a guideline. Legend for map within this aml.

- Lithology - litho_lam
- Distribution of borehole - dis_lam
- Groundwater quality - qual_lam
- Groundwater control area - sub_lam
- Groundwater abstraction - ab_lam

When separate coverage's are needed for the inset maps, give coverage name and 'I' in front of main name, thus igrd_lam, ibnd_lam, improv_lam, iocean_lam, etc.

If you need another coverage for which no name was specified contact the Cartographic Manager so that a standard name can be set.

6.3. EXAMPLE

The following map is an example of the map layout, indicating where all the components are situated on the map sheet.

Since this is a smaller version of the draft map, as there is no complete version available, please note the following:

- do not give any attention to the size of the script
- also ignore the size of the 'map'
- attention should only be given to the placing of the different components and the layout

6 . 2. COVERAGE NAMES

The following standard names for the main map are to be used:

- Grid for main map - grid_lam
- International boundaries (lines and anno) - bnd_lam
- Provincial boundaries - prov_lam
- Ocean - ocean_lam
- Rivers - riv_lam
- Dam - dam_lam
- Road - rd_lam
- Towns (points) - twn_lam
- Metropoles (polygons) - metro_lam
- Elevation - elev_lam
- Precipitation - rain_lam
- Yields - yld_lam

Boorgatdata is verkry vanaf die Nasionale Grondwater Data Basis, Departement van Waterwese en Bosbou.
Paale, riviere en dorp inligting is verkry vanaf Die Hoof Direkoraat Opmetings en Grondinligting, Departement van Grondsake."

This map is not to be used for the purpose of local borehole siting. Lithology may be considered as guidelines only. The user can obtain further geological information from the Council of Geoscience.
The series is produced by Arc/Info software and the data and copies of this map and accompanying brochure are obtainable from:

Groundwater Mapping
Directorate: Geohydrology
Department of Water Affairs and Forestry
Private Bag x313
Pretoria.

Published by:
Department of Water Affairs and Forestry

Printed by:
Government Printer,
Pretoria

Copyright:
State

"Die kaart kan nie gebruik word vir individuele boorgat aanwysings nie. Litologie kan slegs as riglyne beskou word. Die gebruiker kan verdere geologiese inligting vanaf die Raad vir Geowetenskap verkry.
Die kaartreeks is vervaardig met Arc/Info sagteware en die digitale data, kopieë van die kaart en meegaande brosjure kan verkry word by:

Grondwater Kartering
Direkoraat : Geohidrologie
Departement van Waterwese en Bosbou
Privaatsak x313
Pretoria

Gepubliseer deur:
Departement van Waterwese en Bosbou

Gedruk deur:
Staatsdrukker,
Pretoria

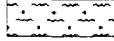
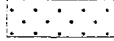
Kopiereg: Staat"

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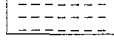
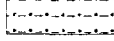
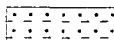
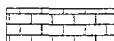
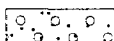
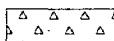
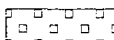
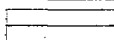
LITHOLOGY

shale-
symbol

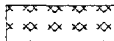
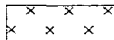
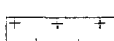
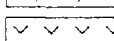
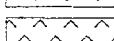
UNCONSOLIDATED ROCKS

- 21  Alluvium
(clay, sand, gravel, boulders)
- 22  Coastal and inland undifferentiated deposits
(unconsolidated to semi-consolidated sediments
including sand, calcrete, calarenite, aeolianite,
conglomerate, clay, silcrete, limestone, etc)

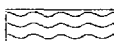
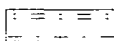

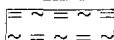
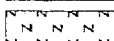
SEDIMENTARY ROCKS

- 23  Predominantly argillaceous rocks
(shale, carbonaceous shale, claystone, mudstone, siltstone)
- 24  Predominantly arenaceous rocks
(sandstone, feldspathic sandstone, arkose,
sandstone-becoming-quartzitic-in-places)
- 25  Argillaceous and arenaceous rocks
(approximately equal proportions)
- 26  Predominantly calcareous rocks
(limestone, dolomite, calcarenite)
- 27  Predominantly rudaceous rocks
(conglomerate, grit, breccia)
- 28  Predominantly diamictite
- 29  Predominantly (banded) iron formation
- 30  Undifferentiated (sedimentary) rocks

IGNEOUS ROCKS

- 31  Predominantly pyroclastic rocks
(tuff, agglomerate, breccia, ignimbrite)
- 32  Basic/Ultrabasic/Mafic intrusive rocks
(dolerite, diabase, diorite, gabbro, dunite, pyroxenite,
norite, anorthosite, hornblendite, carbonatite)
- 33  Acid/Intermediate/Alkaline intrusive rocks
(various granitoids)
- 34  Basic/Ultrabasic/Mafic extrusive rocks
(basalt, andesite)
- 35  Acid/Intermediate/alkaline extrusive rocks
(rhyolite, felsite, quartzporphyry)

METAMORPHIC ROCKS

- 36  Predominantly meta-argillaceous rocks
(slate, phyllite, meta-pelite, schist, serpentine, amphibolite, hornfels)
- 37  Predominantly meta-arenaceous rocks
(quartzite, gneiss, migmatite, granulite)
- 38  Predominantly meta-calcareous rocks
(marble, calc-silicate)
- 39  Predominantly gneissoid rocks with xenoliths
of undifferentiated metamorphic rocks
- 40  Undifferentiated rocks
(mixed lithologies, etc)

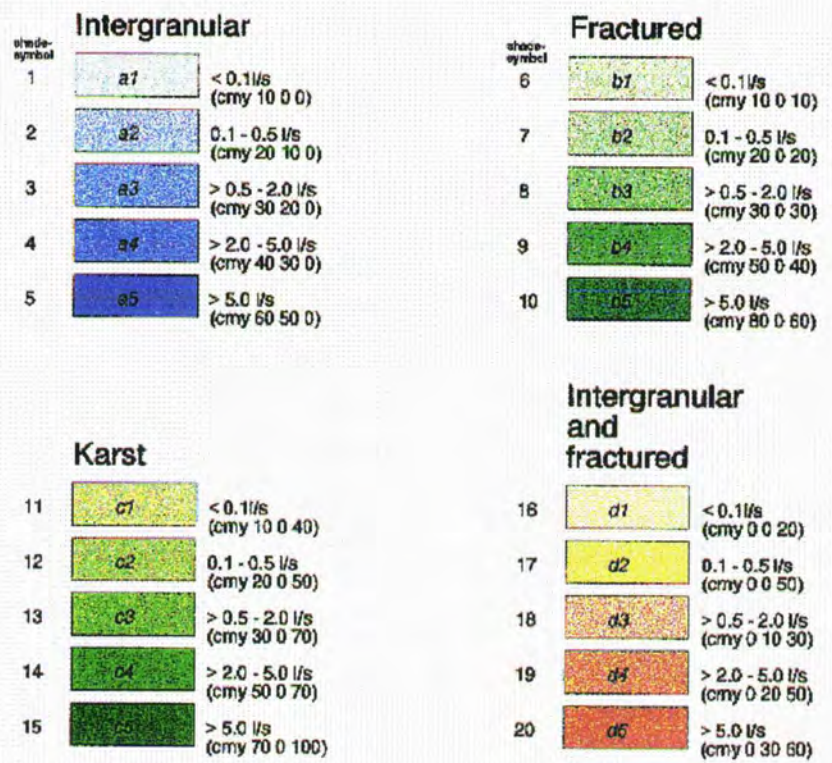
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 (Department of Water Affairs and Forestry)

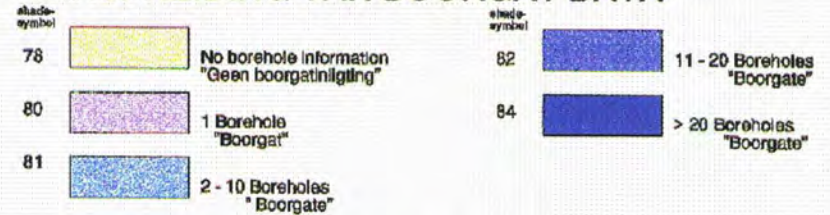
PRJ3SER3/GEOHYDRO/SETS (Pretoria)
 or
 PROJ/FREDA/SETS/500 (Durban)

Contact person: Cartography Manager

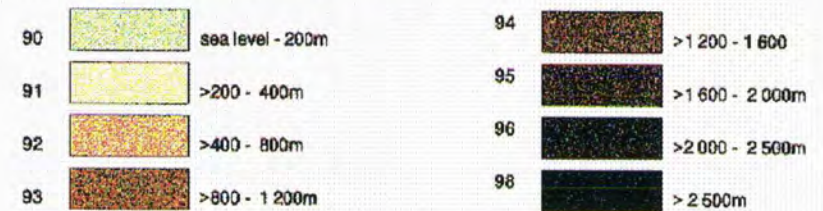
GROUNDWATER OCCURRENCE



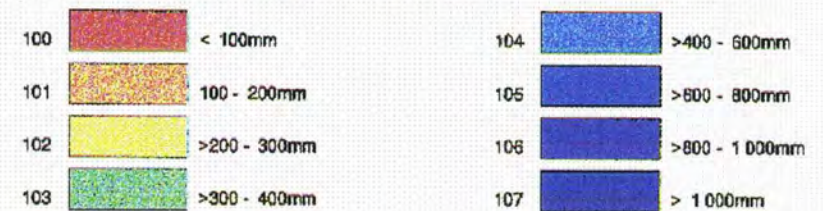
DISTRIBUTION OF BOREHOLE DATA "VERSPREIDING VAN BOORGAT DATA"



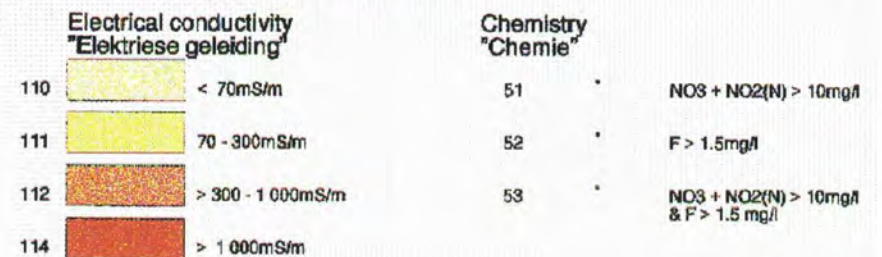
ELEVATION ABOVE MEAN SEA LEVEL "HOOGTE BO SEESPIEEL"



MEAN ANNUAL PRECIPITATION "GEMIDDELDE JAARLIJKE NEERSLAG"



GROUNDWATER QUALITY "GRONDWATER KWALITEIT"



line-symbol		line-symbol	
7	primary river with perennial runoff	25	contour
8	coastline, pan outline, secondary river, river (inset maps)	26	electricity conductivity
53	primary river with intermittent runoff	27	boundary of saline groundwater
9	stream with intermittent runoff	28	isolines of equal groundwater salinity
10	stream with mineralized water	29	area of sea water intrusion
11	surface water divide	30	direction of groundwater flow
12	national road	31	rest water level
13	main road; inset map: national road	32	estimated natural rest water level
14	inset map: main road	33	boundary of area with artesian conditions
15	dam wall	34	groundwater divide
16	town boundary	35	proposed groundwater divide
17	international boundary (1:500 000)	36	boundary for groundwater depletion
18	international boundary (1:500 000)	37	saturated thickness boundary
19	international boundary (1:500 000)	38	saturated thickness, 15m contour
21	international boundary (1:2 000 000)	39	sinhole or doline
22	international boundary (1:2 000 000)	40	Subterranean Government Water Control Area
23	international boundary (1:2 000 000)	41	direction of palaeodrainage
24	provincial boundary (1:500 000)	42	saline water occurring at depth
51	provincial boundary with river (1:500 000)	50	mapsheet outline on Africa map
45	provincial boundary (1:2 000 000)	54	boundary of groundwater abstraction area
52	provincial boundary with river (1:2 000 000)		

marker-symbol		marker-symbol	
1	spring with discharge in l/s	6	thermal spring temp in brackets
2	spring with discharge in l/s - non perennial maximum discharge of 50 l/s	8	town
3	brackish perennial spring with discharge in l/s electrical conductivity in mS/m	10	beacon altitude above sea level
4	spring brackish - non perennial maximum discharge of 50 l/s	11	artesian borehole flow in l/s
5	thermomineral spring	12	waterlevel recorder
		21	fault & inferred fault (+ line symbols 3 & 4)

GROUNDWATER ABSTRACTION

16	•	100 000 - 1 million cubic m/a	13	<i>I</i>	irrigation
17	•	1 - 2 million cubic m/a	14	<i>D</i>	domestic
18	•	2 - 5 million cubic m/a	15	<i>M</i>	mining
19	•	5 - 10 million cubic m/a	57	<i>M</i>	municipal
20	•	> 10 million cubic m/a	64	△	industrial

Basic intrusions(dolerite, diabase, ect)

SEDIMENTARY ROCKS

code-symbol	Symbol	Description
41		Predominantly argillaceous rocks (shale, carbonaceous shale, claystone, mudstone, siltstone)
42		Predominantly arenaceous rocks (sandstone, feldspathic sandstone, arkose, sandstone-becoming-quartzitic-in-places)
43		Argillaceous and arenaceous rocks (approximately equal proportions)
44		Predominantly calcareous rocks (limestone, dolomite, calcarenite)
45		Predominantly rudaceous rocks (conglomerate, grit, breccia)
46		Predominantly diamictite
47		Predominantly (banded) iron formation

IGNEOUS ROCKS

49		Predominantly pyroclastic rocks (tuff, agglomerate, breccia, ignimbrite)
50		Basic/Ultrabasic/Mafic intrusive rocks (dolerite, diabase, diorite, gabbro, dunite, pyroxenite, norite, anorthosite, hornblende, carbonatite)
51		Acid/Intermediate/Alkaline Intrusive rocks (various granitoids)
52		Basic/Ultrabasic/Mafic extrusive rocks (basalt, andesite)
53		Acid/Intermediate/alkaline extrusive rocks (rhyolite, felsite, quartzporphyry)

METAMORPHIC ROCKS

54		Predominantly meta-argillaceous rocks (slate, phyllite, meta-pelite, schist, serpentine, amphibolite, hornfels)
55		Predominantly meta-arenaceous rocks (quartzite, gneiss, migmatite, granulite)
56		Predominantly meta-calcareous rocks (marble, calc-silicate)
57		Predominantly gneissoid rocks with xenoliths of undifferentiated metamorphic rocks

GENERAL FEATURES

70		international state	76		viel or swamp - perennial
71		salt water bodies	77		intensively utilised groundwater
72		fresh water bodies	78		RSA
73		brakish water bodies	79		town area
74		marine flood area	300		spook
		viel or swamp			

CONTACT LIST:

MAPPING MANAGEMENT TEAM

	NAME	CONTACT NUMBER		OFFICE	E - MAIL
		Tel No.	Fax No.		
Project Manager	Paul Seward	(021) 950 7180	(021) 946 3666	Cape Town	OGA@dwaf-wcp.wcape.gov.za
Project Administrator	Anne Conley	(012) 299 2192	(012) 328 6397	Pretoria	WDC@dwaf-pta.pwv.gov.za
Geo-hydrological Manager	Schalk Meyer	(0441) 74 2123	(0441) 74 2123	George	
GIS Manager	Jane Baron	(041) 56 4884	(041) 56 0379	Port Elizabeth	6CE@dwaf-plz.ecape.gov.za
Cartographic Manager	Freda Jonck	(031) 306 1367	(031) 304 9546	Durban	3BX@dwaf-nfl.kzntl.gov.za

