

ESTABLISHING GEOBOTANICAL-GEOPHYSICAL
CORRELATIONS IN THE NORTH-EASTERN PARTS
OF SOUTH AFRICA FOR IMPROVING EFFICIENT
BOREHOLE SITING IN DIFFICULT TERRAIN

by

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“Who has ascended up into heaven, and descended? Who has gathered the wind in his fists? Who has bound the waters in his garment? Who has established all the ends of the earth? What is his name, and what is his son’s name, if you know?” (Proverbs 30:4)

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GLOSSARY

Alluvium	Unconsolidated materials deposited in recent geological times in close proximity to streams and rivers or mountains through the agency of running water.
Aquifer	A stratum which contains intergranular interstices or a fissure/fracture or a system of interconnected fissures/fractures capable of transmitting groundwater rapidly enough to directly supply a borehole or spring.
Aquitard	A confining bed that retards but does not prevent the flow of water to and from an adjacent aquifer – a leaky confining bed. It does not readily yield water to boreholes or springs but may serve as a storage unit.
Biodiversity	(biological diversity) The variety of life forms, including the plants, animals and micro-organisms, the genes they contain and the ecosystems and ecological processes of which they are part.
Biome	A biome is a natural grouping of vegetation according to the life-form of the dominant plants and ecological similarities
Borehole	A borehole (for the research purposes) is basically any drilled narrow shaft (normally vertically) descending below ground level to a geologic layer containing water to be extracted.
Cation exchange capacity (CEC)	By virtue mainly of their colloidal components (both inorganic and organic), most soils possess a negative electrical charge which is balanced by cations so that the system as a whole is electrically neutral. The cations so held by a soil represent a

	definite quantity and can be exchanged by other cations. This quantity is employed as a measure of cation exchange capacity which is given in terms of milli-equivalents per 100 g of material (me %)
Chronostratigraphic unit	An isochronous body of rock that serves as the material reference for all rocks formed during the same span of time.
Climax specie	A species that is self-perpetuating in the absence of disturbance, with no evidence of replacement by other plant species.
Confined groundwater	Groundwater under pressure significantly greater than that of the atmosphere and whose upper surface is the bottom of a layer of distinctly lower permeability than the material in which the water occurs.
Diagenesis	All the chemical, physical and biological changes, modifications and transformations undergone by a sediment during and after its lithification e.g. consolidation, cementation, (re)-crystallisation, but exclusive of weathering and metamorphism.
Divining	The practice of locating groundwater, minerals or other objects by means of a forked twig, pendulum or other quasi- or non-scientific device.
Electrical conductivity	The electrical conductivity is the measure of the ability of water to conduct an electrical current.
Eonothem	The highest ranking chronostratigraphic unit.
Evapotranspiration	Loss of water from a land area through transpiration of plants and evaporation from the soil.
Fault	A surface or zone of rock fracture along which there has been displacement.
Fissure	A surface of fracture or crack along which there is a distinct separation.
Fracture	Any break in rock whether or not it causes displacement, owing to mechanical failure by stress.

	Fractures include cracks, joints and faults.
Geobotanical areas	Certain tree or shrub species that are connected to geological phenomena, which occur in a specific biome, region or locality.
Geobotanical indicators	Recognised tree or shrub species that occur on certain kinds of rock or soil and that indicate to the presence of some geological phenomena e.g. groundwater, mineralization, differences in lithology.
Geobotany	The association of certain tree or shrub species on a certain kind of rock or soil and that can be utilised to indicate possible sources of groundwater, mineral occurrences or other geologic associations.
Geohydrology	The branch of hydrology dealing with subsurface water i.e. water in both the saturated and unsaturated zones.
Geomorphology	The study of the physical features of the surface of the earth and their relation to its geological structures.
Geophysical exploration	The use of geophysical instruments and methods to determine the subsurface conditions by analysis of such properties as density, electrical conductivity, magnetic susceptibility and propagation of elastic waves.
Groundwater	The water in the zone of saturation. It flows into boreholes and wells or debouches as springs.
Intrusion	The emplacement of magma in pre-existing rock; also the igneous rock mass so formed.
Land type	Denotes an area that can be shown at 1:250 000 scale and that displays a marked degree of uniformity with respect to terrain form, soil pattern (geology dependent) and climate.
Lineament	Any line on an aerial photograph or satellite image that is controlled by geological structure e.g. dykes, faults, joints, beds, rock boundaries including

	streams, lines of trees and bushes that are so controlled.
Lithology	Refers to the study and description of the physical character of rocks, particularly in hand specimens and outcrops.
Mafic	An igneous rock e.g. gabbro that is composed chiefly of one or more ferromagnesian minerals – a term derived from m agnesium plus f erric (iron).
Metamorphism	The mineralogical and structural adjustment of solid rocks to physical and chemical conditions which have been imposed at depth below the surface zones of weathering and cementation and which differ from the conditions under which the rocks in question originated.
Palaeo-channel	A buried stream channel.
Parameter	A measurable or quantifiable characteristic or feature.
Pedogenic	Processes that forms soils and defines their classification in a soil series i.e. geology, climate, topography.
Permeability	The capacity of water-bearing material – rock or soil – to transmit water.
pH	A measure of the activity of the hydrogen ions and is expressed as the negative logarithm to the base 10 of the hydrogen ion activity ($\text{pH} = -\log[\text{H}_3\text{O}^+]$). pH-value vary between 1 and 14.
Phreatophyte	A plant that obtains its water from the zone of saturation or through the capillary fringe and is characterized by a deep root system.
Porosity	The property of rock, soil or other material, containing interstices/openings.
Principle of equivalence	A layer whose resistivity is either higher or lower than the layers above and below it. Such layer may

	be difficult to distinguish on a sounding curve, if it's thin or its resistivity contrast to the other layers is small.
Principle of suppression	A layer whose resistivity is intermediate between the layer above and below it. Such layer may be difficult to distinguish on a sounding curve, if it's thin or its resistivity contrast to the other layers is small.
Resistance	The resistance is the measure of the ability of rock or its weathered counterpart to isolate an electrical current,
Saturated zone	A subsurface zone in which all the interstices are filled with water under greater pressure than that of the atmosphere.
Semi-confined groundwater	A mixture between confined and unconfined groundwater. Normally groundwater that is not too deep and is overlain by an aquitard.
Site specific	Refers to conditions which are unique or specific to a certain site or locality.
Soil horizon	Are developed through processes (eg a fluctuating water table) taking place within the soil. A soil horizon is bounded by air, hard rock or by soil material that has different characteristics.
Soil series	Conceptual generalizations of soil based on selected soil properties, (1) diagnostic horizons and (2) other non-diagnostic horizons e.g. soil texture, size grading of the sand fraction, soil colour and the nature of C (organic carbon). Each series is referred to by a geographic name.
Species	A group of organisms that resemble each other to a greater degree than members of other groups and that form a reproductively isolated group that will not produce variable offspring if bred with members of another group.
Termitary	A nest of termites, usually in the form of a large

	mound of earth.
Texture (soil)	The relative proportions of the various size separates in the soil as described by the classes of soil texture shown in the text below. The separation defines sand, loamy sand, sandy loam and sandy clay loam classes. The same is applicable to silt and clay.
Unconfined groundwater	Groundwater of which the upper surface is at atmospheric pressure, or in other words, its upper surface is the water table.
Unsaturated zone	The zone between the land surface and the water table in which interstices contain air or gases generally under atmospheric pressure as well as water under pressure which is less than that of the atmosphere.
Vadose zone	Synonym zone of aeration; unsaturated zone.
Water level	The water surface in a borehole or well.
Water table	The upper surface of the zone of saturation. In other words, the imaginary surface below which all openings/interstices are filled with water.

The definitions are taken from the sources as listed under bibliography.

CHAPTER 1 INTRODUCTION

1.1 GEOBOTANICAL OVERVIEW

Water, and especially groundwater, is a scarce commodity in South Africa. Even if one has access to groundwater resources, at times the water quantity or quality is insufficient to sustain a livelihood. Groundwater that occurs in a certain environment is hidden to the eye since it occurs underground under different geological and geomorphological conditions. Over the years, several studies have been conducted with regards to various concepts of groundwater, for example, hydrogeological properties of aquifers (Botha *et al.*, 1998), geophysical groundwater exploration (Meulenbeld, 1998), vegetation impacts on groundwater (Scott & Le Maitre, 1998), interaction between surface and groundwater (Parsons, 2003), isotope studies on groundwater (Talma & Weaver, 2003). The problem associated with most studies is that they only focus on one specialised field of professionalism and as a result, the outcome of the study is often limited and only applicable or understandable to the specialist or researcher. The problem with nature is that it operates in a closed loop system. Everything is connected. For instance, a wet climate creates the possibility to sustain a luxurious forest. A wet climate on an elevated position can change the picture, since owing to cold conditions and wind exposure, only shrubs or grasses can grow. The role of fire is also important. Furthermore, the geology and soil type of the area further depicts the vegetation of an area as well as the seasonality of rainfall influenced by the orientation of mountain chains. The example mentioned involves the disciplines of soil scientists, geologists, meteorologists and botanists. If all disciplines are used together in order to understand vegetation-groundwater interactions, then more possible and plausible correlations, or merely results, can be obtained. It is consequently important that science understands the complete cycle of water in the environment.

The new approach requires a much greater understanding of the role of vegetation in the hydrological cycle, specifically the neglected area of interactions between vegetation and groundwater (Scott & Le Maitre, 1998). The present study aims to review and organise the available information on this subject, and to investigate the existence of geobotanical-geophysical relationships in the north-eastern parts of South Africa. The term geobotanical, as applied in the present study, means the association of certain tree

or shrub species growing on a certain kind of rock or soil that can be utilised to indicate possible sources of groundwater, since this tree or shrub extracts groundwater from the same source in order to survive. A geobotanical indicator either has to disappear amongst the other vegetation in the veld as one moves away from the different rock or soil type, or if it still occurs, then its appearance has to be distinctly different (size, height, circumference) on the different rock or soil type, if compared to its homogenous species in adjacent areas. The frequency of occurrence of such an indicator must be low and normally a geobotanical indicator is a less common species in a biome, or veld type. Furthermore, with the aid of geology and geophysics, it must be proven that a geobotanical indicator grows in an area that can be chosen for groundwater exploration based on the fact of the gathered geophysical data, geology, soil type, vegetation growth, aquifer characteristics and other factors.

1.2 RESEARCH OBJECTIVES

1.2.1 Motivation

Few hydrogeologists, botanists or ecologists in South Africa have carried out research regarding interactions between groundwater and vegetation. Capacity-building, therefore, should also focus on building inter-disciplinary skills in order to facilitate the trans-disciplinary work needed to support the sustainable utilisation of groundwater resources (Scott & Le Maitre, 1998).

The reserves of groundwater in the world are estimated to be 0.61% (up to a depth of 4000 metres) of the total world water reserves. Salt or brackish water comprises 97.2% of all these water reserves (Ward & Robinson, 1990). From the above it is evident that fresh water comprises only a small percentage of all the available water reserves. Approximately 75% of the total volume of fresh water on the earth is frozen in glaciers, while rivers and lakes hold approximately 0.33%. The remaining 24.67% occurs as groundwater. Since the water in glaciers is not available for general consumption, groundwater forms the largest source of fresh water available to human beings (Botha *et al.*, 1998). Roughly 13% of all water used in South Africa is estimated to originate from groundwater, and in the more arid western two-thirds of the country, groundwater is the sole or primary source of water. Elsewhere in South Africa, many rural communities are

dependent on springs and run-off river water for their domestic needs, both of which, during the dry season, are forms of groundwater discharge (Scott & Le Maitre, 1998). Groundwater would be a preferred water option in many dry areas because of its general availability, even in drought situations, and its relatively good quality (Sami *et al.*, 2002a).

Certain groundwater reservoirs have enormous capacities, thus these are more efficient water reservoirs in place of those for surface water during dry spells (Driscoll, 1989). Groundwater reservoirs are also much less prone to siltation, evaporation and erosion than surface reservoirs thus rendering them more economically viable (Johnstone & Snell, 1993 & Muller, 1993). Groundwater occurs in secondary aquifers in more than 90% of the surface of South Africa. These include groundwater contained in fractures (faults and joints) in hard rocks and to some extent, pores in the weathered zone (saprolite) of these rocks, as well as in dolomite and limestone. Besides this latter source, groundwater storage capacity is limited and tends to occur in localised cells rather than regional aquifers (Scott & Le Maitre, 1998).

Furthermore, the ever increasing population in southern Africa, the corresponding increase in water demand and the social right of a certain amount of free water being supplied to every household in South Africa, create additional pressure on the groundwater resources of South Africa (Johnstone & Snell, 1993 and Economic Project Evaluation (Pty) Ltd, 1996). It is well known that most rural areas in South Africa are dependent on groundwater resources for economic and physical survival. This dependence creates a field that attracts all kinds of people to search or prospect for groundwater resources. The layman with a stick, bottle or other device in hand, indicates possible drilling positions based on the movements of such a device. The study of Meulenbeld (1998) investigated some of the reasons for the movement of the device. Geologists interpret the structure of the rocks in order to locate a drilling spot. Geophysicists with the aid of geophysical instruments locate drilling spots based on data interpretation. However, the point should be stressed that the siting of boreholes with respect to geophysical anomalies, without a conceptual understanding of the geological framework and how it affects the geophysical response, or siting boreholes without an adequate interpretation of the geophysical data implies the probable siting of an unsuccessful borehole. Certain other prospectors may locate drilling spots on the basis

of soil colour, animal life, vegetation, geomorphology or a combination of a couple of the mentioned methods.

The present author acknowledges the importance of groundwater in South Africa and seeks to understand and prove the existence of geobotanical relationships in nature that can indicate favourite drilling spots. Such information aids in the reconnaissance of an area. Geological and geophysical investigations will indicate what the possible origin of such geobotanical indicators could be. Once a few geobotanical indicators are identified and listed, this will significantly contribute to the success of groundwater prospecting carried out by the professional sector in South Africa. Furthermore, Scott & Le Maitre (1998) debate the need for research in the field of the interaction between vegetation and groundwater. The literature review and collation of information regarding vegetation-groundwater interactions in southern Africa indicate that while a reasonable understanding of these interactions exists in the scientific community at large, few examples of detailed studies in southern Africa have been undertaken. Examples of such studies concern the water relations of the vegetation along the Kuiseb River in Namibia which conclude that the taproots of *Acacia erioloba* (camel thorn), *Combretum imberbe* (leadwood) and *Faidherbia albida* (ana tree) access deep water sources. In addition, floods deposit organic matter and nutrients in the sediments along the river banks from which the tree roots can extract these nutrients (Bate & Walker, 1993). Another study, relating to the Cape Flats (Sigonyela, 2006), mentions geobotany-groundwater relationships, but fails to identify any particular species. Some other studies in the geobotany field are restricted to mineral exploration (Cole & Le Roux, 1978 and Mshumi, 2006) and are of little use since only the quantity of minerals present in vegetative matter is determined in this instance. Applied research in the field of geobotany is therefore necessary to improve land-use and groundwater management and conservation. Table 1.1 indicates a rough rating of the state of the knowledge regarding vegetation and groundwater interactions relative to the expected importance of the groundwater resource (by aquifer type) and the significance of vegetation – groundwater interactions.

The focus of the current study will primarily fall on secondary aquifers with some reference to alluvial or palaeochannel aquifers. Secondary aquifers associated with dolomite, limestone and cracks, fissures, etcetera in hard rock will be studied in the

north-eastern parts of South Africa, depending on the occurrence or frequency of the secondary aquifers mentioned. As indicated in Table 1.1, information is lacking regarding secondary aquifers and vegetation-groundwater interactions.

Table 1.1. Summary of information on vegetation – groundwater interactions in Southern Africa and an indication of priority research needs (Scott & Le Maitre, 1998).

	Primary Aquifers			Secondary Aquifers	
	Recent coastal sands	Alluvial	'Kalahari Sand' deposits	Dolomite and Limestone	Cracks, fissure, etc. in hard rock
Importance to households	High locally, e.g. Zululand	Locally important	Low	Low	High
Importance for ecological reserve	Relatively high	Relatively high: localised	Low	Low	Usually low; but high for riparian habitats & upland wetlands
Information on vegetation-groundwater interactions	Some knowledge: tendencies clear	Some situations are well understood	Anecdotal information only; poorly quantified	Unknown	Anecdotal information: indirect from empirical studies
Strength of the vegetation-groundwater interaction	Large	Large	Low to moderate (depending on climate)	Nothing known	Locally very high, e.g. afforestation; but usually low, e.g. western Karoo. In the eastern Karoo (wetter) it is higher.

NATURE BEHAVES IN ITS OWN SUBTLE WAYS, AND NOT AS PRESCRIBED BY MAN

1.2.2 Objectives

Observations in nature reveal that certain tree/shrub species or botanical features occur on certain (preferred) rock types. Deviations in rock structure, rock and soil composition and/or weathering of the rock are often characterised by different botanical growth that can easily be detected in bushy areas. Certain types of botanical diversity could lead geophysicists/geohydrologists to possible geological structures that may be favourable for groundwater exploration. Such knowledge empowers the geophysicist to demarcate areas of (hydro)geological importance with more accuracy and speed after an initial site investigation. The present research will focus on hydrogeological (groundwater) implications in the north-eastern parts of South Africa.

1.2.3 Hypotheses

The aim of the current research is the investigation and possible proof that certain geophysical-geobotanical relationships occur in the north-eastern parts of South Africa.

1.2.4 Limitations of the study

The vegetation and geology in the north-eastern parts of South Africa is diverse, complex and rich. Therefore, it is quite difficult to conduct an in-depth investigation of the existence of all the possible geobotanical-geophysical relationships in the mentioned region regarding various botanical species in the numerous localities. The approach followed is based on gathered case studies and research conducted in new areas selected according to the various geological properties or known geobotanical features. Drilling information is gathered by means of analysed borehole logs or the use of data captured in the National Ground Water Database (NGDB). The present study will therefore propose an approach to geobotanical-geophysical groundwater exploration based on key vegetation species that occur frequently in the north-eastern parts of South Africa. These key vegetation species can be utilised as indicators regarding groundwater. A number of case studies for each key vegetation species will be listed, as well as the association of several key vegetation species with each other in a geobotanical area. This will be useful to assist one in the search for groundwater targets since one key vegetation species may be absent while the others may well be encountered. Following this approach, the study will still succeed in its hypotheses, since key vegetation species will be investigated and described according to their occurrence in different localities and on various geological terrains in the north-eastern parts of South Africa.

1.2.5 Explanation of geobotanical-geophysical relationships

The field of geobotany in South Africa, the practitioners of which are mostly botanists, is not well-established. Botanical research applicable to geobotany focuses on the relationships between vegetation, altitude, climatic patterns and soil moisture (Schulze, 1997). The term geobotany is seldom encountered in literature. Often, reference is made to geophytes, which are, however, bulbous plants and cannot be used as indicators for

groundwater, although a geophysicist or geohydrologist can misinterpret the name. Geobotany is defined as the study of the relationship between certain vegetation types that grow on specific geological entities or in derived weathered soil from these entities. It is recognised that climate plays a role in defining vegetation growth in a certain area.

The purpose of geophysics is to investigate and define groundwater-bearing structures underground, so-called aquifers, in a certain geological and vegetative environment. Obtained geophysical profiles will indicate certain anomalies, which can be interpreted as being groundwater-bearing features in the sub-surface and the type of aquifer in question. With the assistance of known (un)successful boreholes drilled in the vicinity of the observed anomaly, a scientific interpretation of the sub-surface conditions can be made. This approach is a purely geophysical interpretation, established with the aid of geohydrology. However, conspicuous vegetation growth in groundwater-bearing zones has not been investigated. The listing of such conspicuous vegetation species noted in accordance with an observed geophysical anomaly is investigated in the present research. The role that soil nutrients play in supporting certain vegetation, where the nutrients originate from the weathered mother rock, is analysed. The geobotanical-geophysical relationships in the north-eastern parts of South Africa constitute a study that lists and indicates the occurrence of certain vegetation species encountered on or very near geophysically indicated and/or geohydrologically proven (borehole) groundwater-bearing structures in the sub-surface in the north-eastern parts of South Africa. The study area is restricted to these areas owing to the remaining area of South Africa being less vegetated and a lack of experience in the field of geophysical groundwater exploration in the remaining area.

It is important to differentiate between certain aquifers since perched aquifers with vegetation growth are normally not suitable groundwater drilling targets owing to their lower yield and greater susceptibility to drought. The case studies of the current undertaking do not present a perched aquifer commentary because this kind of aquifer was not encountered, which may be an indication that these aquifers with vegetation growth are not so common in the study area and are not expressed on aerial photographs as linear structures.

1.2.6 Importance of the research

The relationship between vegetation (botany) and groundwater is recognised, but not scientifically investigated and published in South Africa, according to Scott & Le Maitre (1998). In the publication by Scott & Le Maitre (1998) titled “The Interaction between Vegetation and Groundwater: Research Priorities for South Africa”, research in the field of vegetation-groundwater interaction is advocated. Unfortunately, the stance adopted is from the field of botany and is not linked to geophysics and geohydrology. Various authors have indicated that South Africa is a dry country, where the surface water resources are impacted on by development (industry) and will increase in cost with time (Lusher & Ramsden, 1992; Muller, 1993; Sami *et al.*, 2002a). Geophysical investigations are sometimes time-consuming and often in conflict with the application of a layperson’s (water divining) methods in South Africa, where these methods are less costly and the results obtained are easy to verify, acknowledge and understand by the movement of his/her dowsing apparatus. Geophysical methods are not understood by the ordinary person and the indicated results are rather confusing. The study conducted by Meulenbeld (1998) describes the reasons behind dowsing and its applications and acceptance.

The experienced and more successful water-diviner utilises geobotanical or vegetation indicators. Soil texture, termitaries and other features form part of the water dowser’s palette. Scientific understanding and acceptance of geobotanical indicators that can be utilised by geophysicists will decrease exploration/reconnaissance time and may increase the success rate. Aerial photographs and some field observations may indicate favourable groundwater exploration targets, but often aerial photographs are not available nor are field observations easy owing to a luxurious vegetation growth that entails quite a number of different trees and shrubs in the rich South African flora kingdom. It must be remembered that not any tree can act as a geobotanical indicator for groundwater. The listing of certain key vegetation species that can serve as geobotanical-groundwater indicators will simplify the task of a professional groundwater practitioner whose knowledge regarding indigenous flora is limited. An increase in the success rate, resulting in less time occupied in field-work will add to the benefit of the work of geophysicists and geohydrologists in the vast groundwater exploration field of South Africa.

1.2.7 Methodology

The relationship between vegetation and groundwater was observed, investigated and applied with success by the researcher. Hence, a number of case studies already exist. Some new case studies will be included, since these will be undertaken in the vicinity of the existing ones, which will indicate borehole depth, the yield of the borehole, borehole logs, geology, geophysical techniques applied, and profiles obtained together with their interpretations. Reference will be made to the conspicuous vegetation observed, while the frequency of conspicuous vegetation occurrence will be noted. This implies the distribution of a certain indicator tree or shrub in the area of research, together with the description of other vegetation types in that area. This also implies the description of such an indicator tree or shrub in relationship with the geology and soil of the area. Soil samples under the indicator vegetation will be taken at different depths and analysed for nutrients. Soil sampling away from the groundwater bearing structure under other, more abundant or lacking, vegetation types will also be taken at the same corresponding depths and these will be analysed in terms of the same soil nutrients. This soil analysis could indicate and explain the growth of certain vegetation types on certain groundwater bearing structures due to the occurrence of certain soil nutrients that are derived from the weathered *in situ* mother rock responsible for the development or creation of a groundwater-bearing zone.

The study will make use of various published maps, if available, namely:

- Geological maps (1:250 000) published by the Geological Survey of SA;
- Aerial geophysical maps (aeromagnetic) (1:250 000) published by the Geological Survey of SA;
- Hydrogeological maps (1:500 000) published by the DWAF;
- Land type series maps (1:250 000) published by the Agricultural Research Council-Institute for Soil, Climate and Water; and
- Veld types of South Africa map (1:1 500 000) -Acocks (1988) published by the Botanical Research Institute.

Without exception, only once permission was granted by the landowner did the present researcher visit the farms and other areas in order to obtain geohydrological information, soil samples or other related matters.

CHAPTER 2 GEOBOTANICAL PRINCIPLES

2.1 INTRODUCTION

The natural relationship of tree (including shrub) growth to a certain habitat can only be explained if a study is carried out on the properties of those entities that define the habitat as well as the needs of tree growth. The present chapter focuses on the parameters of a natural habitat, which comprise geology or rock types, weathering/erosion processes, nutrients and soil, climate, geomorphology and geohydrological principles (including aquifers). Geophysical techniques will be addressed since geophysics can indicate hidden potential geohydrological properties of rocks and soils. Lastly, reference will be made to the functioning of termitaries (nutrient cycling) and certain tree species in connection with geobotanical groundwater prospecting.

2.2 NATURAL HABITAT ENTITIES

2.2.1 Rock types

All rocks can be classified into one of three main groups: sedimentary, igneous, or metamorphic. The classification of igneous rocks can be further subdivided, based on the quartz (SiO_2) content. Felsic or acid igneous rock (i.e. granite and rhyolite) contain abundant quartz (average of 74%), intermediate igneous rocks, such as diorite and andesite, contain an average of 62% quartz, and mafic or basic igneous rock, contain about 51% quartz minerals and a larger amount of calcium-oxide molecules (10%) compared to the previously mentioned groups. Gabbro and basalt are examples of mafic rocks (Birkeland and Larson, 1989 & Snyman *et al.*, 1996).

Secondary rock- and tectonic structures, igneous intrusions and fault zones, will be considered, since these kinds of structures often lead to a change in geomorphology, flora and sub-surface aquifer development.

The chemical composition of different rock types will be discussed in the following sub-sections. Weathering and erosion of these rocks will signal the availability and presence

of the rock-forming minerals in the soil that can be utilised by vegetation. Soil sampling of various geological areas will reveal the importance of nutrient differences in the soil that respectively support different kinds of vegetation.

2.2.1.1 Primary and secondary minerals

Minerals that have persisted with little change in composition since they were extruded in molten lava (e.g. quartz, micas, and feldspars) are known as primary minerals. These are most prominent in the sand and silt fractions after weathering and erosion of the parent rock. Other minerals, such as the silicate clays and iron oxides, have been formed by the breakdown and weathering of less resistant minerals as soil formation progressed. These minerals are called secondary minerals and tend to dominate the clay and in some cases, the silt fraction. The inorganic fraction of the soil is the original source of most of the mineral elements that Liebig (see section 2.2.8) and numerous other scientists have established to be essential for plant growth. Although the bulk of these essential nutrients are held as rigid components of the basic crystalline structure of the minerals, a small but significant portion is found in the form of charged ions on the surface of the fine mineral particles, implying clays (Brady, 1990).

2.2.1.2 Sedimentary rocks

Of the three genetic rock families, sedimentary rocks cover the largest part (about 75%) of the earth's surface (Birkeland and Larson, 1989) and about 65% of South Africa's surface (Snyman *et al.*, 1996). According to Birkeland and Larson (1989), many sedimentary rocks can be considered secondary or derived rocks in that they are composed of bits and pieces of pre-existing rocks held firmly together by a cementing mineral. The resulting texture is termed clastic. These bits and pieces are derived from the weathering and erosion of existing metamorphic, sedimentary and igneous rocks (Snyman *et al.*, 1996). Examples of clastic sedimentary rocks are (1) sandstone, which consists of cemented sand grains; (2) conglomerate, which consists of larger (gravel-sized), rounded, cemented fragments; and (3) shale, which consists of very small indurated, laminated particles of clay. Sedimentary rocks, which form on land and the floors of lakes and seas, are built up by means of the slow deposition of weathered and

eroded material, layer on layer (strata) (Birkeland and Larson, 1989). Chemical compositions of different sedimentary rocks are indicated in Table 2.1.

Table 2.1. Mean chemical composition of sedimentary rocks (Hurlbut & Klein, 1977, Greensmith, 1978 & Boggs, 1987).

Composition in %	Quartz Arenite	Average Sand-stone	Average Shale	Boulder clay	Ironstone	Average Lime-stone	Dolomitised Limestone	Clay
SiO ₂	96.0	78.33	58.10	53.71	24.25	5.19	3.27	71.39
Al ₂ O ₃	0.80	4.77	15.40	13.73	1.71	0.81	0.68	18.05
Fe ₂ O ₃	0.30	1.07	4.02	2.78	0.71	0.54	6.31	1.62
FeO	0.20	0.30	2.45	1.86	35.22	-	-	0.32
MgO	0.04	1.16	2.44	4.92	3.16	7.89	15.38	1.25
CaO	1.60	5.50	3.11	6.38	1.78	42.57	28.85	0.07
Na ₂ O	0.10	0.45	1.30	0.53	0.04	0.05	0.15	0.02
K ₂ O	0.10	1.31	3.24	3.84	0.20	0.33	0.19	3.07
H ₂ O ⁺	0.30	1.63	5.00	3.61	-	0.77	0.22	-
CO ₂	1.10	5.03	2.63	-	27.60	41.54	43.31	-
TiO ₂	-	0.25	0.65	-	-	0.06	0.10	-
MnO	-	0.05	0.05	-	2.11	0.16	0.31	-
H ₂ O ⁻	-	-	-	0.90	0.21	-	-	0.66
P ₂ O ₅	-	0.08	0.17	-	0.91	0.04	0.18	-
Organic C	-	-	0.80	-	1.96	-	-	0.04
S	-	0.07 (as SO ₃)	0.64 (as SO ₃)	-	-	0.05 (as SO ₃)	0.29 (as FeS ₂)	-

2.2.1.3 Igneous rocks

Igneous rocks are those that have solidified from a molten, silica-rich liquid (Birkeland and Larson, 1989). Approximately 10% of the surface of South Africa is covered with igneous rock (Snyman *et al.*, 1996). Igneous rocks are also the origin of intrusive structures, such as dykes and sills. The chemical bulk compositions of igneous rocks exhibit a fairly limited range: see Table 2.2. The largest oxide component, SiO₂, ranges from about 40 to 75 weight percent in common igneous rock types. Rocks that are fairly

low in SiO_2 tend to be dark because of their high percentage of ferromagnesian minerals (mafic rocks) (Hurlbut & Klein, 1977).

Table 2.2. Mean chemical composition of igneous rocks (Brownlow, 1975 & Hurlbut & Klein, 1977).

Composition in %	Syenite	Rhyolite	Granite	Andesite	Basalt	Diorite	Gabbro	Peridotite	Dunite
SiO_2	59.41	74.22	72.08	58.60	52.05	51.86	48.36	43.54	40.16
Al_2O_3	17.12	13.27	13.86	15.38	12.43	16.40	16.84	3.99	0.84
Fe_2O_3	2.19	0.88	0.86	2.22	5.18	2.73	2.55	2.51	1.88
FeO	2.83	0.92	1.67	6.71	10.08	6.97	7.92	9.84	11.87
MgO	2.02	0.28	0.52	3.22	3.95	6.12	8.06	34.02	43.16
CaO	4.06	1.59	1.33	7.02	7.33	8.40	11.07	3.46	0.75
Na_2O	3.92	4.24	3.08	3.84	2.76	3.36	2.26	0.56	0.31
K_2O	6.53	3.18	5.46	1.46	2.07	1.33	0.56	0.25	0.14
H_2O	0.63	1.03	0.53	0.37	2.26	0.80	0.64	0.76	0.44
TiO_2	0.83	0.28	0.37	0.89	1.70	1.50	1.32	0.81	0.20
MnO	0.08	0.05	0.06	0.18	0.24	0.18	0.18	0.21	0.21
P_2O_5	0.38	0.05	0.18	0.25	0.28	0.35	0.24	0.05	0.04

2.2.1.4 Metamorphic rocks

Metamorphic rocks are products of heat, pressure, and fluids acting inside the earth on pre-existing rock material. These rocks cover approximately 25% of South Africa's surface (Snyman *et al.*, 1996). In most types of metamorphism, the rock undergoes little or no change in chemical composition through mineral recrystallisation. The elements originally present simply regroup themselves under conditions of higher temperatures and pressures to form new minerals that are stable in the new subsurface environment (Birkeland and Larson, 1989). The chemical composition of metamorphic rocks is therefore similar to that of the pre-existing rock, such as the chemical composition of slate that will be more or less similar to that of shale. No chemical composition tables are therefore presented but only the name changes of the unmetamorphosed rock after metamorphosis: Table 2.3.

Table 2.3. Metamorphosed rocks and their origin (Brownlow, 1975).

Unmetamorphosed rock	Metamorphosed rock
Shale	Slate/schist/gneiss
Sandstone	Quartzite
Limestone	Marble
Granite	Gneiss
Andesitic tuff	Schist/amphibolite
Shale/mudstone	Hornfels

2.2.1.5 Intrusions and tectonic structures

Bodies of igneous rock occur in a great variety of sizes and shapes. All such bodies, regardless of size and shape, are known as intrusive rocks. Usually, their chemical composition is completely different from that of the host rock that surrounds them (Birkeland and Larson, 1989). This difference in chemical composition often leads to a change in specific flora, geomorphology and sub-surface aquifer development. This will be investigated and discussed in this study. The surface between the pluton (intrusion) and country rock is called the intrusive contact. For the purpose of the present study it is important to differentiate between the two types of intrusions, after Birkeland and Larson (1989): dykes are discordant intrusions – they cut across the layers; while sills are concordant intrusions – they are more or less parallel to the layering of the surrounding strata. Dykes that are more resistant to erosion than country rocks may form semi-continuous topographic walls that extend far across the countryside. Dyke intrusions are most common in terrain undergoing tectonic extension (Birkeland and Larson, 1989). Botha *et al.* (1998) describe mechanical deformation through igneous intrusions on the surrounding rocks. Long stretched dyke features that can easily be observed on aeromagnetic maps, aerial photographs and/or satellite photos, are called lineaments (Gupta, 1991). Lineaments can also be observed when a couple of springs occur in alignment, or in waterfalls, aligned streams, changes in soil texture and colour and conspicuous vegetation growth or alignment due to the presence of seepage/drainage lines and high transmissivity groundwater zones (Earl & Meiser, 1984, Hanson, 1984, Fetter, 1994 and Weiersbye, 2002). According to Chevallier *et al.* (2001), local farmers and diviners prefer drilling alongside geological lineaments. A statistical analysis conducted by Chevallier *et al.* (2001) proved that this observation was correct.

Furthermore, boreholes drilled into these linear structures are often more productive than those drilled away from lineaments. Often lineaments are zones of deformation and pulverisation due to the lower resistance to weathering and erosion than the surrounding rock. This implies zones of higher secondary porosity and permeability that can yield groundwater. The longer a lineament, the higher its groundwater yield might be (Gold, 1980 and Hanson, 1984).

Based on the explanation by Birkeland and Larson (1989), faults are fractures along which movement has occurred. Often, too, the rocks adjacent to a fault will have been pulverised, forming a claylike soft material called fault gouge. In some instances the rocks in the fault zone may be broken and sheared, creating a coarse fault-zone breccia. These broken and pulverised rocks might lead to the creation of a local aquifer associated only with the fault-zone. In the present study, an attempt will be made to identify geobotanical relationships for fault structures that can be observed on the surface, as mentioned in the study by Scott & Le Maitre (1998).

Together with faults, joints as a structural feature or discontinuity might serve as an aquifer. Rocks that are located at, or close to, the earth's surface exhibit cracks and features called joints. Most joints result from deformation of the rocks in which they occur. Tensional stress perpendicular to the joint surface is considered to be a major factor of the originating of joints. Joints are of more than academic interest. From a practical standpoint, they are surfaces of incipient weakness and must be afforded consideration. Sub-surface joints also affect the movement of groundwater (Birkeland and Larson, 1989). Other discontinuities include layering, sedimentary structures, igneous contacts, foliation and folds. A discontinuity is thus basically any interruption in the lithological and physical properties of a rock formation and generally represents the weakest spots in a certain rock (Cameron *et al.*, 1988 & Van Schalkwyk *et al.*, 1995).

Barnard (2000) describes the importance of the above-mentioned geological structures which are found in the current area of study. In the study area the orientation of linear structures can be divided in two principal strike directions, namely either northwest-southeast or northeast-southwest. Talma & Weaver (2003) stress the importance of fractured rocks, since these represent the major source of groundwater supplies in South Africa. In more than 90% of the surface area of this country, groundwater occurs

in secondary openings (fractures and other tectonic structures) in so-called hard rocks: see also Table 1.1.

2.2.2 Weathering, erosion and soil

2.2.2.1 Weathering

Most rocks found in the top several metres of the crust of the earth are exposed to physical, chemical, and biological processes much different from those prevailing at the time the rocks were formed. Because of the interaction of these processes, the rock gradually changes. Collectively the changes are called weathering, and two main types are recognised: chemical and mechanical. Based on Birkeland and Larson (1989), where chemical weathering is dominant, rocks tend to decompose or to decay. When rocks decompose, they are changed into substances with quite different chemical compositions and physical properties than those of the original rock. But where mechanical weathering is dominant, rocks break up into smaller fragments, much as if they had been struck a hammer blow. There are few areas where only chemical or mechanical weathering act alone, but there are many areas where one or the other predominates due to the complex nature of rock formations. The process of erosion changes over time when the material that is removed exposes new geometric and geological conditions (Van Schalkwyk *et al.*, 1995). In the north-eastern parts of South Africa, rocks tend to be prone to chemical weathering due to the higher rainfall and increased humidity in these regions. Mechanical weathering on chemical stable rocks, such as quartzite, can easily be observed in these regions. The climate value (N-value) of Weinert (Van Schalkwyk, 1996) indicates the influence of climate in an area on the weathering and soil-forming processes. If the N-value is larger than 5, mechanical weathering is prominent, but when the N-value is smaller than 5, chemical weathering is prominent. In areas with very low N-values ($N < 2$), residual soil generally consists of a deep soil profile with ferricrete formation on the surface. Very high N-value ($N > 10$) areas are characterised by shallow soils and calcrete formation on the surface. Figure 2.1 illustrates the different chemical processes found in different climates. South African N-values are indicated in Figure 2.2.

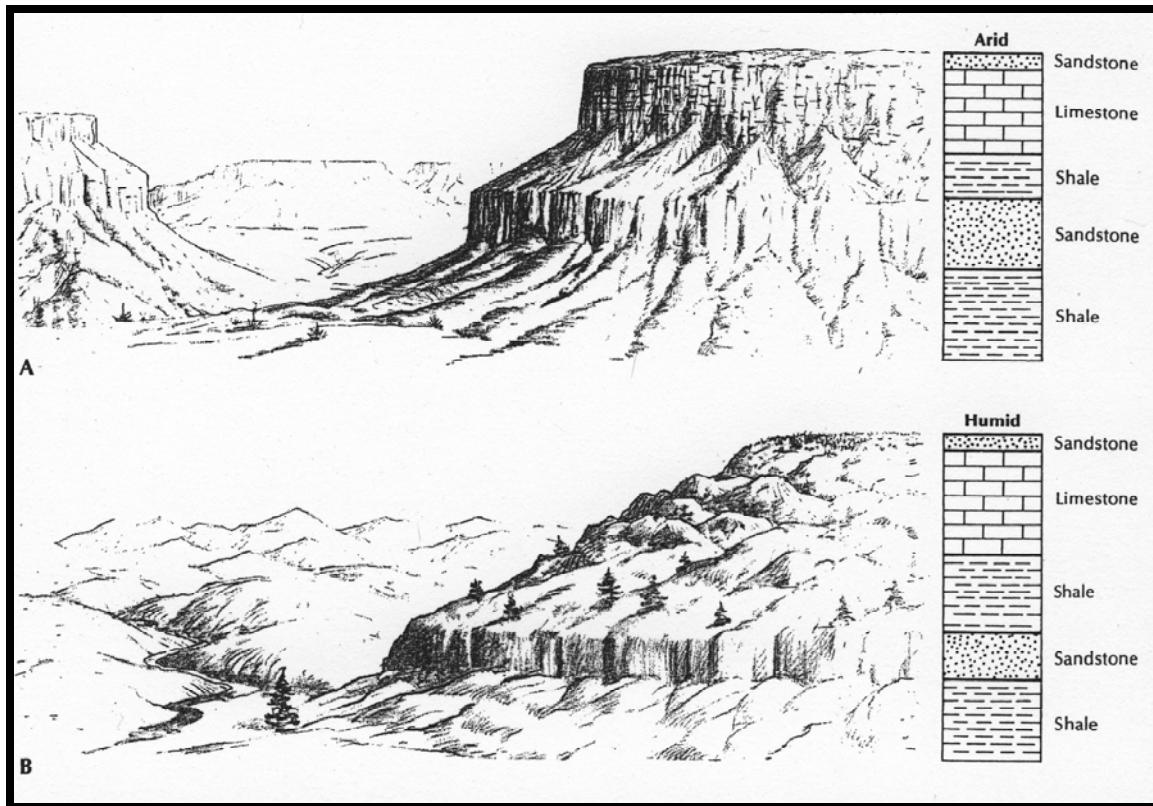


Figure 2.1. Rocks vary in their resistance to weathering and subsequent erosion. Whether a rock forms a steep cliff or a gentle slope partly depends on climate. In an arid climate (A), limestone and sandstone are cliff formers and shale is a slope former, often covered by talus. In a humid climate (B), sandstone is also a cliff former, but limestone weathers by solution to form irregular slopes. Again, shale is a slope former, often covered by a thick soil (Birkeland and Larson, 1989).

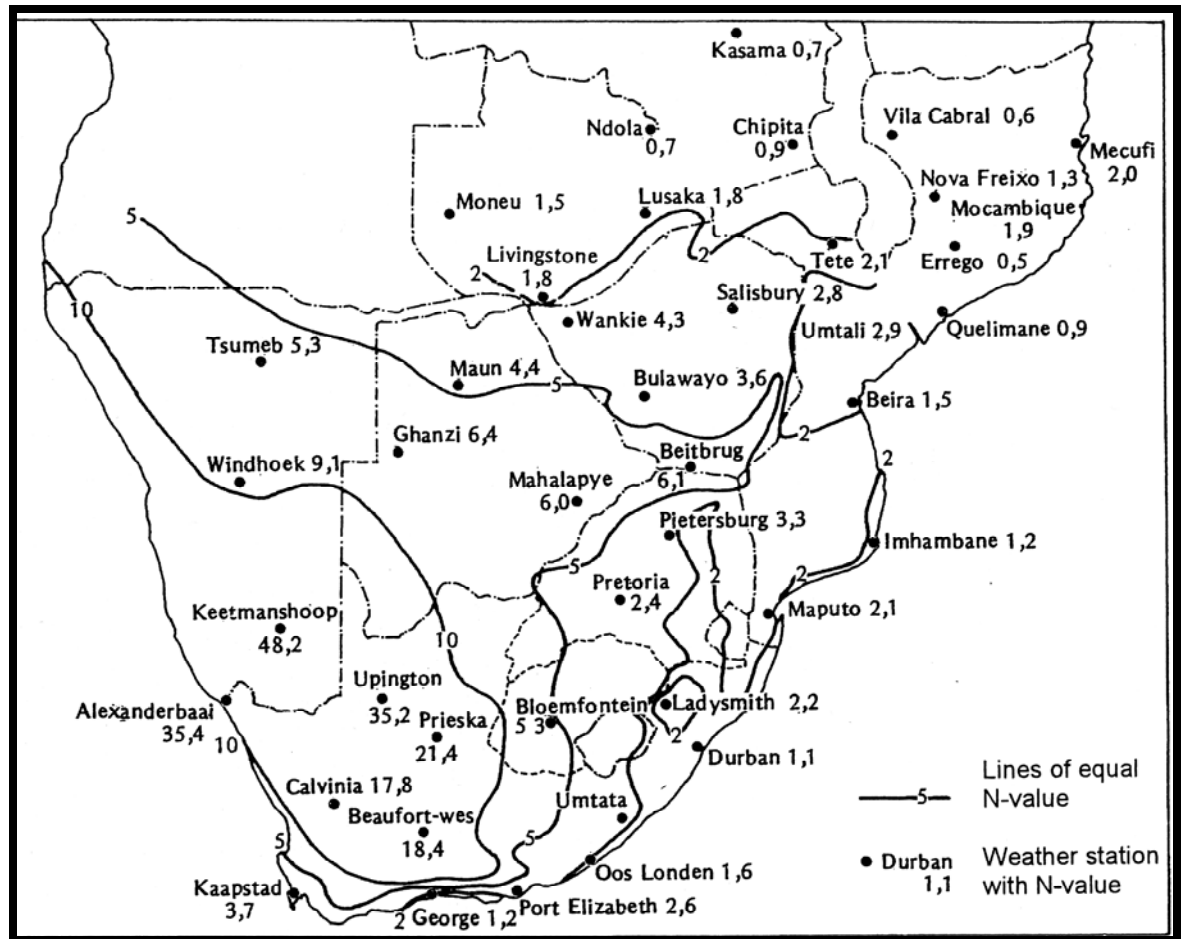


Figure 2.2. South African N-values (Van Schalkwyk, 1996).

Rock masses are seldom homogeneous but are intersected by joints, tension cracks, bedding planes, geological faults and other discontinuities. Discontinuities in a rock formation generally represent the weakest material (Cameron *et al.*, 1988 & Van Schalkwyk *et al.*, 1995), which erode easily and form pathways for water flow and tree rooting. This causes more rock surface area to be exposed to weathering, which etches along discontinuities and causes complex weathering profiles. Weathering is usually more intense along geological structures such as faults and often results in deeply weathered soils along these zones, which are prone to vegetation establishment and growth. Where significant horizontal joints are present in the rock mass, such as stress relief joints that occur frequently in granitic rocks, weathering along these joints may result in the development of corestones in the profile. In general, groundwater is stored within the weathered zone and the underlying fractured rock zone. The shallow groundwater is usually hydraulically connected to the fracture system. This groundwater

(often seasonal in nature) develops on top of the impermeable unweathered bedrock and is often recorded as perched water tables.

2.2.2.2 Erosion

The geological factors that influence the erosion of rock comprise the characteristics of the unweathered bedrock and the characteristics of the discontinuities in the rock. The resistance of a rock against erosion is dependent on the cohesion between particles and the stability of the minerals (Van Schalkwyk, 1995). Erosion processes are actually those, such as wind and water, that transport and deposit weathered material to a different locality from where it was primarily situated on the surface. When the water-yielding properties (or permeability) of a rock increase due to the processes of weathering and erosion, this is called secondary water holding capacity (or porosity) (Fetter, 1994). Van Schalkwyk *et al.* (1995) classify some of the rocks in the study area on the basis of their erosion grade. The sandstone of the Waterberg is susceptible to a range from almost none to heavy erosion, depending on the amount of exposed discontinuities. The susceptibility of dolerite and diabase to erosion also varies from “none to heavy”, depending on the extent and width of joints. Low susceptibility to erosion is recorded for massive quartzite and rhyolite.

2.2.2.3 Soil

Soil, in a broad sense, denotes that part of the geological sphere of interest which concerns mineral residues of weathered rock or unconsolidated sediments with properties attributable to the interaction of parent material, time, climate, topography, and organic substances derived from the fauna and flora at the sites where these materials occur at present (Department of Agricultural Technical Services, 1977, Greensmith, 1978 & Birkeland and Larson, 1989). Soil changes gradually from a weathered state to an unweathered, hard rock at greater depth. The unweathered state is normally without signs of roots, animal life or signs of any other biological life (Department of Agricultural Development, 1991). The soil colour is often derived from the chemical or mineral properties and colour of the bedrock. A true soil is a product of the living environment as opposed to mere weathered rock (Verster *et al.*, 1992). The greatest interest in soil probably stems from its role as a growth medium for plants by

providing physical support, water, essential nutrients, and oxygen for roots. The suitability of soil for sustaining plant growth and biological activity is a function of physical properties (porosity, water-holding capacity, structure, and tilt) and chemical properties (nutrient-supplying ability, pH, salt content, etc.), many of which are a function of the soil's organic matter content. Soil plays a key role in completing the cycling of major elements required by biological systems (carbon, nitrogen, phosphorus, sulphur, etc.) (Doran *et al.*, 1996).

The nature of the soil at any particular locality is principally controlled by the nature of the underlying rock, the climate, and the topography.

Rocks decompose when exposed to water, air and organisms during the process of weathering, which causes the separation of the individual mineral particles of the rock and their alteration, destruction, or resynthesis thus forming new minerals. The weathered rock becomes the parent material from which mineral soils form (Verster *et al.*, 1992). According to Verster *et al.* (1992), a mineral is defined as a naturally occurring element or compound formed by inorganic processes and possesses a definite chemical composition and crystalline structure. Although the bulk of most soils consists of minerals, it is the presence of organisms and organic matter that makes soil essentially different from geological minerals. The organic fraction plays an important role in soils. The organic fraction, or matter, is derived mainly from plants but also partly from animals. It furnishes essential plant nutrients such as nitrogen, phosphorus, potash and sulphur, while, during the process of decomposition, organic acids are formed which aid in the dissolving of soil materials (all nutrients must be in solution in order to be available to plants). The presence of organic material promotes a favourable structure in soils and also attracts and binds a variety of organic and inorganic substances, a process which, in turn, is favourable to cultivation and plant growth (Verster *et al.*, 1992 & Cloete, 2002). Humus, the active fraction of soil organic matter, has a very high CEC (cation exchange capacity) of between 150 and 300 cmol_c/kg, and can adsorb up to about 6 times its own weight in water. As a result the water-holding capacity of the organic matter of rich soils increases and improves the structural condition of soils and therefore greatly reduces the erodibility of soil. Organic matter is often expressed as a percentage of carbon (% C), because carbon is one of the most important elements of life. Other important

chemicals include nitrogen and phosphorus for plant growth, and the metal magnesium (which forms part of the pigment chlorophyll that captures sunlight energy in plants) (Luhr, 2004).

According to Scott & Le Maitre (1998), the ability of vegetation to tap groundwater (i.e. from the saturated zone) depends on the depth to the water table, the penetrability of the profile and the inherent ability of the plant species to develop deep root systems. Plants also extract water from the unsaturated zone, increasing the available water storage capacity of the profile and thus also reducing its recharge from deeper water bodies. Deep root systems can easily be obtained in certain instances since in Southern Africa, cases exist where, between the soil layer and the fractured bed rock, a thick layer (till 70 m thick) of highly weathered to weathered *in situ* regolith is formed (Talma & Weaver, 2003). Regolith is defined as the unconsolidated mantle of weathered rock and soil material on the surface of the earth; loose earth materials above solid rock (Department of Agricultural Development, 1991).

Environmental heterogeneity in soils and geomorphology promotes species richness (Cowling *et al.*, 1997), the reason being that the two essential components that plants absorb and remove from the soil are water and nutrients derived from this heterogeneity and difference in terrain. Plants will be deficient in an essential nutrient element not only when the element in the soil is virtually depleted, but also when a large quantity is present in the soil but an inadequate quantity is sufficiently soluble or available to supply the needs of the plant. Both of these conditions concern the fertility or chemical behaviour of a soil, which in turn is closely related to colloidal properties and soil reaction (Verster *et al.*, 1992). Because of their colloidal properties, clay minerals (and humus to a lesser extent) are the most important constituents that affect the chemical characteristics of soils, the reason being, according to Verster *et al.* (1992), their large surface area per unit mass and the fact that they are electrically charged. These properties cause high chemical activity in soils.

During the current study, soil samples of areas rich in biodiversity and also demarcated by a successful borehole, were taken with a soil auger. These samples were collected at different depths, 0.5 m and 1.2 m, as the indicated depths were sufficient to indicate differences in soil composition at the various soil horizons present (Department of

Agricultural Technical Services, 1977, 1991). The sampled soils were analysed for organic content (C), pH, cation exchange capacity (CEC) and various nutrients (Sulphur (S), Iron (Fe), Manganese (Mn), Zinc (Zn), Potassium (K), Phosphorus (P), Nitrogen (N), Magnesium (Mg) and Calcium (Ca)). When the pH of the soil drops below 5.5, then aluminium (Al) begins reacting and is included as a value larger than zero in the soil analysis (Loock, 2004). The soil samples are analysed by the Institute for Soil, Climate and Water of the Agricultural Research Council (ARC-ISCW) in Arcadia, Pretoria. The methods of analyses are described and presented in the soil guide by the Department of Agricultural Technical Services (1977 & 1991). Soil samples (at the same corresponding depth) of the soils around the biodiversity area that are less vegetated will also be taken and compared.

2.2.3 Climate

The role that climate plays in the formation of soils is known (Birkeland and Larson, 1989) and is not important to discuss in the present study. The climate that defines a particular soil defines the distinct vegetation on that kind of soil. Of the three great natural patterns that dominate the earth's environment, viz. patterns of climate, vegetation and soil, climate is inevitably perceived as the principal dynamic component and the obvious independent variable shaping the other two, especially vegetation, on both micro and sub-continental scales (Akin, 1991). The term climate is a composite concept and may be defined as the 'long range pattern of weather' (Kendrew, 1949), taking into account not only prevailing weather conditions, but also the dynamic and intricate variations that occur diurnally, daily, monthly, seasonally and annually, and in addition allowing for the probability that the climate might vary from the norm (Schulze, 1997). Woodward (1986) suggests a close link between the time for a plant's life cycle to be completed and the temporal variation of the controlling climatic processes. The climatic factors of greatest importance in vegetation development are light, temperature and moisture, all of which vary sub-continentally as well as on a meso- and micro-scale. In much of the earlier literature individual climatic parameters have been treated separately in their relation to vegetation distribution, with little attention being paid to the way in which they might interact. At present, however, there is a greater focus on climatic interactions and the fact that climatic parameters operate in combination to

produce relatively homogeneous environments in which certain plant communities can attain importance (Schulze, 1997).

Permanent differences in amounts of radiant energy intercepted on contrasting exposures may cause marked variations in the distribution of plant communities (as well in geomorphology and soil moisture) (Schulze, 1997). Granger & Schulze (1977) have shown that in the Cathedral Peak area in South Africa the presence of mature *Podocarpus latifolius* (real yellowwood) forest on a cool slope versus *Protea* savanna and subtropical grasses on the corresponding warm slope is related to differences in the energy budget. This factor has to be borne in mind in order for one to understand the presence of different tree species on slopes that vary in orientation.

Low temperatures and frost are often critical in determining plants' survival and hence their distribution (Schulze, 1997). The non-occurrence of trees in a geological environment hinders the application of geobotanical relationships in order to search for hidden groundwater resources and/or altering geological bodies, although the presence of certain grass species, such as *Fingerhuthia sesleriiformis* (thimble grass) and *Imperata cylindrica* (cottonwool grass), can be used to indicate shallow groundwater occurrences (Kent & Enslin, 1965, Vegter & Ellis, 1968 and Van Oudtshoorn, 1994). The non-occurrence of a tree species in a region is often the consequence of the prolonged onset of frost during the colder months of the year. Kotze (1980) & Kunz (1994) indicated in their research that the richly populated tree areas of South Africa, the Bushveld, Coastal Bush regions in Kwazulu-Natal and the Garden Route for example, do not receive any frost whatsoever. The identification of grass species is often more difficult than that of tree species, due to size, dormant winter appearance, the impact of veld fires and inconspicuous growing/flowering patterns.

Rainfall is an important component of vegetation growth. Arid and semi-arid parts of South Africa are recognised by almost no shrub or tree growth. Low rainfall limits tree growth and tree survival, especially during seasons of drought. Trees also experience difficulty in survival on rocky outcrops and/or areas of a limited soil depth. Vegetation in an area redistributes water from rainfall by means of interception, throughfall and stemflow. Once the rainfall reaches the soil, the amount and rate of water-entry into and through the soil is determined by factors such as the physical properties of the soil (e.g.

porosity), soil depth, surface storage capacity, soil moisture deficit and the slope of the surface (some characteristics of which may in turn be affected by vegetation). In the soil profile and weathered rock zone (regolith), water percolation is controlled by soil texture and changes in texture and the presence of macropores, which allow rapid fluxes of water through the unsaturated zone (Scott & Le Maitre, 1998).

Among the various individual climatic parameters that influence vegetation differences on earth, Walter (1972) considers water to be the most important. Limitations in water availability are frequently a restrictive factor in plant development, and water is essential for the maintenance of physiological and chemical processes within the plant and in the exchange of energy and the transport of soluble nutrients (Schulze, 1997). The water that a plant needs can be abstracted from groundwater sources (besides precipitation), if the water table is close to the surface, or from a deeper partially saturated vadose zone associated with a confined aquifer. It must be remembered that evaporation and transpiration processes cause upward movement of water towards the ground surface and consequently provide water to the roots of plants as well (Van Schalkwyk & Vermaak, 2000). The soil-water availability is determined from the local hydrological budget which includes local soil characteristics (Schulze, 1997). Although the annual potential evaporation greatly exceeds the annual precipitation in savannas (Bushveld), there may be times of the year when more water is present in the soil profile than it can hold (Scholes, 1997). Areas with higher soil moisture content can easily be observed in the veld since these areas are often marked by larger and sometimes other tree species. Furthermore, these trees will appear to have darker green or earlier leaves during or after a dry spell. It is important to recognise and focus on the indigenous trees of an area, since exotic trees, such as bluegum and wattle, grow abundantly, are higher and are evergreen (bluegum). Exotics do not have several natural enemies and therefore their growth is more lustrous and obvious.

2.2.4 Geomorphology

The South African landscape is characterised by great diversity and, relative to other parts of the world, great antiquity. A consequence of this antiquity is that most of the soils of the subcontinent are highly weathered and, especially in the wetter regions, relatively infertile. Owing to the steeply dissected landscapes of the wetter eastern

margin of the region and the duplex (sand on clay) structure of many of the soils, the potential for soil erosion is very high (Schoeman & Scotney, 1987). The combination of the relatively infertile soils in the wetter (eastern) parts of South Africa, due to soil leaching and relatively acid soils (pH 5-6), and geological intrusions in these soils with a different soil texture, often leads to conspicuous vegetation growth: see Figures 2.3-2.5. Gorges, ridges and valleys, caused by the weathering of geological intrusions, are sometimes covered with luxurious vegetation, while on the exposed plains and mountainsides, almost no indigenous trees grow. Geomorphological conditions of the area create a microclimate while tree growth is further stimulated by differences in soil texture and quality. Indigenous tree growth on mountainsides is only enhanced if the mountainside is covered with debris, has a deep, nutritious soil profile that is a characteristic product of chemical weathering and if the microclimate allows tree growth (see Figure 2.4 regarding the quartzite reef vegetation and the dense vegetation on the upper parts resulting from a deeper soil profile). The role that geomorphology plays in groundwater occurrence is indicated by Chevallier *et al.* (2001) and also in the observed water levels in boreholes (Fetter, 1994).



Figure 2.3. A prominent quartzite reef (Mozaan Group) (middle of photo) demarcated with conspicuous vegetation growth in contrast with the sparse vegetation growth on the shale (Mozaan Group) planes. Ithala Nature Reserve, Louwsburg, Kwazulu-Natal.



Figure 2.4. A closer picture of the quartzite reef (Mozaan Group) between the shale of the same group. Note the difference in vegetation. Ithala Nature Reserve, Louwsburg, Kwazulu-Natal.



Figure 2.5. The quartzite reef/shale contact (both Mozaan Group). Fracturing in the quartzite reef makes it a better tree growth medium owing to the water holding capacities and rooting space in contrast with the tight, difficult to penetrate, non fractured shale. Ithala Nature Reserve, Louwsburg, Kwazulu-Natal.

2.2.5 Geohydrological principles

2.2.5.1 Origin of groundwater

Nearly all of the water in the ground is derived from precipitation that has soaked into the earth: see Figure 2.6. In addition, some water includes marine sediments when they are deposited.

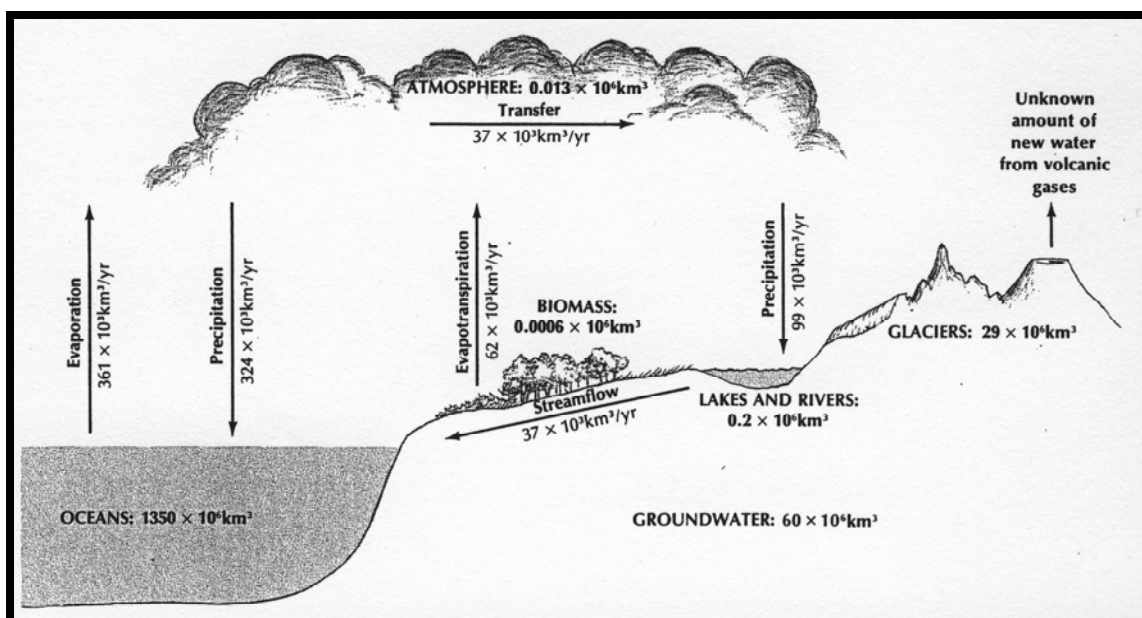


Figure 2.6. The hydrological cycle.

However, the amount of water entering the ground by infiltration is slight – perhaps as little as 0.25 mm per year in some places, more in others. Values of recharge varying between 2-4% of the annual rainfall for regions in South Africa were calculated by Kirchner *et al.* (1991). It is that vast reservoir that was gradually built up over thousands of years from which we draw today – unfortunately, in some areas, more rapidly extracted than it is replenished. In these cases, the groundwater can be considered a non-renewable resource that will be depleted some time in the future. The total amount of groundwater in the world has been estimated at some 8.4 million km^3 (Birkeland and Larson, 1989). A glance back at Figure 2.6 indicates that the amount is greater than that in the rivers and lakes at any one time but less than that in the oceans or glaciers. It is

this great readily available abundance which makes groundwater so important to the development of farms, communities, and industries.

2.2.5.2 Occurrence and movement of groundwater

All the voids, or openings, in unconsolidated sediments and rocks below the water table (the surface at which water stands in wells) are filled with water or are saturated; this area is called the saturated zone (Birkeland and Larson, 1989). Above the water table, in the vadose zone, the pore spaces in the ground may range from completely empty to partially filled by liquid and gas. In many places this water moves slowly downward through the vadose zone to the water table. The water table rarely remains at a static level. Instead, normally it is more likely to be a replication of the ground surface, rising under hills and sinking under valleys. It intersects the surface at lakes, streams and springs (see Figure 2.8).

In South Africa and many other arid and semi-arid countries, the vadose zone may vary in thickness from a few metres to tens of metres, and therefore acts as a very important barrier between the ground surface and the aquifer. This situation does not apply in most of the more developed countries where the groundwater level is close to the surface of the ground. In soil-plant environments the vadose zone plays an important role in supplying the roots of the plant with water molecules or other nutrient molecules (Van Schalkwyk & Vermaak, 2000). The vadose zone represents the top portion of the geological profile. This zone is subjected to weathering, erosion, pedogenic and other processes, often resulting in a complex geological setting. The soils and rocks in the vadose zone are very rarely homogeneous. The top portion of the geological profile may consist of thick layers of transported material, unweathered to completely weathered *in situ* material, poorly to well developed pedogenic soils with clearly defined soil layers, poorly to well developed pedocrete layers or a combination of the above-mentioned and other materials. A range of materials with a variety of physical and chemical properties may occur within this portion and significantly complicate studies of the vadose zone. The variation in physical and chemical properties might be beneficial to vegetation growth wherever these variations are condensed or abundant.

If water is to move underground, rock and unconsolidated sediment must be both porous and permeable. These two properties influence not only the movement of groundwater, but also the rate at which rainwater reaches the water table. Porosity is a major factor in controlling the movement and storage of water in the ground (Todd, 1980). Many factors determine the porosity of rock, such as the packing arrangement of particles, degree of sorting, porosity of the particles themselves, degree of weathering of the rock, lithification due to the load of the surrounding rock, and the amount of cementing material in the void spaces (Bennetts & Pieterse, 1963 & Birkeland and Larson, 1989). The porosity of igneous and metamorphic rocks is largely determined by joint frequency because the rock itself is so dense.

Permeability, according to Sharp *et al.* (1980) and Birkeland and Larson (1989), is a measure of the capability or tempo of a rock or sediment to transmit a liquid through it. Therefore the actual size of the openings in a rock is much more important than the percentage of open space. Large void spaces are obviously more permeable than small ones. For example, a silt or clay may possess a higher porosity than a gravel, but since the void spaces are so small the permeability is lower. Also important are the connections between the openings. If the pore spaces in a rock are not interconnected, the water will not flow, no matter how large those spaces may be. Rocks with little resistance to brittle deformation are often heavily fractured or brecciated and are therefore more permeable.

Not all rocks are equally permeable, nor do they all possess the same capacity to hold water. A permeable, highly porous sandstone layer, for example, may not only be able to hold much more water than its enclosing rocks, but may also provide a route along which groundwater moves with relative ease. Such a layer, one that readily yields water to a well, is termed an aquifer. In contrast a layer that is too impermeable to accept water and allow it to flow, such as one high in silt and clay, is appropriately called an aquiclude (Birkeland and Larson, 1989). The most important feature of an aquifer is its permeability (Fetter, 1994). Two common kinds of aquifers may be distinguished. One is an unconfined aquifer, which may be nothing more than a superficial layer of permeable sand or gravel. The other is a confined aquifer, a layer of permeable material, such as sandstone, between layers of impermeable material, such as shale (Birkeland and Larson, 1989). A combination of the two is possible (semi confined aquifer) where

leakage from the impermeable layer recharges the aquifer or permeable layer (Fetter, 1994). Often, in a confined aquifer, a difference occurs in the hydrostatic pressure (Ward & Robinson, 1990), which is larger than the atmospheric pressure at the top of the aquifer (Hattingh, 1996). The difference in pressure is the force that allows a water level to rise in a borehole that is sunk in a confined aquifer. Water enters an aquifer by surface-water infiltration. The area in which this takes place is the recharge area. Recharge takes place from higher groundwater levels, or perched aquifers, and thus through preferential pathways, probably through cracks or macropores (soil openings larger than the pores occurring in the soil matrix) in clay layers. Water may move downwards until a heavy clay layer is reached, after which water movement is predominantly horizontal (Van Tonder & Kirchner, 1990 and Van Schalkwyk & Vermaak, 2000). This horizontal flow of water movement is an important and necessary factor in plant survival, especially during dry spells. In the north-eastern parts of South Africa, the majority of aquifers encountered and the boreholes drilled into these, are confined in nature (Meulenbeld, 1998). A borehole (for the purposes of the present research) is basically any drilled narrow shaft (normally vertically) descending below ground level to a geological layer containing water to be extracted. A borehole used as a well is completed by installing a vertical pipe (casing) and well screen in order to prevent the borehole from caving in and protect any installed pump from drawing in sand and sediment (Huang *et al.*, 2000).

Generally, the flow within hard rocks is restricted to an interconnected system of fractures, joints and fissures within the rock mass. These discontinuities are mainly the result of large-scale tectonic events within the earth's crust (UNESCO, 1984). Weathering processes exert a significant effect on the flow and storage capacity of the discontinuities. The degree of fracturing, generally, is a function of the strength and composition of the rock. Fine-grained rocks usually show a dense pattern of fractures of limited length. In coarse-grained rocks, fractures tend to be widely spread. High-grade metamorphic rocks contain virtually no fractures while low-grade schists are often highly fractured. Most often, the frequency of fractures has been found to decrease rapidly with depth. Drainage channels are commonly aligned with geological structures and fracture systems. Recharge around drainage channels mainly occurs by infiltration from the streams that cross or closely follow fracture systems, whereas relatively little recharge is directly caused by rainfall (Van Schalkwyk & Vermaak, 2000). Recharge is usually a

function of rainfall (volume, intensity, frequency and aerial distribution), the unsaturated zone (soil type, thickness, slope, soil moisture, geology, fracturing and tectonics) and evapotranspiration (temperature, wind, humidity, soil moisture status, soil type and vegetation type & density) where certain factors play a more vital role in certain areas than others (Bredenkamp *et al.*, 1995).

The geology of South Africa is characterised by numerous dykes and sills intersecting and cutting through older geological formations. The permeability and porosity of these intrusions are almost nil. However, numerous cracks, associated with the intrusion event, caused preferential weathering zones along the sides of the dykes. In the Karoo Supergroup, for example, these zones generally extend beyond 60 m in depth and typical yields range from 3 600 to 108 000 litres per hour (l/h), depending on the area of interest (Fauconnier & Kersten, 1982).

In the present study area the occurrence of groundwater is enhanced by intrusive mafic bodies in the rock. The mafic rocks more readily weather chemically if exposed to water and therefore create increased porosity and permeability at the weathered contact zone between the intrusion and original formation. Weathered basins and palaeo-channels covered with alluvium serve as water-bearing bodies since these features exhibit notably higher porosity and permeability values owing to less compaction, diagenesis and cementing of the particles. Movement of groundwater in the area studied is generally controlled by the orientation and prevalence of secondary features, such as faults, joints and fracture zones, and the distance to rivers where sand and gravel alluvial aquifers exist (Sami *et al.*, 2002b).

Flow dynamics in the north-eastern parts of South Africa are illustrated in Figures 2.7 and 2.8. Note the importance of geological contacts, secondary features and the behaviour of groundwater levels along watercourses and elevated areas.

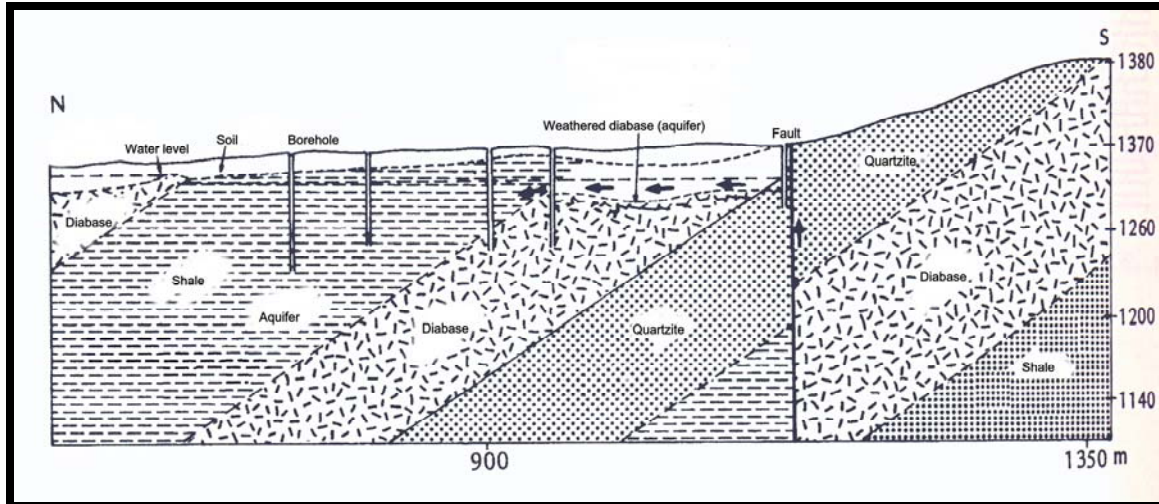


Figure 2.7. The occurrence and movement of groundwater in the Pretoria Group (Hattingh, 1996).

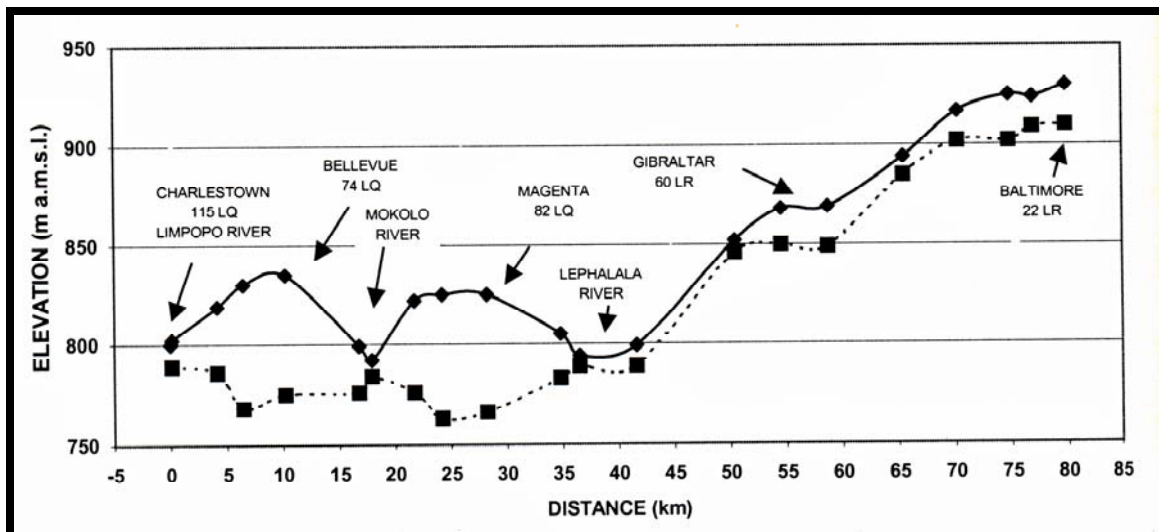


Figure 2.8. The occurrence and movement of groundwater in the study area (Vegter, 2001b).

2.2.6 Geophysical techniques

Various geophysical techniques can be utilised in the search for groundwater or geological features. These techniques include seismic methods, magnetics, gravimetric principles, electromagnetic and electrical direct current techniques. The question is often the desirability of using one or a couple of these techniques in order to obtain the answer being sought. The focus of the present study will fall mainly on the magnetic technique,

which is able to identify areas of magnetic intensity differences (mafic rock contact zones) quite easily, is effective and the cheapest technique compared to the other techniques mentioned. Most case studies and geobotanical indicators are associated with mafic intrusions and can easily be defined by this technique. In certain cases the electromagnetic and electric direct current techniques will be employed, since these techniques will be more efficient in a certain geological environment. The gravimetric and seismic methods are not employed because they are too cumbersome, expensive and time-consuming to be employed in ordinary market orientated groundwater exploration.