EDITORIAL BOARD

	NAME	CONTACT NUMBERS		OFFICE	E - MAIL
		Tel No.	Fax No.		
Director: Geo-hydrology	Eberhard Braune	(012) 299 2670	(012) 328 6397	Pretoria : Pat 313	WAA@dwaf-pta.pwv.gov.za
Deputy Director Geo-hydrology	Bill Orpen	(012) 299 2689	(012) 328 6397	Pretoria : Pat 317	
Deputy Director Geo-hydrology	Dziem Dziembowski	(012) 299 2680	(012) 328 6397	Pretoria : Pat 318	
Cartographer & Linguist	Franz Coetzee	(024) 55 3012		Somerset West	

eMAIL ADDRESSES: DWAF REGIONS

REGION ADDRESS

INTERNET ADDRESS

DWAF-ECP (Eastern Cape - Cradock) %user%@dwaf-ecp.ecape.gov.za
 DWAF-HRI (JWQS - Roodeplaat dam) %user%dwaf-hri.pwv.gov.za
 DWAF-NTL (Natal - Durban) %user%@dwaf-nfl.kzntl.gov.za
 DWAF-NUC (Pretoria - Verwoerdburg HVD/TVL) %user%@dwaf-uc.pwv.gov.za
 DWAF-OFS (Orange Free State - Bloemfontein) %user%@dwaf-ofs.ofs.gov.za
 DWAF-PTA (Pretoria - Head Office) %user%@dwaf-pta.pwv.gov.za
 DWAF-WCP (Western Cape - Cape Town) %user%@dwaf-wcp.wcape.gov.za

MAP AUTHORS

NAME	CONTACT NUMBERS		OFFICE	E - MAIL	MAPS
	Tel No.	Fax No.			
Heine Barnard	(012) 299 2692	(012) 328 6397	Pretoria		2526 Johannesburg
Willem du Toit	(012) 299 3080	(012) 328 6397	Pretoria	WDF@dwaf-pta.pwv.gov.za	2126 Alldays 2130 Pafuri 2330 Phalaborwa 2326 Pietersburg
Brian Dyason	(021) 950 7100	(021) 946 3666	Cape Town		2714 Alexander Bay 2916 Springbok
Georgina King	(031) 306 1367	(031) 304 9546	Durban	3CI@dwaf-nfl.kzntl.gov.za	2730 Vryheid 2928 Durban
Schalk Meyer	(0441) 74 2123	(0441) 74 2123	George		3117 Calvinia 3317 Cape Town 3320 Oudtshoorn 3324 Port Elizabeth
Gert Nel	(041) 56 4884	(041) 56 0379	Port Elizabeth	6CA@dwaf-plz.ecape.gov.za	2530 Nelspruit
Mike Smart	(021) 950 7100	(021) 946 3666	Cape Town	OGD@dwaf-wcp.wcape.gov.za	3126 Queenstown
Gawie van Dyk	(051) 430 3134	(051) 430 8146	Bloemfontein		2522 Vryburg
Eddie van Wyk	(012) 299 3129	(012) 328 6397	Pretoria	WDW@dwaf-pta.pwv.gov.za	2518 Keetmanshoop
Alan Woodford	(021) 950 7100	(021) 946 3666	Cape Town	OGB@dwaf-wcp.wcape.gov.za	3122 Beaufort West

GIS SUPPORT

NAME	CONTACT NUMBER		OFFICE	E - MAIL
	Tel No.	Fax No.		
Jane Baron	(041) 56 4884	(041) 56 0379	Port Elizabeth	6CE@dwaf-plz.ecape.gov.za
Elretha Louw	(021) 950 7100	(021) 946 3666	Cape Town	OGF@dwaf-wcp.wcape.gov.za
Eric Maritz	(031) 306 1367	(031) 304 9546	Durban	3BQ@dwaf-ntl.kzntl.gov.za
Werner Stadler	(021) 950 7100	(021) 946 3666	Cape Town	OGG@dwaf-wcp.wcape.gov.za

CARTOGRAPHERS

NAME	CONTACT NUMBERS		OFFICE	E - MAIL	MAPS
	Tel No.	Fax No.			
Surita Hauptfleisch	(012) 299 2535	(012) 323 2123	Pretoria	APE@dwaf.pwv.gov.za	3126 Queenstown 3324 Port Elizabeth
Freda Jonck	(031) 306 1367	(031) 304 9546	Durban	3BX@dwaf-ntl.kzntl.gov.za	2522 Vryburg 2518 Keetmanshoop
Etienne le Roux	(012) 299 2998	(012) 323 2123	Pretoria	AEJ@dwaf-pta.pwv.gov.za	2530 Nelspruit 3324 Port Elizabeth
Eric Maritz	(031) 306 1367	(031) 304 9546	Durban	3BQ@dwaf-ntl.kzntl.gov.za	2730 Vryheid
Heléne Mullin	(012) 299 2217	(012) 323 2123	Pretoria	ANC@dwaf.pwv.gov.za	2126 Alldays 2130 Pafuri Phalaborwa 2326 Pietersburg 2526 Johannesburg
Quinton Wolmarans	(012) 299 2531	(012) 323 2123	Pretoria	APG@dwaf.pwv.gov.za	2928 Durban

1b Dolerite depiction



DEPARTEMENT VAN WATERWESE EN BOSBOU
DEPARTMENT OF WATER AFFAIRS AND FORESTRY
WES-KAAPSTREEK WESTERN CAPE REGION
REPUBLIEK VAN SUID-AFRIKA/REPUBLIC OF SOUTH AFRICA



DARLINGSTRAAT 80 DARLING STREET, KAAPSTAD/CAPE TOWN

Telefoon: (021) 45-7025
Telephone: (021) 45-7330

Faks/Fax: (021) 461-8798

Privaatsak X9075
Private Bag
Kaapstad
Cape Town
8000

Navrae: M C Smart
Enquiries:
19/4/8
Verwysing:
Reference:

8 August 1995

The Director
Directorate Geohydrology
Private Bag X313
PRETORIA
0001

Attention: Mr Dziembowski

DEPICTION OF DOLERITE ON 1:500 000 HYDROGEOLOGICAL MAPS

Herewith a suggested method for dolerite depiction as requested by Mr Braune on 26 July 1995.

Lithologies are to be depicted as a faint grey background ornament on the 1:500 000 hydrogeological maps series. Over much of South Africa however dolerite intrusions are too abundant or intricate to be depicted as an individual lithology at 1:500 000 scale - without a "messy" looking result. A standardized method for simplifying the depiction of dolerite on hydrogeological maps is required. It is essential that the method be:

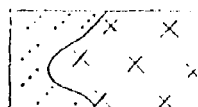
- simple
- easy to apply consistently

It is therefore recommended that:

- A mixed ornament be used for intricately intruded lithologies. A sandstone intruded by dolerite is given as an example below.



- Where "large" bodies occur the dolerite be depicted by the dolerite ornament only. For example a sandstone intruded by a large dolerite body would be depicted as below.



A measure of subjectivity will come in here - a guideline needs to be developed as to what constitutes a "large" body to be depicted and what does not.

A number of related topics are dealt with below:

AREAS OF DIFFERING STYLE OF DOLERITE INTRUSION

Areas of differing intrusive style can usually be distinguished (eg. areas intruded by dykes only or sheets only or mixtures of dykes and sheets).

For simplicity no attempt will be made to distinguish areas of differing intrusive style. The map user will be referred to the geological maps and brochure for this kind of geological detail.

PROBLEMS:

Foreseeable problems and suggested solutions are given below:

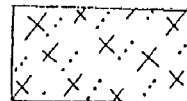
WHAT ABOUT CASES WHERE THE DOLERITE IS "FRACTURED AND WEATHERED"?

Because the "large" bodies of dolerite are individually depicted there is no problem with depiction as fractured and weathered. The bodies can individually be assigned to the fractured and weathered category. See below.



□ = Fractured +
Weathered

In the case where individual dolerites are not shown, the entire lithology is assigned to the "fractured and weathered" category.



Arguments in favour of this approach are that:

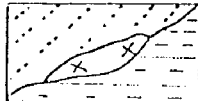
- while the lithology is mixed, dolerite invariably constitutes the drilling target.
- the weathered dolerite is in hydraulic continuity with the fractured host lithologies.

HOW TO DECIDE WHETHER THERE IS ENOUGH DOLERITE TO WARRANT DEPICTION

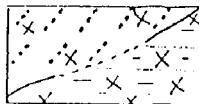
This should be left to the area expert, but a guideline % surface coverage could be set eg. Less than 10% dolerite coverage at surface does not warrant recognition in the background ornament.

WHAT ABOUT LITHOLOGICAL BOUNDARIES?

Instances will arise where a lithological boundary (eg. sandstone contact with shale) is intruded by dolerite along part of its length.



Exclusion of the dolerite will result in a "gap" in the lithological boundary.



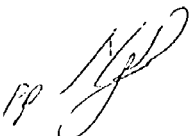
This will have to be closed by interpolation. Because the Karoo rocks (those most affected by dolerite intrusion) are relatively flat dipping, lithological contacts often parallel topographic contours making interpolation relatively simple.

CONCLUSION

Two forms of portrayal are necessary to adequately depict the dolerite:

- "Large" dolerite bodies should be individually depicted with the dolerite ornament only
- Where dolerite intricately intrudes the host, a mixture of both the dolerite and host ornaments should be used.

This letter has been circulated to all members of the internal mapping committee for their consideration prior to the next meeting.


Assistant Director
CAPE TOWN

Appendix 2: Chronostratigraphic column

Chronostratigraphy

1	2	3	4	5	6
65 140 195 230 345 395 435 500 570 1180 2070 2620 3090	PHANEROZOIC	Cainozoic	Quaternary	Q	<u>Fluvial deposits (Q)</u>
			Tertiary	T	<u>Whitesand Formation (T-Qw); Langebaan Formation (T-Q1); Velddrif Formation (T-Qv); Kalahari Group (T-Qk); Bredasdorp Group (T-Qb); Algoa Group (T-Qa); Berea Formation (T-Qbe); Bluff Formation (T-Qb1)</u>
		Mesozoic	Cretaceous	K	<u>Zululand Group (Kz)</u>
			Jurassic	J	<u>Uitenhage Group (J-ku); Bumbeni Complex (Jb); Dolerite (Jd); Drakensberg Group (Jdr); Lebombo Group (Jl)</u>
			Triassic	Tr	<u>Clarens Formation (Trc); Elliot Formation (Tre)</u> <u>Molteno Formation (Trm)</u>
		Paleozoic	Permian	P	<u>Beaufort Group (P-Trb)</u> <u>Ecqa Group (Pe)</u>
			Carboniferous	C	
			Devonian	D	<u>Witteberg Group (Dw); Bokkeveld Group (Db)</u> <u>Dwyka Group (C-Pd)</u>
			Silurian	S	
			Ordovician	O	<u>Natal Group (O-Sn); Table Mountain Group (O-St)</u>
		Cambrian	E	<u>Klipheuwel Group (EK)</u> <u>Cape Granite Suite (N-E)</u>	
		PROTEROZOIC	Namibian	N	<u>Kango Group (Nk); Gamtoos Group (Nga); Kaalmans Group (Nka); Malmesbury Group (Nm); Gariep Complex (Ng); Nama Group (Nn); Vanrhynsdorp Group (Nv); Hlobane Complex (Nh); Macala Complex (Nma); Mambula Complex (Nmb); Mlalazi Complex (Nml); Sithilo Complex (Ns); Tugela Rand Complex (Nt); Tugela Group (Ntu); Mfongoal Group (Nmf); Ntingwa Group (Nnt); Mapumulo Group (Nmp)</u>
					<u>Okiep Group (Mok); Bushmanland Group (Mb); Korannaland Sequence (Mk); Waterberg Group (Mwa); Wilgenhoutsdrif Group (Mw); Volop Group (Mv); Uitraai Formation (Mu); Blouberg Formation (Mbl); Kaffirskraal Complex (Mka); Koringkoppie Complex (Mkk); Orange River Group (Mo); Soutpansberg Group (Ms); Little Namaqualand Suite (Mli); Hangoor Suite (Mho); Keimoes Suite (Mk); Granite-gneiss (MB); Vioolsdrif Uite (Mvi); Lebowa Granite Suite (Mle); Hartley Formation (V-Mha); Lucknow Formation (V-Mlu)</u>
			Vaalian	V	<u>Rooiberg Group (Vr); Pretoria Group (Vp); Chuniespoort Group (Vc); Black Reef Formation (Vbl); Groblersdal Group (Vg); Wolkberg Group (Vw); Griquatown Group (Vqr); Campbell Group (Vca); Vryburg Formation (Vvr); Rustenburg Suite (Vru); Meinhardskraal Granite (Vmo); Schiel Alkaline Complex (Vsa); Mpageni Granite (Vmpg); Diabse (Vdi); Mashashane Suite (R-Vmh); Mashishimale Suite (R-Vms); Hartewater</u>
Randlan	R		<u>Amalia Group (R-Va); Zoetlief Group (R-Vz); Klipriviersberg Group (R-Vk); Platberg Group (R-Vp); Central Rand Group (Rcr); West Rand Group (Rwr); Dominion Group (Rd); Salisbury Kop Granite (Rea); Harmony Granite (Rha); Hout River Gneiss (Rho); Bulai Gneiss (Rbu); Rooiwater Complex (Rro); Marydale Group (Z-Rm);</u>		
ACHAEOZOIC	Swazian	Z	<u>Messina Suite (Zms); Nsuzu Group (Zns); Halfway House Granite (Zhh); Eastern Mpumalanga granite areas (ZB); Basement Complex (Z); Bait Bridge Complex (Zbb); Bandellerkop Complex (Zb); Pietersburg Group (Zp); Giyani Group (Zgi); Gravelotte Group (Zg); Moodless Group (Zm); Fig Tree Group (Zf); Onverwacht Group (Zo); Nondweni Greenstones (Zn); Kaap Valley Granite (Zka); Kraaipan Group (Zk); Sand River Gneiss (Zs); Unnamed gneissio rocks (ZC)</u>		

1 = Million Years B.P. (B.P. = Before Present)

2 = Eonothem (Eon)

3 = Erathem (Era)

4 = System (Period)