2.2.6.1 The magnetic technique

The magnetic technique is able to measure and represent variations in the local magnetic field caused by local magnetic anomalies or variations in magnetic susceptibility in certain near-surface rocks (Dobrin, 1976). The magnetic susceptibility contrast of a geological body with the surrounding formations makes it possible to determine the body's location and possible shape. Magnetic anomalies are caused by magnetic minerals (mainly magnetite and pyrrhotite) contained in the rocks (Telford *et al.*, 1990). Examples of such rocks are diabase, dolerite and andesite (all igneous). Typical magnetic anomalies or geological features include lineaments, dykes, sills (igneous intrusions) and contacts between rocks that differ in magnetic properties (Vegter, 2001a), and along these features preferential groundwater flow can occur, either along the contact zones or fractures in these features (Sami *et al.*, 2002a). The total field proton precession magnetometer is able to measure such anomalies. The instrument depends on the measurement of the free-precession frequency of protons that have been polarised in a direction approximately normal to the direction of the earth's field. The protons induce a voltage that is a function of the precession frequency (Botha *et al.*, 2001). Magnetic anomalies caused by geological features such as lineaments, dykes, sills and/or faults can easily be observed on aeromagnetic field intensity maps (e.g. anomalies) and remote sensing methods, such as aerial photographs (e.g. geological features) (Gupta, 1991 and Chevallier *et al.*, 2001).

The current study employs a GEOTRON G4 proton magnetometer. This instrument measures the total component of the geomagnetic field (ΔT) with an accuracy of 1nT

(Geotron, 1998). Parasnis (1979) and Telford *et al.* (1990) discuss the basic concepts and the functioning of the instrument. The interpretation of the results is based on the field data and the construction of a conceptual model, based on geological and geophysical information. The anomaly predicted by the model is calculated and compared with the observed field anomaly. Parameters such as the body's dimensions, depth, position and strike are valuable. The interpretation is non-unique, but the incorporation of independent information might reduce the amount of indefinite mathematical solutions to the model (Darracott & Richards, 1975, Blakely, 1995 & Hattingh, 1996). The following figure (Figure 2.9) indicates the essence of strike, width and depth.

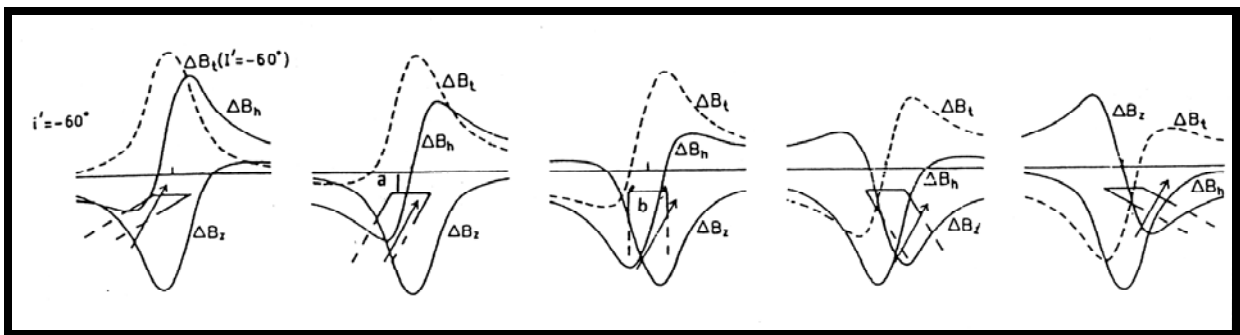


Figure 2.9. Magnetic anomaly across a sill, with $b=2a$. The width of the sill is b and the depth of the sill is a . All the ΔB_t curves (total geomagnetic field) are valid for an east-west strike of the sill (Parasnis, 1979).

2.2.6.2 Frequency domain electromagnetic (FDEM) technique

The electromagnetic (EM) technique measures the electrical conductivity of the ground by utilising a source and a receiver. In a few EM ground systems the source energy may be introduced into the ground by direct contact, although inductive coupling is mainly employed; invariably the receiver receives its signal from induction (Telford *et al.*, 1990). The transmitter, being the artificial source, creates an alternating magnetic field by the propagation of continuous alternating voltage wave or transient electromagnetic fields through a coil, which causes currents to flow in and over the subsurface by induction. If a conductive zone is present, stronger secondary currents are induced in these zones. These induced currents, which are dependent on the conductivity, size and geometry of the conductor, will possess their own secondary magnetic field. The receiver then

measures the magnetic field strength of this induced field. By comparing the actual measured field and the calculated field at the receiver, against the transmitter field, the presence of a conductive zone can be deduced (Van Zijl & Köstlin, 1986 and Telford *et al.*, 1990).

The FDEM induction techniques are best suited for detecting steeply dipping good conductors at shallow depths since the conductivity depends on the clay content, the porosity, the dissolved mineral content and the water saturation of the rocks (Palacky, 1994). Therefore, this technique is ideal for detecting weathered structures and zones such as faults, lineaments and fractures or water with a high total dissolved solids content (Telford *et al.*, 1990 and Sami *et al.*, 2002a). The weathering of the host rock results in water-saturated clays, which are among the most common geologic conductors (Palacky, 1994). The presence of water in discrete fracture zones or water-saturated clays renders lineaments, faults and fracture zones more conductive. Since these are zones of fragile host rock, the weathering process advances more rapidly along these lines and can thus be detected by electromagnetic techniques. Therefore, the whereabouts of lineaments and fracture zones represents important information with regards to groundwater exploration. However, the electromagnetic method cannot directly distinguish between permeable fracture zones and zones of water-saturated clay where the yield is usually low to moderate (Palacky, 1994). The present researcher employed the EM-34-3 and the Genie-SE88 machines, both of which operate in the frequency domain (Geonics and Botha *et al.*, 1992), thus implying that the equipment transmits and receives continuously on one frequency at a time.

2.2.6.2.1 EM-34-3

The EM-34-3 machine (manufactured by Geonics) operates in two different modes; the horizontal dipole (HD) and vertical dipole (VD). The different dipole modes make it possible to intercept horizontal and vertical bodies of different electrical conductivity in the subsurface (secondary field). With a longer coil spacing (up to 40 metres; $L = 40$ m), deeper conductive bodies can be observed and measured (to a depth of about 60 metres). The current researcher utilised a coil separation of 40 metres at a frequency of 400 Hz since Arcone (1981) & Botha *et al.* (1992) mention that this configuration creates the lowest electrical conductivity of the transmitter/receiver spacing, and the contrast

between the HD and VD is consequently the largest. The 40 metre coil spacing creates a significant negative conductivity anomaly across a possible conductor in the VD mode. Results obtained must be plotted between the two coils. The receiver is calibrated in terms of apparent conductivity (plotted as mS/m).

Interpretation of results obtained with the EM-34-3 can be explained according to Botha *et al.* (1992):

- When both the transmitter and receiver coils are located to one side of the conductor, the response is positive since the primary and secondary magnetic fields at the receiver location are added to each other.
- When either the receiver or transmitter coil is located directly over the conductor, the response is zero due to the zero coupling configuration of the coils with the secondary magnetic field or conductor respectively.
- When both coils straddle the conductor, the secondary magnetic field measured at the receiver coil opposes the primary field and the response is negative.

Conductor coupling refers to the orientation between the target and primary EM-field. For a conductor to be energised by the magnetic field, optimum coupling occurs when the magnetic field is perpendicular to the largest surface of the conductor (refer to Figure 2.10).

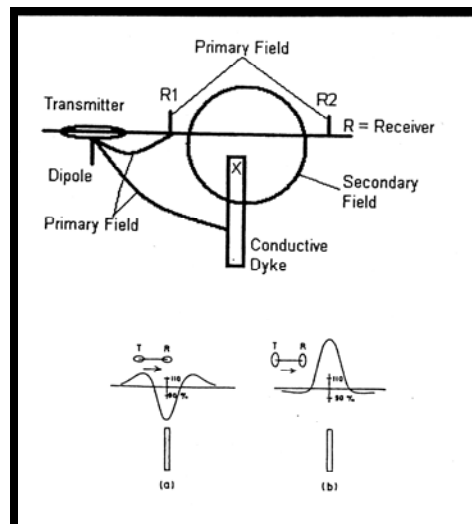


Figure 2.10. Origin of electromagnetic anomalies in the transient sender – receiver system (Parasnis, 1979). The response of the secondary electromagnetic field for the (a) VD and (b) HD configuration across a conductor is depicted.

2.2.6.2.2 Genie-SE88

The Genie-SE88 is a moving-source horizontal loop EM system and is manufactured by Scintrex. The system measures the ratio of vertical magnetic field amplitudes at two well-separated frequencies. By measuring the amplitude ratio, advantage is derived from the absence of an inter-connecting cable, levelling and freedom from noise due to errors in coil position or orientation (Van Zijl & Köstlin, 1986 and Botha *et al.*, 1992). During the present study, a frequency of 337.5 Hz (Hertz) was used for the selected signal frequency and a frequency of 112.5 Hz for the selected reference frequency. Johnson & Doborzynski (1986) indicated that in this frequency mode, targets of high conductance (such as groundwater) will yield favourable negative readings: see Figure 2.11. Various coil separations from 6.25 to 200 m can be selected. For the said study, a coil separation of 100 m was used. Interpretation of Genie data provides only semi-quantitative estimates of source parameters of near vertical conductors, most importantly location, dip, depth of burial and conductance. Measurements are plotted midway between the transmitter and receiver.

The Genie-SE88 was only utilised in the Limpopo Granulite-Gneiss belt because certain rocks are magnetic (magnetic quartzites) and disable the use of the magnetometer. Furthermore, Botha *et al.* (1992) and Vegter (2001b) proved the Genie-SE88 to be a valuable tool in groundwater reconnaissance and exploration in the above-mentioned geological area. The EM-34-3 machine was not used in the area due to machine operating difficulties and errors.

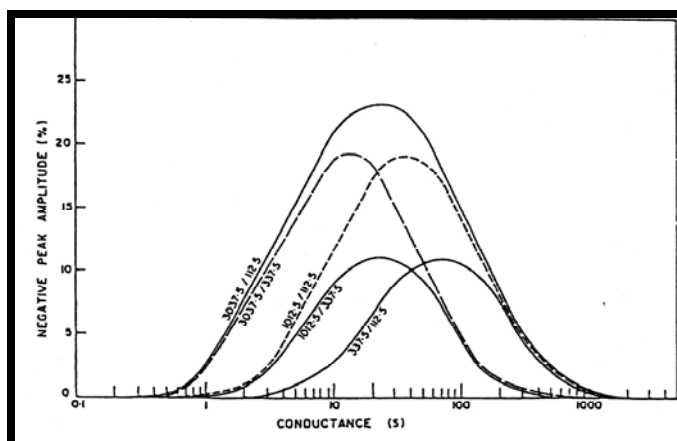


Figure 2.11. Genie response diagrams for the five possible frequency pairs over a conductive body. After Johnson & Doborzynski (1986).

2.2.6.3 Electrical resistivity technique

According to Dobrin (1976), the resistivity technique is employed to map boundaries between layers that possess different conductivities when an electrical current at low frequencies flows through the earth materials and the response of these materials is measured. The resistivity technique employs an artificial source of direct current, which is introduced into the ground through point electrodes. The procedure is to measure potentials at other electrodes in the vicinity of the current flow. Because the current is also measured, it is possible to determine an effective or apparent resistivity of the subsurface (Telford *et al.*, 1990). The measured effective or apparent resistivity (ρ_a) of the subsurface is largely electrolytic and is a function of the subsurface body's connected pore spaces, grain boundaries in fractures, fault lines, bedding planes and joints, while this determines the quantity of current that can pass through this body (Bowen, 1980). The measured apparent resistivity will decrease when the porosity or (mineralised) water content of the body increases (Keller & Frischknecht, 1982 and Karous & Mareš, 1988). The resistivity of different rock types depends on (Sami *et al.*, 2002a):

- The conductivity of the contained water, e.g. the amount of dissolved solids in the water;
- The amount of water in the formation, e.g. the degree of saturation; and
- The manner in which the water is distributed in the formation, e.g. the porosity.

The aforementioned conditions imply that weathering, faulting, shearing and dissolution lower the resistivity of a formation by increasing porosity and fluid permeability. On the other hand, cementation, unconnected pore space in a formation, compaction and metamorphism of a formation will result in an increase in resistivity due to the reduction in fluid permeability.

The results have to be plotted immediately in order to obtain a mathematically defined, shaped, sounding curve or graph. Irregular patterns on the curve indicate noise or wrong data (Van Zijl, 1987). The resistivity technique is superior, at least theoretically, to all the other electrical methods, because quantitative results are obtained by utilising a controlled source of specific dimensions. In the study undertaken by Meulenbeld (1998), results obtained with the electrical resistivity technique are discussed at length.

In the current study a G41 GEOTRON resistivity meter was used in the Schlumberger array. The Schlumberger array is effective for measuring a geo-electrical section of the subsurface below the resistivity meter with an increased cable spacing. Bhattacharya & Patra (1968), Koefoed (1979), Parasnis (1979) and Keller & Frischknecht (1982) discuss the theory of this array. The interpretation of electrical curves obtained from the said array is based on the match between the obtained curve and the geology and geo-electrical parameters of the measured subsurface (Van Zijl, 1987). Curve-matching techniques involve modelled curve sheets as indicated in Joubert (1986) or modelling with the aid of a computer program such as the one of Zohdy (1989).

2.2.6.4 Profiling and sounding

Basically there are two methods of making geophysical measurements. The first is by means of an expanding array, which permits the operator of the equipment to reach deeper and deeper beds or rocks. This is called electrical sounding, where the Schlumberger array for direct current resistivity applications is often used. This array can obtain increased depths of investigation by placing the current electrodes A and B further and further apart. It is important to note that when geological beds or strata dip more than 45°, the data obtained through the electrical sounding is of no use as a result of electrode and lateral effects (Van Zijl, 1987). The second prospecting technique is termed horizontal profiling because the subsurface is investigated in a lateral direction with arrays of a more or less constant depth of investigation. This is achieved either by keeping the dimensions of the array constant and moving the entire array from station to station or by keeping the current electrodes stationary and moving the potential electrodes over an area where the electric field, and thus the depth of investigation, is uniform (Van Zijl, 1987). The magnetic and EM techniques are frequently utilised for profiling purposes. The EM techniques involve the use of a moving transmitter and moving receiver, where the transmitter and receiver are moved along the survey line, usually with a fixed distance between them (Van Zijl and Köstlin, 1986). The magnetometer is a versatile tool in geophysical profiling because it records data at set station intervals along a certain specified traverse or survey line.

It is important to remember that during sounding, the survey has to be carried out parallel to the strike of the formation. However, during profiling, the survey line has to be

perpendicular to the strike of the formation or anticipated anomalous body (Parasnis, 1979). If the target strike direction is known beforehand from airborne data or geological maps, time can be saved in conducting profiles and obtaining quality data. Sounding has to be employed in the case of palaeochannel investigations, the presence of deep weathering beds and the estimation of the geo-electrical properties of the bedrock. Profiling is required in the event of the presence of dykes, sills, faults, lineaments and other intrusions and structures of deformations of limited extent in the surrounding rock (Koefoed, 1979, Keller & Frischknecht, 1982, Van Zijl, 1987 & Telford *et al.*, 1990).

2.2.7 Remote sensing

Remote sensing refers to the science and art of obtaining information about an object by means of an apparatus where the apparatus is not in contact with the object itself (Lillesand & Kiefer, 1979). An applicable remote-sensing method that is either readily available or inexpensive is aerial photography, the photographs of which are obtainable from the Department of Public Works. These scale of these photographs is approximately 1:50 000 and they are easily comparable with ordinary 1:50 000 topographic maps. Some background on remote sensing is discussed in Meulenbeld (1998). For the present study it is important and essential to demonstrate that geobotanic indicators are noticeable on aerial photographs and their uniqueness is highlighted by means of linear growth patterns, solitary standing, conspicuous growth, etcetera. The following figures (Figures 2.12a-c) indicate different geobotanic growth and occurrence patterns on aerial photographs, where all figures are representative of the case studies presented.



Figure 2.12a. The farm Blokdrift 512KQ (case study 5). A diabase intrusion demarcated by linear, dense vegetation growth (A) (darker texture).



Figure 2.12b. The farm Hartbeesfontein 394KR (case study 30). Linear, moist (dark texture) patterns due to a lineament (A) in the Bushveld that are even manifested on the circular irrigation-pivot lands (P).

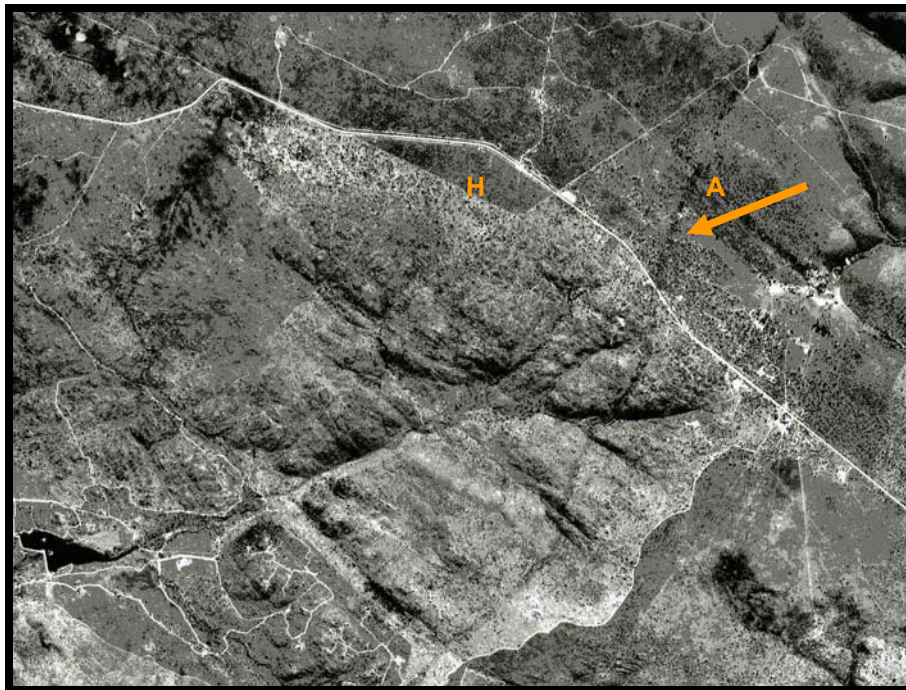


Figure 2.12c. The farm Droogekloof 471KR (case studies 6 & 25). A lineament (A) that cuts across the farm Droogekloof and various lithologies, remarkably visible as a result of dense and localised vegetation growth among the scattered plants between the granite hills (Lebowa Granite Suite) (H).

2.2.8 Nutrient cycling

Nutrient availability, especially nitrogen and phosphorus, is extremely important in the structure, function and composition of tree communities (Scholes 1990, 1993). Both of these elements are seldom present in available forms and in significant quantities in the soil. Termites, conspicuous in many tree communities, are significant detritivores (Marais, 1990 & Scholes, 1997). Different rocks constitute different soils with particular nutrients. These particular nutrients in a small area, for example on a weathered dyke, define unique tree growth at times, especially when termites can recycle these nutrients. Some species of plant, such as those of the *Acacia* species, have nitrogen-fixing bacteria living in their roots. The bacteria take nitrogen gas from the air and reduce it to nitrate, a plant nutrient (Luhr, 2004). In the vicinity of the *Acacia* species, one will be able to find more conspicuous vegetation (grasses, shrubs and trees) growth than in the open veld, due to the higher availability of nitrate. Weathered dyke material constitutes clayey soils that are highly fertile (De Jager, 1993) and are able to sustain luxurious vegetation growth, such as *acacias*. One will often find termitaries associated with areas rich in underground water and/or nutrients (Marais, 1990). An examination of termites in the Waterberg, conducted by the well known Eugéné Marais, proved several points, namely:

- Termite communities could not exist for a single day in terrible drought without water;
- Termite communities develop shafts by which water is conveyed;
- These shafts are quite deep (over 15 metres); and
- Termites need water in order to survive. It is an essential component of the fungi garden that plays an important role in their food digestion process.

Water diviners often use a termitary to locate a drilling spot. The reason might be that a conspicuously aligned termitary needs water in order to survive, and such an alignment might indicate the presence of groundwater. Termitaries are also known in areas of heavier soil that support a more palatable vegetation (grasses and trees/shrubs) than the open veld (Acocks, 1988), often as a result of the points mentioned above. It is not out of the ordinary to find tree clusters associated with a termitary, which may result from a bird that rests on a termitary and drops a seed that germinates, owing to the favourable conditions. However, the chances are probably equal that a bird rests on a stone, dead tree trunk or other feature, and owing to more unfavourable conditions,

germination does not take place. Furthermore, certain tree species, at times, are only associated with a termitary, such as *Scolopia zeyheri* (thorn pear) (Van Wyk & Van Wyk, 1997).

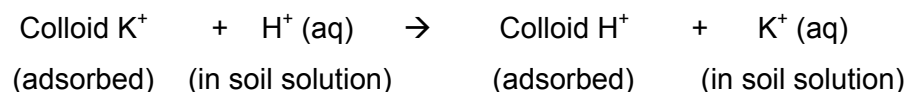
The luxuriant growth of vegetation in clayey soils, rather than on other types of soils, can be explained according to Van Schalkwyk & Vermaak (2000) and Casey & Meyer (2001). Since water is a bipolar molecule, it is attracted to soil grains, especially clay minerals, because of the net electrical charges that may occur on the surfaces of soil grains. Permanent negative charges occur on the surfaces of clay minerals, caused by isomorphous substitution. Net electrical charges also occur on the edges of clay minerals and on the surfaces of allophane and hydroxides of iron and aluminium, because of their incomplete crystal lattices (White, 1989). This phenomenon is partly responsible for water being held in the soil matrix, particularly that of clay soils, as well as for the cohesion and plasticity of clay soils. The charges on a mineral surface can be calculated by measuring the difference in moles of charge contributed, per unit mass, by cations and anions absorbed from an electrolyte solution at a known pH. The cations and anions absorbed, are known as the Cation Exchange Capacity (CEC) and Anion Exchange Capacity (AEC), respectively, and are expressed as cmols charge per kilogram. The chemical methods behind the determination of CEC values are presented in Sobczyk *et al.* (1987) and the Department of Agricultural Technical Services (1977). Soil sampling and parameters analysed during the present study are discussed under the soil sub-heading (2.2.2.3). The results and case studies are presented in Chapters 3-5 and Annexure 1.

A further reason for luxuriant plant growth is the principle of the beneficial effects of organic matter in soil. Mineral elements in the soil are essential for plant growth, as reported by the eminent German chemist Justus von Liebig, whose research led to the concept that certain factors were essential for plant growth and that if any one of these factors was limited, plant production would be reduced accordingly. This principle, called the law of the minimum, remains valid today, and may be stated in a practical manner as follows: *The level of plant production can be no greater than that allowed by the most limiting of the essential plant growth factors* (Brady, 1990). Allison (1973) listed the important contributions of organic matter to soil: (1) it is the major natural source of inorganic nutrients and microbial energy, (2) it serves as an ion exchange material and a

chelating agent to hold water and nutrients in an available form, (3) it promotes soil aggregation and root development, and (4) it improves water infiltration and water-use efficiency. Most organic matter values are derived from organic carbon (organic C) and are usually highly correlated with organic nitrogen (organic N) in soil (Unger, 1968). Organic matter binds mineral particles into granules that are largely responsible for increases in the amount of water a soil can hold, and is a major soil source of phosphorus and sulphur and the primary source of nitrogen (three elements essential for plant growth) (Brady, 1990). But the overall potential for S to affect organic C and N in soil is not large (Rasmussen & Collins (1991). Important to note is that organic matter content increases with increasing precipitation and decreases with increasing temperature (Rasmussen & Collins, 1991). Organic matter is the main source of energy for soil organisms. Without it, biochemical activity would almost cease. Biological systems are carbon controlled and N affects soil organic matter mainly through its influence on residue production, where the energy for this system is derived from nitrogen-assimilating bacteria that grow in the nodules of the roots of legumes, such as those of the *Acacia* species (Brady, 1990). Increases in N result in higher vegetative production since this reduces the movement of soluble N out of the root zone. In South Africa, Scotney & Dijkhuis (1990) established that, where the encroachment of *Acacia karroo* had taken place over a 32-year period, the levels of organic matter, total nitrogen and mineralisable nitrogen had recovered to almost those of the virgin soil. The absorption of essential elements is determined not only by the availability of soil-held nutrients but by their proximity to the root surfaces. As roots penetrate the soil, they make contact with and absorb ions found in the soil solution as well as those held on the surface of the soil colloids. Also, nutrients in the soil solution can move to the roots and can then be absorbed (Brady, 1990). Together, according to Brady (1990), an increase in humus is observed, since the capacity of the humus to hold water and nutrient ions greatly exceeds that of clay, its inorganic counterpart. Small amounts of humus increase the capacity of the soil to promote plant growth.

The extremely small particle size of clay and humus implies a large surface area per unit weight. Also, they exhibit surface charges that attract negatively and positively charged ions and water. The attraction (adsorption) of ions such as Ca^{2+} , Mg^{2+} , and K^{+} on the surfaces of colloidal clay and humus is not as exciting as the exchange of these ions for other ions in the soil solution. The intimate contact between soil solution ions and

adsorbed ions renders such exchanges possible. For example, an H^+ ion released to the soil solution by a plant root can readily exchange itself with a potassium ion (K^+) adsorbed on the colloidal surface. The K^+ ion is then available in the soil solution for uptake by the roots of plants (Brady, 1990). A simple illustration of such cation exchange illustrates this point:



Most physical properties of soils are also controlled by clay and humus. In terms of weight, humus particles have greater nutrient- and waterholding capacities than clay particles. However, since clay is generally present in larger amounts, its total contribution to the chemical and physical properties of the soil will usually equal or even exceed that of humus.

Soil, plant, pasture and climatic factors all influence the concentrations and biological availability of minerals in plant matter. Most naturally occurring imbalances of trace minerals caused by trace mineral levels in plants are a direct consequence of soil chemistry (Reid *et al.*, 1984), but unfortunately, these factors do not influence all minerals in the same manner. For example, a high soil pH can decrease plant levels, and availability, of Fe, Mn, Zn, Cu and Co, but also increase Mo and Se levels and availability (McDowell, 1985). Clays with high cation exchange ratios can release trace minerals under acid digestive conditions, thus increasing the amount of available copper, iron, manganese, zinc, and a number of macro-elements (Casey & Meyer, 2001) that support vegetation. On the other hand, a low soil pH ($pH < 5.5$) creates soil acidity. Soils derived from shale and sandstone are often characterised by poor vegetation, especially tree and shrub growth, owing to the chemical restriction on root development introduced by Al (aluminium) toxicity. Toxicity caused by Al due to a pH less than 5.5 is characteristic of high rainfall areas (>750 mm per annum), such as the Highveld of South Africa (Beukes, 1995). Furthermore, a deficiency in nutrients such as N, P, Ca, Mg and Mo is observed. Soils derived from weathered sandstone and/or gritstone are high in sand and gravel content. Such soils are easily leached out and therefore depleted in nutrients. The low clay content of such soils contributes to a decrease in CEC (Beukes, 1995). Hence, the organic content of these soils is also minimal (less than 0.7%).

2.2.9 Biodiversity and vegetation

2.2.9.1 Biodiversity and biomes

South Africa has one of the richest floras in the world (Cowling & Olivier, 1992). The high level of species endemism is another distinct feature of the southern African flora (Goldblatt, 1978). The current study area covers the moist highveld grassland (grassland biome), afro-montane and inland forest (grassland and forest biomes), undifferentiated bushveld and woodland and thorn (*Acacia*) bushveld (savanna biome), although these areas are not considered to be centres of plant diversity and endemism (Van Wyk & Van Wyk, 1997). The nature of the land cover can exert a large influence on recharge (Scott & Le Maitre, 1998) since the ability to reduce infiltration by means of an extensive vegetation soil cover is larger than that of a poorly vegetated area, owing to an increased interception of seeping water by the roots. However, evaporation and transpiration processes cause upward movement of water towards the ground surface and so provide water to the roots of plants as well (Van Schalkwyk & Vermaak, 2000). In this sense, the vegetation supports itself by intercepting recharge water as well as subsurface water.

A biome is a natural grouping of vegetation according to the life-form of the dominant plants and ecological similarities (Rutherford & Westfall, 1996). According to Scott & Le Maitre (1998), the two biomes in the study area are:

- Savanna biome: This biome is characterised by a grass layer and a distinct upper layer of woody plants and covers 33.7% of South Africa. Savanna occurs in a wide variety of situations from sea level to 2 000 m and from 235 – 1 000 mm of rainfall per year. Soils range from rocky and shallow to deep Kalahari sands. There is a divergence of opinion regarding the rooting behaviour of savanna trees and shrubs and therefore, also, concerning the importance of vegetation groundwater interactions. Some believe that root systems only penetrate as deeply as the typical wetting depth of the summer rains, with grass roots being dominant in the upper soil and trees in the deeper layers. Many species have extensive lateral roots which can also produce sinker roots. Root and isotope studies indicate that woody plant root systems often access unsaturated layers or groundwater at substantial

depths (+10 m) where the profile permits root growth. Certainly, vegetation groundwater interactions are important in the riparian communities, especially forests, in this biome and these communities are sensitive to the lowering or raising of water tables.

- Grassland biome: The dominant life form in this biome formally comprises grasses and woody plants which are confined to certain habitats (e.g. rocky areas, riparian strips). Grasslands cover 26.4% of South Africa over a wide range of annual rainfall, but presently, at least half of the natural grasslands are under cultivation. Grass roots are generally confined to the upper 0.5-1.0 m of the soil but can penetrate 3 m or more. Interactions with groundwater will be limited to reducing recharge by interception and moisture uptake from the unsaturated zone, except in discharge areas such as wetlands and riparian strips.

2.2.9.2 Rooting

Observations of the depths of root systems have revealed that, in general, studies of root systems in plants indicate that the roots will penetrate as deeply into the soil as is required to reach the available water, being restricted only by soil or regolith characteristics that prevent rooting or by permanent water tables (Canadell *et al.*, 1996 and Jackson *et al.*, 1996). Although deep roots may only comprise a small fraction of the system, they may be critical for plant survival. Just a few roots penetrating apparently impenetrable soil layers (e.g. massive laterite layers) can sustain even large trees (Doley, 1967 and Stone & Kalisz, 1991). Many shrub species have roots penetrating 3-10 m or more where this is possible (Specht & Rayson, 1957 and Dodd *et al.*, 1984). Many, but by no means all, savanna trees are commonly deep rooted, with legumes such as *Acacia*, reaching depths of 3-20 m and even >53 m in one recorded case. Many species in arid and semi-arid environments possess shallow, spreading root systems which are used primarily to scavenge water for storage in the plant; these include most succulents such as cacti, aloes and even the baobab, *Adansonia digitata* (Caplan, 1995). Scott & Le Maitre (1998) suspect a link between the baobab growth, available groundwater reserves and the baobab collapsing, but more research on this topic is recommended by them (see Chapter 4).

The association of certain trees with unconfined aquifers is well documented and studied in forestry and mining. Exotic pines and *eucalypti* are grown in coastal flat zones and are discussed at length by Scott & Le Maitre (1998). The mining applications are studied by the Restoration & Conservation Biology Research Group of Wits (Weiersbye, 2002).

A special class of rooting tree that must be mentioned is phreatophytes. The rooting depth is on average 5 m, with a maximum depth that ranges between 4-12+ m. The phreatophytes are species that are able to grow roots to depths needed to tap water tables or other relatively stable water sources (not necessarily unconfined aquifers). Most phreatophytes maintain high transpiration rates and often make exclusive use of groundwater, even where other superficial sources are available (Scott & Le Maitre, 1998). In the study by Meulenbeld (1998) it was mentioned that, in the South African context, the species *Combretum erythrophyllum* (river bushwillow) and *Syzygium* can be classified as phreatophytes. For pollution plume mapping, associated with the goldmines situated in the Free State and North-western Province, species of *Acacia* and *Rhus* were also recognised as phreatophytes (Weiersbye, 2002). Riparian species such as *Acacia xanthophloea* (fever tree) and *Ficus* (fig species), have different watering requirements. The *Acacia xanthophloea* communities tend to occur on higher ground than *Ficus sycomorus* (common cluster fig) communities in the Pongola River flood plain communities. Both vegetation types are dependent on easy access to water while being sensitive to flooding, requiring well drained upper soil layers (the *Ficus* more than the *Acacia*) (Furness & Breen, 1980). Another riparian tree species that is dependent on an alluvial aquifer in the bushveld south of the Limpopo, is the *Croton megalobotrys* (large fever-berry) used by De Beers Consolidated Diamond Mines as an indicator for changes in the water level resulting from mining activities. In the arid north-western parts of South Africa in the proximity of Kathu, Scott & Le Maitre (1998) describe the survival of a woodland of *Acacia erioloba* (camel thorn) trees, where a single aquifer appears to underlie the forest and the depth to the water table usually ranges between 7 and 15 m (maximum of 20 m). It is quite feasible that the forest trees are at least partially dependent on abstracting water from the Kathu Aquifer since it is known that these trees display a rooting depth of 60 m in this environment (Canadell *et al.*, 1996).

Scott & Le Maitre (1998) mention *Rhus lancea* (karree) and other *Rhus* species that can indicate good groundwater sources, though these may not necessarily grow in likely or

obvious localities for groundwater. The rooting depth of *Rhus* species can extend to 13.2 m (Canadell *et al.*, 1996). Also, an obvious row of healthy trees may indicate a weathered zone or fracture in the rock where one is more likely to drill a successful borehole. Meulenbeld (1998) warns against the presence of possible geobotanical indicators near a fence because birds that sit on such a fence might drop seeds and, in a manner of speaking, be responsible for the germination of a tree or shrub along such a fence.

A distinct difference in tree species and tree appearance can be observed in sand plains and clay rich soils. Sand plains in the north-eastern parts of South Africa are vegetated by *Ochna pulchra* (peeling plane), *Burkea africana* (wild seringa) and *Terminalia* (cluster-leaf species) (all are non thorn trees or shrubs) species. Species of *Terminalia* always occur on sandy soil or in sandveld (Bonsma, 1976). Scott & Le Maitre (1998) describe *Ochna pulchra* roots extending up to 4 m from the stem and 'individuals' were often connected to others by lateral roots to form clones. Most roots were located in the upper 0.6 m of soil and penetrated the gravel layer, but stopped at the bedrock (2.2 m depth). *Burkea africana* root systems spread up to 20.5 m from the tree, most roots were present in the upper 0.4 m; 'heart' roots (near the stem base) and occasional sinkers reached bedrock. The *Terminalia* root system was primarily shallow and spread to a depth of 0.12-0.35 m and 3.6-6.6 m from the stem. Tap-roots penetrating beyond 1.52 m were observed by Strang (1969), but most roots of grasses in the savanna were found in the 0-200 mm layer and trees in the 150-610 mm soil layers. Furthermore, the sub-habitats characterised by the grass *Eragrostis pallens* (broom love grass) and the shrub *Ochna pulchra* exhibited drying out only in the upper 0.6 m of the profile, leaving a well-watered profile below this depth. Thorn trees, such as the *Acacia* species, typically cover clay rich soils. The *Acacia karroo* (sweet thorn) is one of the most widespread and versatile of southern African *acacias* (Barnes *et al.*, 1996). In the most arid parts it will only grow where it has access to permanent underground water since it is not very drought tolerant (Scott & Le Maitre, 1998), but the underground water may be associated with clay layers, which are not good aquifers for the exploitation of a supply of groundwater. Deep rooting is recorded for woody plants, such as *Acacia* (to > 50 m), which is quite extraordinary as the mean maximum depths of the root systems for trees are 7.0 ± 1.2 m and 5.1 ± 0.8 m for shrubs (Canadell *et al.*, 1996). Drilling in the Clarens

Sandstone in the Waterberg Coal fields indicated root fragments at depths of 9 or 10 m (Scott & Le Maitre, 1998).

Of importance in the present study, is the ability of roots to penetrate deep weathered or fractured soil and rocks in order to withdraw quantities of water in order to survive and hence the presence of plants may serve as a possible geobotanical indicator for exploitable groundwater resources. Dye (1996) proved, in his study, that where a deep soil, or deeply fractured or decomposed rock occurs, the vigorous *eucalypts* can exert a large impact on groundwater without necessarily having access to saturated zone water. The weathering of mafic dykes in the Barberton greenstone belt that enriches the soil in Fe and Mg and hence supports a greater number of trees, shrubs and aloes than the surrounding granite-derived soils, was described and photographed by Anhaeusser (1999). Jennings (1974) found roots of *Boscia albitrunca* (shepherd's tree) at a depth of 68 m in a disused borehole in Botswana. Furthermore, it was noted that linear formations of trees typically indicate dykes, joints or fault planes, which may provide better soil or water for deep rooted plants. Rows of *Acacia erioloba* in eastern Namibia are indicators of deeper buried channels with coarse sediments and more water. In the Ghanzi district of Botswana, *Combretum imberbe* (leadwood) appears to indicate fresh shallow groundwater; while west of Tsienyane, *Acacia erioloba* and in the area of the Nata Ranches, the palm (*Hyphaene* probably *benguelensis*, real fan palm) indicates saline groundwater. Figures 2.13 and 2.14 indicate the importance of an igneous intrusion to support tree growth and access to groundwater resources in contrast with the surrounding rock. The influence of acid, sandy soil on root development was considered in the preceding section.