5 = Symbol

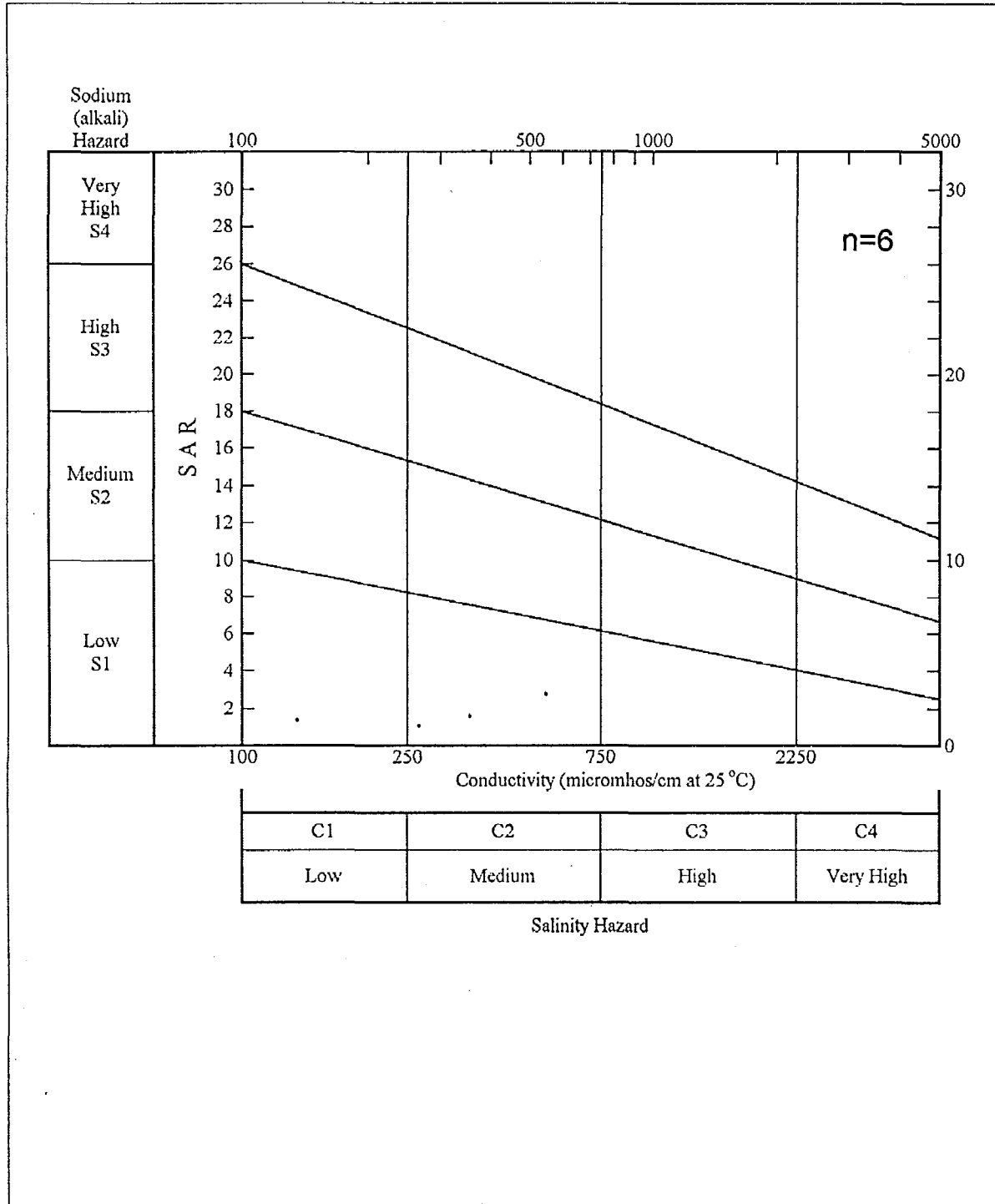
6 = Complex, Suite, Group, Formation (with symbol)

underlined if outcropping in study area.

3a Wilcox diagrams per lithology

Wilcox Diagram

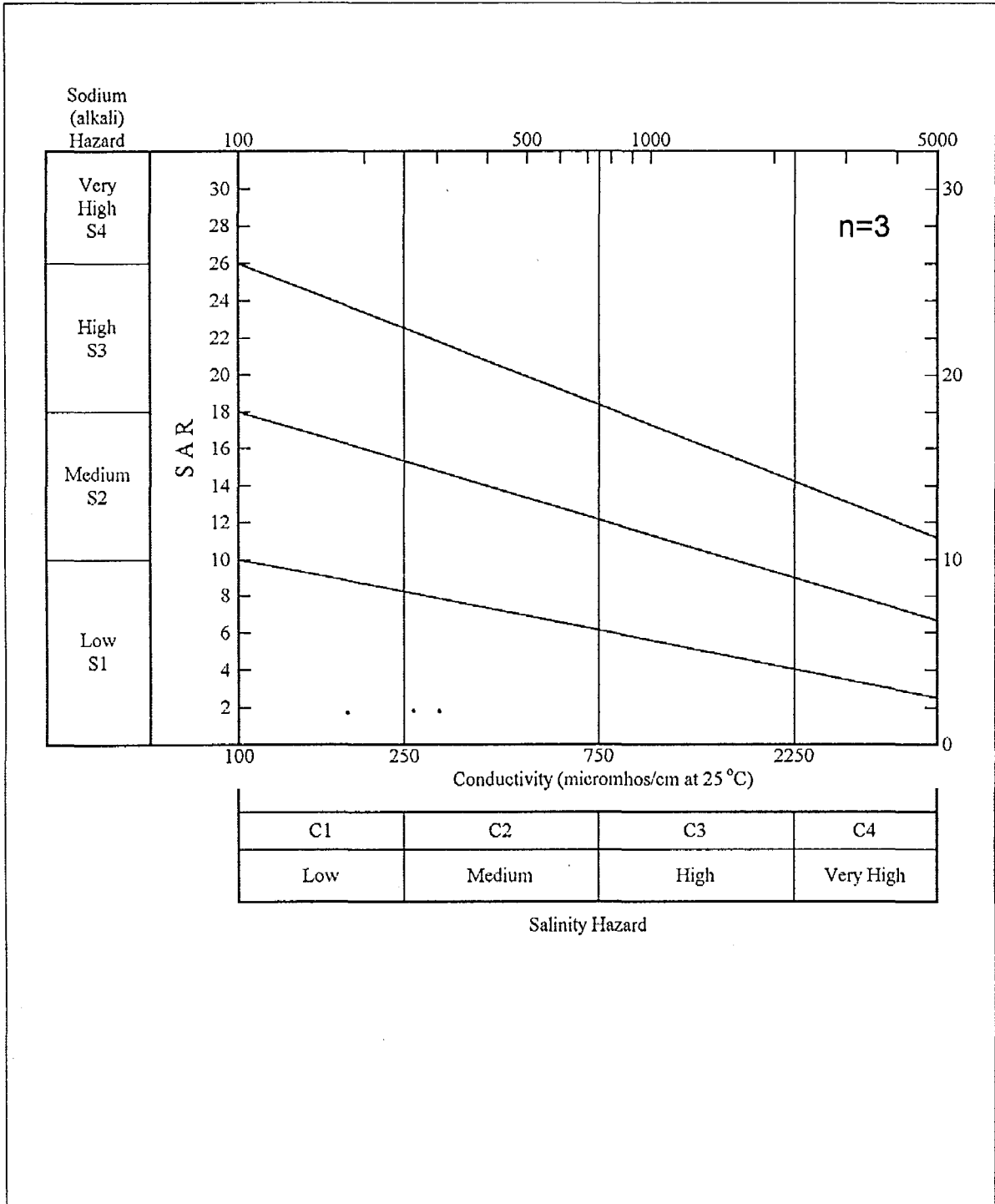
Wilcox Diagram



Natal Group

Wilcox Diagram

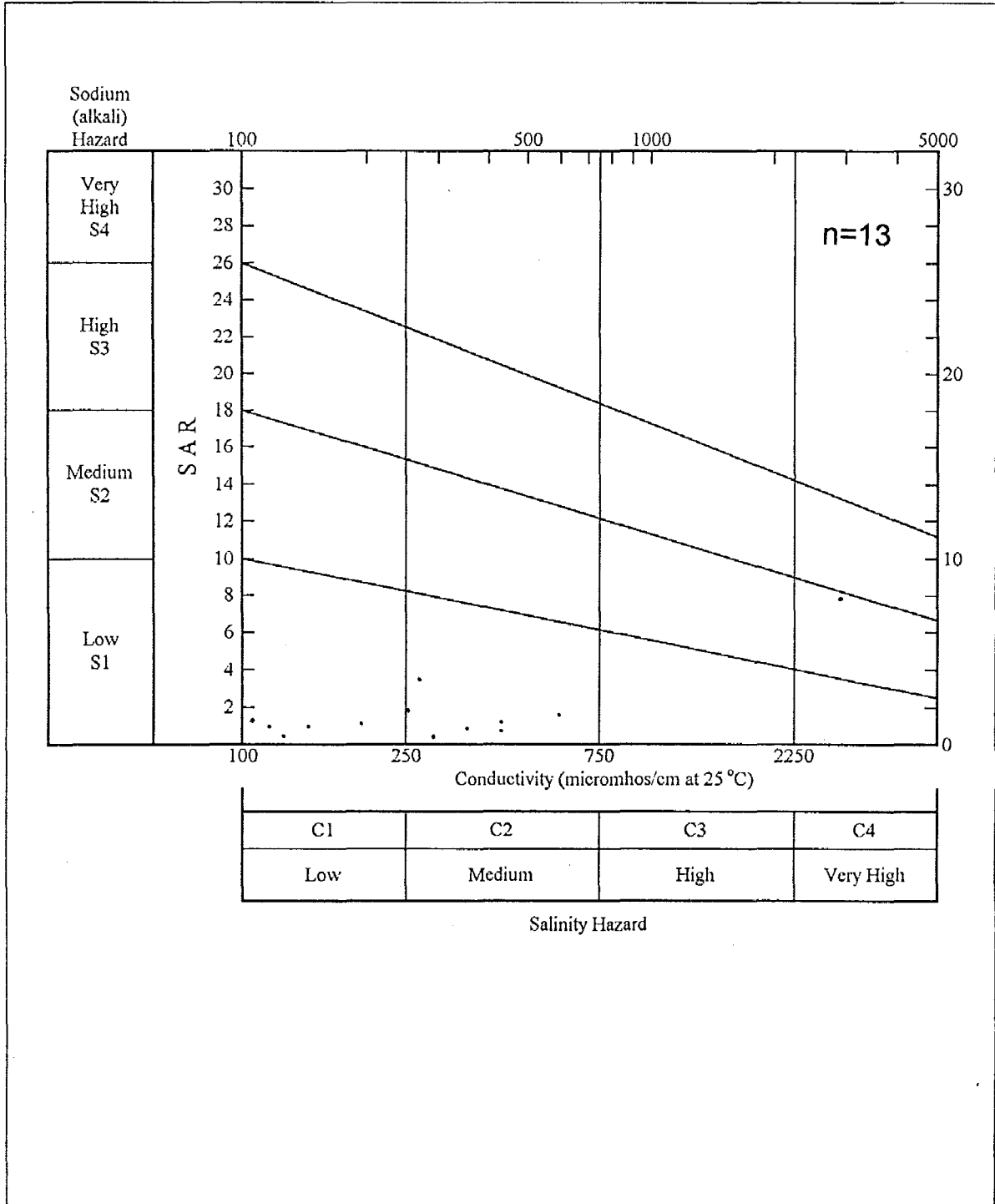
Wilcox Diagram



Dwyka Group

Wilcox Diagram

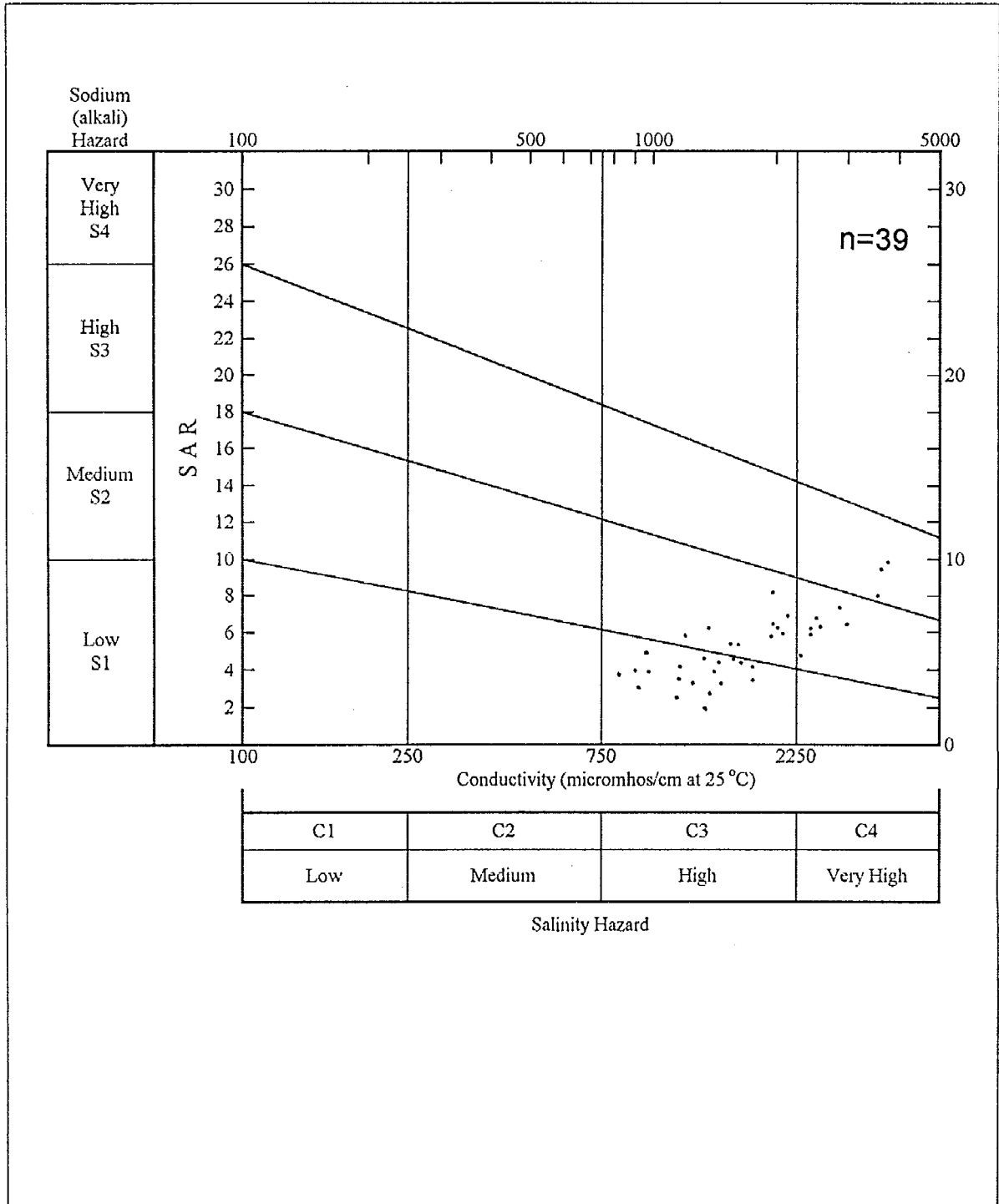
Wilcox Diagram



Ecca Group

Wilcox Diagram

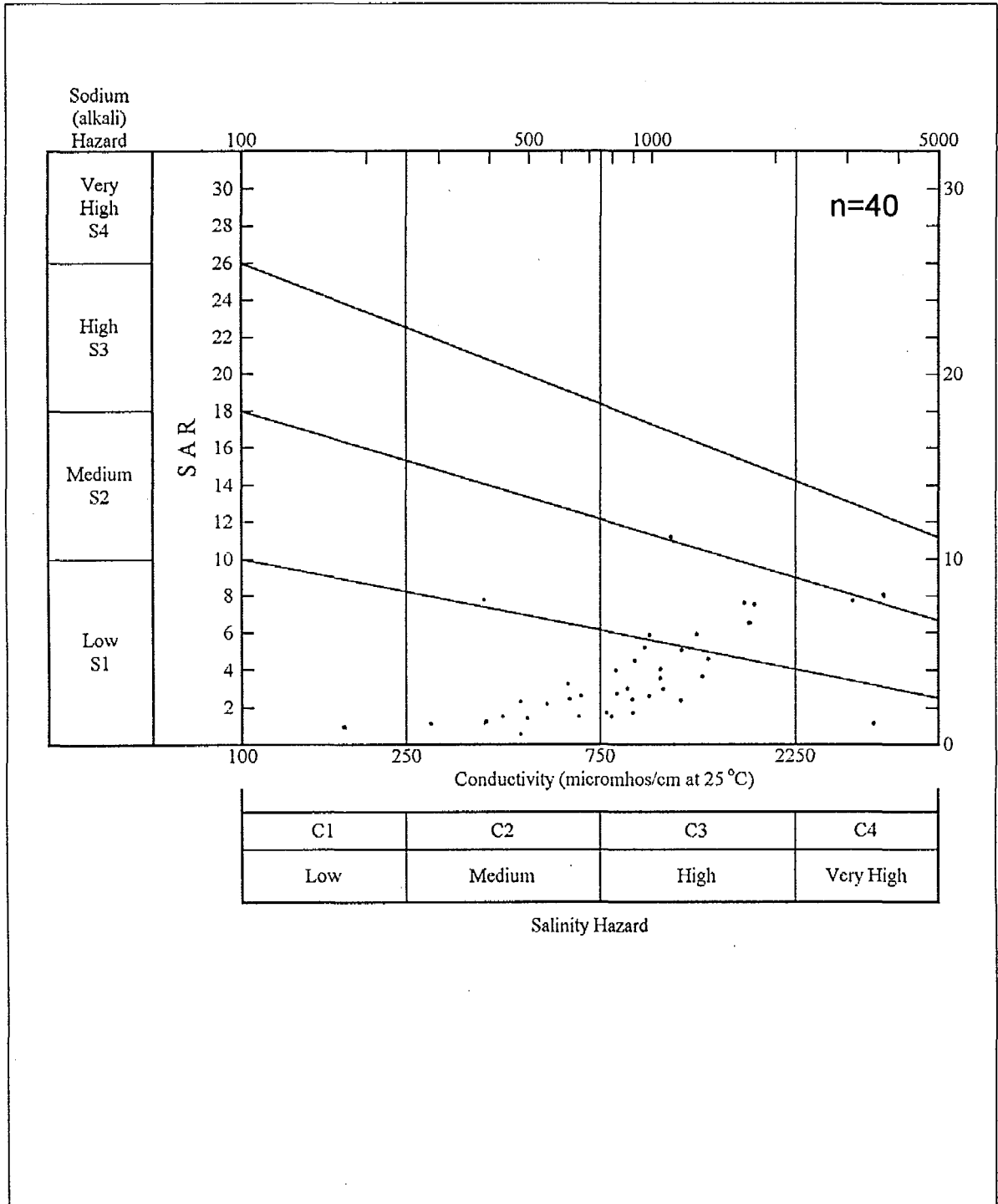
Wilcox Diagram



Beaufort Group: Adelaide Subgroup (Middleton Formation)

Wilcox Diagram

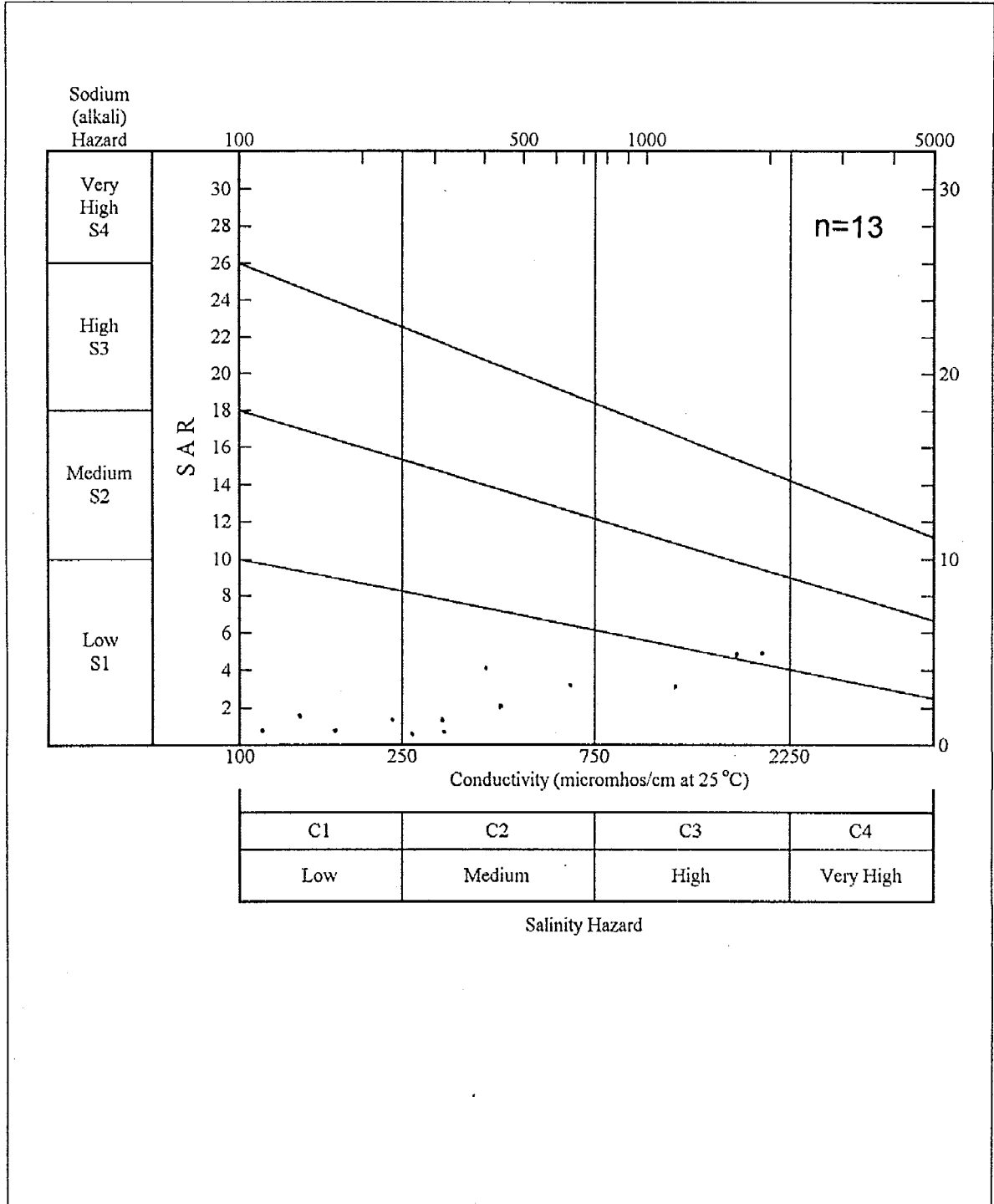
Wilcox Diagram



Beaufort Group: Adelaide Subgroup (Balfour Formation) RSA

Wilcox Diagram

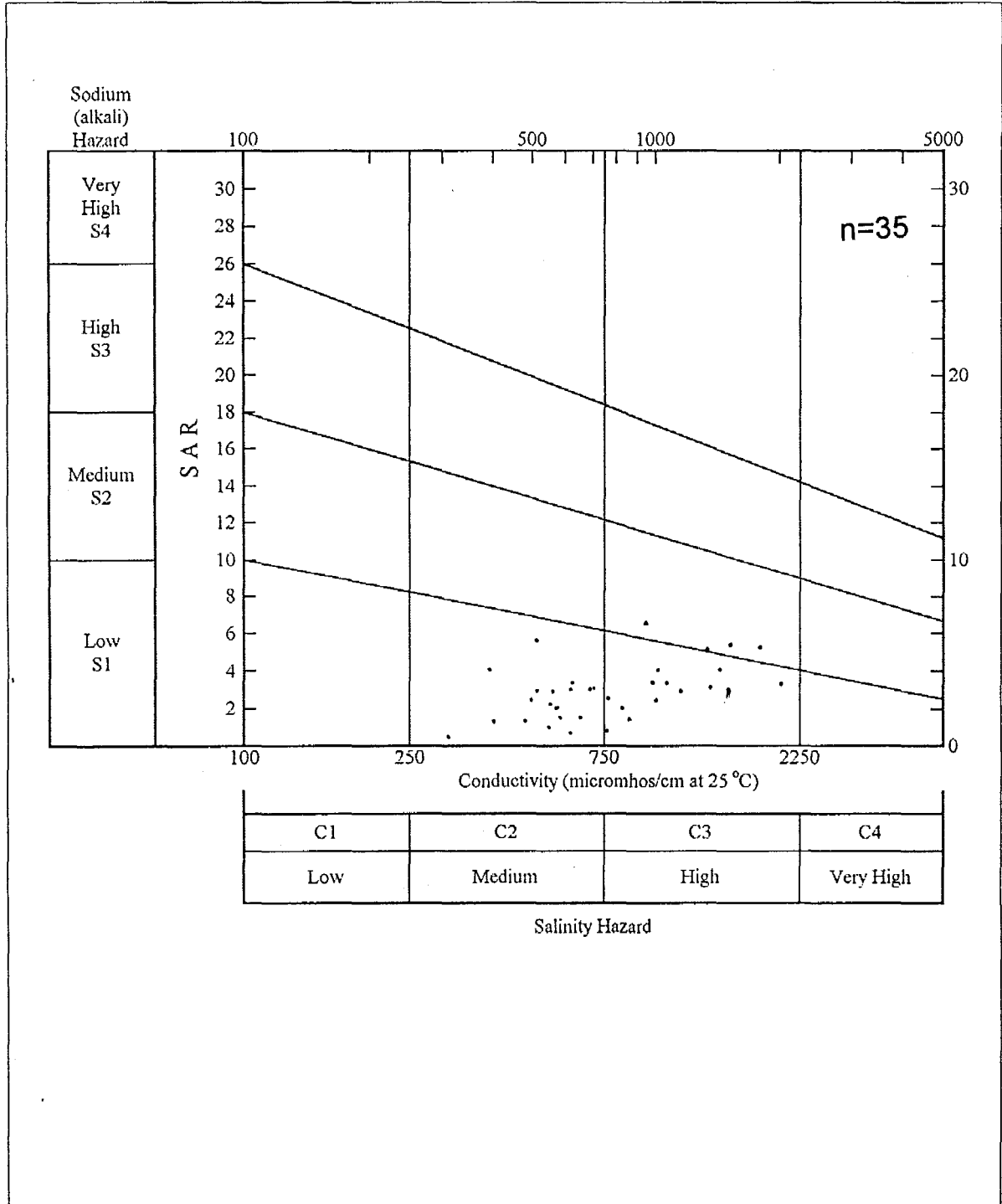
Wilcox Diagram



Beaufort Group: Adelaide Subgroup (Balfour Formation) Transkei

Wilcox Diagram

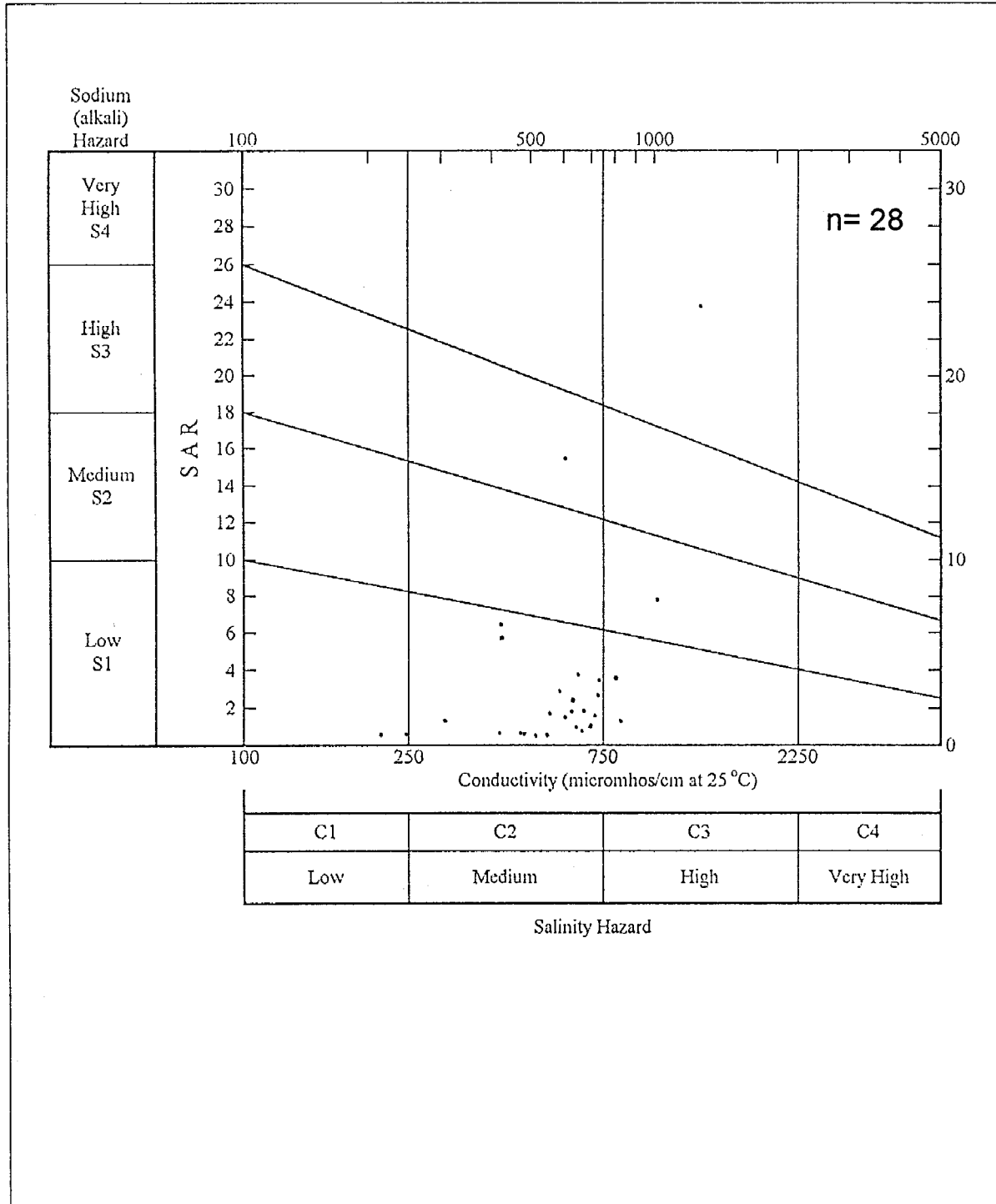
Wilcox Diagram



Beaufort Group: Tarkastad Subgroup (Katberg Formation)