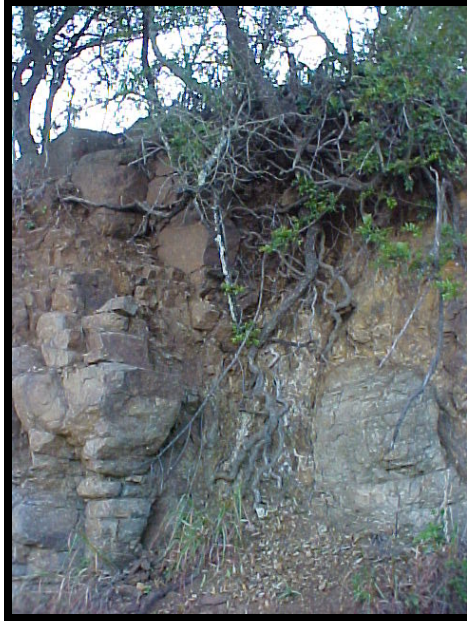


Figure 2.13. Conspicuous rooting along a diabase intrusion. Ithala Nature Reserve, Louwsburg, Kwazulu-Natal.



Figure 2.14. Roots directed to the nutritious, weathered and fractured diabase intrusion in contrast with the almost absent roots in the shale of the Mozaan Group. The intrusion supports different tree species to those encountered on the shale plains. Note the deformation of the shale alongside the intrusion. Ithala Nature Reserve, Louwsburg, Kwazulu-Natal.

2.2.9.3 Characteristics of vegetation water use

The base-line for the water use characteristics of vegetation (that is, vegetal modification of recharge potential) types is a function of the following factors (Scott & Le Maitre, 1998):

1. Stomatal conductance (or its inverse, the resistance to water flow through the leaves) and stomatal behaviour;
2. Leaf area index (area of leaves relative to ground surface area);
3. Seasonality of leaves: evergreen, cold deciduous or facultative deciduous; and
4. Rooting depth and effectiveness of roots at various depths.

The availability of water to plants in the soil profile is a function of (i) plant rooting characteristics (the ability and tendency to root deeply or otherwise); (ii) the penetrability of the soil to roots; and (iii) the water holding capacity of the soil (texture and porosity). The importance of groundwater is stressed by the following parameters: depth to groundwater (accessibility to plants); porosity and permeability of aquifers; storage capacity of the aquifers; and controls exerted by lithology (frequency and location of sources of groundwater).

The focus of chapter four will fall on practical situations (case studies) where certain tree species occur on or in the immediate vicinity of geological intrusions or possible water holding zones (increased porosity and/or permeability). The occurrence of tree species is quite dependent on the above-mentioned characteristics of vegetation water use. The case studies will attempt to identify certain aspects indicated in this section.

2.3 Approach

Geobotanical-geophysical groundwater exploration is dependent on the following. Any investigation regarding groundwater must be guided by the geology and expected geohydrological conditions of the area, or the aquifers to be expected and the depth of water strike. This will define the type of geophysical method to be utilised. These three factors explain why, how, what and where one should investigate. The discussion of geophysical methods and anomalies in Chapter 5, as well as the published geophysical profiles and soundings in the annexure, will be of some assistance. Aerial photographs,

if available, are an excellent tool in undeveloped areas in order to define geological features such as lineaments, vegetated linear structures, faults, fracture zones, etc. Land type maps and the representing soil series are of some assistance where there is much heterogeneity among the soil series and soils that are more enriched in nutrients can host geobotanic indicators. Thereafter, by means of field observations, it is important to verify that what is identified on the maps, is actually visible in the field. With the guidance of the listed geobotanic species in their lithologic and biome environment, one has to search for these which are normally found in close association with the geological features as identified on the aerial photographs. Soil sampling can be undertaken since in most cases, higher CEC-values (see Chapter 5) are representative of geobotanic indicators, although this is costly. An analysis of soil samples so as to measure CEC-values can be of great assistance in cases where the vegetation has been cleared, and these cases are associated with geological features and geophysical anomalies. Higher CEC-values can be regarded as places of former geobotanic indicators.

CHAPTER 3 APPLIED GEOBOTANY

3.1 INTRODUCTION

The previous chapter dealt with factors that contribute to geobotanical phenomena. The relationship of various natural entities were discussed, for example, soil chemistry differences that contribute to variations of distinct vegetation growth, and hence to the formation of geobotanical phenomena. This chapter focuses on geobotany as observed in practice in the Pretoria region.

3.2 GEOBOTANICAL OBSERVATIONS IN LITERATURE

The geology of the Pretoria region, as indicated by van Tonder (1999), is considered by Meulenbeld (2001) to link botanical species to the specific geologic and geomorphical environments. Three ridges of resistant quartzite dominate the geology of the Pretoria region, running from the North West Province past Hartbeespoort, west of the city, through to the eastern suburbs. The northernmost and most conspicuous ridge is that of the Magaliesberg, which is separated from the Daspoort quartzite ridge to the south (variously known as the Daspoortrand, Silverton Ridge, and Bronberge) by a broad valley underlain by Silverton shales (less resistant to weathering). The Strubenkop shale, Hekpoort lava and Timeball Hill shale underlie the valleys to the south of the Daspoort quartzite range. The ground then rises to the slopes of the Skurweberg, Langeberge, Skanskop, Klapperkop, and Waterkloof Ridges, all of which are formed by the Timeball Hill quartzite. The geomorphological term for such topography is *cuesta*, and in South Africa it is often referred to as *Bankenveld* topography. To the north of the Magaliesberg, the granite and gabbro of the Bushveld Igneous Complex can be found. Towards Johannesburg (south of the Timeball Hill quartzite), the dolomite of the Malmani Subgroup outcrop is situated. Towards the southwest, granite of Swazian age outcrops on the road towards Sandton.

Other geobotanical references in literature were mentioned above with respect to the study conducted by Bate & Walker (1993) regarding the relationships with water of the vegetation along the Kuiseb River in Namibia, geobotany-groundwater relationships in

the Cape Flats, without mentioning geobotanic species (Sigonyela, 2006), and are related to mineral exploration (Cole & Le Roux, 1978 and Mshumi, 2006).

3.3 USE OF MAPS

Different maps can be used and are available for investigation in order to establish links between vegetation, soil, geology, climate and hydrogeological conditions.

- The classification of land type maps denotes an area to be depicted on a scale of approximately 1:250 000 and indicates areas characterised by a high degree of uniformity in respect of climate, terrain form and soil pattern. The chief criteria for the delineation of land types include the pattern and density of the drainage system, relief, and the slope, profile and extent of every unit of terrain. A terrain unit is defined as being any part of the land surface with a homogeneous form and slope, with other land units together comprising a particular land type. Five basic terrain units are referred to throughout the classification system, namely crest, scarp, midslope, footslope and valley bottom. These maps are referenced according to the soil type, classification, and chemical analysis of relevant soil profiles.
- A geological map of an area (1:250 000), in conjunction with aerial geophysical maps (1:250 000) as published by the Geological Survey of South Africa, is a versatile tool for basic reconnaissance studies. The planning of geophysical techniques to be utilised in a certain terrain can be carried out prior to the actual fieldwork. Expected large intrusive bodies, bedding planes, strikes, folding, faults and geological units are distinctively displayed, either as coloured features or contoured entities, where in the background, essential topographic information such as farm names, towns, roads, streams, etcetera is indicated. Smaller geological bodies are not indicated and the application of a magnetometer in an area where no major intrusive bodies on the geological map are evident, is still advocated. Geological and aerial geophysical maps represent the general geological/geophysical conditions of the case studies included in the present research.
- The Department of Water Affairs and Forestry (DWAF) is currently publishing hydrogeological maps of South Africa. Although the scale is small (1:500 000), a general overview and aquifer characteristics of geological units can be obtained at a glance and this is included in the current study. This contributes to groundwater exploration in order to determine success rates and expected groundwater yield.

However, because of the scale, these maps can only be used as a reference or starting point since South African aquifers are, by exception, quite unique in their characteristics due to the old and complex geology of many regions. Aquifer yield cannot be simplified on a regional scale. Hydrological unit abbreviations, derived from these maps, are utilised in the present research (see Table 3.4 for explanation).

- The last useful map, especially in connection with geobotany, is the map entitled, *Veld Types of South Africa*, published by the Botanical Research Institute in Pretoria, and which accompanies the work of Acocks (1988). Due to the fact that veld types do not change significantly over small distances, a scale of 1:1 500 000 for the map is quite adequate. Numbers and colour coding on the map make cross references to the work of Acocks (1988) and accordingly to trees, shrubs and grasses that occur in such a zone, and can easily be consulted. Furthermore, geobotanical species, as observed and identified during this study can be listed accordingly as either commonly occurring in such a veld type and geology/soil, or as being less abundant and therefore will probably only grow in specific conditions. Each case study is related to the map indicating veld types.

3.4 GEOBOTANY: THE PRETORIA EXAMPLE

As illustrated in paragraph 3.2, Pretoria can be used as an example to illustrate the principle of geobotany since various tree species can be found in the city of Pretoria on different rock types. Acocks (1988) and Meulenbeld (2001) address the distribution of various tree species on the different rock types and subsequent veld types around the city. The rock types mentioned derived from weathered soils (paragraph 3.2 above), were sampled by means of a hand auger at a depth of 0.5 m and distinct tree species that occur on these soils were tabled: see Table 3.1 (a full analysis of the soil samples is represented in the annexure). Represented values in all the other tables similar to Table 3.1 indicate the available nutrients for root and plant development. The Pretoria instance sets the general example and application of geobotany for the remaining case studies. A generalised magnetic profile along the different geological areas in the vicinity of Pretoria is provided in Figure 3.1. The profile orientation is indicated in Figure 3.2. Note that the average rooting depth of tree species is referenced from Canadell *et al.* (1996), while that not referenced in the work by Canadell *et al.* (1996), is noted from related species mentioned in his study.

Table 3.1. The Pretoria geobotany example.

Parameter	Swazian Granite	Malmani Dolomite	Timeball Hill Quartzite	Hekpoort Andesite	Daspoort Quartzite	Silverton Shale	Magaliesberg Quartzite	Bushveld Complex Norite	Bushveld Complex Granite	Karoo Sandstone & Shale
Geological formation (see Figure 3.2)	Swazian Granite (1)	Malmani Subgroup (2)	Timeball Hill Formation (3)	Hekpoort Formation (4)	Daspoort Formation (5)	Silverton Formation (6)	Magaliesberg Formation (7)	Main Zone: Rustenburg Layered Suite (8)	Nebo Granite (9)	Ecca Group (10)
pH	6.29	6.68	5.50	5.79	5.07	4.57	5.08	7.54	5.83	5.54
CEC (cmol _c /kg)	4.17	8.42	17.87	18.18	8.4	5.74	3.37	55.84	3.13	2.64
Clay %	22.0	26.0	22.0	42.0	10.0	30.0	22.0	52.0	12.0	12.0
Silt %	16.3	30.7	41.1	30.2	25.9	28.8	11.0	28.6	3.8	12.7
Sand %	61.7	43.3	36.9	27.8	64.1	41.2	67.0	19.4	84.2	75.3
Distinct tree species	Grassland	1. Acacia karroo 2. Dombeya rotundifolia 3. Rhus lancea	1. Ochna pulchra 2. Brachylaena rotundata 3. Euclea crispa 4. Vangueria infausta	1. Acacia caffra 2. Gymnosporia buxifolia 3. Rhus lancea	1. Protea caffra 2. Mundulea sericea	Grassland	1. Englerophytum magalisanum 2. Vangueria infausta	1. Euphorbia ingens 2. Acacia karroo	1. Cussonia paniculata 2. Terminalia sericea 3. Grewia flavescentis	1. Faurea saligna 2. Sclerocarya birrea 3. Rhus lancea

Average rooting depth of the indicated species (m)	1 - 2	13 - 50	2 - 7	13 - 50	3 - 7	1 - 2	4 - 8	4 - 50	2 - 8	2 - 13
Average depth of weathering (m)	1.2	2.7	0.5	3.1	0.4	0.8	0.2	3.4	1.1	1.3
Average aquifer yield (l/h)	2 800	7 000	3 000	6 750	3 000	3 400	3 000	6 000	2 600	3 000
Average borehole depth (m)	45	35	45	60	50	35	45	35	55	60
Average depth of water strike (m)	31	21	32	31	37	24	37	22	43	29
Average static water level (m)	16	12	19	17	16	10	16	10	21	16
Land type series	Bb1a Glenrosa	Ab2a Hutton	Ib7a Rock	Ba9a Hutton	Ib3c Rock	Ba8b Mispah	Ib3a Rock	Ea3a Arcadia	Fa4b Glenrosa	Ae20b Hutton

Veld type	61 Bankenveld	61 Bankenveld	19 Sourish Mixed Bushveld	20 Sour Bushveld	19 Sourish Mixed Bushveld	19 Sourish Mixed Bushveld	19 Sourish Mixed Bushveld	13 Other Turf Thornveld	19 Sourish Mixed Bushveld	16 Kalahari Thornveld
Hydrogeo- logical unit	D3	B3	D2	D3	B2	D3	B3	D3	D3	D2

The average aquifer yield, average borehole depth, average water strike and average static water level were obtained from Frommurze (1937) and Meulenbeld (1998). It must be noted that the value presented is only an average for the geological formation. Information obtained from the land type maps and accompanying memoir stems from the Land Type Survey Staff (1987), veld type information from Acocks (1988) and hydrogeological information from DWAF: Johannesburg (1999). The soil colour was identified and classified in the veld according to the Corstor Colour Gauge that lists 168 different soil colours. Average weathering depth is extracted from the indicated Land Type Survey Staff while the average rooting depth of the geobotanical indicators is referenced from Canadell *et al.* (1996).

The geology of the Pretoria area and the sampling points are indicated in Figure 3.2. Figure 3.3 depicts the 1:250 000 land type series map of the same area as presented in Figure 3.2. Common names of the tree species indicated in Table 3.1 are mentioned in Table 3.2, while the climate of Pretoria is captured in Table 3.3. The aquifer classification as used by the DWAF: Johannesburg (1999) and indicated in the hydrogeological unit column of Table 3.1, is indicated in Table 3.4.

Analyses of soil samples as presented in Table 3.1 and other similar tables were undertaken as follows: pH presented is pH (H₂O), P obtained through the Bray 1 method, cations like Ca, Mg, K, Na and CEC by ammonium acetate, heavy metals Fe, Mn and Zn through 0.1M HCl extract, Al by 1M KCl extract, %C by the Walkley-Black method, Total N obtained by means of the TKN digestion method (total Kjeldahl nitrogen) and lastly, S is a result of Ca Phosphate analysis.

From Table 3.1 the following remarks can be made:

- Intermediate and mafic igneous rocks (andesite and norite) tend to support deep rooted thorn tree species because the soil horizon is weathered to a clay and is more nutritious than its granitic counterpart, based on the higher CEC-values, organic carbon, total N% and available cation values. A higher CEC-value indicates the presence of other micrometals that are not indicated in the analysed samples (micrometals such as Ti, Co, Mo, Se, etc.) (Loock, 2005).
- The low availability of Fe in iron-rich soil derived from iron-rich rocks (mafic norite and andesite, as well magnetic quartzite), especially magnetite (Fe₃O₄), is due to the fact that magnetite does not weather easily and is basically non-soluble owing to its oxidised state (Loock, 2005).
- In certain cases higher available Zn values are observed in the presence of higher Mn values. This can be attributed to the fact that Mn acts as a basin for Zn deposition (Loock, 2005).
- Basic igneous rocks tend to support trees, where thorns or spines are absent, and even grassland owing to a very shallow, sandy, weathered soil horizon and the lower nutritional value of the soil (%C, CEC, cations). Sandy soils are also prone to nutrient leaching as a result of their loose structure, increased pore space and resulting decline in CEC. Shallow weathering can be attributed to the higher quartz content

since quartz is less prone to chemical weathering in this region. Hence, the prominent quartzite cliffs and ridges.

- Quartzite supports tree growth in cracks, joints and weathered intrusive zones, but the nutritional value of the quartzite-derived soil is quite low. Amorphous Fe and Mn surrounding SiO₂ crystals can be found that are responsible for higher Fe and Mn values than expected. The soil and rock is often of a reddish colour owing to the presence of amorphous Fe (Loock, 2005). Only non-spine tree species are encountered. It is interesting to note that the presence of magnetite in the quartzite of the Timeball Hill Formation might supply more nutritional value to the weathered soil profile. Note the distinct difference between the Timeball Hill versus the Daspoort and Magaliesberg quartzite samples and the associated geobotanical species.
- Soil derived from shale and sandstone (Silverton Formation and Ecca Group), possesses very little nutritional value and tends to be quite acidic. Only grass species are encountered in these geological areas. Higher acidity in soils leads to an increase in Al, possible root poisoning, and an increase in the solubility of heavy metals that restricts root development and growth of vegetation. In more general terms, soil with higher resistivities tend to be less supportive of tree development, based on a higher sand (leaching) content and hence higher Al-values. Organic carbon and CEC-values are thus lower, resulting from the absence of abundant deep rooting-mediums.
- The average yields of aquifers vary between 360-7200 l/h. This value represents only a general overview of the Pretoria region and the case studies will provide an in depth focus on a certain area with aquifer yields varying from 0.0- >18 000 l/h.
- As often observed in geophysics, a higher soil sand content tends to increase the resistivity of the soil.
- From the results tabled in Table 3.1 one can deduce that norite is the most supportive substance for root and tree development due to its high CEC-value which implies that more nutrients and soil-water are available. However, magnetic quartzite and andesite are also supportive of root and tree development, based on their high organic carbon content, cation availability and total N content. Tree growth in poor quality soil derived from sandstone and shale belonging to the Karoo Supergroup north of the Magaliesberg can be ascribed to the fact that (severe) frost is almost absent.

- The differences in soil characteristics presented in Table 3.1, based on soil samples gathered for the purpose of this study and on comparisons with other published soil samples from the same area, stress the fact that soil differs from spot to spot. Every sample is a unique representation of the soil conditions at that specific place, time and depth. This is entirely true and essential for the sampling method employed for the present study. Specific soil samples related to conspicuous vegetation growth are only taken at the direct spot where such vegetation occurs and nowhere else.

The application and value of geobotany is located in the presence of different soil types in an area owing to the weathering of the original rock type. The different soil types depict variations in vegetation or botany. Differences in rock types create aquifer conditions. Different rock types and aquifer conditions possess characteristic or merely unique geophysical responses that can be measured by means of geophysical instruments. It can thus be assumed that distinct variations in vegetation and, in particular, as regards certain species can be used as an indicator for groundwater exploration by means of geophysics.

Table 3.2. Common names of tree species mentioned in Table 3.1.

Latin Name	Common Name
Acacia caffra	Common hook-thorn/Gewone haakdoring
Acacia karroo	Sweet thorn/Soetdoring
Brachylaena rotundata	Mountain silver oak/Bergvaalbos
Cussonia paniculata	Highveld cabbage tree/Hoëveldse kiepersol
Dombeya rotundifolia	Common wild pear/Gewone drolpeer
Englerophytum magalismontanum	Transvaal milkplum/Stamvrug
Euclea crispa	Blue guarri/Blou ghwarri
Euphorbia ingens	Common tree euphorbia/Gewone naboom
Faurea saligna	Transvaal beech/Transvaalboekenhout
Grewia flavescens	Sandpaper raisin/Skuwerosyntjie
Gymnosporia buxifolia	Common spike-thorn/Gewone pendoring
Mundulea sericea	Cork bush/Kurkbos
Ochna pulchra	Peeling plane/Lekkerbreek
Protea caffra	Common sugarbush/Gewone suikerbos
Rhus lancea	Karree/Karee
Sclerocarya birrea	Marula/Maroela
Terminalia sericea	Silver cluster-leaf/Vaalboom
Vangueria infausta	Wild medlar/Wildemispel

Table 3.3. Climatic Data of the Pretoria Area (Land Type Survey Staff, 1987, Schulze, 1997).

	Quantity
Average Yearly Temperature (°C)	18.2
Minimum Temperature (°C)	-2.7
Maximum Temperature (°C)	34.8
Average Yearly Rainfall (mm)	619.0
Elevation (m)	1200-1600
Evaporation (mm/year)	2000-2250
Frost area?	Slight: average 91-days a year

Table 3.4. Aquifer Classification according to DWAF: Johannesburg (1999) & Messina (2002).

Aquifer Type	Borehole yield class (median l/h) (excluding dry boreholes)				
	0.0 - 360	360 - 1800	1800 - 7200	7200 - 18000	> 18000
Intergranular	A1	A2	A3	A4	A5
Fractured	B1	B2	B3	B4	B5
Karst	C2	C2	C3	C4	C5
Intergranular and fractured	D4	D2	D3	D4	D5

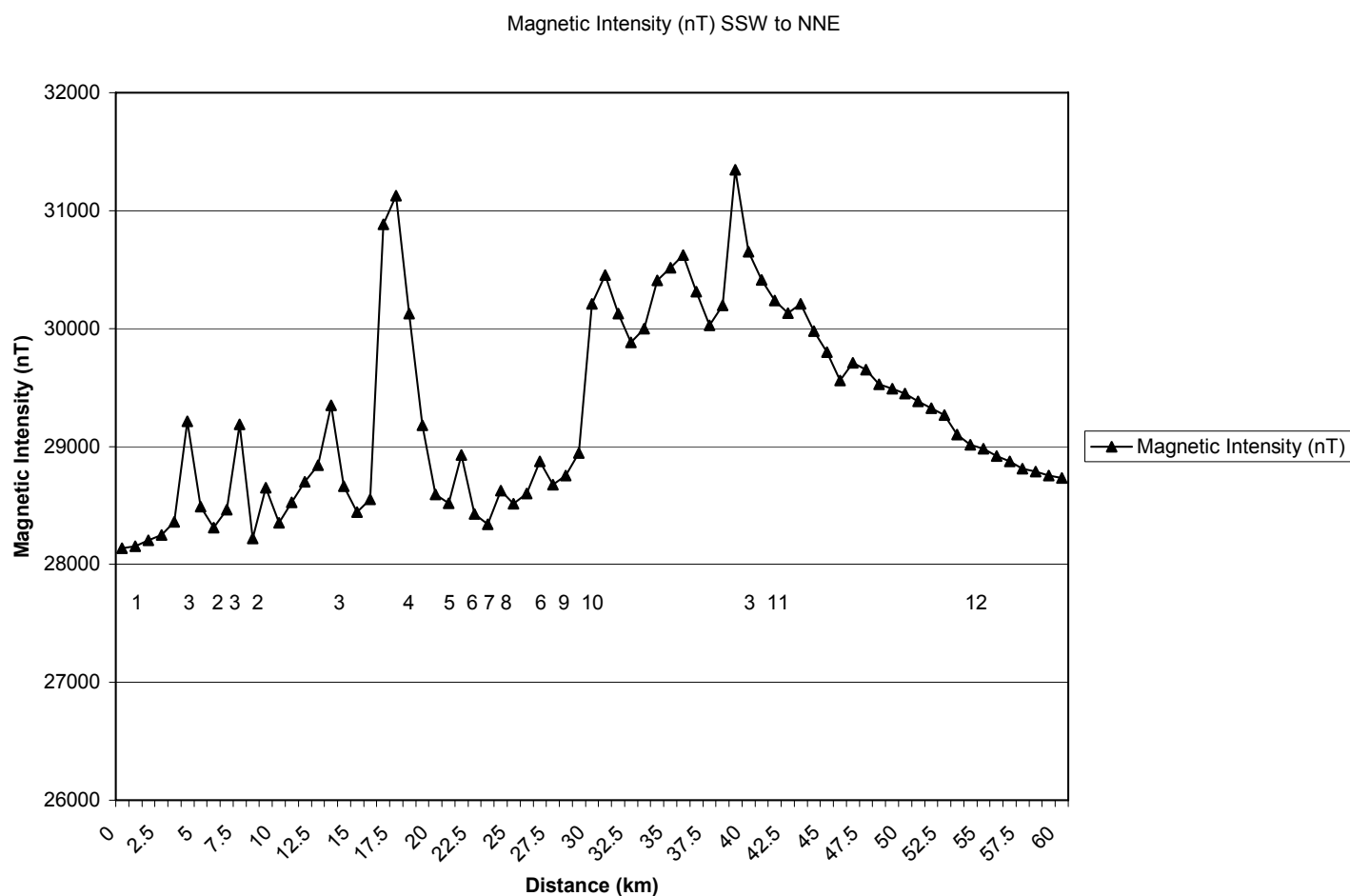


Figure 3.1. Generalised magnetic profile through the Pretoria area. The numbers indicated signify the following: 1 = Swazian granite, 2 = Malmani dolomite, 3 = Lineament, 4 = Timeball Hill quartzite, 5 = Timeball Hill shale, 6 = Hekpoort andesite, 7 = Daspoort quartzite, 8 = Silverton shale, 9 = Magaliesberg quartzite, 10 = Bushveld Complex norite, 11 = Bushveld Complex granite & 12 = Karoo sandstone and shale.

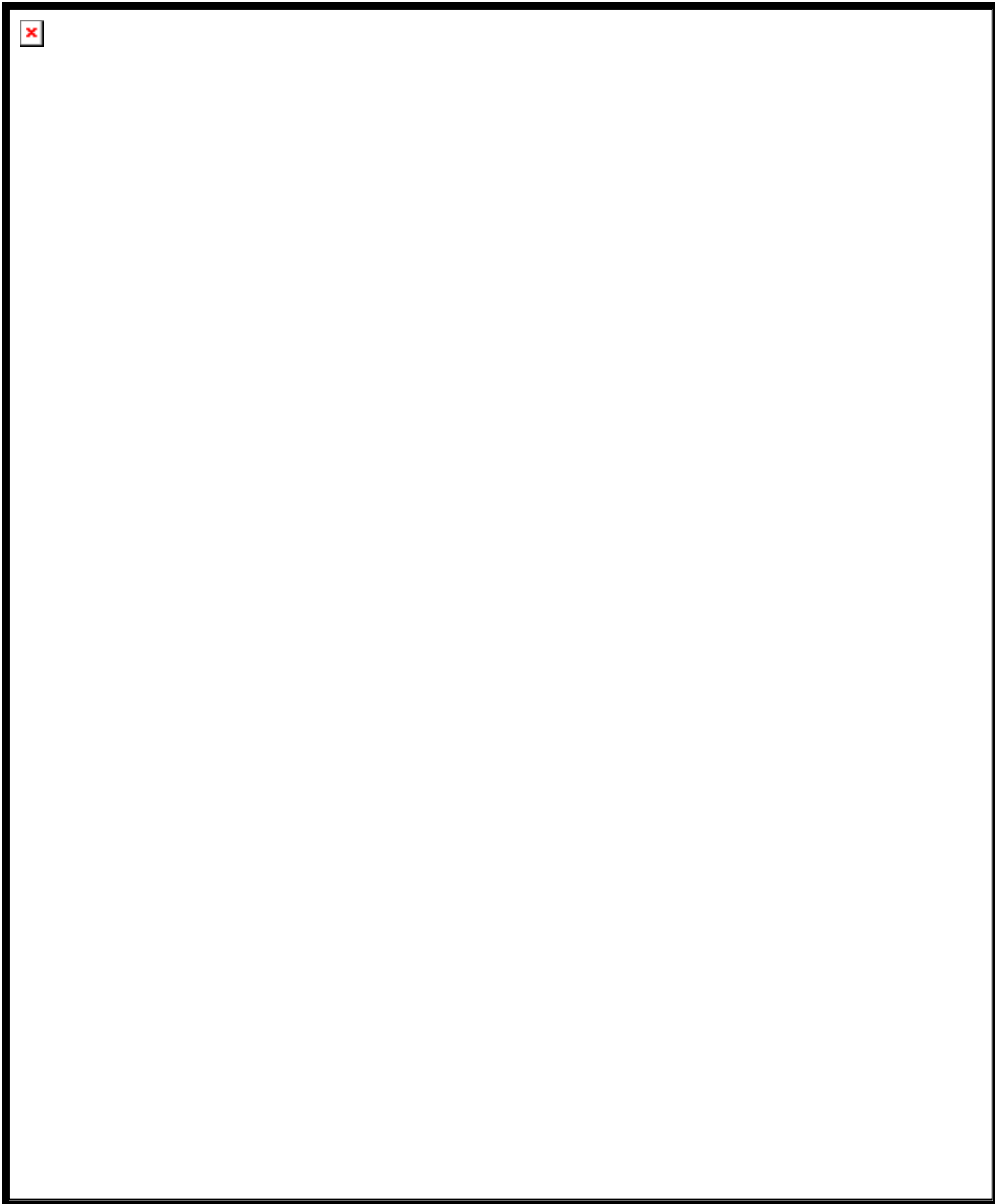


Figure 3.2. The geology of the Pretoria area and the sampling points as represented in Table 3.1 (Pretoria, 1978).

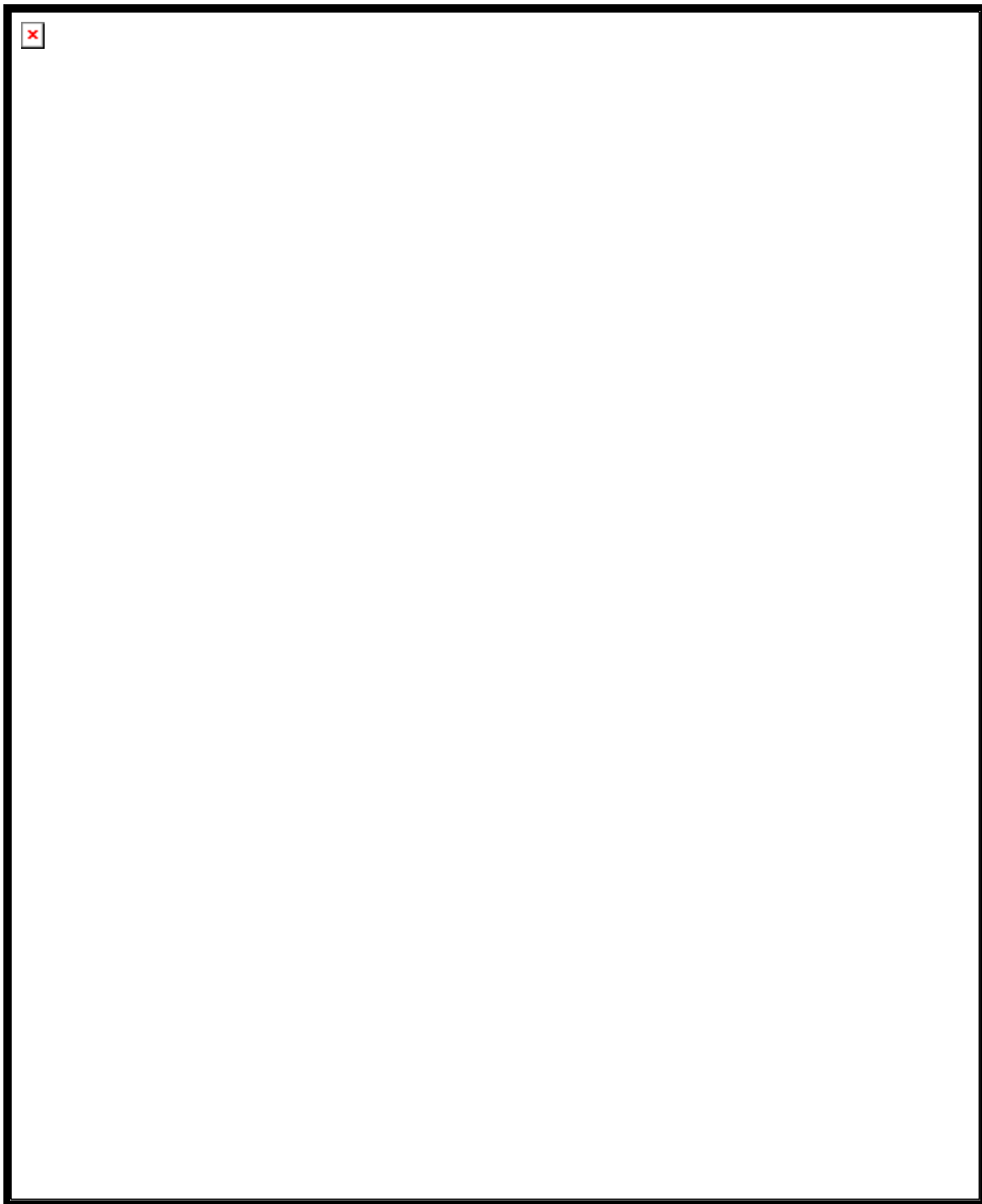


Figure 3.3. The land type series of the Pretoria area and the sampling points as represented in Table 3.1 (Pretoria, 1985).

Table 3.5. Explanation of abbreviations

Geological map (Figure 3.2)		Land Type map (Figure 3.3)	
Abbreviation	Lithology	Abbreviation	Soil series
Z	Granite-gneiss	Ab1a	Hutton
Vbr	Quartzite, conglomerate, shale	Ab2a	Hutton
Vmd	Dolomite, chert	Ae21b,c	Hutton
Vt	Shale, siltstone, quartzite	Ba7b	Hutton, Shortlands
Vha	Andesite	Ba8b	Rock, Mispah, Glenrosa, Clovelly, Hutton
Vdq	Quartzite	Ba10a	Hutton
Vsi	Shale, hornfels	Ba23a,c	Hutton
Vm	Quartzite	Bb1a	Glenrosa, Mispah, Wasbank
VI	Hybrid gabbro, gabbro, norite	Bb2a	Glenrosa, Mispah, Wasbank
Vg	Gabbro, norite	Ea2b	Shortlands
Vu	Ferrogabbro	Ea3a	Arcadia
Mr	Granophyre	Fa4b	Mispah, Glenrosa, Glencoe, Clovelly
Mn	Granite	Ib3a	Rock
di	Diabase	Ib4a	Rock
s	Syenite	Ib7a	Rock
Pe	Shale, sandstone, grit, conglomerate		

3.5 CASE STUDIES

The localities of all the fifty case studies presented in the current and subsequent chapters are depicted in Figure 3.4. The relevance of the case studies with respect to botany is discussed in Chapter 4.

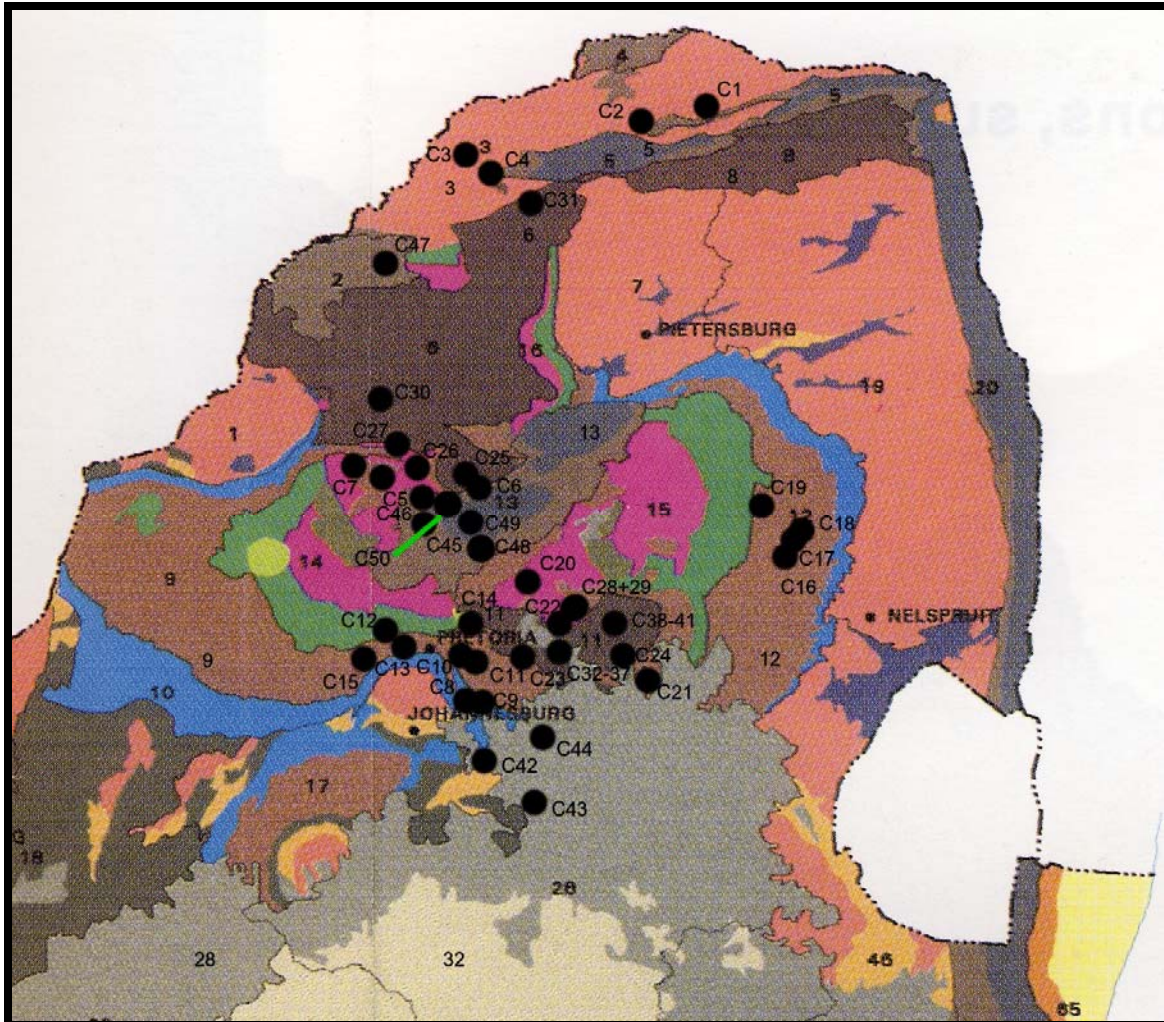


Figure 3.4. Geological map indicating the locality of the case studies (denoted by C and followed by the case study number).

Table 3.6. Abbreviations of geological units presented in Figure 3.4 (Vegter, 2001a).

Number on map	Groundwater region and principal water-bearing rocks
2	Waterberg Coal Basin. Karoo Supergroup tillite, sandstone, granulestone, shale, mudstone, coal, conglomerate, siltstone, remnants of basalt
3	Limpopo Granulite-Gneiss Belt. Swazian metaquartzite, leucogneiss, amphibolite, metapelite, marble, calc-silicate rocks; Swazian Alldays Gneiss, Randian Bulai Gneiss; alluvium
6	Waterberg Plateau. Waterberg Group sandstone, feldspathic sandstone, shale, conglomerate, mudstone, granulestone, siltstone, trachyte, trachyandesite, diabase
9	Western Bankeveld. Pretoria Group shale, quartzite and andesite intruded by Rustenburg Layered Suite mafic rocks and diabase.
10	Karst Belt. Chuniespoort dolomite and chert; subordinate Black Reef quartzite, conglomerate and shale
11	Middelburg Basin. Dwyka tillite outliers on Waterberg Group sandstone, conglomerate overlying Vaalian Loskop Formation of sandstone, shale, conglomerate and volcanic rocks
12	Eastern Bankeveld. Pretoria Group shale, quartzite and andesite intruded by diabase.
13	Springbok Flats. Letaba Formation basalt; subordinate Karoo shale, mudstone, sandstone, siltstone
14	Western Bushveld Complex. Rustenburg Layered Suite mafic rocks; Rasehoop Suite granophyre; Lebowa Suite granite
15	Eastern Bushveld Complex. Rustenburg Layered Suite mafic rocks; Rasehoop Suite granophyre; Lebowa Suite granite; Rooiberg rhyolite; Vaalfontein gneiss and migmatite
28	Eastern Highveld. Ecca Group shale, sandstone and coal; dolerite sheets and dykes; minor exposure of Dwyka Formation tillite, reworked tillite, conglomerate and sandstone.

CHAPTER 4 CASE STUDIES

In the current chapter, the present author discusses fifty case studies distributed across the north-eastern parts of South Africa. These studies indicate the geobotanical-geophysical relationships that exist on these localities with reference to geology, geohydrology, geochemistry, remote sensing and land type maps. Maps relating to geology and land type as well as aerial photographs of the locality are included in the annexure for each case study. The case studies will be presented according to the chronological sequence of the geology, starting from the oldest to the most recent rocks.

4.1 SWAZIAN EONOTHEM: LIMPOPO GRANULITE-GNEISS BELT

Information pertaining to the particular case study area regarding its geographic locality, climate, veld types, geology, geohydrology, geophysics, geobotany, soil sampling is tabled for all case studies (consult annexure).

1. *Beck 568MS*

The farm Beck (568MS denotes the farm number in the registration division according to a specific degree square) is situated to the east of the main road from Louis Trichardt to Messina. Several diabase intrusions in the granite-gneiss bedrock can be observed on the geological map and interpreted from aerial photography (see annexure). The magnetic method was employed in order to trace the diabase intrusions and the results presented in Figure 4.1. No other geophysical methods were employed owing to the dense vegetation growth of the area because these are hindrances to cable layouts crucial to the operation of the Schlumberger sounding method and electromagnetic EM3-34 profiling. The direction of the magnetic traverse was based on the strike of the observed lineaments on the aerial photograph (northeast-southwest and east-west), in order to cross these.

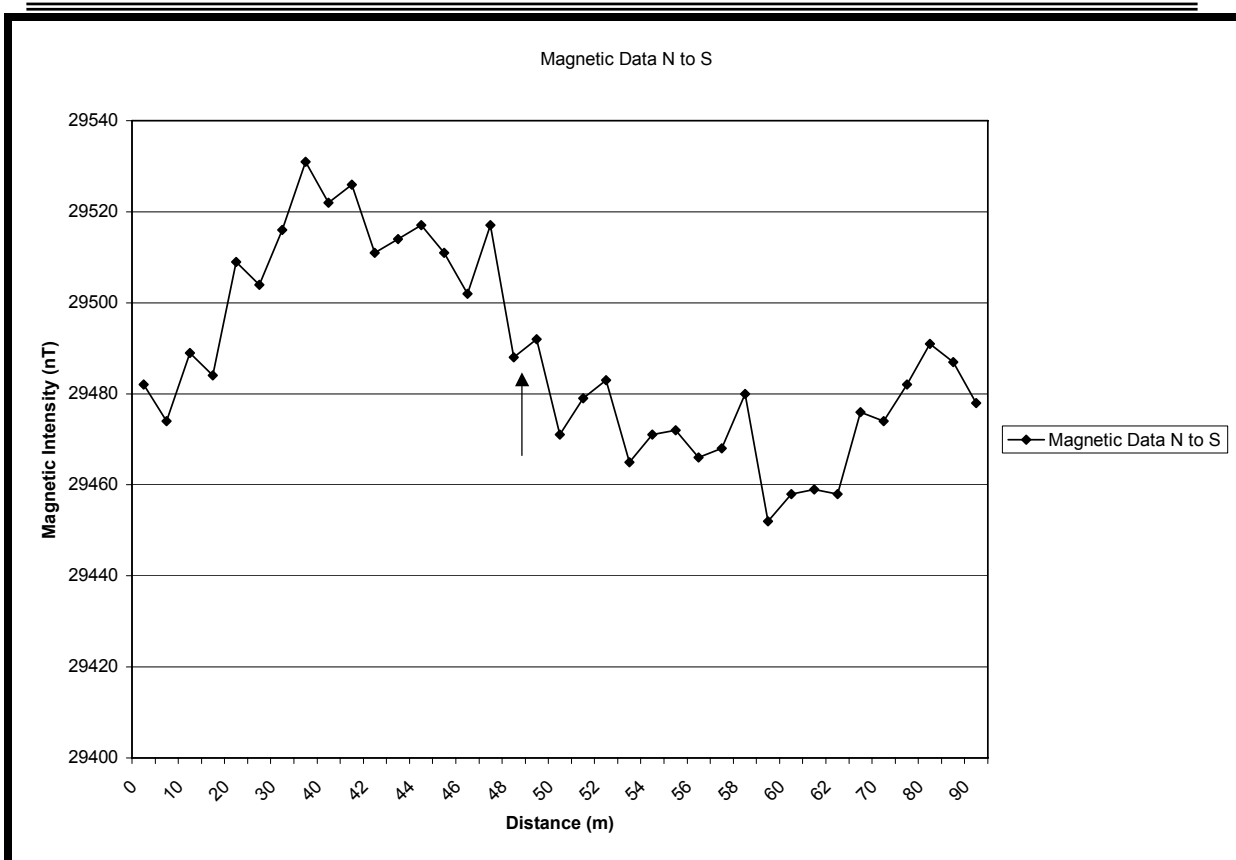


Figure 4.1. Observed magnetic intensity readings on the farm Beck 568MS.

A peg was placed at station 48 m. Although a small difference in magnetic intensity is observed (amplitude of 70 nT), a gigantic *Adansonia digitata* (Baobab) tree was observed alongside the decline in magnetic intensity. Soil samples were taken in the proximity of stations 48 m (Table A1.3a) and 39 m (Table A1.3b). The borehole was drilled to a depth of 78 m, a water strike at 58 m and the borehole log indicated 0-3 m sand; 3-56 m gneiss with fractures; 56-59 m fractured, water-bearing diabase; 59-78 m gneiss. The water yield at station 48 m was approximately 650 l/h. The small difference in magnetic intensity is attributed to a small, fractured dyke situated at greater depth. The occurrence of *Adansonia digitata* in this environment is limited to a small number of reasonably sized trees around the intrusion. Measurements with the magnetometer around these trees indicated significant variations in the measured magnetic intensity (50-100 nT).

The soil analysis indicated that the soil at the baobab tree is rich in P, Ca, Mg, K, Na, Fe, Mn, Zn and N. Furthermore its pH is reasonably high (6.64-8.27), with a low possibility of Al toxicity and high values of organic carbon and CEC, indicating humus enriched soil

with more active micro-organisms that contribute to micro-mineral recycling (Cloete, 2002) and the availability of a greater amount of micro-metals. The low resistivity value of the soil indicates the presence of clay or humus. The soil sample taken at station 39 m indicates a huge difference in soil qualities. A high resistivity ($>6000 \Omega$), low organic carbon and CEC-values and lower cation values indicate a different plant rooting environment. The land type map is not of any assistance in this area, since it only indicates Hutton soil cover. Variations in the soil series across the various lithologies are not evident and therefore field observations and soil sampling is crucial in order to verify differences in the local soil series. The baobab tree is most probably rooting on the weathered, clayey, nutritious contact zone between the fractured gneiss and the water-bearing diabase intrusion. Further away from the diabase intrusion no baobab trees were observed.

***Adansonia digitata* is the geobotanic indicator in this case study. This tree species occurs on fractured/weathered diabase contact zones as indicated by magnetic profiling. The diabase contact serves as a confined aquifer in the Limpopo Granulite-Gneiss Belt.**

2. Command 588MS

The geomorphology of the area is characterised by low ridges consisting of calc-silicate rock and marble belonging to the Gumbu Group (Vegter, 2001b). Intrusions of diabase cut through these ridges and can easily be identified on aerial photographs as well as in the veld. Therefore, this was selected as an exploration target. The magnetic traverse is evident in Figure 4.2, while Figure 4.3 presents a magnetic traverse along an existing dry borehole on the farm (near station 95 m).

The magnetic traverse (Figure 4.2) was run at an angle to the strike of the anticipated intrusive body, but perpendicular to the strike of the calc-silicate rocky ridge. Diabase intrusions will display a distinct contrast in magnetic intensity if compared to the host rock while this renders it an excellent groundwater exploration tool. The aerial photograph (annexure) indicates small linear bodies with a mainly north-west strike. An increase of about 3000 nT is observed. Numerous *Colophospermum mopane* (mopane) trees are observed but since they are abundant they cannot be used as geobotanical

indicators. Along the intrusion, several medium-sized *Adansonia digitata* (baobab) trees were observed, especially near station 95 m. Two pegs were placed, one at 60 m and the other one at 95 m. Although the peg at 60 m appears to be some distance removed from the magnetic anomaly as observed at station 95 m, and this is apparently the edge of the diabase intrusion, some conspicuous vegetation growth occurred in this area. A large number of *Commiphora mollis* (velvet corkwood) were observed here, the only place on the farm where they grew. It was decided to drill the peg at 95 m which yielded 500 l/h, and a water strike at a depth of 46 m. It is evident that the weathered diabase acts as the confined aquifer due to its higher porosity and permeability if compared to the host rock. The borehole log indicated:

0 – 2 m: sand

2 – 18 m: calc-silicate rocks with a distinct cleavage

18 – 43 m: fractured marble

43 – 47 m: weathered diabase (water strike at 46 m)

47 – 84 m: unweathered diabase

84 – 95 m: gneiss.

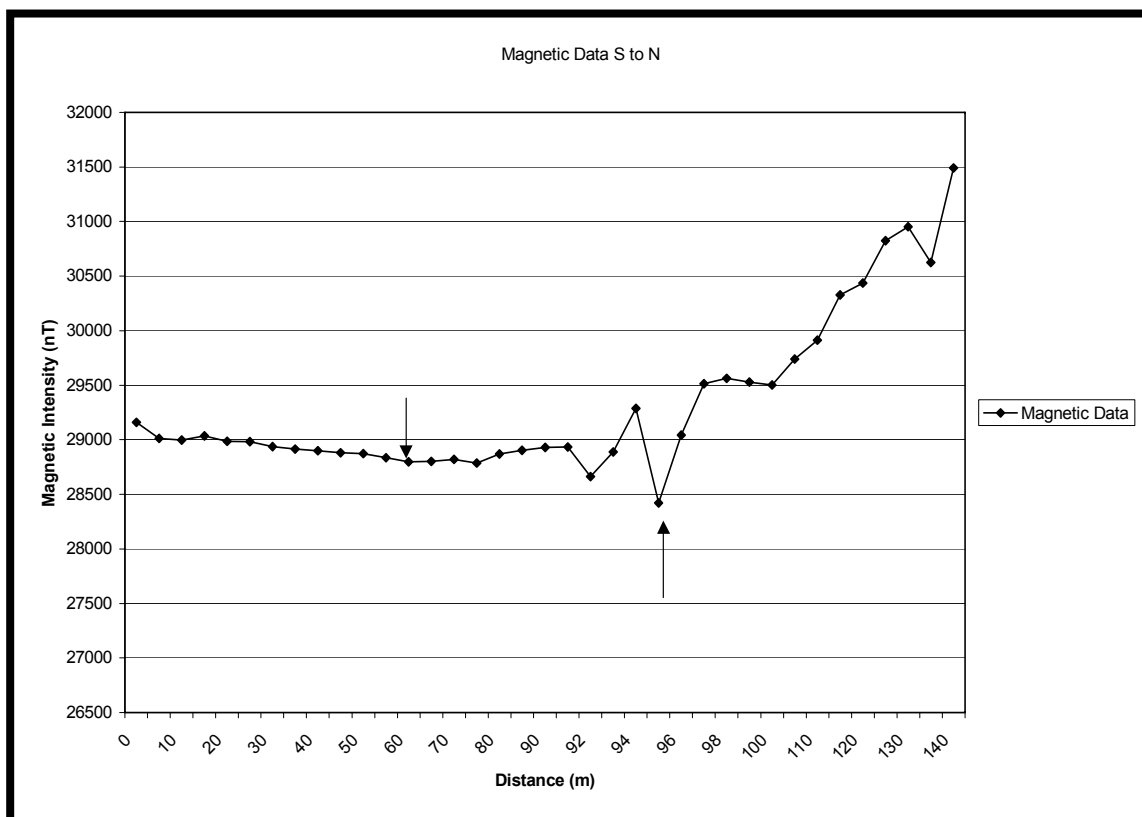


Figure 4.2. Observed magnetic intensity readings at the farm Command 588MS.

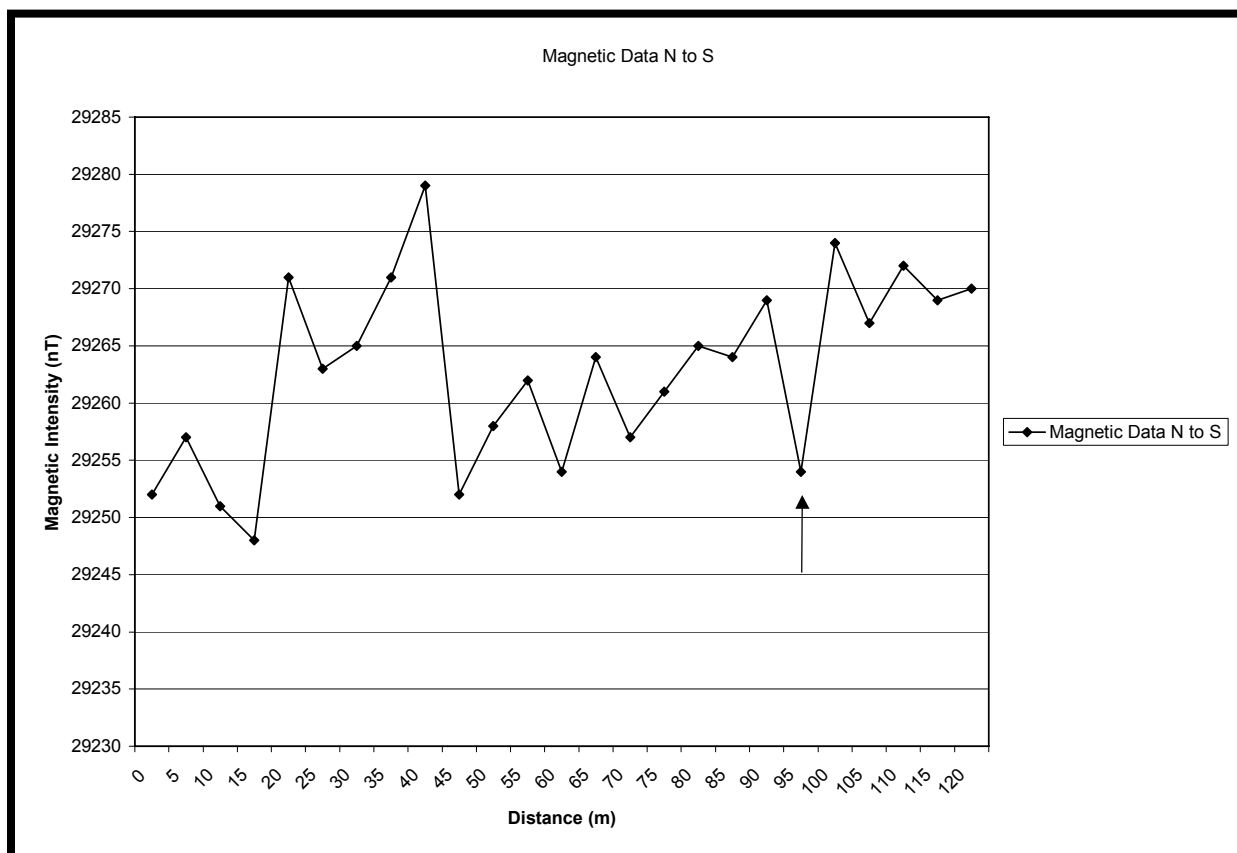


Figure 4.3. Observed magnetic intensity readings along the dry borehole at the farm Command 588MS.

Neither a magnetic intrusive body nor any geobotanical indicators were observed in the vicinity of the dry borehole (marked by the arrow, Figure 4.3). According to the farm owner, a layman with a stick sited the borehole.

Soil samples were taken in the region of station 95 m (Table A1.3a) and at station 80 m (Table A1.3b). The soil samples obtained for analysis at the baobab tree mentioned indicated the same trend in soil nutrients as observed at the farm Beck, previously stated: pH-value over 8, extremely higher Ca and Mg values (probably owing to the presence of weathered calc-silicate rocks), low resistivity of the soil and higher humus content, based on the %C and CEC-values. Values of Fe and Mn are high at a shallow depth at the intrusion, where these values decrease in depth, except for Zn (1.2 m). It is possible that the baobab and velvet corkwood trees are rooted in the weathered diabase zone and take up nutrients (cations) from this zone. When parts of the tree die, these dead parts cause the nutrients to be absorbed from the aquifer available and enrich the soil on the surface with these nutrients. The opposite is true for the soil sample obtained

away from the intrusion. The variation in the Fe and Mn values can be attributed to the fact that both samples were collected in the vicinity of the intrusion, but only at the opposite sides there of. No conspicuous tree growth was observed at the spot where the soil sample at station 80 m was taken. However, the weathered and fractured contact area of the intrusion, where the baobab and velvet corkwood are observed, can support root development and tree growth due to the higher nutritional value of the soil, higher humus content and fracturing/weathering of the rock. The land type map indicates the presence of Hutton soil in the sandy areas, while the rocky ridge is properly indicated by denoting rock.

***Adansonia digitata* is the geobotanic indicator in this case study since it occurs on fractured/weathered diabase contact zones.**

3. Wolwedans 68MR

Numerous diabase intrusions occur amongst the gneiss in this area. The veld type is quite different from the Mopane Veld as observed in the first two cases mentioned above. Since this farm was visited after the Zoetfontein case (next case study), the experience and results gathered from that farm were applied to this case. A geobotanical investigation was carried out in conjunction with the geological maps of the area so as to focus on the diabase intrusions. A spot was found that was conspicuously aligned with the following tree species (station 337 m): *Combretum imberbe* (leadwood), *Pappea capensis* (jacket-plum) and a few young *Adansonia digitata* (baobab) trees. The Genie SE-88 traverse across this alignment yielded the data as presented in Figure 4.4. The traverse was laid out north-south because diabase dykes exhibit an east-west strike in this area (see the geological map, annexure). The Genie was utilised due to the presence of magnetite quartzite that produces erroneous readings with the magnetometer. The Genie is a suitable groundwater exploration method in such a geological setting (Vegter, 2001b).

Two pegs were placed, one at station 337 m and the remaining peg at 445 m. Both pegs were drilled, but the one at 337 m was more economically feasible to equip in order to supply water to game at a yield of about 770 l/h. Position 337 m is interpreted as being

the edge of the diabase intrusion by the gneiss and as one moves further away into the weathered diabase, a deeper weathering profile is observed (station 445 m).

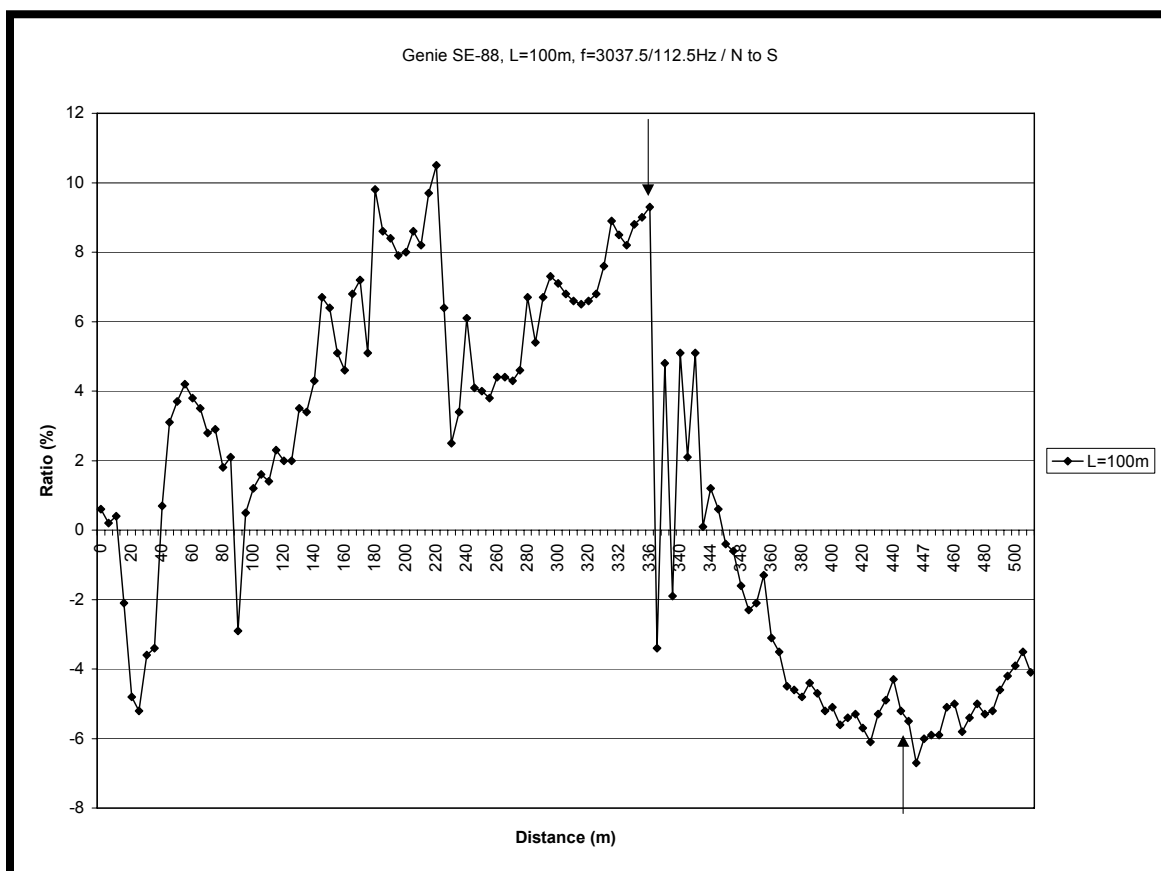
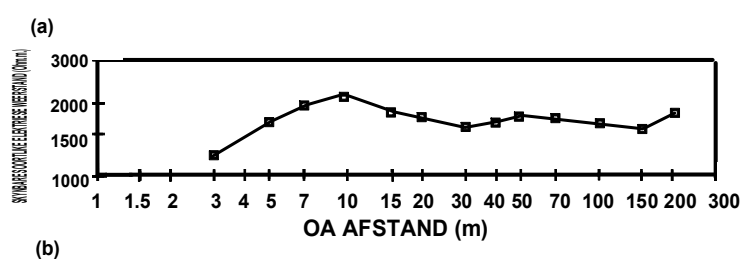


Figure 4.4. Genie SE-88 profile at Wolwedans 68 MR. Coil separation of 100m and operated at a frequency of 3037.5/112.5 Hz.

At this point a Schlumberger depth sounding was performed (see Figure 4.5). The electrodes were spaced in a north-south direction since this is the average strike direction of the quartzite. The interpretation of the depth sounding indicates that the aquifer is at a depth of about 30-68 m (layer 5) which corresponds with the drilling results. Water was struck at a depth of 52 m. The overburden, according to the drilling results, was mainly clay (0 – 2 m), calcrete (2 – 7 m), quartzite boulders (7 – 15 m), quartzite (15 – 46 m), the weathered diabase (46 – 54 m) that is the confined aquifer, the unweathered diabase (54 – 67 m), and gneiss from 67 m till 85 m. Soil samples were taken in the vicinity of station 337 m (Table A1.3a) and at stations 320 m and 315 m, due to unweathered rock encountered at several sites.



Depth sounding model:

Layer	1	2	3	4	5	6
ρ (resistivity)	1131	3712	1275	1989	1634	2890
h (thickness)	2.3	4.4	8.8	14.1	38.7	

Figure 4.5. Schlumberger depth sounding at station 445 m.

The soil samples taken at the spot where the trees *Combretum imberbe* (leadwood), *Pappea capensis* (jacket-plum) and a few young *Adansonia digitata* (baobab) occur indicate alkaline soil conditions (pH ~ 9), low soil resistivity and overall higher nutritious levels in the soil than the other two samples. The CEC-values are quite high. The soil samples obtained at station 320 m (depth 0.5 m) indicate anomalous P, K, Fe, Zn, N and organic carbon values compared to the other samples gathered on this farm. The application of agricultural fertiliser in this part of the farm is unlikely and these values indicate different chemical properties to that of the *in situ* weathered rock. Although the organic carbon value is high in this spot, the CEC-value and sulphur value are small compared to the soil samples taken at the spot where the conspicuous vegetation

growth was observed. No specific vegetation growth at station 320 m was observed, although it was densely covered by grasses (*Eragrostis* species). According to the land type map, notable differences in the soil series occur in the vicinity of the borehole location. The geobotanic community is representative of the Glenrosa soil series that constitutes higher values of clay, cations, conductivity, organic carbon and CEC, compared to the Hutton soil series that is representative of the non-geobotanic community. The Glenrosa soil series is a weathered product of the marble, calc-silicate rocks and mafic granulite, whereas the Hutton soil series occurs where weathered metaquartzite, minor magnetite quartzite and massive magnetite occur (higher sand content).

***Adansonia digitata*, *Combretum imberbe* and *Pappea capensis* are the geobotanic indicators in this case study since these occur on fractured/weathered diabase contact zones in association with quartzite.**

4. Zoetfontein 154MR

The presence of magnetite quartzite on the farm Zoetfontein makes the application of the magnetic technique quite useless. Therefore, it was decided to utilise the Genie SE-88 in this environment (Figure 4.6) (see also case study number 3 for reasons). The signatures of the Genie SE-88 instrument denote a drop in the frequency ratio over preferred drilling spots, or the presence of more conductive (than the surrounding rock) intrusive bodies. Geophysical groundwater exploration targets were identified on an aerial photograph of the farm. These targets display an east-west strike and therefore the traverses were laid out north-south. One particular target, as presented in the current case study, was characterised by some interesting tree species in the vicinity of magnetite quartzite outcrops. These include *Combretum imberbe*, *Pappea capensis*, *Ximenea americana* (blue sourplum), *Protasparagus* species (wild asparagus) and *Adansonia digitata* trees. This appeared to be quite promising since the traverse along the existing borehole (yield 500 l/h) also indicated evidence of the species *Ximenea americana* (Figure 4.7). This traverse was laid out for calibration purposes (see aerial photograph in annexure). The *Ximenea* specie was found to be a geobotanical indicator on rhyolite in the Bronkhorstspuit-Verena area by Meulenbeld (1998).

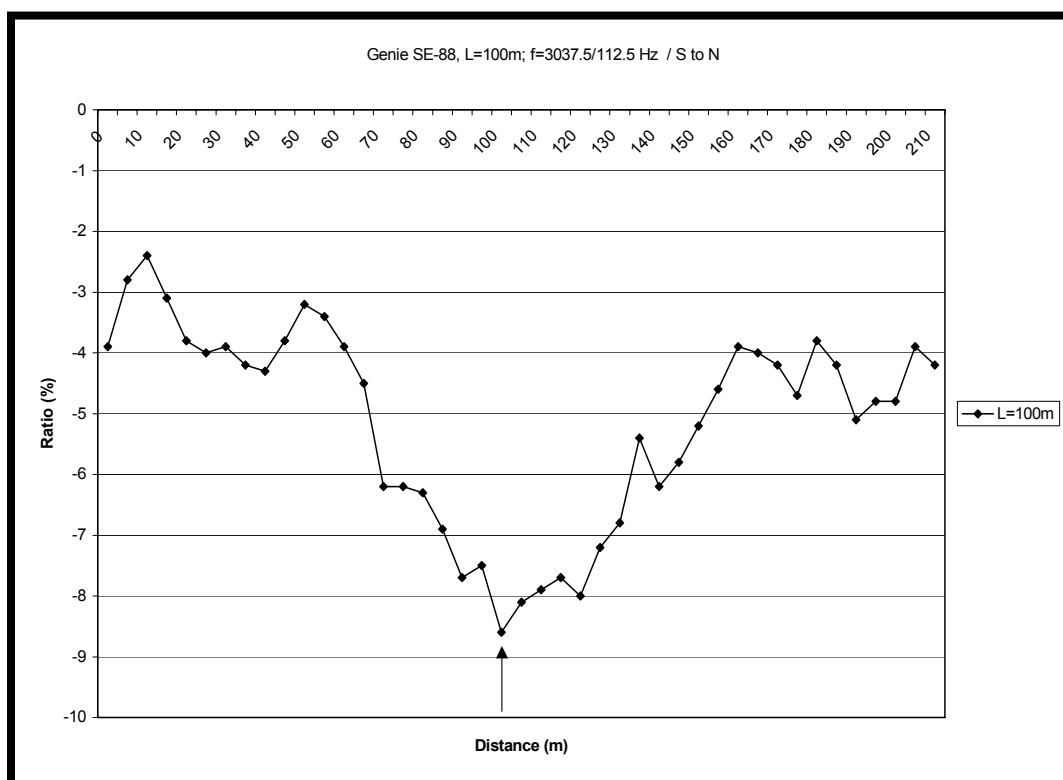


Figure 4.6. Genie SE-88 traverse on the farm Zoetfontein 154MR.

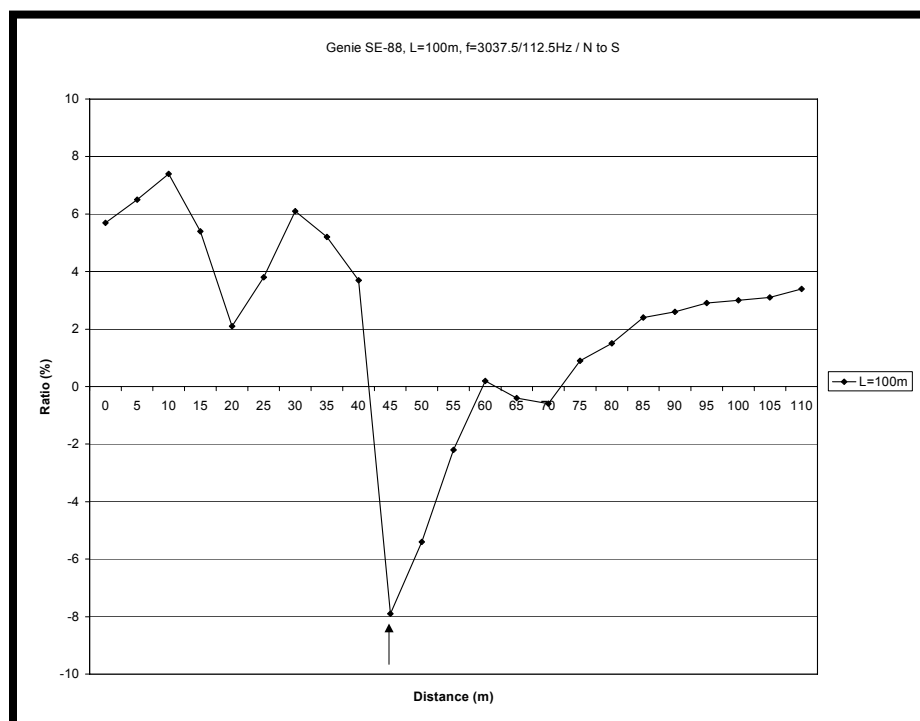


Figure 4.7. Calibration traverse on Zoetfontein 154MR. Existing borehole position denoted by the arrow.

The arrow in Figure 4.6 indicates the drilling spot. The borehole was drilled to a depth of 85 m and the water strike was found at 37 m. The drilling depth was based on the published work by Vegter (2001b). The borehole log indicates fairly constant quartzite, except for some water-bearing fracturing between 35-39 m in depth. When this hole was drilled, eventually no water was present. The hole filled with water only after a few days. Due to the clayey nature of the rocks and low yielding aquifers (<3600 l/h, this borehole yielded 650 l/h), the drilling process seals the sides of the borehole and only afterwards, as a result of the water pressure, are the holes opened again. The problematic nature of the clays and weathered rocks in this area is described by Vegter (2001b). This phenomenon forces the rocks rather to act as aquicludes. Aquifers are only encountered at greater depth owing to the fracturing of metamorphic rocks and the weathering of mafic rocks.

Soil samples were taken around the point marked (Table A1.3a) and the station 65 m (Table A1.3b). The soil characteristics at the drilling spot indicate an extremely nutritious soil that can support vegetation with ease as deduced from all the analysed elements in particular, P, Ca, Zn, %C, N, CEC and S, that are more abundant compared to those of the other sampled site near station 65 m. The soil of the geobotanic community is indicative of a Glenrosa soil series, whereas the non-geobotanic community represents a Hutton soil series. The Glenrosa soil series is generally more nutritious compared to the Hutton soil series and is derived from clay-based rocks (fractured rocks, mafic rocks and gneiss).

***Adansonia digitata*, *Combretum imberbe*, *Pappea capensis* and *Ximenea americana* are the geobotanic indicators in this case study since they occur on fractured zones in quartzite.**

4.1.1 Remarks

The case study area exhibits a poor historical success rate with <40% of boreholes yielding water of more than 360 l/h. Borehole yields fall mainly in the category between 36 and 3600 l/h, with the median yield of successful boreholes being only 1400 l/h. Only 13% of boreholes yield more than 7200 l/h. Dry boreholes, as well as high yielding ones have been drilled in all lithologies and are not restricted to any specific rock type (Sami

et al., 2002a). The borehole data presented in this case study does not yield any other quantity of groundwater since the groundwater is still governed by the same geology and conditions. No fault zones have been explored. However, it has to be borne in mind that all four boreholes were successful. Dry boreholes were present on the farms visited: some of these are discussed in the current undertaking. This is a reminder of the difficulty of locating groundwater and of the fact that one cannot just drill anywhere. It is of crucial importance to understand the geology of the area and geohydrological properties before one employs a certain geophysical method. The use of the Genie SE-88 apparatus in this environment is highly advisable and combined with Schlumberger soundings, magnetics (if allowed) and electromagnetics (EM34-3) will yield adequate results. These geophysical methods combined with geobotanical indicators can improve the success rate of siting a successful borehole, but further research with regards to this subject is recommended in this geological region. The geobotanical indicators listed can be used as useful exploration tools. The occurrence of baobab (*Adansonia digitata*) trees in a savanna (Bushveld) area can be associated with sub-surface water saturation as in the Tarangire National Park south-east of Lake Manyara in Tanzania where these trees display an unusually abundant distribution in the wetlands and the Tarangire drainage system (Bothma & Walker, 1999). The soil characteristics at a geobotanical site (see Table 4.1) are quite different from those of the surrounding soils. It is difficult to state whether different soil characteristics exist owing to the weathered intrusive rocks or the plant roots that draw deeper situated minerals to the surface for plant utilisation so that when the roots die off these minerals become part of the humus and hence an increase in the organic carbon and/or CEC values is experienced. The weathered intrusive rocks seem to initiate the plant growth because, in the event that no minerals are available, no root or plant development will be possible, especially in the case where these minerals are vital for the development of a certain plant species.

The soil results indicated in Table 4.1 indicate a distinctive shift in soil characteristics at the site where geobotanical indicators, as listed, grow and a successful borehole is situated. Moving slightly away from this position, the sampled soils indicate extremely different soil characteristics at that other sampled point. The lesson is often learned in geophysics that a few metres can make a major difference in successful borehole siting, owing to the incline and structural orientation of the aquifer or geological body. The same applies to this case. From a geophysical point of view, a decline in soil resistivity

most often points towards the presence of groundwater. However, in this case, it is only representative of the upper 1.2 metres of the earth and no conclusions can be drawn from this regarding the presence of groundwater at an extended depth at that point. The remarkable lower resistance compared to the surrounding soils indicates clayey soil or saturated conditions in a certain area in the veld that may be the result of a deeper lying aquifer and the soil/water combination are supportive of vegetation growth. Only geophysics can provide results if a deeper situated aquifer with a drop in resistivity compared to the country rock is present.

Table 4.1. Comparisons between the soil characteristics of geobotanical indicators and their surroundings.