Wilcox Diagram

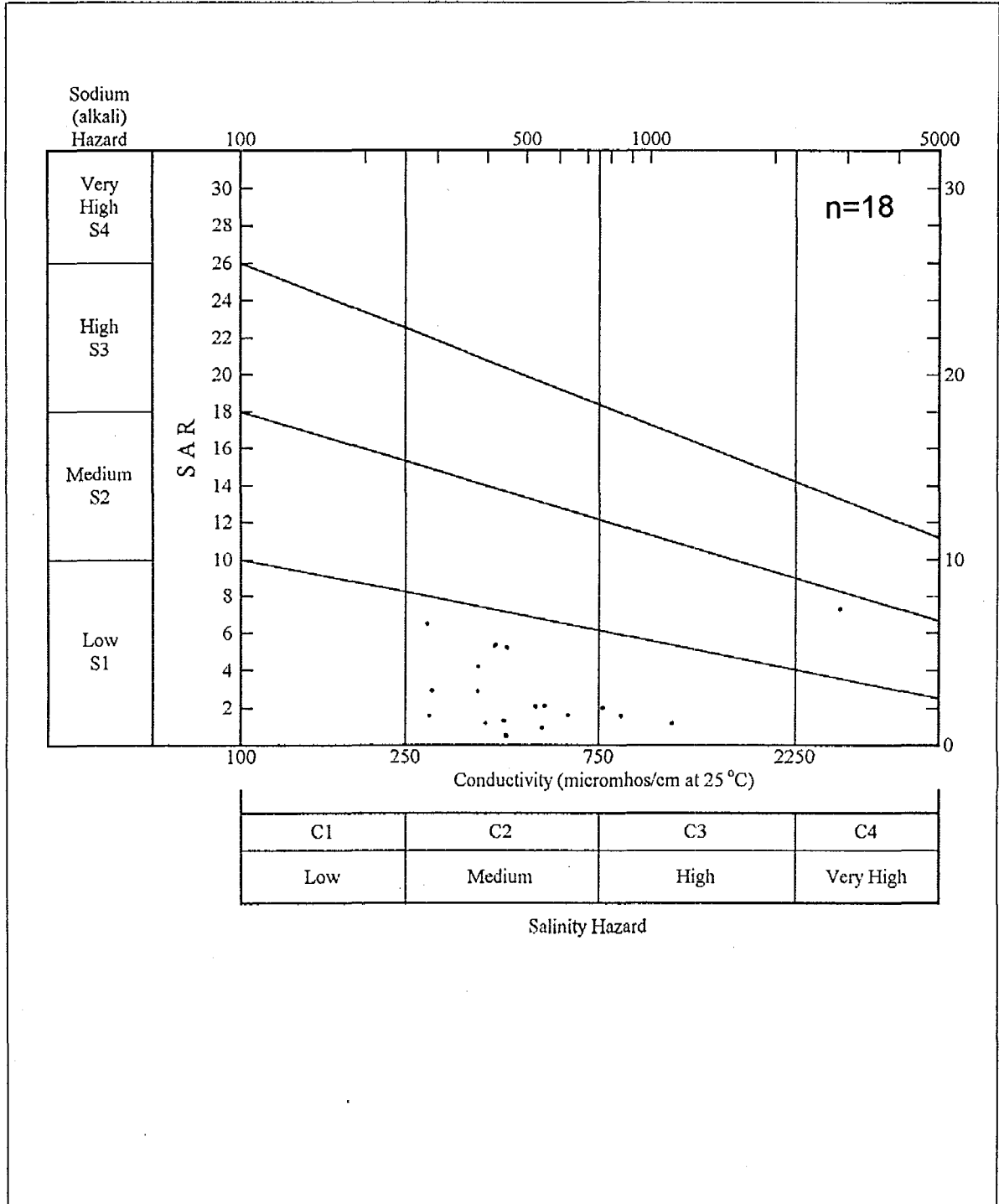
Wilcox Diagram



Molteno Formation

Wilcox Diagram

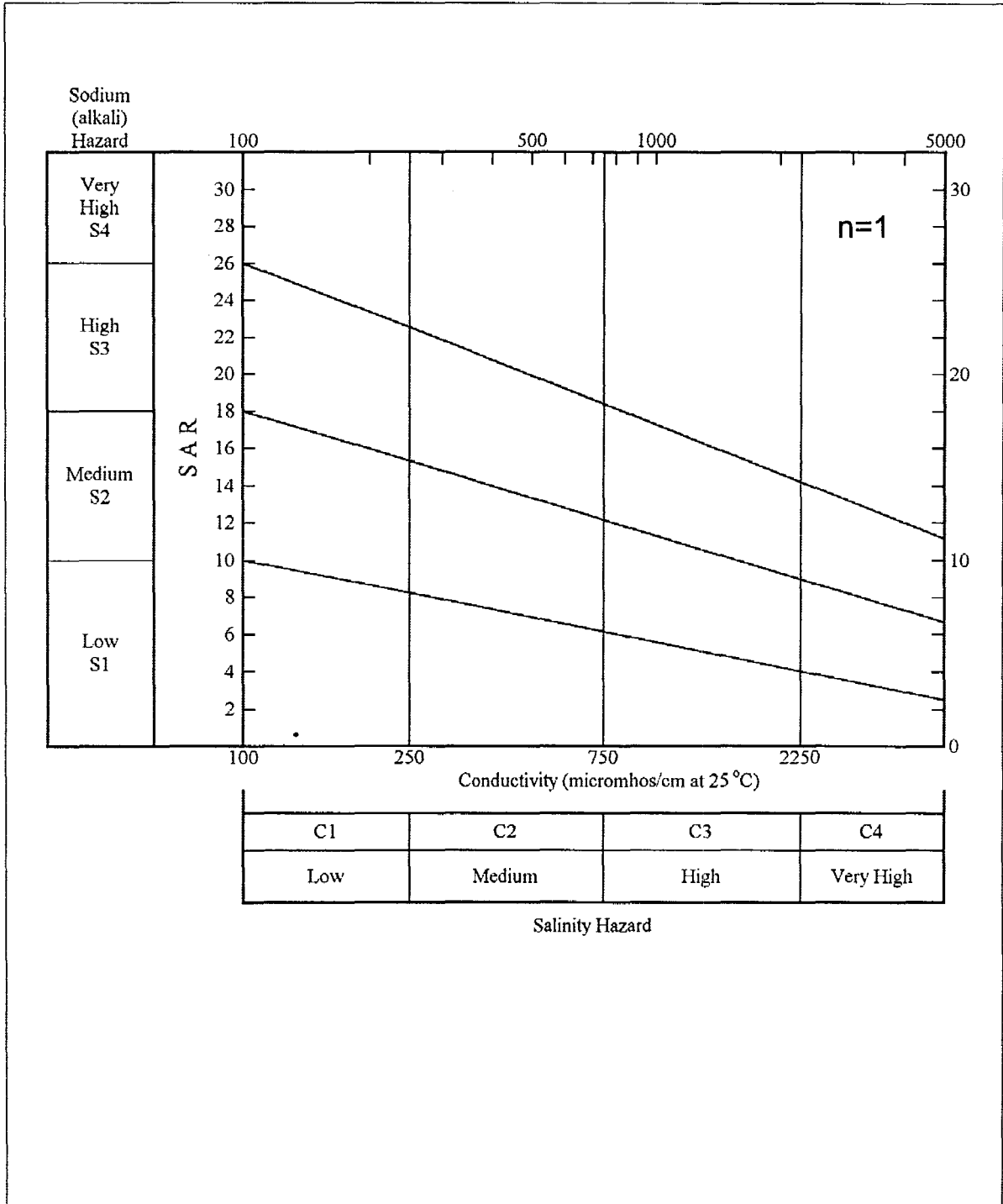
Wilcox Diagram



Elliot Formation

Wilcox Diagram

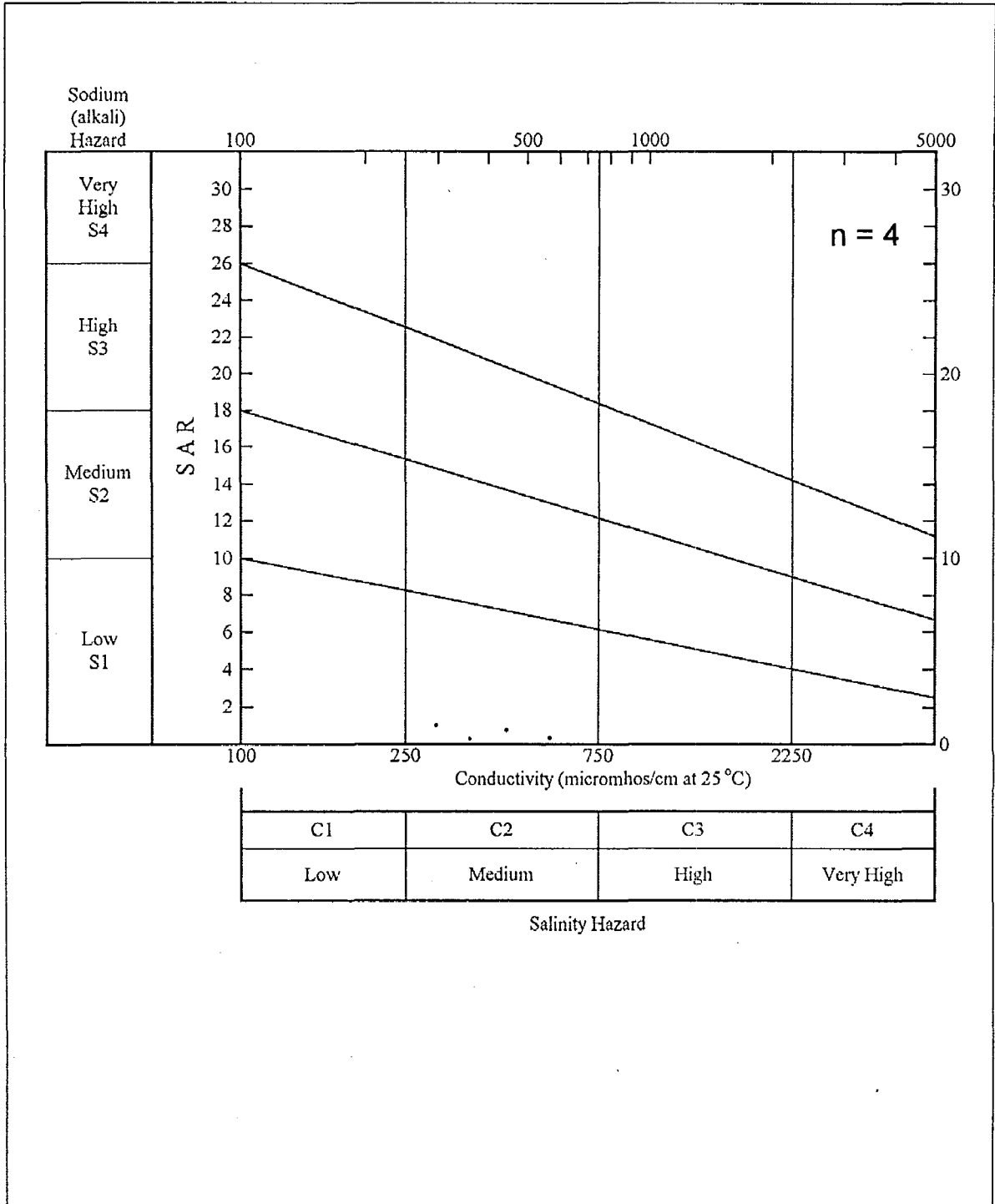
Wilcox Diagram



Clarens Formation

Wilcox Diagram

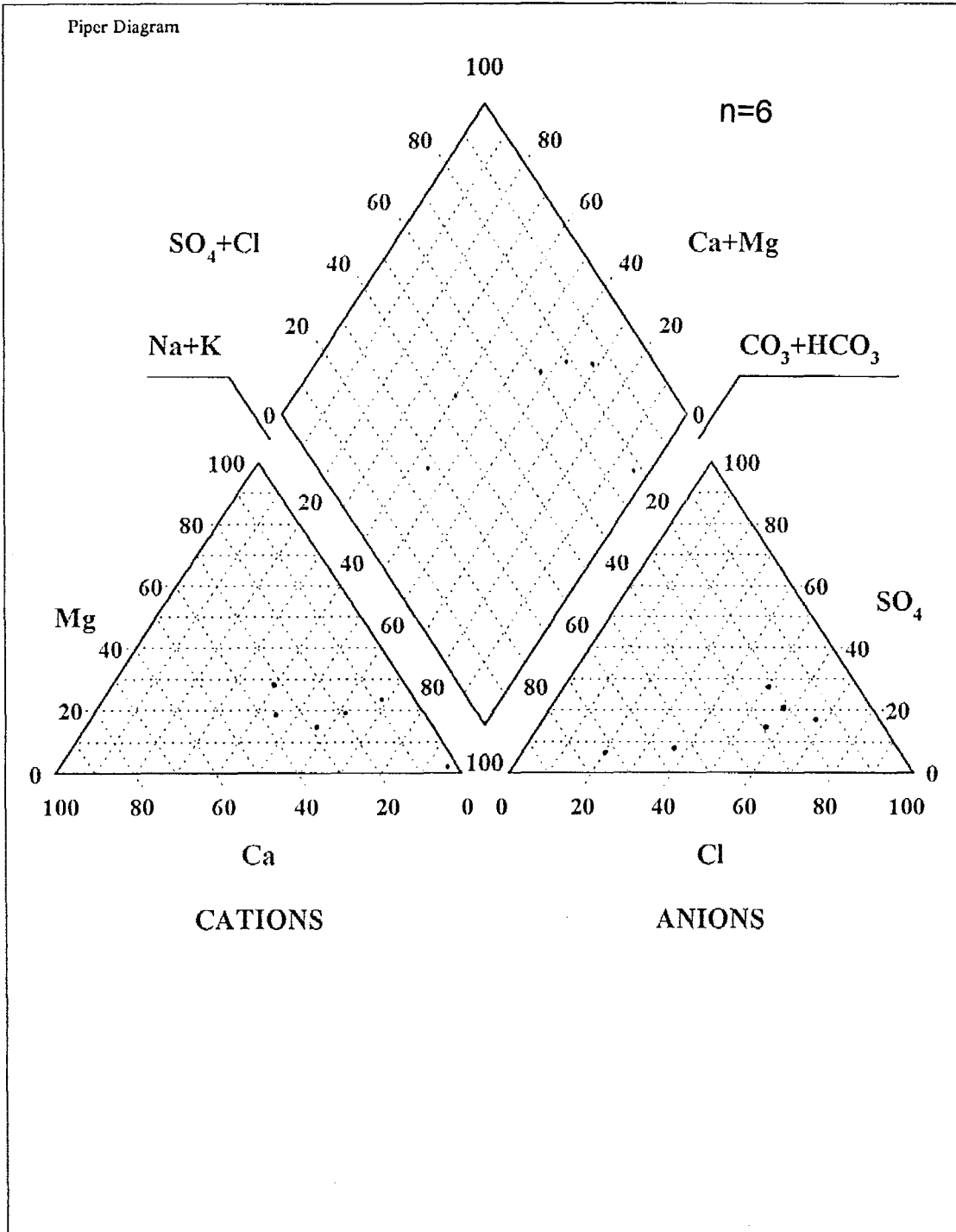
Wilcox Diagram



Drakensberg Group: Basalt lavas