Parameter	Geobotanical community (A)	Surroundings (B)
pH	4.7-9.0	5.0-7.2
P (mg/kg)	3.9-104.6	2.4-12.8
Ca (mg/kg)	1180-5589	187-653
Mg (mg/kg)	239-2273	62-290
K (mg/kg)	110-225	38-258
Na (mg/kg)	43-644	10-32
Fe (mg/kg)	24.2-472.2	46.7-215.5
Mn (mg/kg)	37.45-497.2	40.8-306.0
Zn (mg/kg)	0.51-11.8	0.38-4.10
Al (cmol _c /kg)	0.000-0.971	0.045-0.379
Resistance (Ω)	560-1900	2000-6400
%C	0.6-7.3	0.1-2.7
Total N%	0.037-0.501	0.012-0.196
S (mg/kg)	11.78-102.44	8.19-79.78
CEC (cmol _c /kg)	11.556-29.786	2.608-9.107
Geobotanical indicator species under column A	<i>Adansonia digitata</i> (baobab) <i>Combretum imberbe</i> (leadwood) <i>Commiphora mollis</i> (velvet corkwood) <i>Pappea capensis</i> (jacket-plum) <i>Ximenea americana</i> (blue sourplum) warrants more study	
Geology	Diabase and other basic rocks intrusions, Magnetite quartzite	Granite-gneiss
Aquifer yield (ℓ/h)	500-770	Not applicable

Other phenomena expressed in Table 4.1 include a distinctive difference in the range of the values of Ca and Na. This may be due to the fact that in this area basic, ultrabasic and calcsilicate rocks are rich in Ca and Na (a mineral like plagioclase) and as a result of weathering are found in abundance in the soil profile. The pH of the soil varies, as in the case of Zoetfontein, and the magnetic quartzite indicated a lower pH, hence a higher Al-value, but a considerably higher humus, Zn, P, S and total N% content. It is essential to analyse the humus content (%C and CEC) in order to establish geobotanical areas/points of interest because the soil pH can be misleading in certain cases. The one anomalous soil sample obtained at Wolwedans (station 320 m) will be excluded since it indicated enrichment in certain cations and heavy metals. If this is the case, then the rest of the soil samples collected away from the geobotanical indicators all indicate a general marked decrease in P, Mg, K, %C and heavy metal values compared to the soil samples taken at geobotanical indicator spots.

Vegter (2001b) states that metaquartzite can be singled out as a more favourable groundwater target. Although no metaquartzite was studied, magnetic quartzite exhibits more or less the same geological properties (ignoring the magnetite content). The results presented in this case study favours magnetic quartzite as a rich geobotanical/geohydrological indicator. Since bands of this quartzite occur in certain parts of the Limpopo Granulite-Gneiss Belt, these can be utilised for groundwater exploration if the geobotanical indicators mentioned are present.

At the time of the current study it is too soon to establish conclusive results concerning soil characteristics at geobotanical indicator sites for possible geophysical groundwater exploration. However, the case studies below will further investigate these phenomena by means of a journey through geological time, thus investigating different rock types, weathering profiles and soil chemical properties.

4.2 VAALIUM EONOTHEM: ROOIBERG-WARMBATHS AREA: QUARTZITE OF THE LEEUWPOORT FORMATION AND DOLOMITE OF THE MALMANI SUBGROUP

Information pertaining to the case study area regarding its geographic locality, climate, veld types, geology, geohydrology, geophysics, geobotany, soil sampling is tabled (see annexure).

5. Blokdrift 512KQ

Northeast of the old tin-mining town of Rooiberg, between Warmbaths and Thabazimbi, the farm Blokdrift 512KQ is situated on a plain of quartzite and shale (Leeuwpoort Formation), intersected by several intrusive bodies and small faults. The northern section of the farm is located on the rhyolite mountains of the Rooiberg Group (the Elandsberg). The strike of the intrusive diabase and rhyolite bodies lies northwest-southeast and that of the fault structures in the opposite (northeast-southwest) direction. These features act as groundwater zones with their increased porosity and permeability due to fracturing and weathering. The occurrence of diabase intrusions (dykes) is far more abundant than those consisting of rhyolite. However, the geological map (Thabazimbi, 1974) indicates the presence of such a rhyolite dyke on the specific farm. Experience has proven that rhyolite is not a suitable aquifer owing to its resistance to weathering, hence the occurrence of rhyolite mountains on the farm and elsewhere. Guided by aerial photographs and geological maps supplied by the Rooiberg Tin Mine's Geological Section, the locality of intrusive diabase bodies and some faults could more or less be easily referenced in the field. The aerial photograph (annexure) indicated an abnormally dense, and in comparison with the surrounding trees in the area, higher linear tree growth. According to the orientation of this linear geobotanic feature and information drawn from the geological maps, it was interpreted that the linear structure with the conspicuous tree growth was a diabase dyke in quartzite and shale.

The magnetic and electromagnetic anomalies obtained are indicated in Figure 4.8 and the directions of the traverses were planned to cross intrusive bodies. Soil samples were taken at stations 110 m (drilling position) and 155 m, owing to the width of the structure. Geobotanic indicators at station 110 m included species such as *Zanthoxylum capense* (small knobwood), *Ficus sur* (broom cluster fig) and *Acacia karroo* (sweet thorn).

Although *Acacia karroo* is abundant on this farm and the surrounding areas, the height of the *Acacia karroo* species growing on the weathered contact zones of the diabase intrusion is exceptionally different from those surrounding them or even further away and can even be observed on the aerial photograph. Therefore, this difference must be noted since it alters the frequency of appearance in height of this species. Based on the distinction with regards to height and its linear growth pattern, it can be classified as a geobotanic indicator. Tamboti (*Spirostachys africana*) is considered to be a geobotanic indicator for groundwater in this area, according to various farmers in the Rooiberg area. Unfortunately, no case studies relating to Tamboti trees were encountered in the Rooiberg area. It is believed by these farmers that Tamboti trees grow on clay soil that is the product of weathered intrusive diabase (so-called 'blouklip'). The importance of Tamboti trees (normally they grow in a linear cluster) as a geobotanic indicator for groundwater requires further investigation in other geologic formations.

The indicated borehole drilling position at station 110 m yielded 60 000 l/h, where the borehole log indicated clay (0-2 m), weathered diabase (2-27 m), diabase boulders (27-34 m), less weathered diabase (34-38 m) and unweathered diabase (38-75 m) with a water bearing fracture at 70 m. The depth of water strike can be contributed to the dewatering of shallower aquifers resulting from the surrounding tin mines. Another existing borehole is situated at station 70 m with a yield of 5 000 l/h. Luxurious vegetation growth only occurred around station 110 m, where some large *Acacia karroo* trees were growing around station 70 m. This stresses the importance of employing geophysical groundwater siting to determine the optimum drilling position in the aquifer. The western signature of the anomaly is not well defined, owing to the infrastructure and dense bush that restrict access. The amplitude of the magnetic intensity is minimal (about 40 nT), but the decline in electrical conductivity is significant as one moves from the conductive weathered diabase (clay) towards the resistant quartzite and shale overburden (silt and sand). Significant weathering (aquifer conditions) of the intrusive contact can be identified between stations 90 and 120 m. Towards the east, homogenous stratified earth can be interpreted since the electrical components (HD and VD) are more or less parallel to the remaining profile.

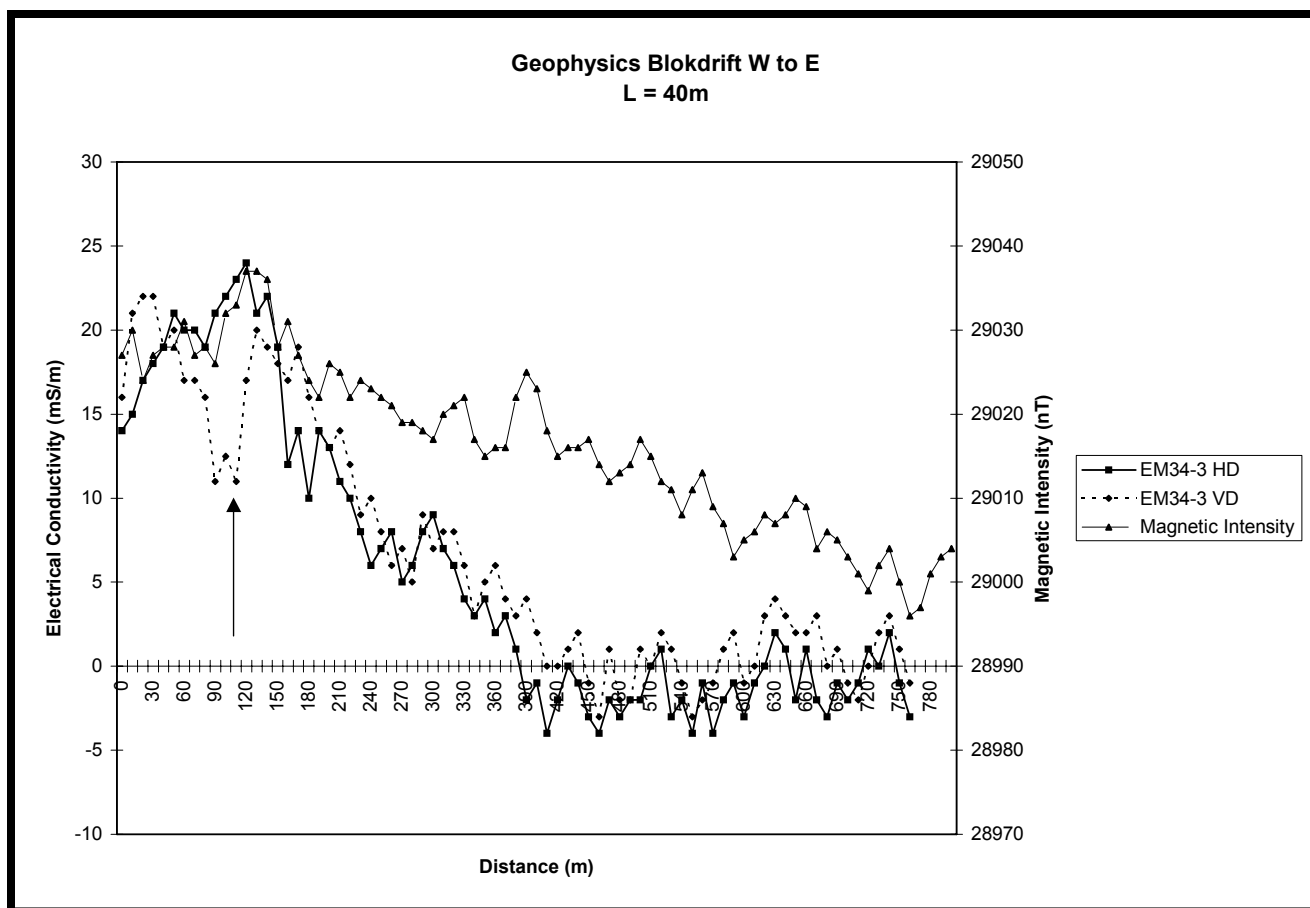


Figure 4.8. Geophysical profiles of the farm Blokdraft 512KQ.

The soil samples indicate acid pH conditions for both samples, probably owing to the extent of weathering of the diabase intrusion and typical of the Clovelly soil series (land type Fa4k, see annexure). The most significant parameters of the samples are higher Na, Mn, conductivity, S, %C and CEC-values for the geobotanic community at station 110 m compared to those at station 155 m. Of importance is the difference in %C and CEC-values for this case with corresponding conductivity/resistivity values as obtained in the field with the EM34-3 between both stations.

***Zanthoxylum capense*, *Ficus sur* and *Acacia karroo* are the geobotanic indicators in this case study. The growth of these tree species is noticeable only on the linear structure as observed in the aerial photograph which yielded a substantial quantity of groundwater when drilled. The *Acacia karroo* species on the linear structure are considerably higher than the surrounding trees of the same species.**

6. Droogekloof 471KR

Just north of Warmbaths a small mountain range occurs that stretches from west (Mabula) to east (Warmbaths). The mountains are part of structural changes that occurred due to the formation of the Waterberg Group (Schutte, 1974). The farm Droogekloof 471KR hosts the Zwartkloof anticline, Boschpoort fault, Droogekloof thrust and a concealed fault that separates rocks belonging to the Karoo Sequence from rocks of pre-Karoo age. This case study is situated on the Droogekloof thrust and the concealed fault zone. The farm is located on the road from Warmbaths towards Thabazimbi and borders the mountain range on its northern side. The thrust is responsible for a small localised outcrop of the Pretoria Group, namely dolomite of the Malmani Subgroup and quartzite of the Black Reef Formation. The total width of the Pretoria Group is approximately 800 m, where some lineaments are intrusive. The rest of the farm is covered with sandstone of the Clarens Formation (Karoo Supergroup), granite belonging to the Nebo Granite (Lebowa Granite Suite) and rhyolite of the Schrikkloof Formation, Rooiberg Group. It was decided to concentrate on the dolomite for groundwater exploration, owing to its locality for irrigation purposes and suitability in acting as an aquifer in contrast with granite and rhyolite.

The geophysical profile across the dolomite is indicated in Figure 4.9. The reason for utilising the magnetic method is based on the occurrence of intrusive rocks (lineaments) in the dolomite and the presence of geobotanical indicators along suspicious linear depressions. The traverse was conducted from the west to the east since the aerial photograph (annexure) indicates that some linear structures on this farm exhibit a north-south strike.

Previously, persons utilizing the Schlumberger sounding technique sited a dry/unsuccessful borehole at station 6 m. This spot was also investigated (Figure 4.10) and sampled for soil analyses. The electrodes were spaced in an east-west direction since the dolomite does not have a strike or gradient as indicated on the geological map and this was the clearest way for the electrodes to be laid out owing to the dense bush. The H-curve and interpretation obtained render it unclear as to why this spot was selected for drilling. Most probably, the reason was the decline in resistivities near OA

distance 7-10 m, but unfortunately, at this spacing, only a representation of the upper 10 m of earth can be obtained. Drilling chips indicate that the borehole was drilled in solid dolomite for 90 m.

The borehole yielding 100 000 l/h is situated at station 29 m (see the arrow). The magnetic profile indicates an amplitude of approximately 170 nT. At station 29 m is a narrow, linear depression (weathered zone of an intrusion) with some vegetation species that one is unlikely to encounter at other places on the farm. A rare species that occurs is *Zanthoxylum capense* (small knobwood) in association with *Euclea crispa* (blue guarri), although the guarri occurs more frequently in other locations that were not investigated. However, the *Euclea crispa* species will be discussed as a geobotanic indicator in some other case studies where its frequency of distribution is more restricted and conspicuous. Drilling of the peg at station 29 m indicated some clay (0-3m), characteristic of the Avalon soil series, weathered dolomite (3-9m), dolomite (9-36m), weathered diabase boulders (36-38m), dolomite (38-50m), a dolomite cavity of about 7 m thick at a depth 50 m and solid dolomite from 57 till 60 m. Water strike occurred in the cavity at 50 m.

Soil sampling at station 6 m (dry borehole) and 29 m (successful borehole) indicated higher Ca, S, %C and %N values and a drop in resistivity with an increase in depth for the geobotanic (*Zanthoxylum capense*) locality, although no difference in CEC can be observed. This might be attributable to the fact that most of the surface at both stations is covered with a brownish black loam covered with vegetation, and is rich both in humus and clay. Vegetation occurring at the dry borehole includes species such as *Faurea saligna* (Transvaal beech) and *Acacia caffra* (common hook-thorn), but these are quite common in the Sour Bushveld veld type.

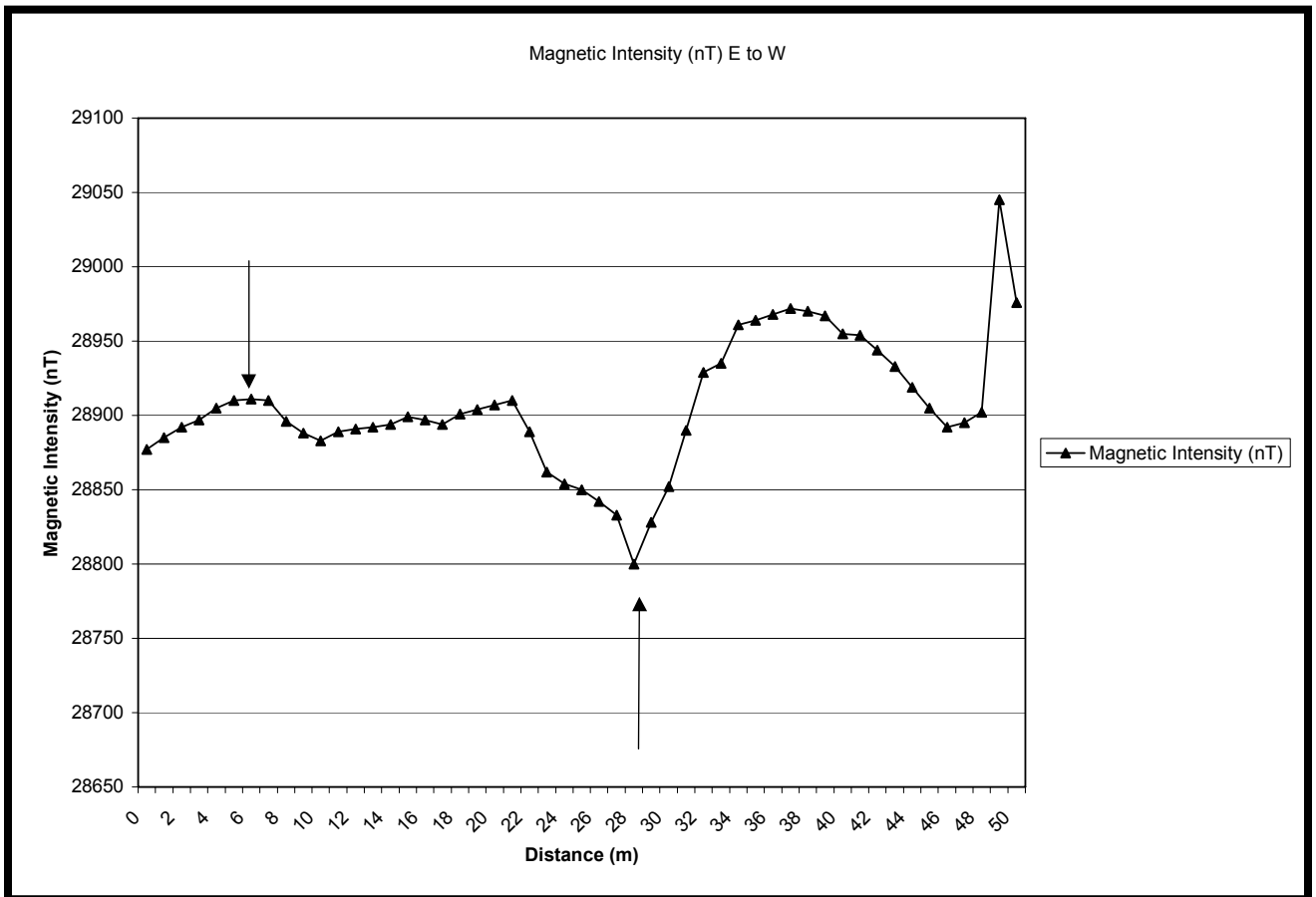
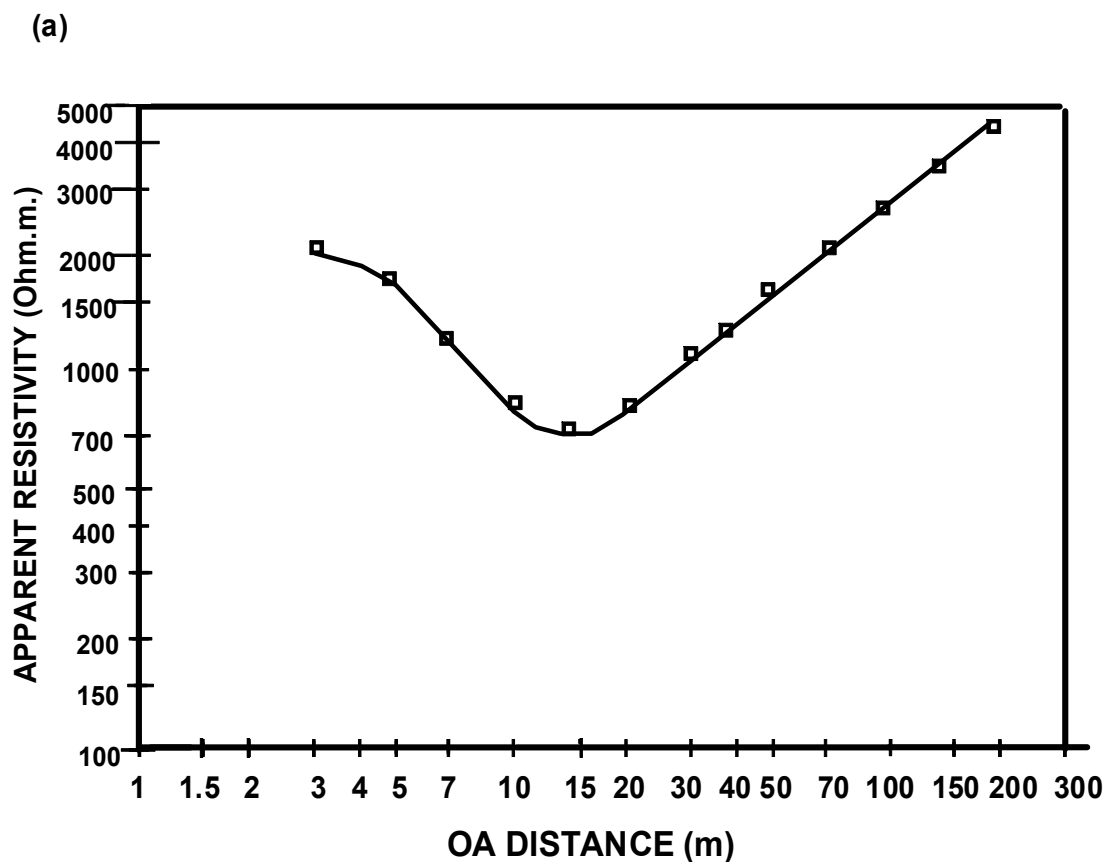


Figure 4.9. Magnetic profile on the farm Droogekloof 471KR.



(b)

Depth sounding model:

Layer	1	2	3	4
ρ (resistivity)	3126	512	1058	10000
h (thickness)	1.8	7.4	11.3	

Figure 4.10. Schlumberger sounding at the dry borehole, station 6 m, Droogekloof 471KR.

Zanthoxylum capense is the geobotanic indicator in this case study since it is established on the weathered edge of a linear intrusion and sinkhole structure. This species prefers clay soil and is therefore not easily encountered among the rocky and sandy outcrops on other parts of the farm.

7. Vaalfontein 491KQ

The western limb of the quartzite belonging to the Leeuwpoort Formation is surrounded by mountains consisting of granophyre (the so called Boshoffs Berge) and plains of granite, both igneous rocks belonging to the Bushveld Igneous Complex. No significant intrusive bodies are indicated on the geological Thabazimbi (1974) geological map. This interesting geological occurrence can be found on the farm Vaalfontein 491KQ, between the old mining town of Rooiberg and Thabazimbi. The occurrence of quartzite, granophyre, granite and no significant intrusive bodies poses the possibility of poor aquifer conditions owing to the nature of these rocks and their resistance to weathering. Furthermore, granite that tends to exhibit weathering basins occurs only at a few sites on the farm and cannot be economically exploited owing to its isolated location on the farm. A non-perennial stream borders the western portion of the farm. Some boulders of diabase were found in the stream, which increases the possibility of encountering a weathered diabase intrusion that can act as a confined aquifer. Groundwater exploration was confined in the vicinity of the stream by means of the magnetic and electromagnetic methods in order to identify intrusive bodies. Thereby, possible palaeo-channels may be associated with the intrusion that increases the possibility of encountering groundwater since such channels can act as useful unconfined or semi-confined aquifers. No depth soundings were done owing to the vegetation and close proximity of the border game fencing of the farm. The geophysical profiles as measured on the farm are presented in Figure 4.11. The orientation of the profiles (east-west) is based on the northwest-southeast to north-south strike of identified lineaments on the farm. The borehole was sited and drilled at station 27 m, in the close vicinity of large *Rhus lancea* (karee) and *Acacia karroo* (sweet thorn) trees. Upon close inspection at other sites on the farm, it was clear that the frequency of occurrence of these trees was quite low and if they occurred, then they were less prominent in size.

The geophysical profile as indicated in Figure 4.11 indicates a significant anomaly over the 50 m of the profile. Around station 27 m a magnetic anomaly of about 130 nT can be observed. However, the electromagnetic data does not indicate a significant weathering horizon owing to the prominence of the vertical dipole over the horizontal dipole and small variations in the readings of both in the area of station 27 m. The vertical dipole increases after station 30 m owing to the unweathered vertical nature of the intrusion.

The reason for applying the $L = 40$ m coil separation is to achieve deeper penetration of the electromagnetic currents and hence a deeper exploration depth. The intrusion is small, since it is some 10 m in extent, but suggests a significant possible aquifer in these surroundings.

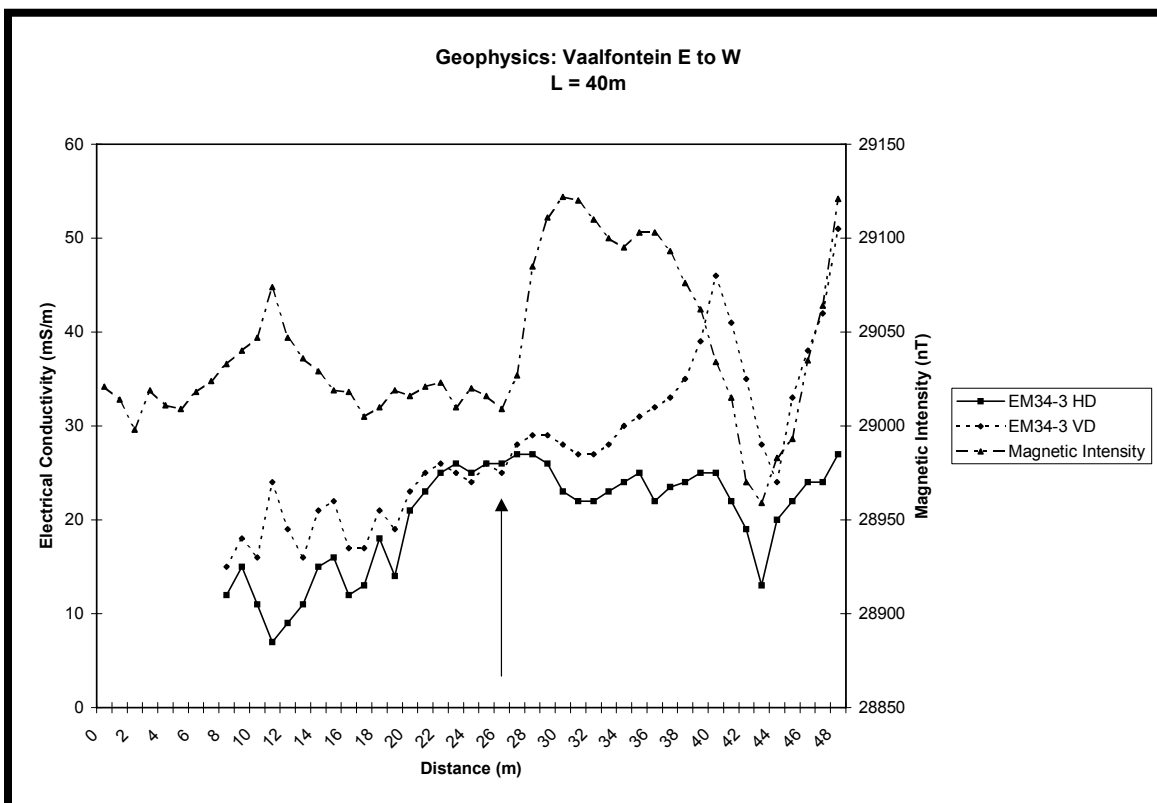


Figure 4.11. Geophysical profile on the farm Vaalfontein 491KQ.

Upon drilling of the peg at station 27 m numerous boulders belonging to granophyre and quartzite were encountered, which made the drilling process more difficult. These boulders most probably represent a palaeo-channel. However, no water was encountered in this palaeo-channel. At a depth of about 40 m, some clay and weathered diabase boulders were encountered and water was struck at a depth of 45 m. At 48 m solid diabase was struck till 85 m. The yield of the borehole is estimated to be 1 500 l/h and is utilised for a game watering-trough. The complete borehole log is:

- 0 – 3 m: sand and gravel (alluvium)
- 3 – 17 m: boulders of quartzite and granophyre
- 17 – 39 m: quartzite
- 39 – 48 m: clay, weathered diabase boulders
- 48 – 85 m: unweathered diabase.

Soil samples were taken at station 27 m and station 16 m on the quartzite plain. The soil samples at station 27 m (borehole and geobotanic position) indicate a predominance of P, Al, lower resistivity, S, %C and %N. Although higher Al levels can restrict root and plant development, the botanic difference between the geobotanic site and the other site with no geobotanic indicators, appears not to be significant in nature owing to higher levels of P, %C and %N at the geobotanic site. From an agricultural perspective, elements such as N, P and C are crucial and very beneficial to root and plant development. The abundant presence of these elements might trigger vegetation growth and specific vegetation types of another kind (species or size). Owing to the presence of alluvium at the drilled spot (geobotanic community) and the soil sampling depth, the soil quality analysis does not reveal the true geochemistry of the weathered *in situ* rock, as indicated by the Hutton soil series on the land type map (annexure). The high permeability of the gravel, boulders, deposited nutrients and organic matters resulting from floods and the high nutritional value of the weathered diabase will enhance rooting and rooting depth.

***Acacia karroo* and *Rhus lancea* are the geobotanic indicators in this case study. These species are associated with a confined aquifer (weathered diabase in quartzite). It is important to recognise the geochemistry of the soil under the alluvium cover and the ability of the soil to support tree establishment owing to variations in weathering and lithologies.**

4.2.1 Remarks

Unfortunately, little is known or has been published regarding the geohydrological parameters of this specific study area. The Polokwane (2003) geohydrological map can be utilised as a reference tool, but nothing more on account of its scale. Comparing the obtained results with similar outcrops of the mentioned rocks in other areas with more hydrogeological data, it becomes obvious that the case at Blokdrift 512KQ is exceptional, even in the presence of an intrusion. It must be taken into account that the Rooiberg geological area has undergone severe structural deformation over the last millennia and therefore created multiple aquifers in the Rooiberg basin. The aquifer at Droogekloof 471KR is representative of dolomite, although one must remember that

siting of such a borehole depends on the utilisation and adequate interpretation of obtained geophysical data and any geobotanic indicators. The existing dry borehole at Droogekloof 471KR is a resemblance of failure in this regard. Quartzite is a difficult aquifer due to its resistance to weathering and erosion. The yield of the borehole at Vaalfontein 491KQ is representative of other boreholes drilled in quartzite in the Pretoria surroundings (Frommurze, 1937) and Meulenbeld (1998).

The geophysical methods employed obtained satisfactory results, and to use magnetics, electromagnetics and Schlumberger soundings for groundwater consulting services is effective and can yield positive results. To begin a geophysical traverse on an unexplored farm is extremely difficult, but with the aid of aerial photographs and geobotanic indicators, a quick and effective beginning can be made after a reconnaissance investigation on the farm with the use of a vehicle on existing roads. Listed geobotanical indicators and sampled soil from these and surrounding areas are indicated in Table 4.2.

All the geobotanic indicator sites have, in common, higher organic carbon content and sulphur concentrations combined with lower soil resistivity values. Higher levels in the total available nitrogen content are also evident in two cases. No distinct contribution of CEC towards geobotanic indicator sites can be made regarding these case studies since it has higher values than the non-geobotanic site only at Blokdrift 512KQ. Regarding cation values, the geobotanic site indicates higher Na values, whereas at Droogekloof 471KR, the geobotanic site's soil is enriched in Ca. Higher Na values can be attributed to a greater amount of Na feldspars in the diabase compared to the quartzite host rock and increased Ca values, owing to the presence of more available Ca in the weathered dolomite environment along the intrusion. Higher amounts of available nutrients than for the soil samples taken in the vicinity of the geobotanic indicator sites are not discussed since these samples were randomly obtained, based on the absence of any interesting or suspicious phenomenon in the field and anomalies on the geophysical profile. It will be difficult to cross-reference any of these significant soil parameter values of the various types of soils with the actual situation in the field.

Table 4.2. Comparisons between the soil characteristics of the geobotanical indicators and their surroundings.

Parameter	Geobotanical community (A)	Surroundings (B)
pH	4.50-7.60	4.74-6.53
P (mg/kg)	2.05-21.83	1.54-14.53
Ca (mg/kg)	115-2891	100-886
Mg (mg/kg)	49-299	36-363
K (mg/kg)	18-159	16-206
Na (mg/kg)	5-61	1-46
Fe (mg/kg)	24.4-213.3	16.8-182.0
Mn (mg/kg)	16.5-1318.3	27.7-1402.1
Zn (mg/kg)	0.10-0.55	0.43-0.82
Al (cmol _c /kg)	0.000-2.156	0.000-1.202
Resistance (Ω)	2000-4800	4200-24000
%C	0.24-3.37	0.10-1.69
Total N%	0.023-0.252	0.010-0.106
S (mg/kg)	22.09-166.44	21.06-37.89
CEC (cmol _c /kg)	2.842-10.500	3.824-10.716
Geobotanical indicator species under column A	<i>Acacia karroo</i> (sweet thorn)-appearance <i>Ficus sur</i> (broom cluster fig) <i>Rhus lancea</i> (karee)-appearance <i>Zanthoxylum capense</i> (small knobwood), sometimes in association with <i>Euclea crispa</i> (blue guarri)	
Geology	Diabase intrusions in quartzite and associated with cavities in dolomite	Quartzite, Dolomite
Aquifer yield (l/h)	1 500-100 000	Not applicable

4.3 VAALIUM EONOTHEM: DOLOMITE OF THE MALMANI SUBGROUP IN THE PRETORIA AREA

Information pertaining to the case study area regarding its geographic locality, climate, veld types, geology, geohydrology, geophysics, geobotany, soil sampling is tabled (see annexure).

8. Elandsfontein 412JR (1)

This smallholding was visited as a result of the lowering of water tables in the area and the resulting drying up of boreholes. Some small sinkholes existed on the farm, but do not form part of the study area. A magnetic traverse was run along such a sinkhole which indicated a drop in the magnetic intensity to a value of 27775 nT, see Figure 4.12. Owing to the fact that only a small portion of this smallholding was geophysically investigated, it was decided to run parallel south-north magnetic profiles with a spacing of 50 m between the profiles and 10 m between the stations. This data was contoured by means of Kriging and the application of the SURFER software. The entire farm rests on dolomite of the Malmani Subgroup. No lineaments or suspicious tree growth is observed on the aerial photograph (see annexure), but according to the geological map, a lineament cuts through the farm in the southwestern corner.

The contoured magnetic data can be observed in Figure 4.13. The magnetic intensity in the study area varies from 28340 to 28490 nT. No distinct magnetic lineaments can be observed, although higher magnetic intensity readings can be seen in the centre of the plotted area. Low magnetic readings close to the house and its infrastructure were treated with caution due to the presence of iron and electric structures (noise). The magnetic intensity at the sinkhole (27775 nT) was taken into account, since cavities do not contain magnetic minerals but primarily air and will respond as a magnetically low area on a contoured map. This reading was re-checked from three different directions, yet no variance was evident. No noise was detected in this area. Therefore, a contrast between a magnetic low and high was preferred to site a borehole. Some anomaly between the gravimetric and magnetic methods can be seen in their distinct formulas (Telford *et al.*, 1990):

$$F_m = \frac{1}{\mu} \left[\frac{p_1 p_2}{r^2} \right] r_1$$

$$F_g = G \left[\frac{m_1 m_2}{r^2} \right] r_1$$

, where

F_m and F_g is the force exercised on the dipoles or masses p and m ,

$1/\mu$ is the magnetic permeability,

G is the universal gravitational constant,

r represents the distance between m_1 - m_2 or p_1 - p_2 , and

r_1 is the unit vector from m_2 (p_2) to m_1 (p_1).

From these formulae it can be deduced that the basic difference between the gravimetric and magnetic methods is based in the measurement of gravitation or magnetic permeability. Cavities possess less gravimetric attraction due to the existence of air and its lower density compared to that of rock. Cavities basically possess no magnetic permeability owing to the fact that air does not contain many magnetic particles compared to the surrounding rock. Both methods will record lower readings above a cavity, although the gravimetric method will be more accurate than the magnetic method, since it deals entirely with gravimetric principles and gravity differences in rock. The magnetic method cannot be used to map or identify cavities but only as a reconnaissance tool.