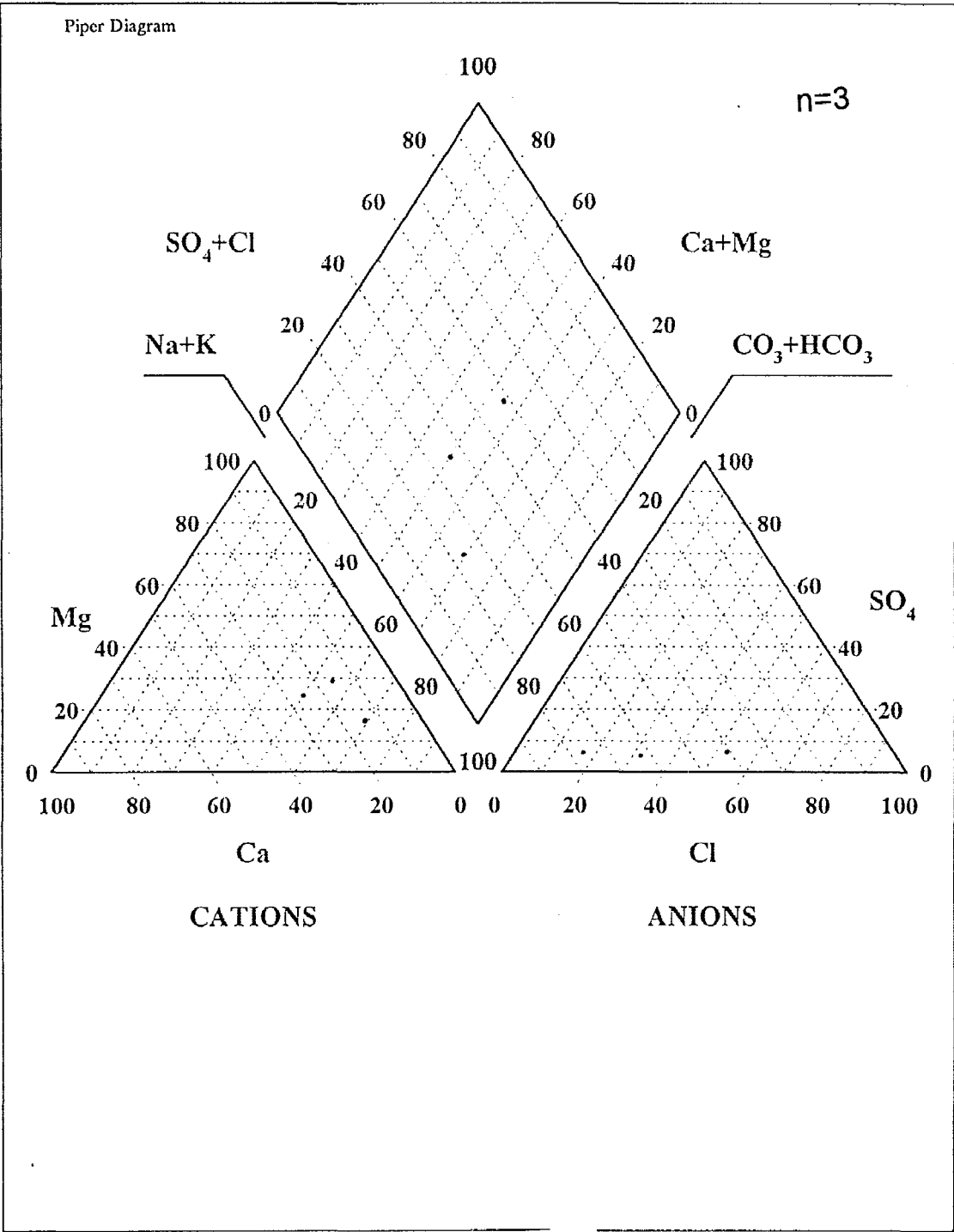
3b Piper diagrams per lithology

Piper Diagram



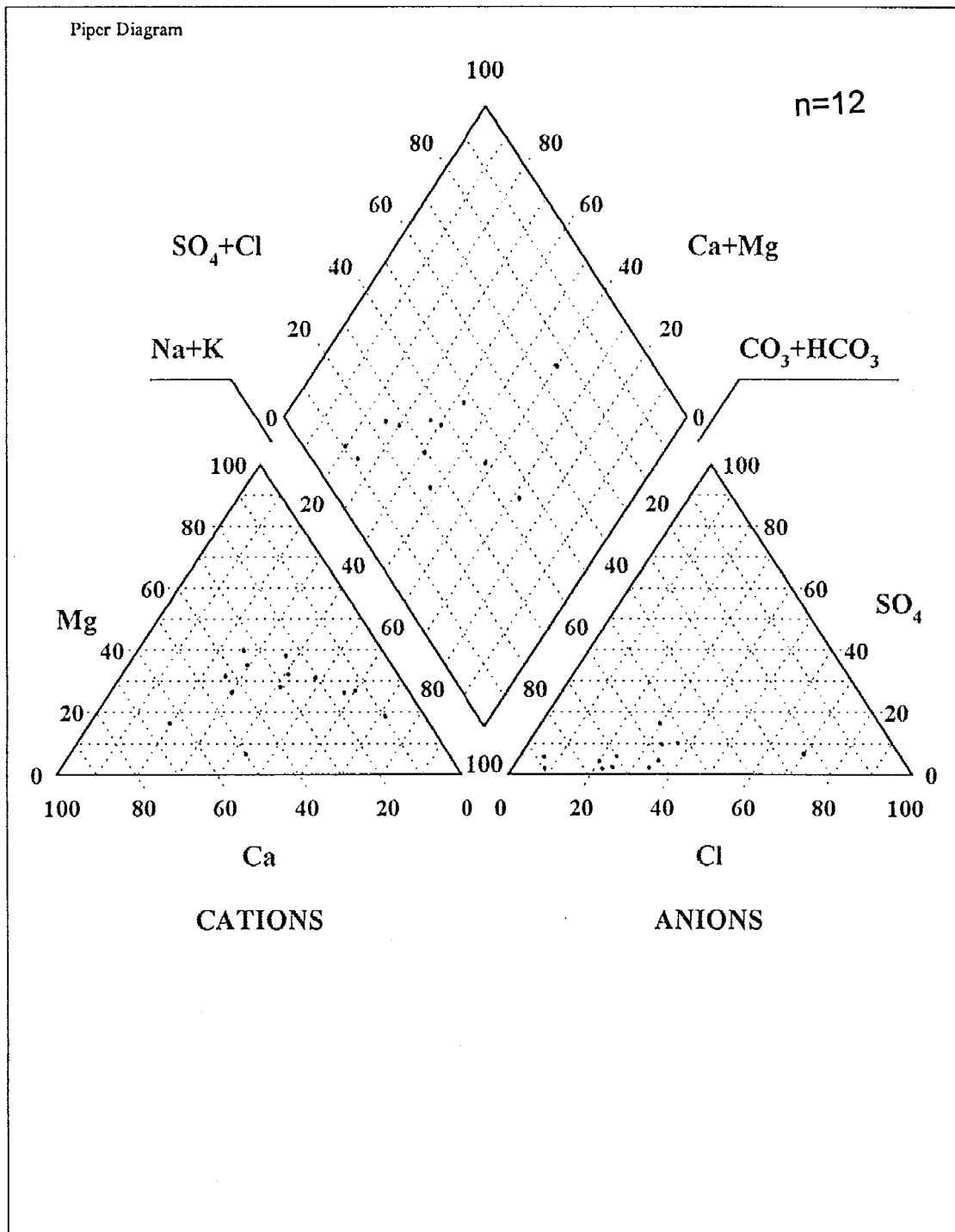
Natal Group

Piper Diagram



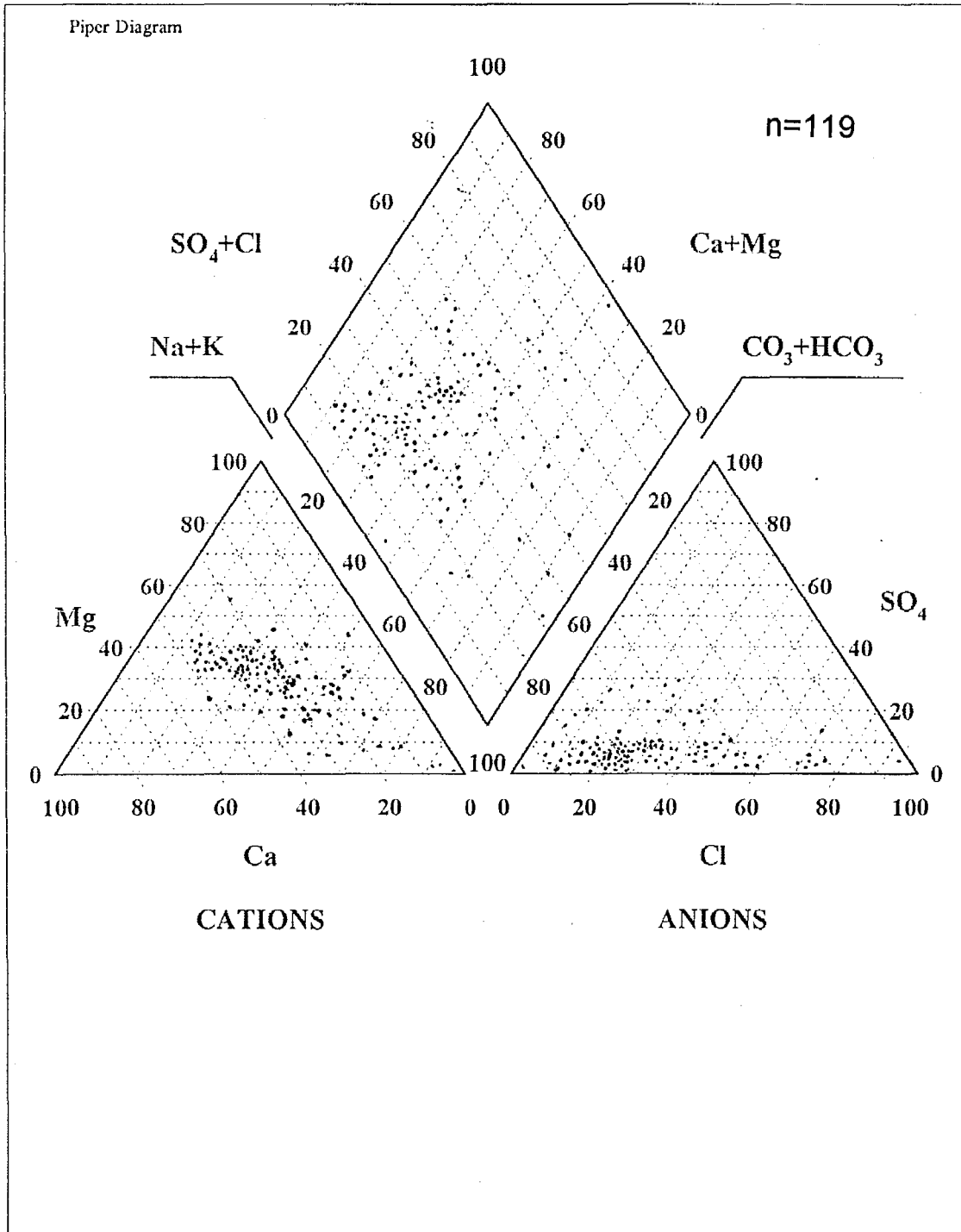
Dwyka Group

Piper Diagram



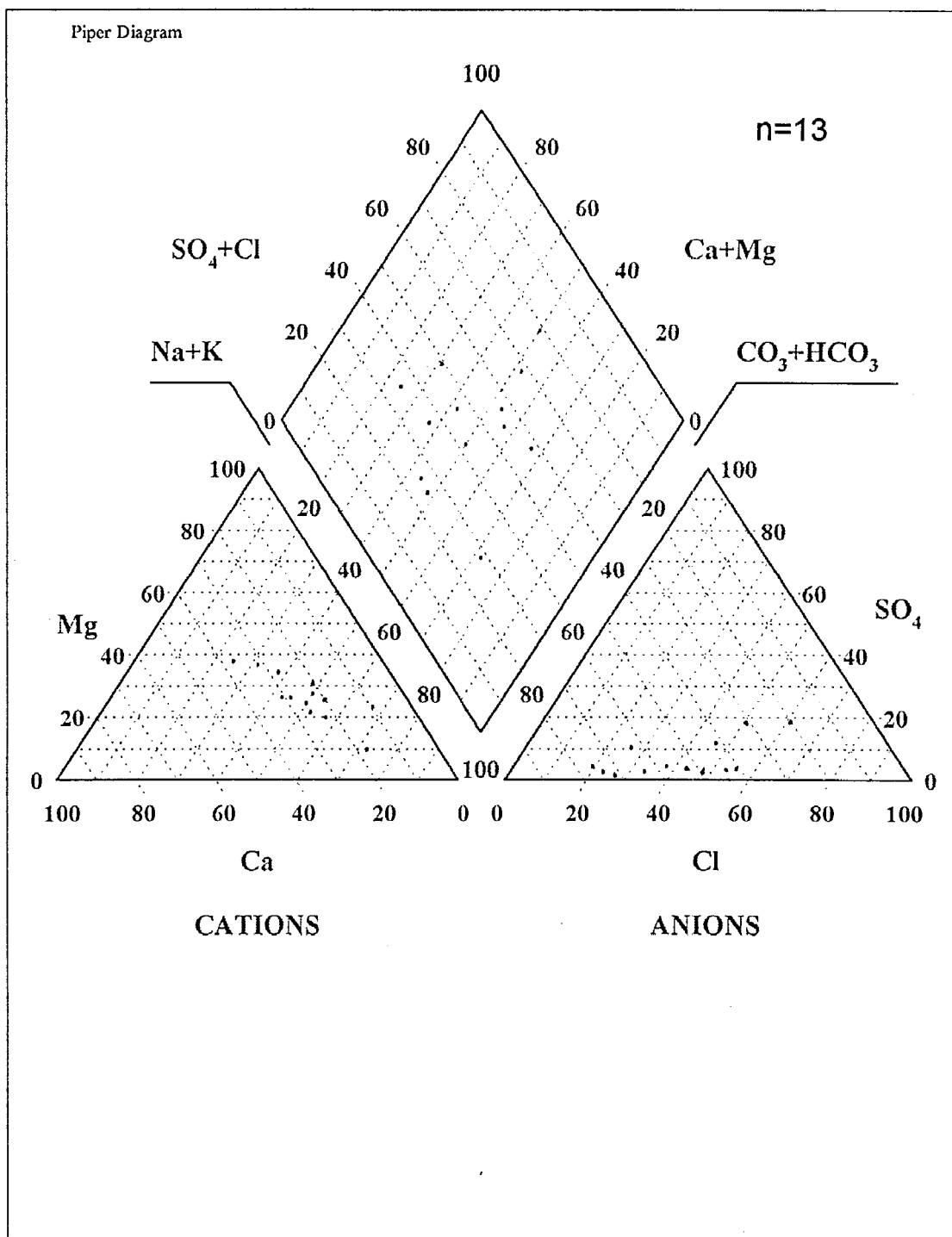
Ecca Group

Piper Diagram



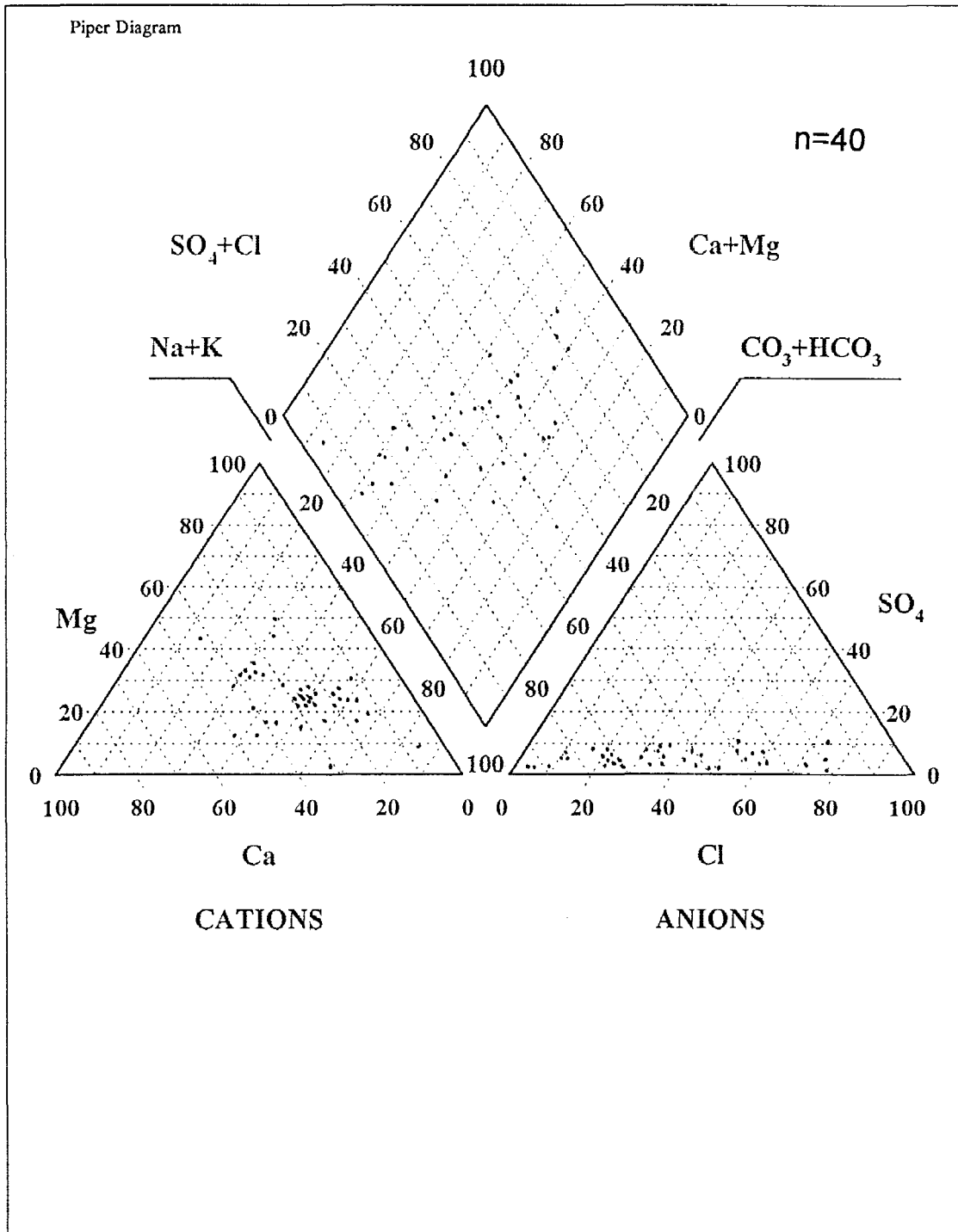
Beaufort Group: Tarkastad Subgroup (Burgersdorp Formation)