The green cross as indicated in Figure 4.13 denotes the position selected as the best drilling spot, because of the differences in magnetic intensity and the magnetic gradient. This site was further investigated by a sounding to establish the presence of lower resistivities in the sub-surface, since cavities filled with water will indicate a decrease in resistivity (Figure 4.14). The electrodes were laid out north-south owing to the availability of open space in this direction and the absence of a strike associated with the dolomite. The Schlumberger sounding yielded a QH-curve, which indicates weathering in depth above the resistive bedrock. The extent of weathering is approximately from 17-59 m below the surface. This seemed suitable for groundwater drilling since the depth of the water strike in this area is approximately 46 m and thereby the water table is lowering. The sounding model corresponds with the borehole log because it indicates 0 – 2 m clay, 2 – 7 m weathered dolomite, 7 – 42 m dolomite with small chert layers, 42 – 48 m cavity and water strike (46 m) and 48 – 50 m dolomite. This site was drilled and yielded 22 000 l/h. Certain shrubs were obviously associated with the spot mentioned, *Acacia karroo* and *Rhus lancea*. The frequency of occurrence of these shrubs in this area was low. However, it must be taken into account that most of the indigenous vegetation of the area had been destroyed caused by intensive farming practices. Soil samples were

taken of the geobotanic site at the drilling spot and another one some 30 m to the south (see Table A1.7a&b). According to the land type map (annexure), no variation in the soil series occurs at this site. The pH of the soils is constant, as well as the P and exchangeable available cations. The Ca-value at the geobotanic site is very high in the first 500 mm with a drop in resistivity. The geobotanic site indicates higher organic carbon content, as well as the total nitrogen content, but some variation in sulphur and CEC-values occurs, with an increase in depth compared to the site with no geobotanic indicators and not favourable geophysical data. Variations in the geochemistry of the soil can be attributed to the weathering of different types of rocks and fracturing of dolomite above the cavities. The presence of small mafic intrusions in the dolomite cannot be excluded, because of the existence of lineaments. Geobotanic occurrences could be a result of weathering patterns along these weathered mafic intrusions, fractured dolomite and the enrichment by nutrients caused by these processes.

No correlation is evident between the soil sample indicated on the land type map and the soil samples taken on-site at the locality of the case study. Only the K, %C and Zn values can be compared. This stresses the point that soil varies in space and soil sampling at geobotanic areas is extremely important in order to gather information on the soil that supports these tree roots and their development, compared to soil with bare vegetation growth. General maps are of little value for a detailed study such as this, but nevertheless, indicate some useful data for comparisons between different climate zones and geological areas.

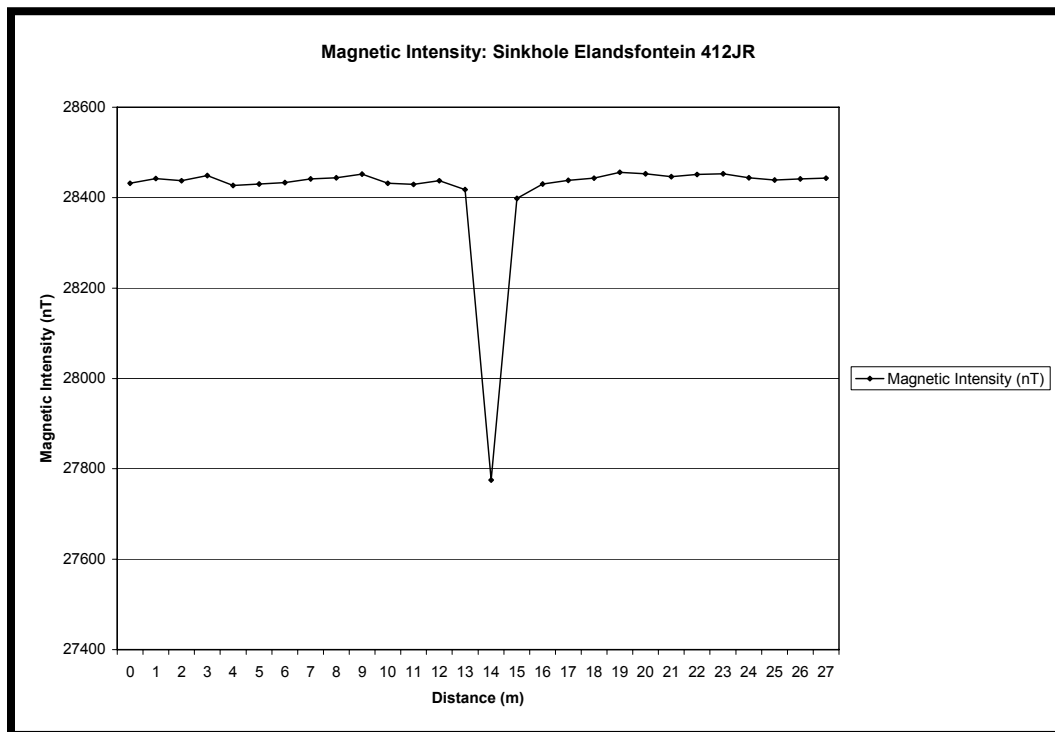


Figure 4.12. Magnetic intensity along the sinkhole (station 14 m) at Elandsfontein 412JR.

Magnetic Map of the farm Elandsfontein (1)

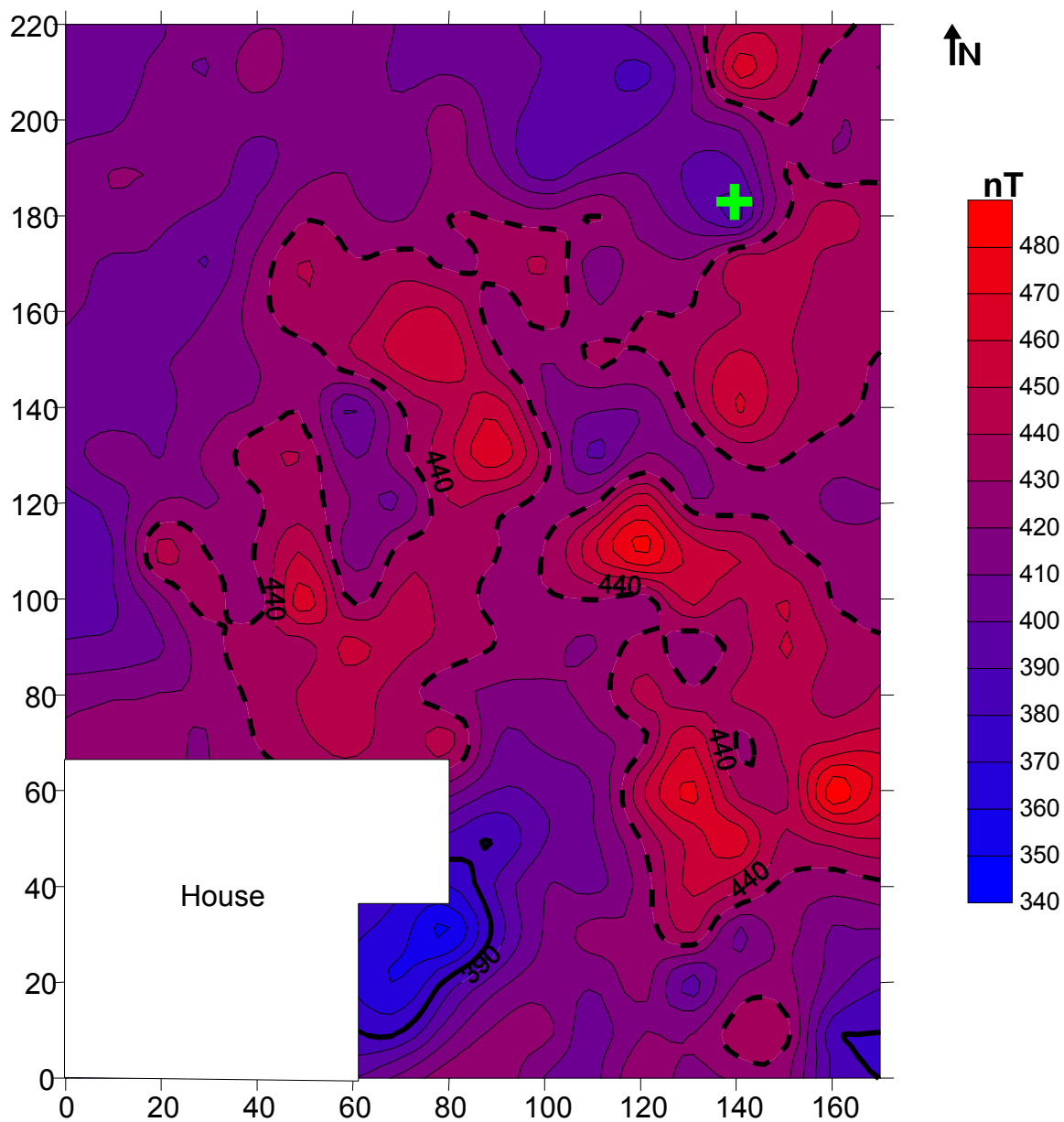


Figure 4.13. Contoured magnetic data of the farm Elandsfontein 412JR (1).

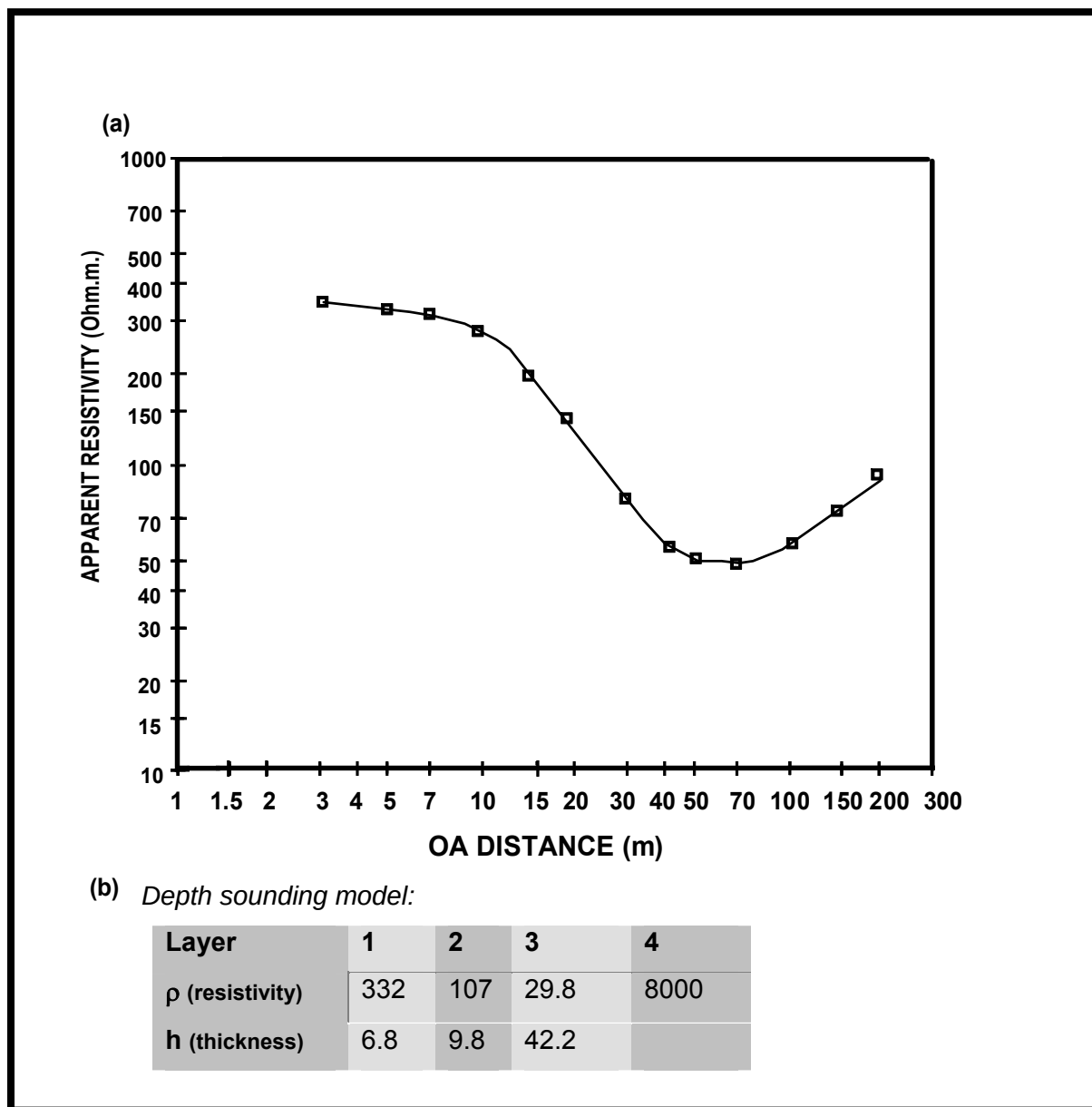


Figure 4.14. Schlumberger depth sounding on the farm Elandsfontein 412JR (1).

Acacia karroo and *Rhus lancea* are the geobotanic indicators in this case study since they grow on soil that is enriched in Ca and CEC owing to weathering and fracturing of rock. The geohydrology of the area is governed by mafic intrusions and cavities in the dolomite.

9. Elandsfontein 412JR (2)

The geology is more complex at this site since the dolomite of the Malmani Subgroup is bounded in the west by quartzite of the Boshhoek Formation that stretches north to south. Furthermore, a Karoo Supergroup (Dwyka Formation) shale and soil overburden covers the dolomite in places, possibly up to several metres thick. Several faults and diabase lineaments are indicated on the geological map (Pretoria, 1978). These secondary features form excellent groundwater exploration targets. Faults occur in the Boshhoek Formation and strike east-west, whereas lineaments strike north-south. Due to the variations in geology and hence the geomorphology, geobotanic indicators are present at several points on the farm. Large quartzite boulders, old sinkholes, diabase boulders and a spring limit agricultural practices and therefore these features can support vegetation growth. Numerous *Acacia karroo* and *Rhus lancea* trees occur, although they vary in size. Owing to the high frequency of occurrence of these tree species, another geobotanic indicator was sought in association with these trees that may indicate more feasible drilling spots. Such tree species are *Celtis africana* and *Euclea crispa* (blue guarri). It is believed that the species *Celtis africana* indicates areas of deeper weathering in dolomite (Stigter, 2005). The presence of a spring on the farm, located about 800 m from the survey area, with a yield of approximately 10 800 l/h indicates the occurrence of groundwater. This spring is located close to the diabase lineament in dolomite. The magnetic and electromagnetic methods were utilised and the results are presented in Figure 4.15. A station spacing of 5 m was maintained with a coil spacing of 40 m for the EM34-3. The layout of the profiles in an east-west direction was based on the strike of the lineaments so as to cross these. The lineaments will provided a well-defined signature with these methods.

The geophysical profile indicates an increase in magnetic intensity at station 170 m, mainly owing to the presence of a lineament and alternating HD and VD signatures. These variations can be assigned to dipping strata in the vicinity of the lineament. Preference was given to a contrasting HD-VD reading, with HD>>VD. The horizontal dipole is a representation of weathering basins or contacts, whereas the vertical dipole indicates less weathered, vertical structures. The position at station 265 m (see arrow, Figure 4.15) was preferred owing to its decrease in magnetic field and alternation of HD/VD dominance. The specie *Euclea crispa* was encountered at this site together with

Acacia karroo and *Rhus lancea*. *Euclea crispa*'s frequency of occurrence on the farm is low (the writer only counted four species in an area of approximately 70 ha). A few *Celtis africana* trees were observed. The rest of the geophysical profile indicates a tendency of $VD \gg HD$, especially in the western portion of the profile. It can be assumed that the lineament dips to the west. A decline in electrical conductivity to the east can be seen. The eastern portion was covered with numerous quartzite pebbles that are more resistive to conducting current.

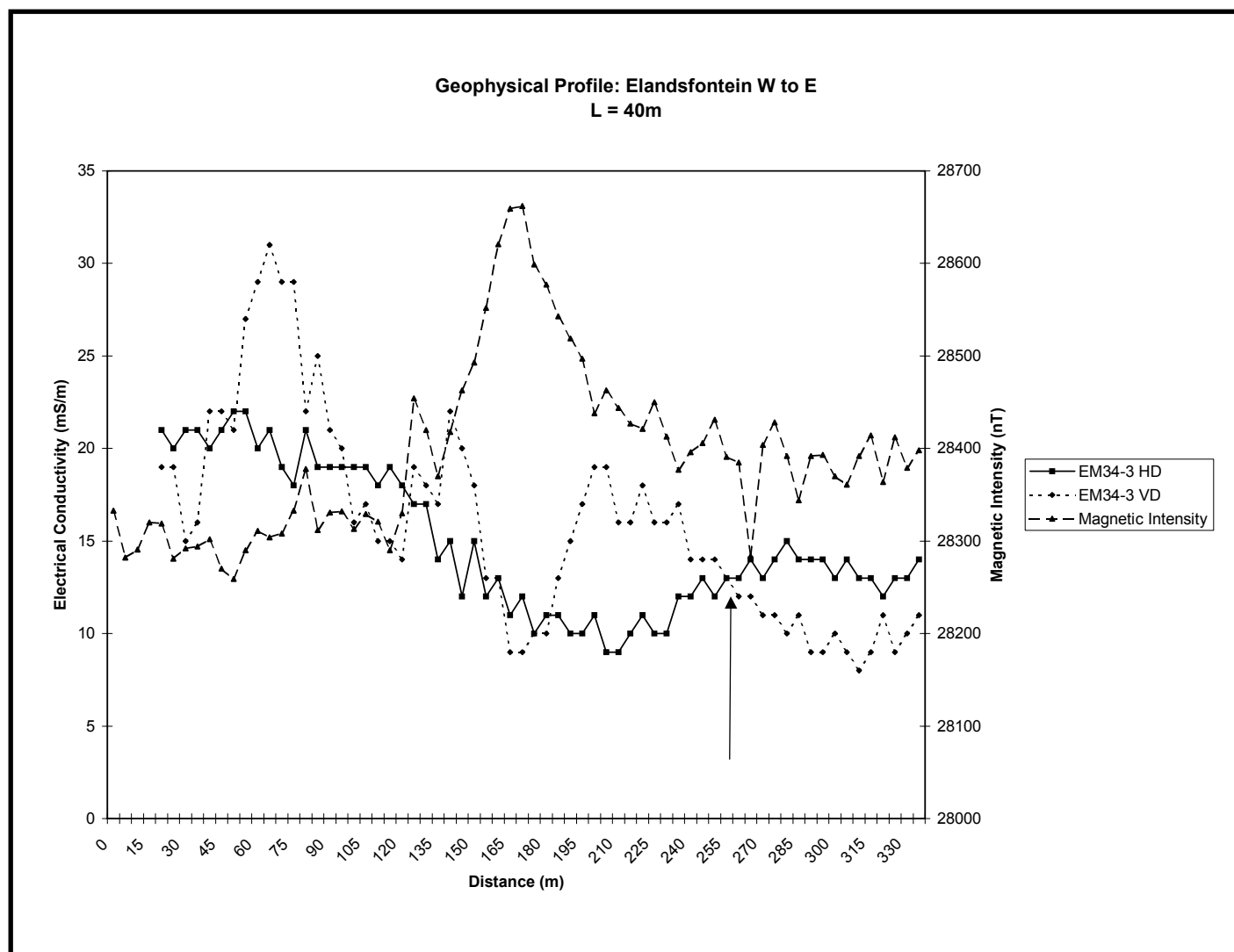


Figure 4.15. Geophysical profile at Elandsfontein 412JR (2).

Station 265 m yielded 45 000 l/h, with a water strike at about 43 m. The aquifer consisted of weathered diabase (clay and boulders) in the dolomite, where the latter possesses an extremely porous and permeable honeycomb structure.

Soil sampling at station 265 m and 225 m indicated a decrease in pH for the geobotanic community. Furthermore, the geobotanic site contains higher amounts of available P, Mg, Zn and a higher CEC-value. The resistance of the soil is considerably higher than that of the other spot, most probably because the other spot was located close to the middle of the lineament that has weathered to clay. The %C is slightly lower with greater depth at the geobotanic community, but indicates an increase of %N with depth compared to station 225 m, although the S values are considerably lower at the geobotanic community.

***Acacia karroo*, *Celtis Africana*, *Euclea crispa* and *Rhus lancea* are the geobotanic indicators in this case study. These are associated with the weathered dolomite/diabase contact zone that serves as a confined aquifer.**

4.3.1 Remarks

Geobotanic indicators or species are restricted on the Highveld, mostly owing to climatic factors. However, these species that occur must be utilised. The dolomite of the Malmani Subgroup, as discussed above, supports some vegetation, which was investigated together with the gathered geophysical information and soil characteristics. The existence of such geobotanical indicators needs to be embraced since Scott & Le Maitre (1998) lacked information on this topic. However, more case studies will increase the probability that the mentioned species are true geobotanic indicators of dolomite. The appearance of similar geobotanic indicators in other geological terrain must also be considered. The reasonable yields of the two boreholes indicated support the existence and use of the given geobotanical indicators in this area, depending on the frequency of occurrence of these species. Both karst aquifers are associated with dolomite weathering and water-bearing structures, such as cavities or honeycomb structures. The geophysical-geohydrological exploration of lineaments in dolomite is strongly recommended for groundwater purposes. The impact of the lowering of water tables on the success rate of these newly sited boreholes is not known since pump tests and

water table measurements previous to these borehole sitings are not available and cannot therefore be quantified. The information in Table 4.3 represents a summary of the comparisons between soil characteristics of the geobotanical indicators of the Malmani Subgroup and their surroundings.

Table 4.3. Comparisons between the soil characteristics of geobotanical indicators and their surroundings.

Parameter	Geobotanical community (A)	Surroundings (B)
pH	5.16-6.73	6.04-6.52
P (mg/kg)	1.07-3.40	1.02-2.77
Ca (mg/kg)	221-1859	243-877
Mg (mg/kg)	252-496	193-416
K (mg/kg)	49-211	92-178
Na (mg/kg)	9-40	8-138
Fe (mg/kg)	59.3-188.8	176.0-340.1
Mn (mg/kg)	434.0-1381.3	1203.4-1615.8
Zn (mg/kg)	0.24-2.77	0.23-1.95
Al (cmol _c /kg)	0.519-0.589	0
Resistance (Ω)	2400-5200	1600-5200
%C	0.34-0.81	0.06-0.95
Total N%	0.035-0.071	0.022-0.117
S (mg/kg)	10.84-88.25	20.97-134.38
CEC (cmol _c /kg)	8.470-14.658	3.727-7.989
Geobotanical indicator species under column A	<i>Acacia karroo</i> (sweet thorn)-appearance <i>Celtis africana</i> (white stinkwood) <i>Euclea crispa</i> (blue guarri) <i>Rhus lancea</i> (karee)-appearance	
Geology	Diabase intrusions in dolomite and associated with cavities in dolomite	Quartzite, Dolomite, Shale (Dwyka Formation)
Aquifer yield (ℓ/h)	22 000 – 45 000	Not applicable

The soil characteristics of the geobotanic sites of the two abovementioned case studies generally indicate a wide variety in pH and hence Al toxicity may occur. However, owing to the availability of cations, and the higher content of organic carbon, nitrogen and the notable CEC values, root and tree support is clearly feasible. Therefore, it appears that Al toxicity is not a major concern for these geobotanic cases. The presence of heavy metal in concentration does not seem too important, since the Fe and Mn values vary considerably and, often, these concentrations in the geobotanic sites are somewhat lower than those of the other site sampled. In these cases the availability of Zn is higher at the geobotanic site.

The geophysical methods applied Schlumberger soundings, the magnetic method and the electromagnetic EM34-3 apparatus, yielded favourable results. The relationship between employing the magnetic and gravimetric methods to indicate possible sub-surface cavities requires further investigation. The obtained profiles are clear and owing to conductive earth, higher electrical conductivity readings are obtained that are less sensitive to erroneous coil orientations and ease the accuracy and speed of the exploration (Botha *et al.*, 1992).

4.4 VAALIUM EONOTHEM: ANDESITE AND GABBRO IN THE PRETORIA-BRITS AREA

Information pertaining to the case study area regarding its geographic locality, climate, veld types, geology, geohydrology, geophysics, geobotany, soil sampling is tabled (see annexure).

10. Mooikloof Estate (1)

The estate is laid out on shale of the Timeball Hill Formation and andesite belonging to the Hekpoort Formation. Both formations are part of the Pretoria Group, Transvaal Sequence. The geomorphology comprises undulating terrain with steep ridges, koppies and rocky outcrops, mostly in the areas underlain by andesite. The shale constitutes a gently dipping surface and small even patches of veld. Notably, the shale is covered with exotic bluegum and wattle bushes, where remains of indigenous vegetation cover are still evident on the andesite. This indigenous vegetation cover, representing Bankenveld

botany, is an extremely helpful tool in groundwater siting utilising the aid of geobotanical indicators. Species of Highveld cabbage tree (*Cussonia paniculata*) and *Acacia* are common on the andesite and were not recognised as being geobotanic indicators in this habitat. The 1 ha smallholding visited evidenced three dry boreholes on site. These boreholes were sited by the drill operator with the aid of some self-made water divining device. This operator apparently also used geobotanical indicators; however, these were exotic wattle trees that grow tall and are evergreen. The evergreen appearance compared to the deciduous growth of most other indigenous vegetation species created a pitfall. Therefore, it is not recommended that one refer to any exotic species as geobotanic indicators, unless no indigenous species occur, and then only with extreme caution. Certain parameters such as height and circumference of the stem, can be utilised.

Owing to the small and restricted size of the property (1 ha), this site and the remaining site on Mooikloof Estate (2), were surveyed by means of the magnetic method in station intervals of 5 m and with line/profile spacing of 50 m and thereafter contoured. The programme SURFER was utilised for the contouring of the data, by Kriging of the data points. The representation of the obtained magnetic contour map is depicted in Figure 4.16 with a magnetic profile across the sited borehole position in Figure 4.17. The magnetic intensity reaches a low for the survey area in the centre of the survey. The interpretation is that this could represent one of the many faults that cross the area in this vicinity as indicated on the Pretoria (2528) geological map. These faults strike southwest-northeast. The presence of this fault structure diminishes any small local magnetic anomalies on the contoured map. Along this fault, some fracturing and deep weathering will occur and are responsible for a decline in the topography in the centre of the survey area and the growth of some indigenous vegetation. The sited borehole is indicated by a green dot in Figure 4.16 and an arrow in Figure 4.17. This borehole is 60 m deep with a yield of 15 000 ℓ/h.

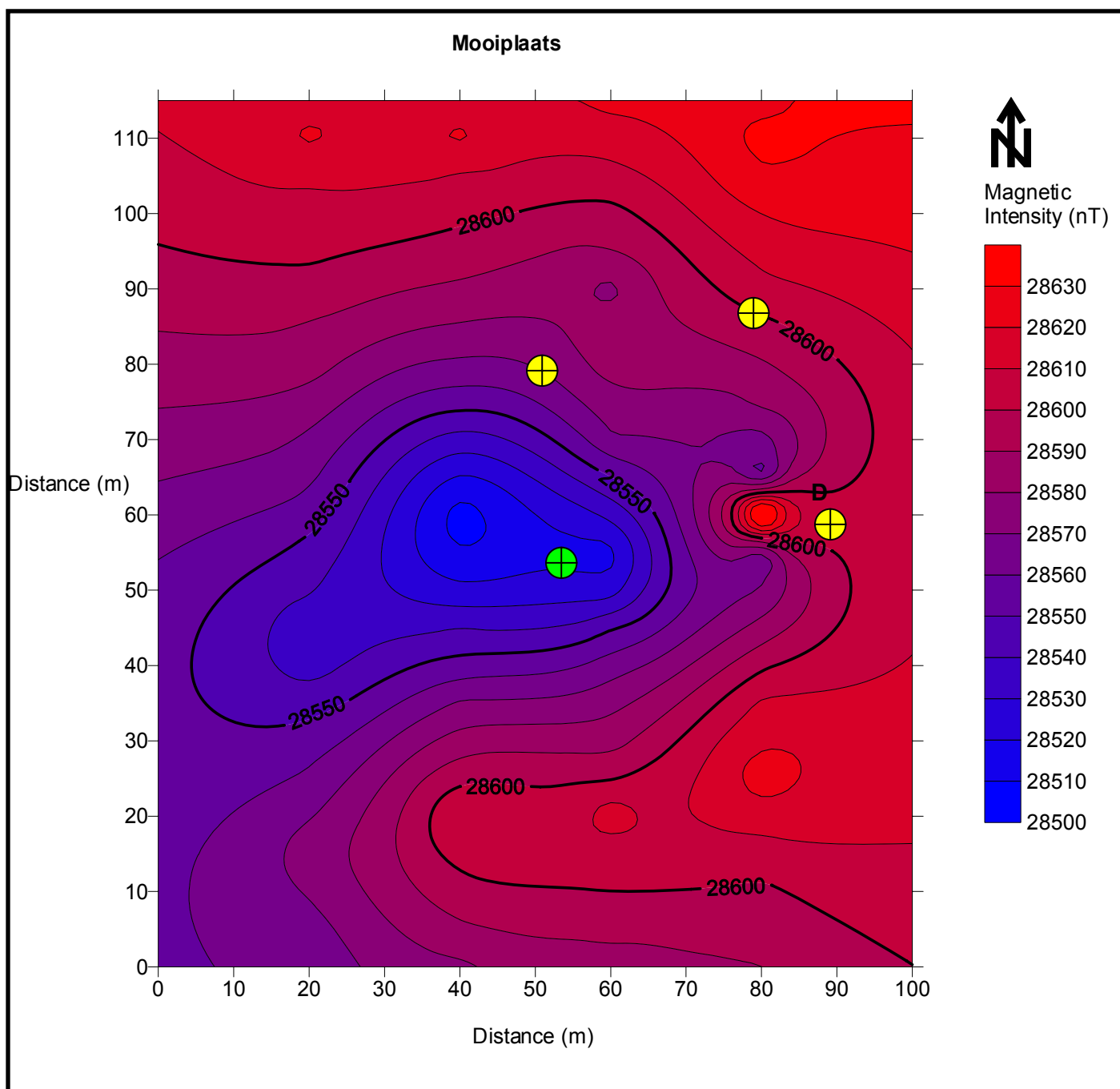


Figure 4.16. Contoured magnetic data of Mooikloof Estate (1). **Figure 4.16.** Contoured magnetic data of Mooikloof Estate (1).

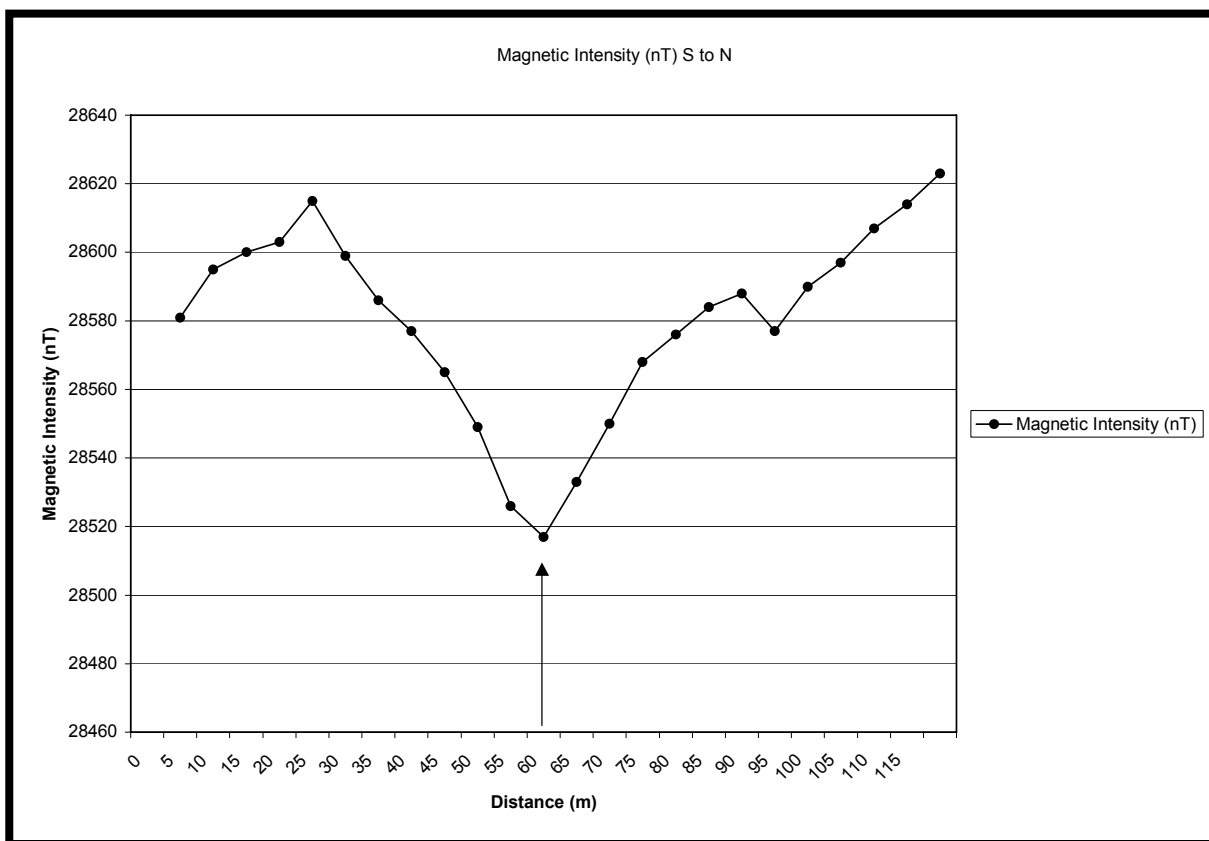


Figure 4.17. Magnetic profile across the sited borehole (arrow), Mooikloof Estate (1).

The sited borehole in Figure 4.16 (green dot) is surrounded by a few blue guarri (*Euclea crispa*) shrubs among Highveld cabbage trees and *Acacia* species. It is the only place on this smallholding and in the immediate vicinity that is covered with blue guarri. Meulenbeld (1998) previously noted the value of *Euclea crispa* as a geobotanic indicator on an extinct rhyolite volcano (see case studies under Chapter 4: Rhyolite of the Rooiberg Group). This geobotanic indicator is associated with a low magnetic intensity area (Figure 4.16), most probably due to intense weathering and fracturing of the rock as indicated by the borehole log, which revealed:

0 – 1 m: clay

1 – 7 m: weathered andesite boulders with lime inclusions

7 – 21 m: weathered andesite

21 – 26 m: fractured and brecciated andesite (water strike at 23 m)

26 – 60 m: unweathered andesite.

The yellow dots in Figure 4.16 represent the dry boreholes in the vicinity of exotic wattle trees. The magnetic data indicates poor drilling sites because of high magnetic intensity values. It would be interesting to understand why the instrument of the layman indicated favourable drilling results (groundwater) at these dry sites. The average depth of the three dry boreholes is 80 metres.

The results of the soil sampling are quite noteworthy. The soil sampling analyses tabled in Table A1.9a are representative of the drilled spot (green dot). The soil sampling analyses indicated in Table A1.9b were gathered at one dry borehole (yellow dot marked 'D') next to a wattle tree. The soil from the successful borehole indicates a higher pH, decreased values of P, high values of available cations in the typical order of availability and exchangeability: $\text{Ca} > \text{Mg} > \text{K} > \text{Na}$, lower soil resistance values and increased CEC-values. Values of organic carbon, S and total N are equal. The moderately higher values of Ca and Na in the soil sampled next to the successful borehole indicate the presence of free lime, which may be the weathered product of plagioclase feldspars that mainly constitute andesitic rock and weathered Dwaalheuwel Formation consisting of chert (Schumann, 1985). The soil properties near the wattle trees indicated somewhat higher amounts of available P and Fe. The greater quantity of nutrients found at the spot of the successful borehole indicates significant weathering of mafic rock. Such weathering generally constitutes a water-bearing feature and is therefore important in this rocky environment (see the land type map, annexure).

If the characteristics of the successful borehole are compared with the results published by Frommurze (1937), then the general borehole information, such as the depth and water strike, compares favourably with these. However, the yield of the borehole is almost three times as much as the average yield of the Hekpoort Formation in the Pretoria area. The difference in yield stresses the importance of utilising geobotanic indicators in the field as a guide for geophysical groundwater exploration.

***Euclea crispa* is the geobotanic indicator in this case study. Deep weathering of mafic rocks and groundwater is associated with this tree species.**

11. Mooikloof Estate (2)

Another smallholding (1 ha) was geophysically investigated for the purpose of domestic groundwater supply borehole siting on the Mooikloof Estate. The previous case study, number 10, dealt with certain aspects of the Mooikloof Estate environment. This case study area is also underlain by andesite of the Hekpoort Formation and numerous andesite outcrops and boulders are scattered on the surface. The terrain next to the road (southern portion of the magnetic contour plot), is fairly flat. However, the terrain suddenly dips steeply towards the north after about 50 m from the road for the remainder of the magnetic contour plot. Some Highveld cabbage trees (*Cussonia paniculata*), blue currant (*Rhus zeyheri*), common hook-thorn (*Acacia caffra*) and sweet thorn (*A. karroo*) are commonly found, but spread out, on this smallholding. They grow mostly along cleavages and joints in the andesite boulders on the surface. A few other tree species, localised in bush-clusters in the northwestern portion of this smallholding, occur, such as *Clerodendrum glabrum* (tinderwood), *Euclea crispa* (blue guarri) and *Zanthoxylum capense* (small knobwood). Species of *Acacia* and a few trees of *Cussonia paniculata* are also present in the bush-clusters. The presence of tinderwood, blue guarri and small knobwood together served as geobotanical indicators for the possible selection of a drilling spot. The magnetic method was utilised because it would indicate the likelihood that groundwater could be present in the vicinity of these geobotanical indicators. The contoured magnetic data is displayed in Figure 4.18 (SURFER programme and Kriging of the data) and a magnetic profile along the sited borehole position in Figure 4.19.