Piper Diagram



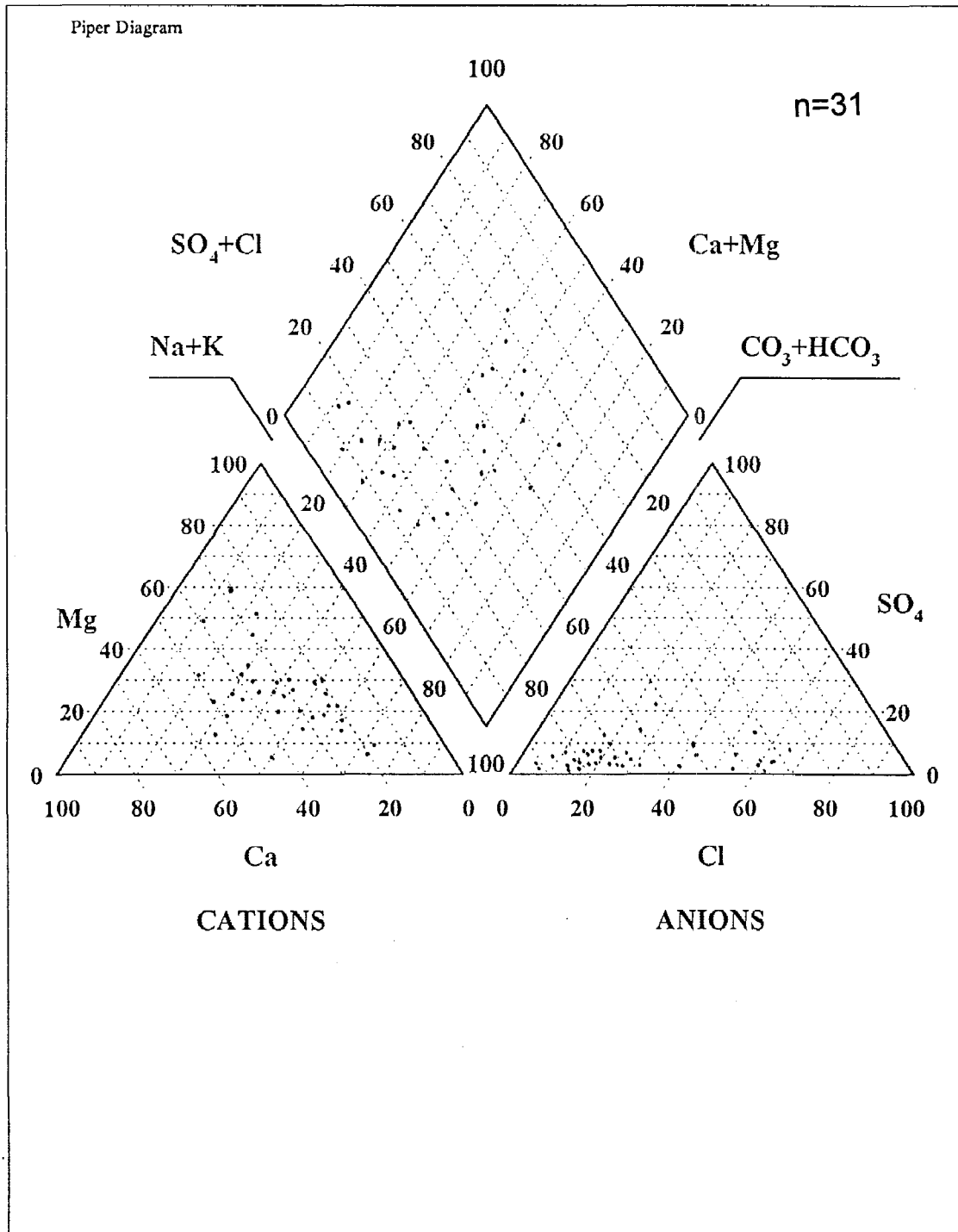
Beaufort Group: Adelaide Subgroup (Balfour Formation) Transkei

Piper Diagram



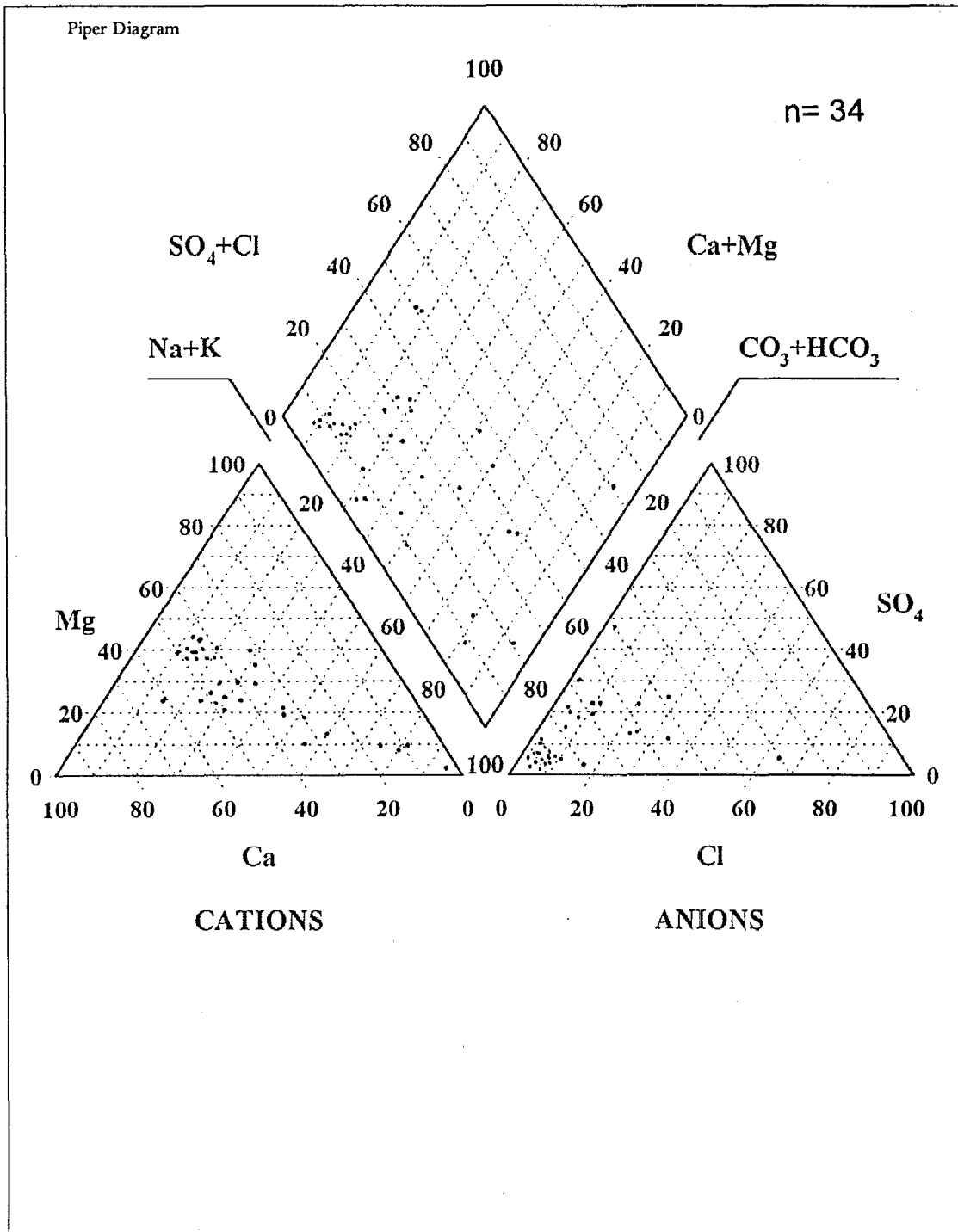
Beaufort Group: Adelaide Subgroup (Balfour Formation) RSA

Piper Diagram



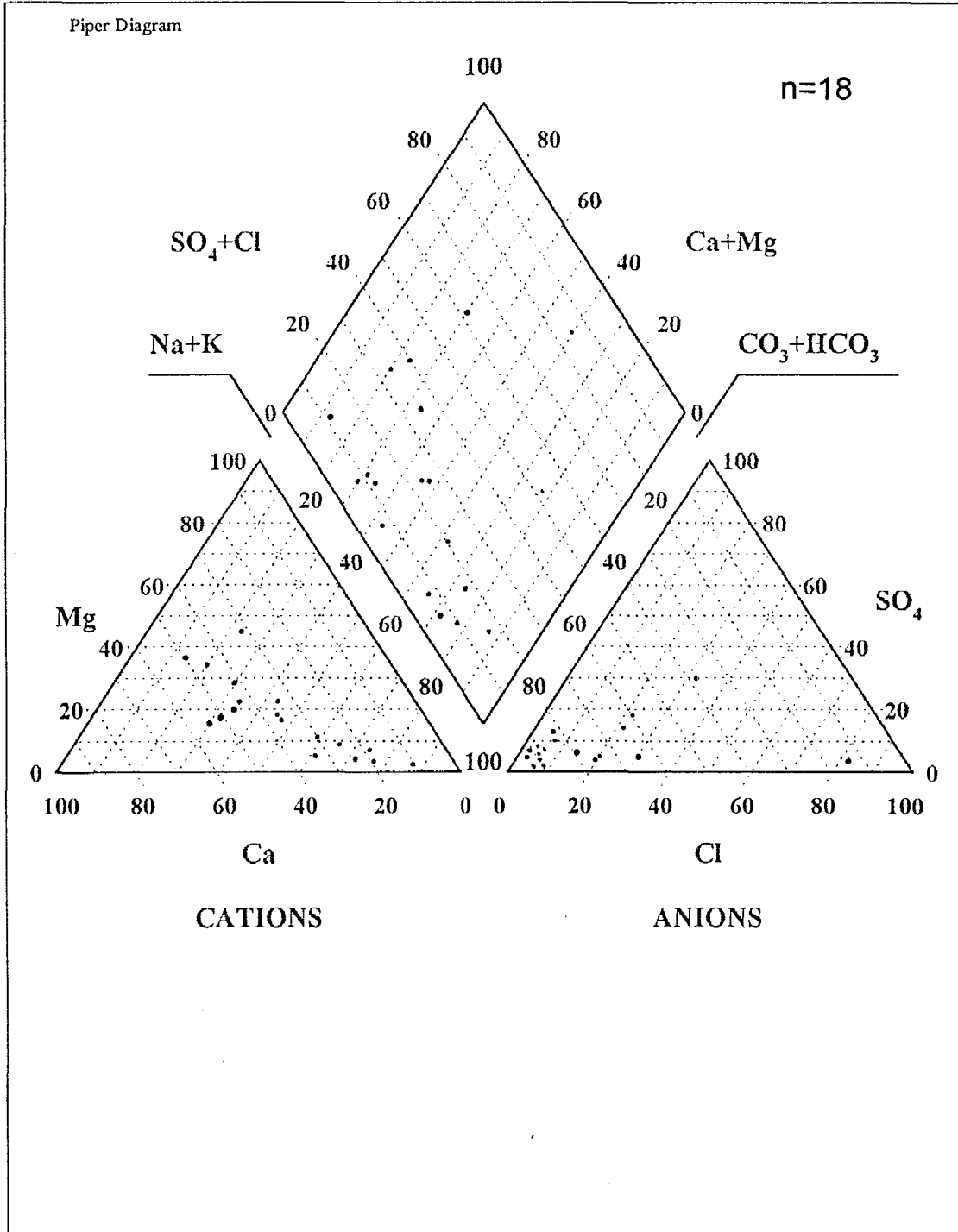
Beaufort Group: Tarkastad Subgroup (Katberg Formation)

Piper Diagram



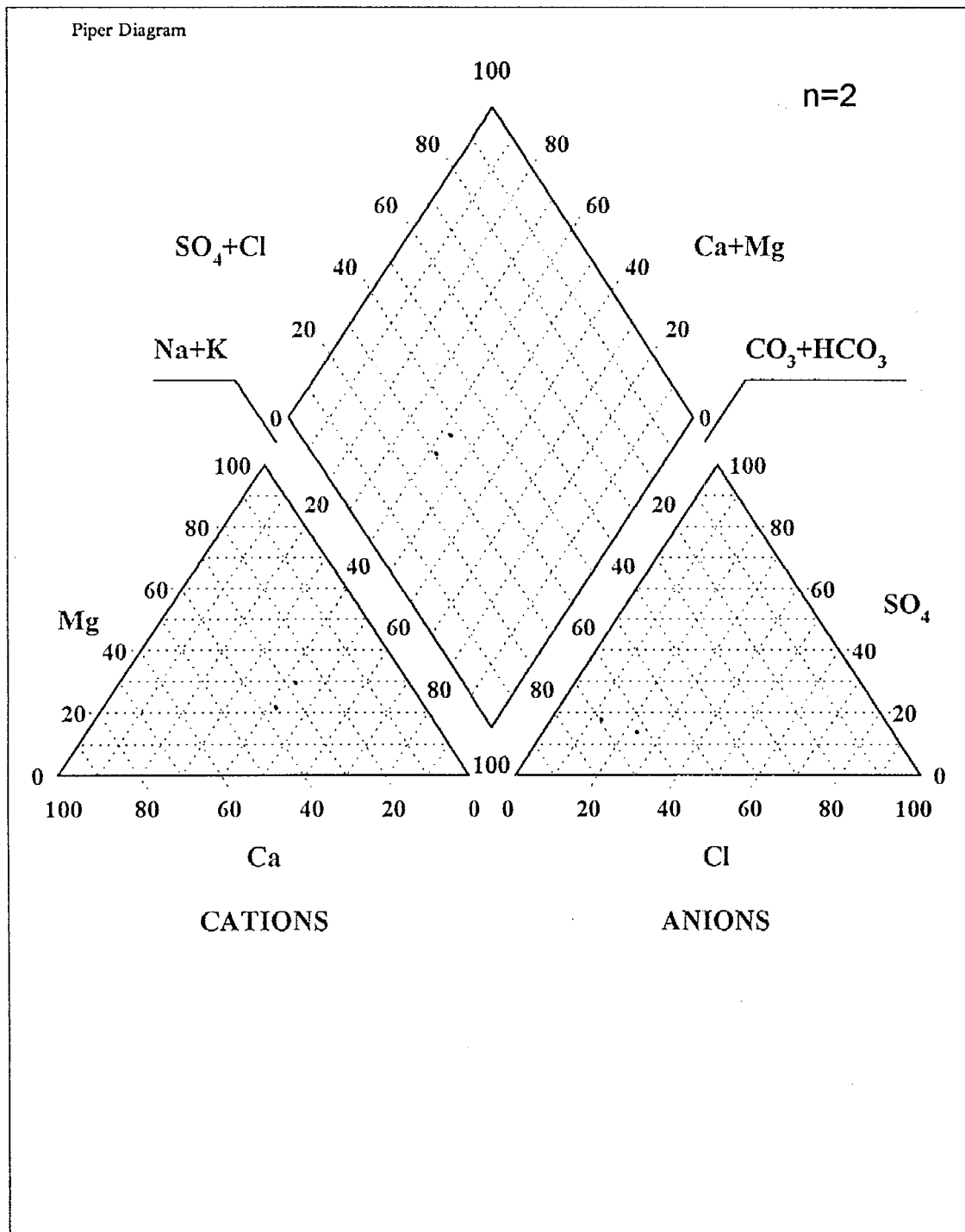
Molteno Formation

Piper Diagram



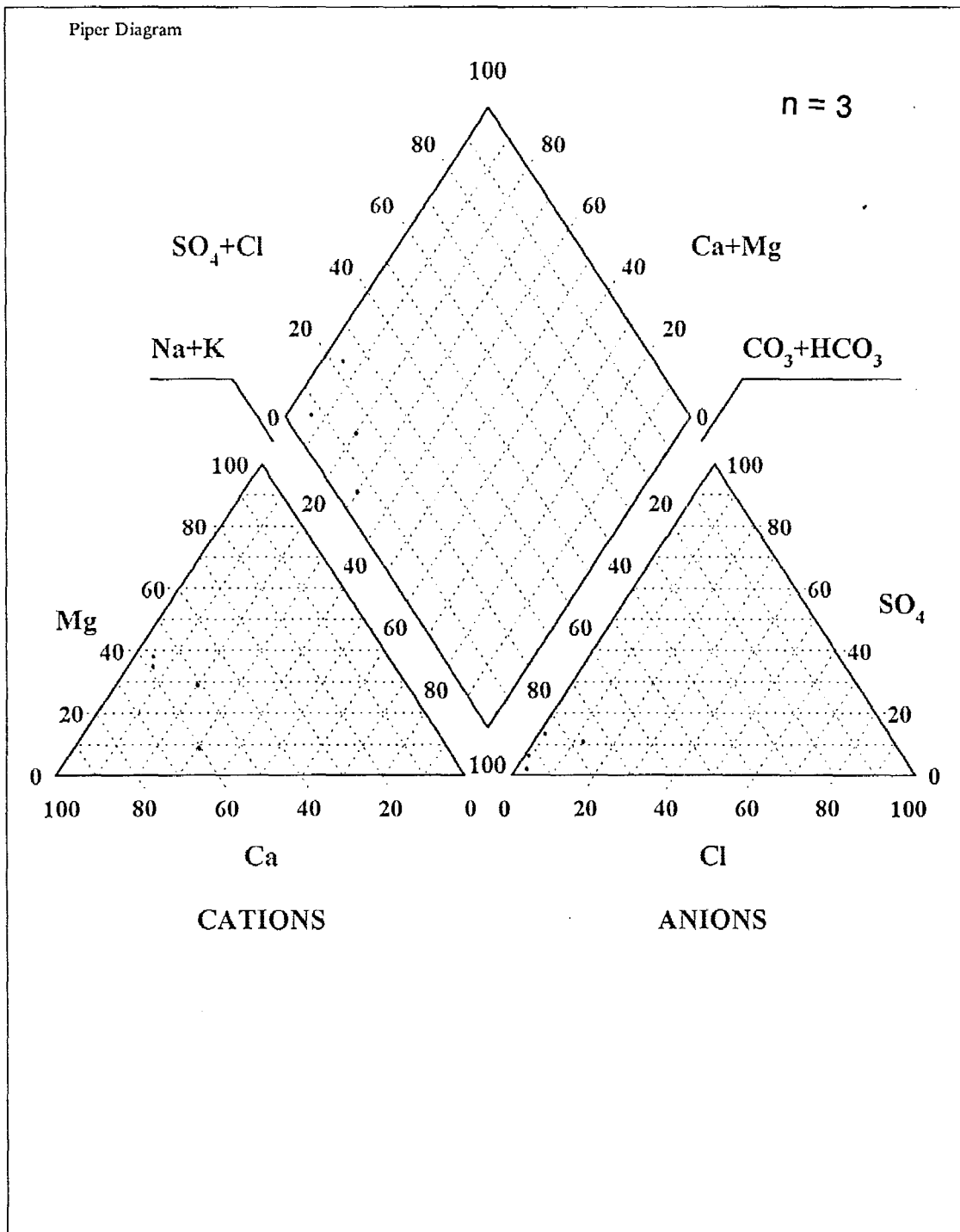
Elliot Formation

Piper Diagram

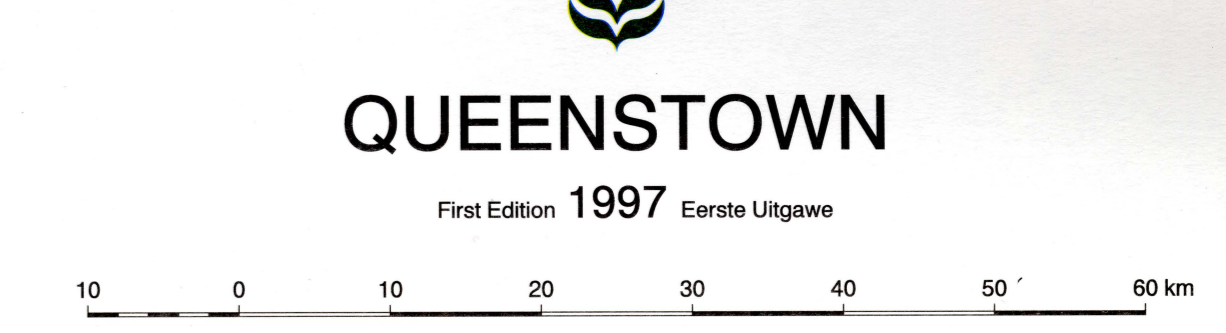


Clarens Formation

Piper Diagram



Drakensberg Group: Basalt lavas



M.C. Smart - Map Author / Kaartskrywer
E. Louw - GIS Specialist / GIS Spesialis
S. Hauptfleisch / H. Mullin - Cartographer / Kartograaf

The groundwater occurrence and groundwater quality maps, and the conceptual illustration were compiled by M.C. Smart. The lithology was adapted by M.C. Smart from the 1:250 000 scale published Geological map series. Permission from the Council for Geoscience to make use of their information is gratefully acknowledged. E. Louw was responsible for the compilation of the borehole distribution map. Precipitation and elevation data were obtained from the Council for Geoscience. Water resources, rivers and streams, and compiled by H. Mullin. Borehole data were obtained from the National Groundwater Data Base (NGDB) and the former Transvaal Department of Land, Agriculture and Forestry data base. Data of roads, rivers, towns and the coastline were obtained from the Civil Directorate, Surveys and Land Information, Department of Land Affairs and edited by the Department of Water Affairs and Forestry.

Principal groundwater occurrence / Hoof grondwater voorkomste

Table with 5 columns representing borehole yield class (median l/sec) and 4 rows representing aquifer types: Intergranular unconsolidated, Fractured, Karst, and Intergranular and fractured unconsolidated. Legend for borehole yield range and median borehole yield in the 1.5 - 2.0 l/sec interval.

Note: Groundwater occurrence depicts the aquifer type(s) with the highest borehole yield which does not always correlate with surface lithology.

Surface lithology / Oppervlakkige litologie

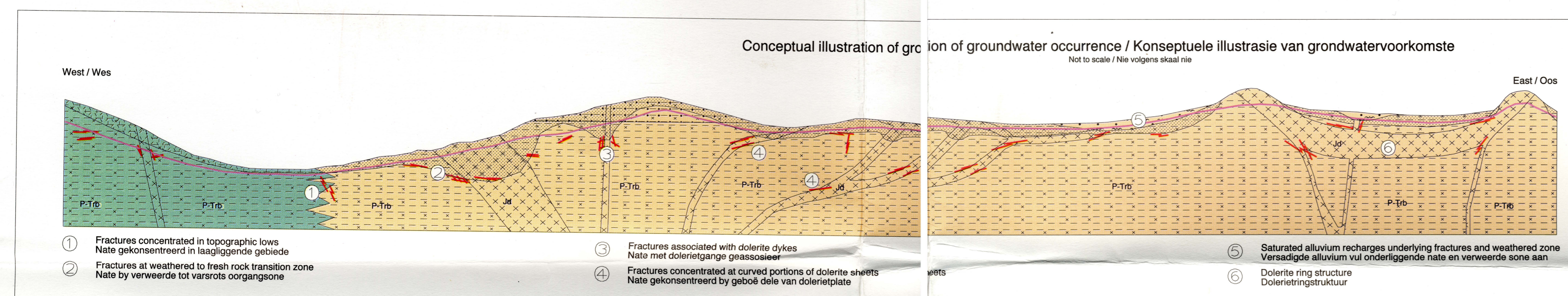
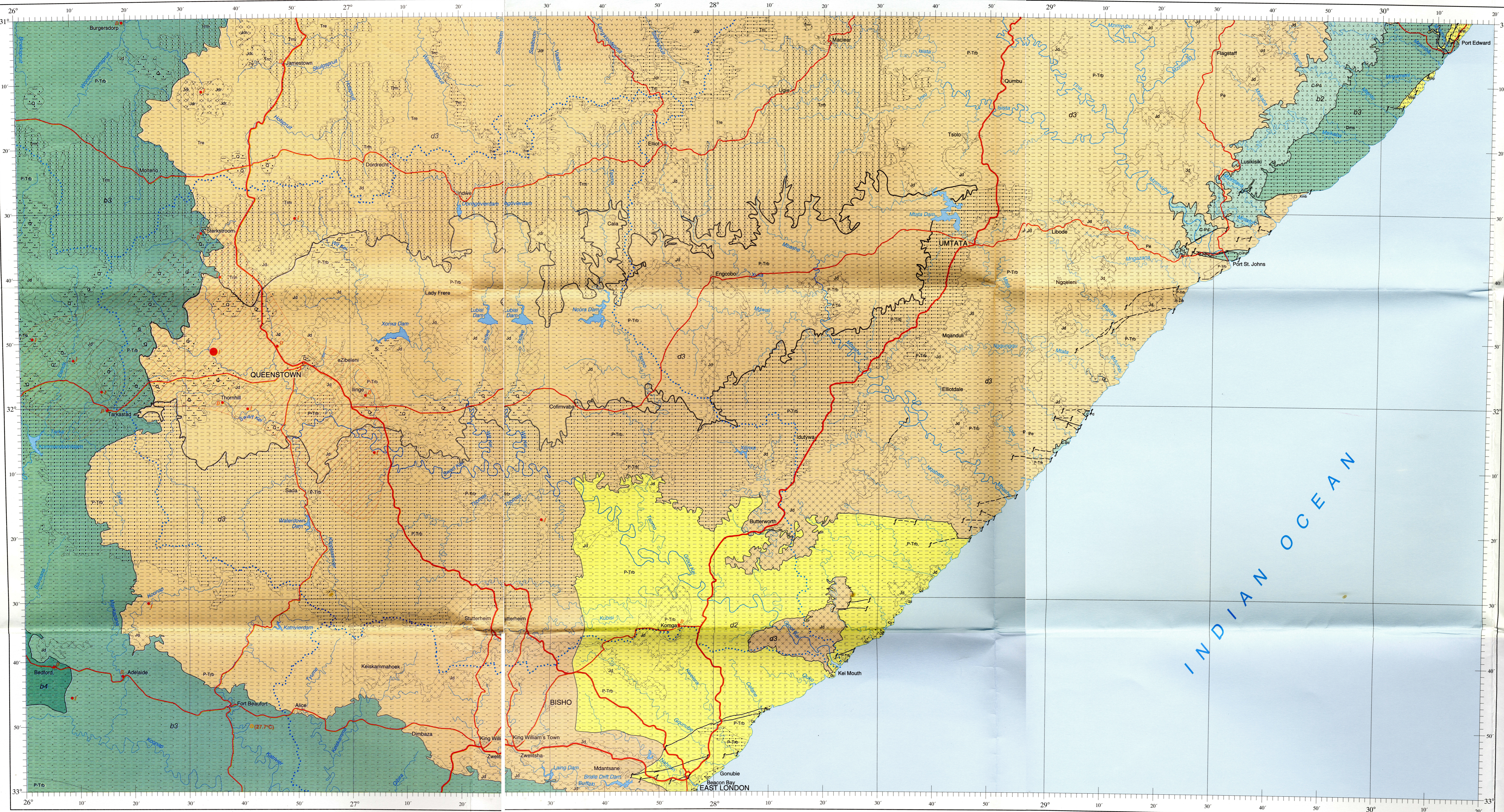
- Aluvium (clay, silt, sand, gravel, boulders)
Undifferentiated coastal deposits (unconsolidated to semi-consolidated)
Predominantly argillaceous rocks (shale, carbonaceous shale, claystone, mudstone and siltstone)
Predominantly arenaceous rocks (sandstone, feldspathic sandstone, siliceous sandstone, calcareous sandstone, calcareous shale)
Aglauclite and arenaceous rocks (approximately equal proportions)
Predominantly rhyolitic rocks (conglomerate)
Predominantly diamicite (tillite)
Undifferentiated metamorphic rocks (mixed lithologies)
Mafic intrusive rocks (dolerite)
Predominantly pyroclastic rocks (tuff, agglomerate, breccia)
Mafic extrusive rocks (basalt)
Lithological / stratigraphical boundary
Fault / versuiveling
Inferred fault / vermoede versuiveling

Large scale groundwater abstraction

- 3-5 million m³/a
0.1-1 million m³/a
Irrigation
Domestic
Industrial
Thermal spring (°C)
Warmed (°C)
Primary drainage region boundary
Pienarij river
Standsvloedrivier
Non-perennial river
Niet-standhoudende rivier
Dam / Dam
City town area
Stad / Dorpsgebied
Inset map: Town
Inset map: District
National road
Nasionale pad
Main road
Hoofpad; Inset kaart: Nasionale pad
Inset map: Main road
Inset kaart: Hoofpad
Provincial boundary
Provinsiale grens
Not applicable to this map

Chronostratigraphy

Chronostratigraphic column with columns for geological time periods (Cretaceous, Mesozoic, Paleozoic, Archeozoic) and geological stages (Quaternary, Tertiary, Permian, Carboniferous, Devonian, Silurian, Ordovician, Cambrian, Namibian, Moolakian, Vaalian, Rindian, Swazian).



This general hydrogeological map is part of the 1:500 000 Hydrogeological map series of the Republic of South Africa. The map is not to be used for the purpose of local borehole siting. Simplified lithology may be considered as guidelines only. Further geological information can be obtained from the Council for Geoscience. The map series is produced with ArcInfo software. Digital data, copies of this map and accompanying brochure are obtainable from: Directorate: Geohydrology, Department of Water Affairs and Forestry, Private Bag X313, Pretoria, 0001. State copyright 1997.