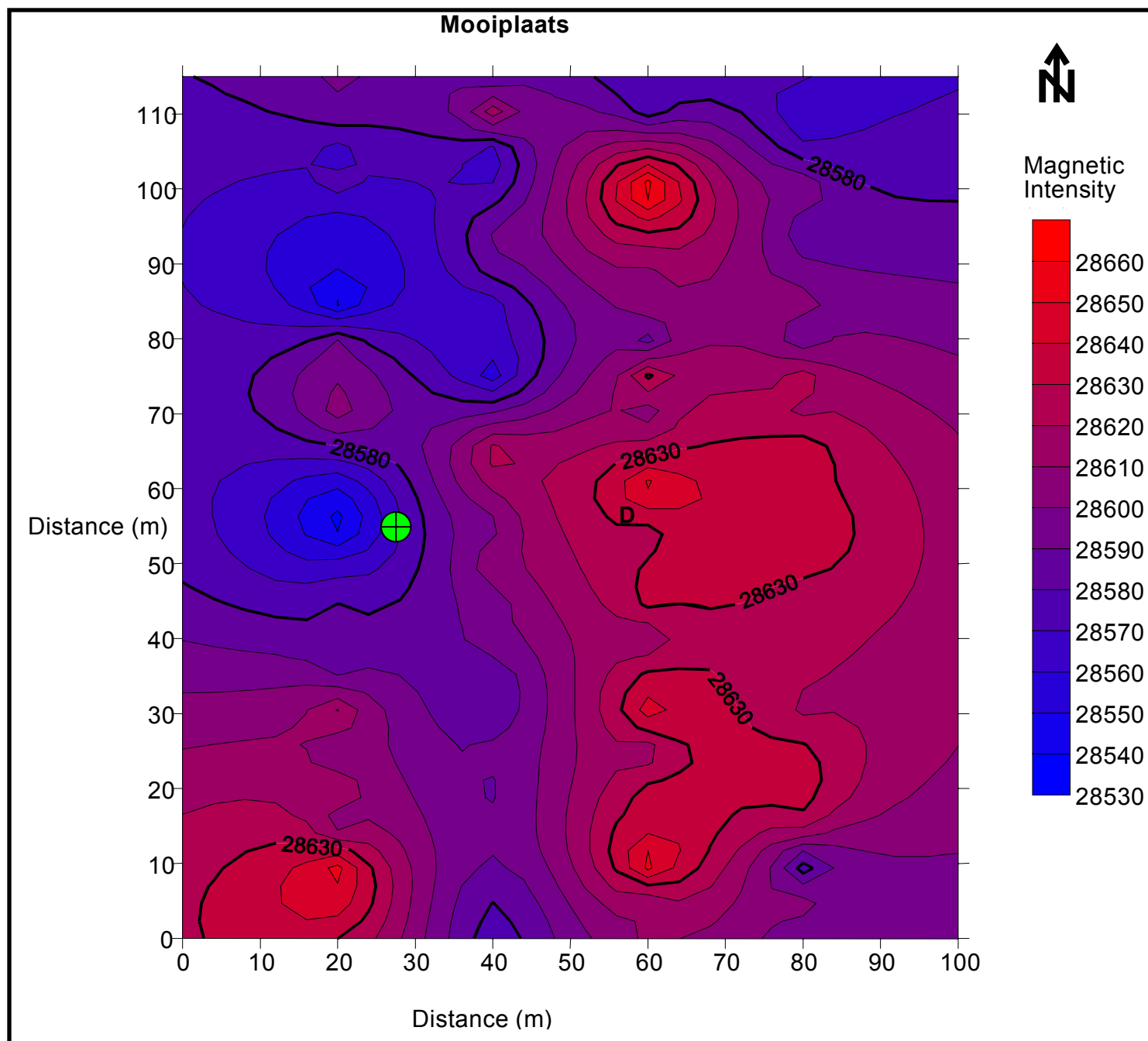


Figure 4.18. Contoured magnetic data: Mooikloof Estate (2).

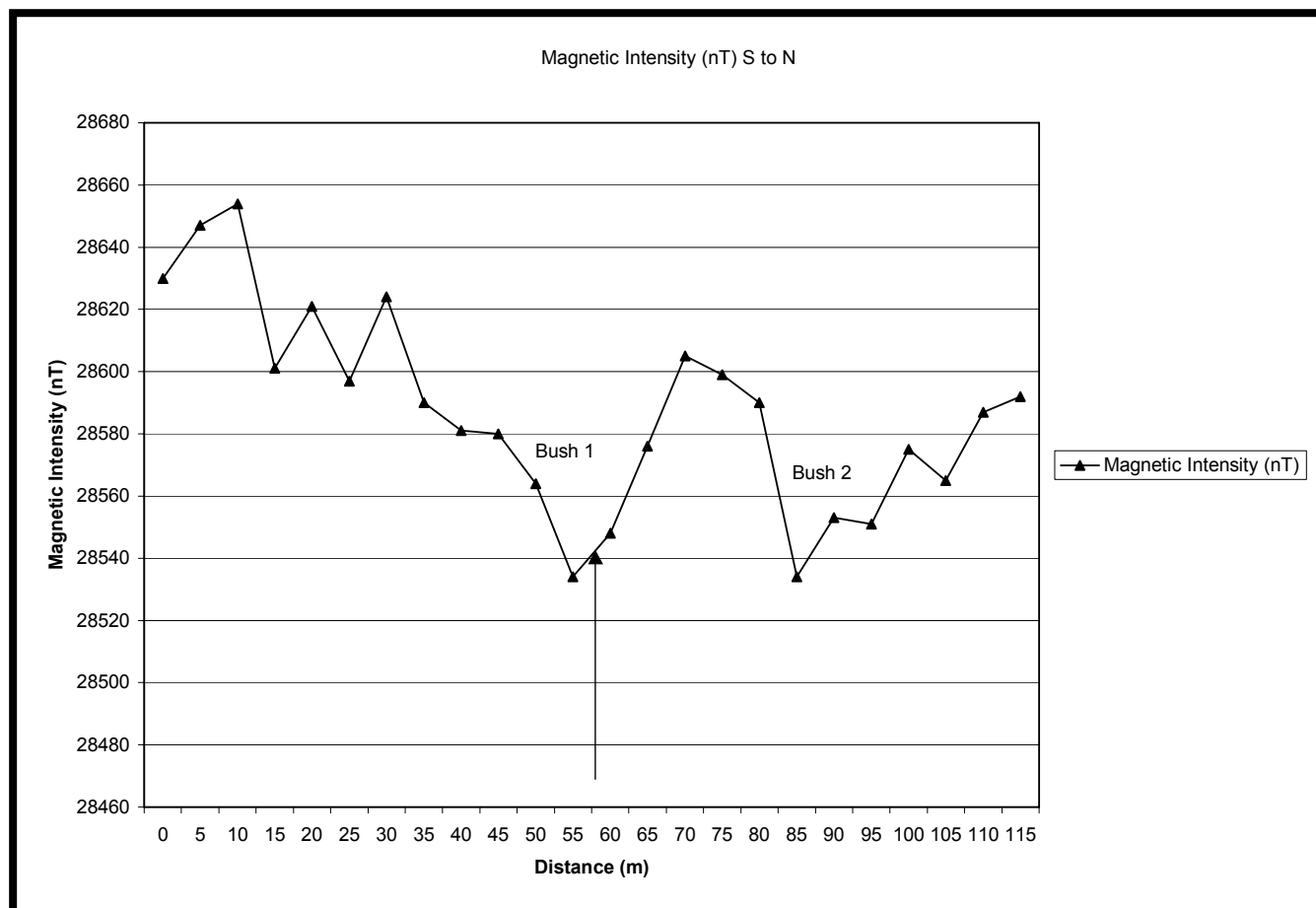


Figure 4.19. Magnetic profile along the sited borehole indicated by the arrow, Mooikloof Estate (2). The name ‘bush’ indicates the presence of bush-clusters.

The borehole was sited in the vicinity of bush-cluster 1 since this bush-cluster is separated from bush-cluster 2 by a magnetic high. The latter is most probably the result of less weathering and fracturing of the andesitic rock in the sub-surface. The green dot in Figure 4.18 indicates the borehole that was sited and drilled with a yield of 20 000 l/h. The borehole log of this spot is notably similar to the log described in the previous Mooikloof case study. The magnetic data indicates that the area occupied by the bush-clusters records the lowest magnetic intensity for the area investigated and covered by the magnetic survey. A lower magnetic intensity can be attributed to the higher degree of weathering of andesite which therefore creates confined aquifer conditions between weathered rock particles. Soil-sampling took place at the borehole site, bush-cluster 1, and the soil sample representing unfractured rock or higher magnetic intensity values at the station marked D, about 30 m east of the position of the borehole.

It is quite obvious from the tabled analysis of the soil samples indicated in Tables A1.9a&b, that the pH, Ca, Mg, Fe, surface resistance, organic carbon, total N and the CEC-values are higher for the geobotanic/bush-cluster 1 community than the soil sampled in the vicinity of the unfractured andesite rock; however the sulphur values of the soil derived from this rock are higher. Variations of P, K, Na, Mn and Zn availability occur according to the depth. Once again, as in the previous Mooikloof Estate case, an increase in free lime is observed at the geobotanic community owing to the weathering of plagioclase feldspar andesite or derived from chert. The higher organic carbon, total N and CEC-values indicate larger amounts of humus and greater fertility in the sub-surface that supports vegetation growth, especially since the pH is suitable and no traces of exchangeable Al that can imply Al-toxicity are evident.

***Clerodendrum glabrum*, *Euclea crispa* and *Zanthoxylum capense* are the geobotanic indicators in this case study. Deep weathering of mafic rocks and groundwater is associated with these tree species and is important in this soil series.**

12. Brits Industrial Area

The town of Brits is situated approximately 10 km north of the Magaliesberg mountain range on a vast plain of mainly gabbro and norite rocks belonging to the Rustenburg Layered Suite of the Bushveld Igneous Complex. To the north of the town an outcrop of granite and granophyre of the Bushveld Igneous Complex can be found. Brits is situated between two major north-south striking faults that prominently cut through the Magaliesberg. The Crocodile River flows between these fault structures. A local hydrocensus revealed that the majority of residents in the eastern Brits suburbs have access to groundwater by means of a borehole. The strike of groundwater occurs between 10 and 20 metres below the surface. Yields vary, but most boreholes supply more than 7 200 l/h. The case study presented is localised in the Brits Industrial area, southeast of the town. As just noted, gabbro or norite underlies the entire area. These weather to a thick black turf, thus it is difficult to find outcrops of these rocks in the field. Small ridges of about 0.5 m in height, covered with bushes, occur, although these bushes also grow on the turf plains. The bushes on the ridges display a greater

biodiversity of species that can be used as geobotanic indicators. It is suspected that these ridges are the result of exfoliation. The purpose of siting a borehole in this environment is to monitor the movement of industrial pollution plumes. Owing to the fact that a number of Brits residents utilised groundwater, it was important to site boreholes between the polluted areas and town residents along possible groundwater pathways.

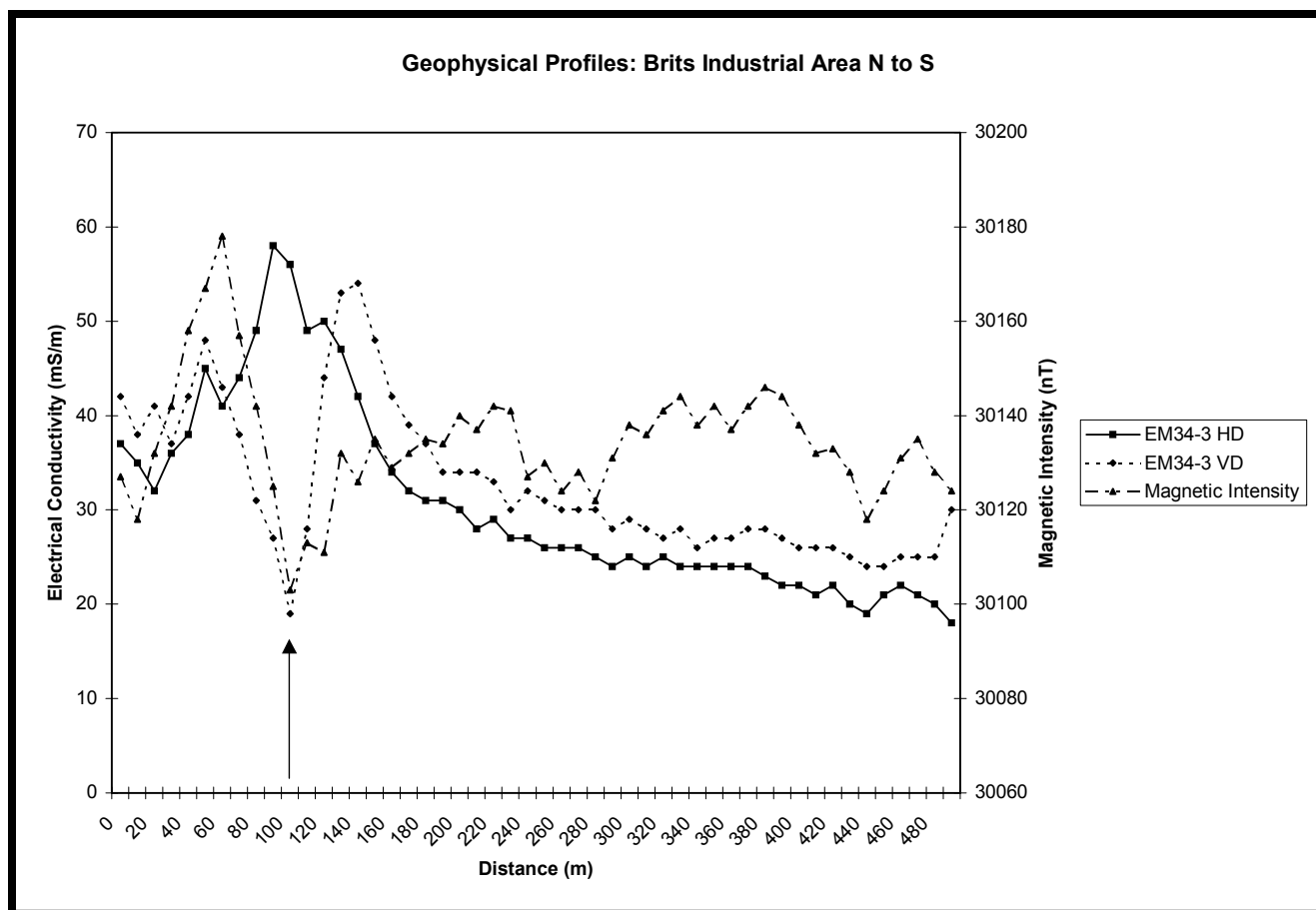


Figure 4.20. Magnetic profile of the Brits Industrial area.

These pathways could be deep weathered basins or along cracks such as exfoliation structures. Owing to time constraints, it was decided to use only the magnetic and electromagnetic methods as a quick reconnaissance tool and to site boreholes. The traverse was run in a north-south direction in order to cross the exfoliated ridges with a luxuriant vegetation establishment (see aerial photograph, annexure). The geophysical profiles are illustrated in Figure 4.20. The arrow denotes the position of the drilled borehole. Other boreholes were also sited, but with lesser yields and were not associated with geobotanic indicators. These are not discussed here, since the data is confidential and not important to this study. The borehole log revealed that only gabbro

was drilled. The aquifer in question is situated on the contact zone between unweathered and weathered gabbro at a depth of 17 m in the exfoliation features.

The position of the arrow in Figure 4.20 indicates the drilled borehole with a yield of 18 000 l/h. Geobotanic species that occur in this spot are *Clerodendrum glabrum* (tinderwood), *Rhus lancea* (karee) and *Ziziphus mucronata* (buffalo-thorn) together with *Acacia karroo* (sweet thorn), *Ehretia rigida* (puzzle bush) and *Gymnosporia buxifolia* (common spike-thorn). Species of *Acacia karroo* and *Gymnosporia buxifolia* are commonly found on the turf plains (see also Acocks, 1988). The geophysical profile (Figure 4.20) presents a distinctive anomaly in the region of station 110 m, in the vicinity of the geobotanic indicators, where a distinctive drop in the magnetic intensity, VD values and a significant increase in the HD component of the EM34-3 can be observed. It is the only spot on the traverse where HD>VD. The variations in conductivity and magnetic intensity at this station can be attributed to a deeper weathering of the gabbro along an exfoliation plane. Deeper weathering and exfoliation structures are water-bearing features. At other stations on the profile, for instance stations 280 and 440 m. species of *Acacia karroo* occupy the black turfveld, but with no significant signature on the geophysical profile to indicate any relationship to aquifers or weathering in the sub-surface.

Typical black turf (Arcadia soil series) was sampled at the geobotanic community (station 110 m) where the borehole was drilled. Notably higher values of Ca, K, P, S, conductivity, Zn, organic carbon and total N are present in the soil obtained and analysed from the geobotanic community. However, a sharp increase in the CEC value is observed with an increase in depth. Although the pH of the soil is a little lower than the pH of the soil of the remaining site (station 70 m), it is only slight. Of interest is the variation in Ca, Mg, Na and K values, most probably owing to the composition of the original parent rock and its rock-forming minerals Plagioclase ($\text{NaAlSi}_3\text{O}_8$ - $\text{CaAl}_2\text{Si}_2\text{O}_8$) and Hornblende $(\text{Ca},\text{Na})_{2-3}(\text{Mg},\text{Fe},\text{Al})_5(\text{Si},\text{Al})_8\text{O}_{22}(\text{OH})_2$ and the weathered state of these (chemical formulas derived from Hamilton *et al.*, 1990).

Clerodendrum glabrum, *Rhus lancea* and *Ziziphus mucronata* are the geobotanic indicators in this case study. Exfoliation and weathering of gabbro give rise to luxuriant, linear growth of vegetation on these features. Groundwater is associated with the exfoliation planes and weathering profile.

4.4.1 Remarks

Plagioclase feldspatic rocks (mafic to ultramafic rocks) such as andesite and gabbro host certain geobotanic species that can be utilised to a great extent in order to obtain plausible aquifer yields that are somewhat above the average yield of the geological formations. The case studies based on geophysical profiles and contour plots indicate that areas of fracturing, weathering and exfoliation make excellent groundwater exploration targets that are mostly covered by geobotanic species such as *Clerodendrum glabrum* (tinderwood), *Euclea crispa* (blue guarri), *Rhus lancea* (karee), *Zanthoxylum capense* (small knobwood) and *Ziziphus mucronata*. These species tend to grow in areas of lower magnetic intensity and where the HD>VD for the EM34-3, owing to the physical reasons mentioned above. Although other species such as *Acacia karroo* (sweet thorn) occur frequently, such species are either typical of the veld type or widely and commonly distributed with no conspicuous characteristics since these can be found almost anywhere in South Africa.

Elements that occur in higher concentrations at the geobotanic sites, according to the analysis of the soil samples, are Ca, Mg (for andesite case studies), K, %C, %N and CEC values. In addition, the conductivity of the soil is greater and the Al toxicity is lower. Table 4.4 is a summary of the ranges between which soil parameters vary in the soil analysed.

The average depth of boreholes drilled in the geology of this section as listed by Frommurze (1937) compares favourably with the results obtained from this study. However, the water strike was shallower and increased yields were evident in this new study.

Table 4.4. Comparisons between the soil characteristics of geobotanical indicators and their surroundings.

Parameter	Geobotanical community (A)	Surroundings (B)
pH	5.54-7.89	5.06-8.18
P (mg/kg)	3.19-22.85	3.28-19.43
Ca (mg/kg)	1771-10849	721-10829
Mg (mg/kg)	460-1431	273-3053
K (mg/kg)	108-562	95-272
Na (mg/kg)	19-61	22-186
Fe (mg/kg)	14.02-139.21	20.29-199.07
Mn (mg/kg)	107.08-425.05	56.61-393.77
Zn (mg/kg)	0.84-11.68	0.41-2.29
Al (cmol _c /kg)	0.00-0.060	0.00-0.317
Resistance (Ω)	310-2200	400-2200
%C	1.01-4.11	0.73-1.60
Total N%	0.064-0.275	0.042-0.100
S (mg/kg)	14.20-36.25	10.55-60.83
CEC (cmol _c /kg)	1.00-55.32	8.725-52.555
Geobotanical indicator species under column A	<i>Clerodendrum glabrum</i> (tinderwood) <i>Euclea crispa</i> (blue guarri) <i>Rhus lancea</i> (karee) <i>Zanthoxylum capense</i> (small knobwood) <i>Ziziphus mucronata</i> (buffalo-thorn)	
Geology	Fractured andesite (Hekpoort Formation), fault zones and weathered basins in gabbro (Rustenburg Layered Suite)	Andesite and gabbro
Aquifer yield (ℓ/h)	15 000 – 20 000	Not applicable

4.5 VAALIUM EONOTHEM: SHALE AND QUARTZITE OF THE PRETORIA GROUP IN THE PRETORIA AREA

Information pertaining to the case study area regarding its geographic locality, climate, veld types, geology, geohydrology, geophysics, geobotany, soil sampling is tabled (see annexure).

13. Kameeldrift 313JR

The low-lying area that defines a wide plain between the quartzite topography of the Magaliesberg and Daspoort ridge is locally known as the 'Moot'. The Moot consists of shale of the Silverton Formation with intrusive diabase sills and dykes that possess a distinct east-west strike. Most of this area is divided into agricultural smallholdings. The farm Kameeldrift 313JR is one of the original farms which has been divided into smallholdings because of its close proximity to the city of Pretoria, namely approximately 15 km west of the city. Owing to the numerous subdivisions and development of the original farm, much of the indigenous vegetation that could have been useful as geobotanic indicators, has been cleared. However, patches of indigenous vegetation still exist. It was observed that the diabase dykes, some less than a metre in width, have weathered to polished boulders that outcrop on the surface. In conjunction with geobotanic indicators, geologic conditions and geophysical profiles, borehole siting for irrigation purposes could be selected; see Figure 4.21. The geophysical profile orientation was north-south in order to cross the diabase intrusions. The weathered contact zones of the diabase intrusions act as aquifers because shale is an aquitard in this geological setting.

The geophysical profile as indicated in Figure 4.21 depicted some significant local magnetic anomalies in the vicinity of stations 40 m and 130 m with a total amplitude of about 30 nT. Zones of deeper weathering in the proximity of these magnetic anomalies (probably small diabase dykes) are clearly depicted by the electromagnetic data where the $HD \gg VD$. This data represents a conductive sub-surface with areas of deeper weathering than others (e.g. at stations 90 m and 180 m) and possible contact zones (aquifers) with the small dykes. The arrow in Figure 4.21 indicates the position of the drilled borehole and from where the soil was sampled. The other soil sample was taken at station 70 m. Geobotanic indicators observed in the region of station 90 m (the

position of the borehole) are *Acacia karroo* (sweet thorn) and *Zanthoxylum capense* (small knobwood). Although *Acacia karroo* is widely scattered in this veld type, the occurrence of *Zanthoxylum capense* is very limited and, in fact only one specimen was found growing in a radius of approximately 1 km at station 90 m. Water strike occurred at a depth of 24 m and the yield of the borehole 12 000 ℓ/h, about 3 times more than the average yield of the Silverton Formation in this region as described by Frommurze (1937).

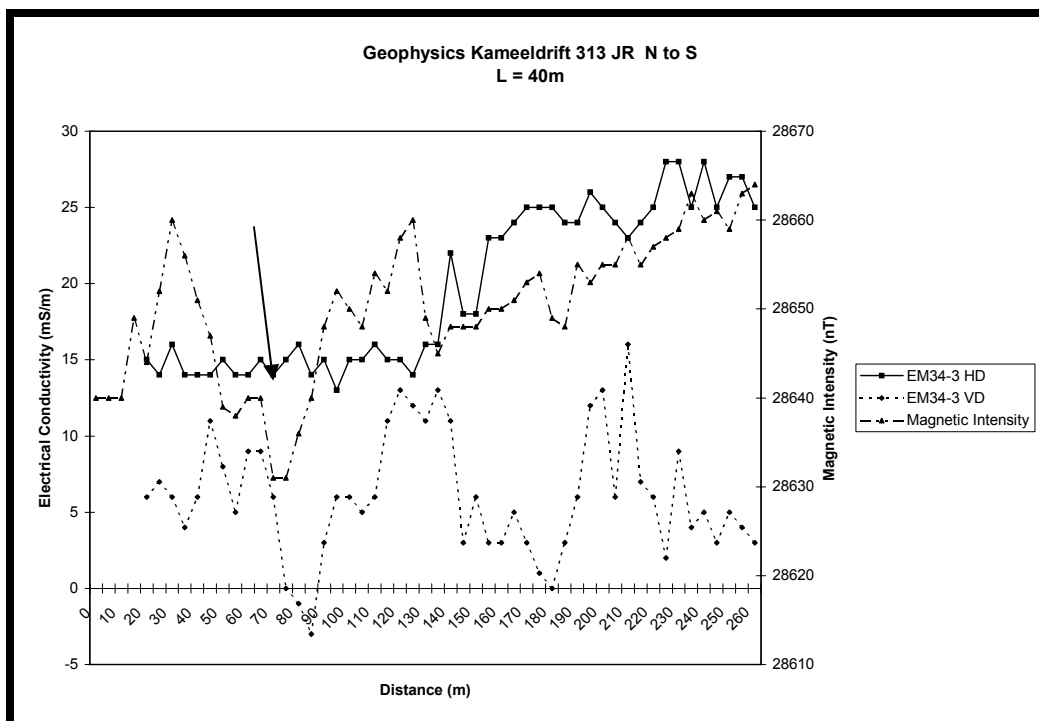


Figure 4.21. Geophysical profile on the farm Kameeldrift 313JR.

Higher values of pH, cations (Ca, Mg, K, Na), heavy metals (Fe, Mn, Zn with depth), sulphur and CEC are connected with the intrusion and borehole locality and resembles a Hutton soil series. The shallow sample (0.5 m) indicated higher values of C and N. The resistance of the soil is also lower than that of the other sample which is indicative of less weathering in the sub-surface, as reflected by the geophysical profile in Figure 4.21. The higher pH of the clay soil at the borehole, compared to the loam soil of the remaining point sampled, indicates fewer signs of Al-toxicity in the analytical results of the soil and hence, is more beneficial to sustain vegetation growth together with increased levels of available nutrients and CEC. The soil sample taken at the non-

geobotanic site is representative of the Clovelly soil series. Both Hutton and Clovelly soil series occur in the land type Ba8a (see annexure).

***Acacia karroo* and *Zanthoxylum capense* are the geobotanic indicators in this case study. Both species occupy the linear vegetation patterns visible on the aerial photograph. These linear vegetation patterns resemble weathered diabase, the aquifer in this geological setting. *Acacia karroo* can, in this case only, be used as a geobotanic indicator if it grows in the presence of the latter species.**

14. Kameelfontein 297JR

The Rayton Formation northeast of Pretoria, in the vicinity of the small mining village of Cullinan, depicts a rugged environment with a Bushveld character (Sourish Mixed Bushveld veld type). Numerous small hills of quartzite covered with a sandy soil, abundant quartzite boulders and pebbles are scattered in a clay rich plain derived from weathered diabase. Some small quartzite partings outcrop in the field among the clay soil. The presence of nutrient-rich clay and nutrient-poor sand in the same environment give rise to huge variations in the botany, with divided small-leaved thorn trees being found on the clay soil and trees with no thorns at all and larger, entire leaves established on the sand soil. The variations in the soil texture and lithologies render the application of geophysical profiling methods, such as the magnetic and electromagnetic techniques, very useful.

Trees and shrubs that occur in the Sourish Mixed Bushveld can be observed on the farm with relative ease: species such as *Acacia caffra* (common hook-thorn), *A. karroo* (sweet thorn), *A. robusta subsp. robusta* (brack thorn), *Rhus gueinzii* (thorny karee), *Peltophorum africanum* (weeping wattle), *Pappea capensis* (jacket-plum) and *Ziziphus mucronata* (buffalo-thorn). The *Acacia* and *Ziziphus* species favour clay-rich soil and the other species occupy sandy soil. The species *Euclea crispa* (blue guarri) also occurs in this environment, but its frequency is so high (about 30 species per hectare) that the likelihood that it could serve as a geobotanic indicator in this habitat was discarded. The geohydrological information presented by Frommurze (1937) indicates a deeper aquifer (about 30 m deep) with poor water-yielding properties (3 000 l/h), in terms of intensive agricultural farming practices such as irrigation. The presence of the geobotanic indicators *Ximenia caffra* (sourplum), *Ziziphus mucronata* and *Pappea capensis* is

noteworthy because of their irregular occurrence and low distribution frequency on this farm, although these are considered by Acocks (1988), as also representing characteristic vegetation of this veld type. The inclusion of *Pappea capensis* as a geobotanic indicator is based merely on its occurrence and growth in the Bushveld north of Warmbaths and its observed association with surface water bodies or in close proximity to water boreholes that did not form part of this study because no data was available, or owing to its occurrence in a game reserve.

The aerial photograph (annexure) indicates some lineaments on this farm. The orientations of these lineaments are east-west and southwest-northeast. It was decided to run the geophysical profiles north-south in order to intersect the lineaments and accessibility was relatively easy since most roads on this farm run north-south. The aerial photograph clearly indicates the linear pattern of the lineaments among the scattered vegetation.

Certain unweathered diabase intrusions and sand-enriched soil caused by the lower conductivity of the sub-surface are evident in the geophysical profile in Figure 4.22. These intrusions are approximately 10 m in extent and are prominent near stations 50 m and 150 m. The electromagnetic data indicates a layered earth scenario at most of the stations because $HD \approx VD$ (a parallel trend). The arrow in Figure 4.22 denotes the position of the drilled borehole that was sited because of the presence of a diabase dyke/lineament and narrow weathered conditions on its flank ($HD > VD$). The weathering zones in this environment are critically narrow owing to the abrupt differences in $HD > VD$ readings for a few stations. Therefore, borehole siting must be precise and accurate drilling is essential. Groundwater was struck at a depth of 38 m with a yield of 8 000 l/h. The geobotanic indicators of this spot, mentioned earlier, occur at station 135 m (borehole/arrow). The borehole log of this drilled borehole indicated:

0 – 2 m: sand

2 – 37 m: fractured quartzite

37 – 40 m: weathered diabase (water strike at 38 m-confined aquifer)

40 – 51 m: unweathered diabase

51 – 53 m: slightly weathered diabase (no water)

53 – 70 m: quartzite.

Soil sampling results indicate favourable conditions for the growth of vegetation and its establishment at the intrusive contact (station 135 m) compared to the sedimentary rock derived soil at station 165 m. The soil characteristics of the geobotanic community are typical of the Hutton soil series and the other soil sample is representative of the Mispah soil series (see also the land type map, annexure). Values of pH, cations, heavy metals and humus are considerably higher at the intrusive contact; note the organic carbon and CEC-value of the shallow sample (0.5 m). It is interesting to observe that in most cases the concentration of free P is lower in the geobotanic community than in the other. This phenomenon will be investigated in-depth in further case studies. One explanation could be that the vegetation is absorbing the free phosphorus available since its concentration is a factor ten less than that of its nearest listed cation, Na, and it is easier to measure and observe because of the smaller quantities available in the soil.

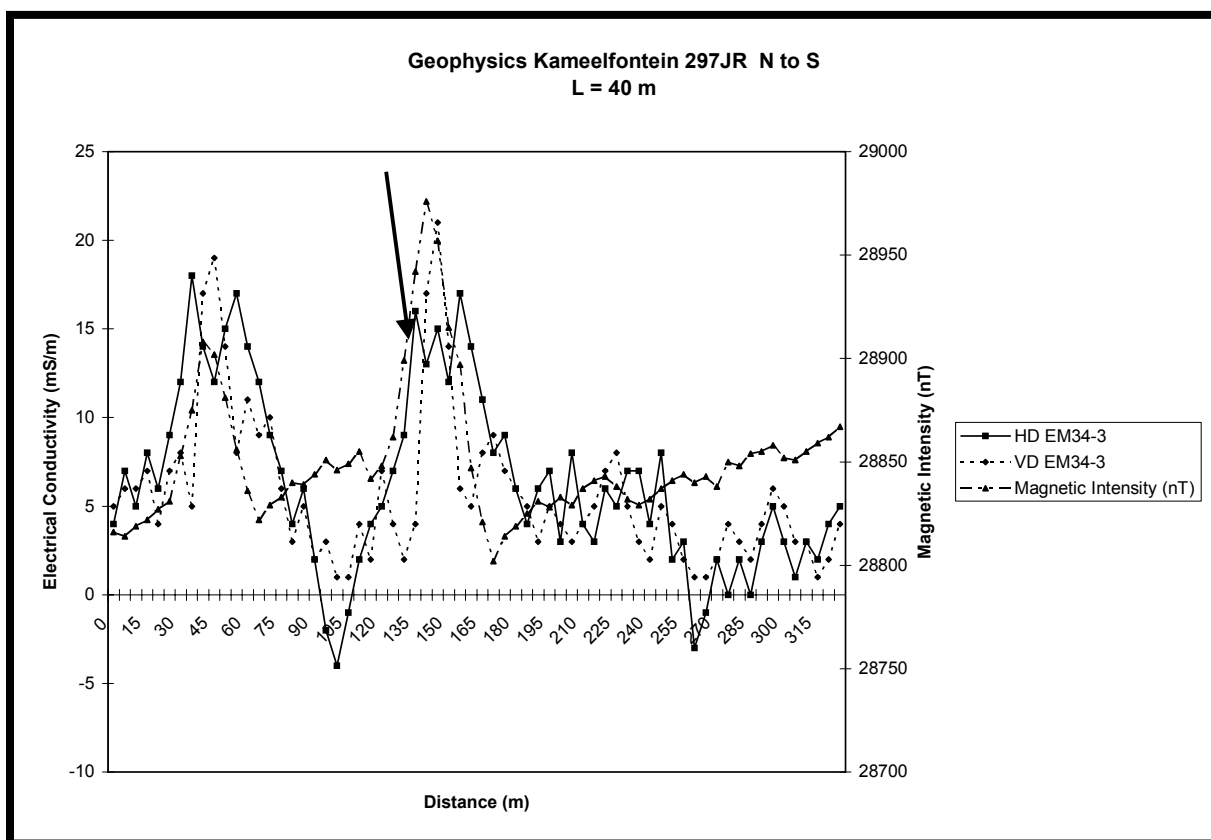


Figure 4.22. Geophysical profile on the farm Kameelfontein 297JR.

Ximenia caffra and *Ziziphus mucronata* are the geobotanic indicators in this case study. These species are associated with the weathered, water-bearing contact zone of the diabase intrusion/lineament and are not obvious in other parts of the farm. The species *Pappea capensis* is also listed as a geobotanical indicator, but further research on this species is warranted. Other species that occur on this vegetated farm are not considered geobotanical indicators, based on their local abundance.

15. Skeerpoort 477JQ

The geology of the farm Skeerpoort 477JQ compares favourably with the geology of the farm Kameeldrift 313JR which has already been described (case study number 13). Shale of the Silverton Formation strikes east-west, with intrusive diabase in the same strike direction. The aerial photograph (annexure) indicates a small lineament on the farm that strikes north-south and this was the geophysical exploration target. Hence, the geophysical profiles were laid out east-west. Weathered lineaments are normally aquifers. The even topography is disturbed by a valley caused by ages of erosion created by the Skeerpoort River, west of the Hartbeespoortdam. The area investigated is approximately 2 km east of the village of Skeerpoort on the northern slope of the Skeerpoort River valley, facing the Magaliesberg. The soil is covered with rock debris, mainly diabase, and aeolian sand.

The borehole currently in use yields only 1 000 l/h and a geophysical investigation was requested to locate a borehole with a higher yield. The area of investigation was restricted to a portion of about 5 ha on the slope facing the Magaliesberg due to its close proximity to infrastructure for equipping the new borehole. Since it was located in the Mixed Bushveld veld type, the focus was placed on the notation of different and less common tree species.

The area investigated with a magnetometer and the electromagnetic EM34-3 instrument indicates a difficult environment in which to site a borehole with distinct water-bearing features in the sub-surface owing to a uniform magnetic field as well as buried vertical structures with little weathering (VD>HD) (see Figure 4.23). The only station that

detected some significant deep weathering was at 105 m and thereafter an increase in the vertical dipole-horizontal dipole amplitude of the electromagnetic instrument readings is observed, indicating the presence of buried, unweathered vertical structures once more. It is difficult to establish what kind of vertical structures are present (also because of the limited extent of the geophysical profile), but, owing to the presence of diabase rock debris and the observed lineament on the aerial photograph, the structures could be diabase or hornfels that are more resistant to weathering and hence a positive topography is created. Confidence in borehole siting (arrow in Figure 4.23) was enhanced by the following geobotanic species that were established at station 105 m: *Acacia karroo* (sweet thorn), *Clerodendrum glabrum* (tinderwood) and *Rhus lancea* (karee). The specie *Acacia karroo* is quite often observed on this farm, but not this noticed circumference and height of this species and its association with the other two tree species. The borehole drilled at this spot yielded 2 500 l/h and water was struck at a depth of 33 m deep. Although poor for the average yield of this formation, according to Frommurze (1937), it is an improvement on the previously sited borehole in this geological environment, given the restricted size of the exploration area. The borehole log of the drilled borehole indicated that weathered diabase was struck at a depth of 32 m, the water strike occurred at 33 m and unweathered diabase was encountered from 34 to 39 m. The rest of the borehole log consists of shale and hornfels.

Part of this study entails soil sampling in order to quantify significant differences in soil nutrients at geobotanic indicator sites linked to the presence of different soil, rock and water characteristics. Soil samples were taken at stations 105 m (borehole) and 80 m, where VD>HD and more resistive, and unweathered conditions in the sub-surface are anticipated. The pH of the geobotanic site is alkaline at the surface but tends to be acidic, increasing according to depth, although available cations are abundant throughout the entire sampled horizon compared to the soil analysis of station 80 m. Heavy metal concentrations vary, but distinctive lower resistivities are noted as well as the higher values for organic carbon, sulphur, nitrogen and cation exchange capacity.

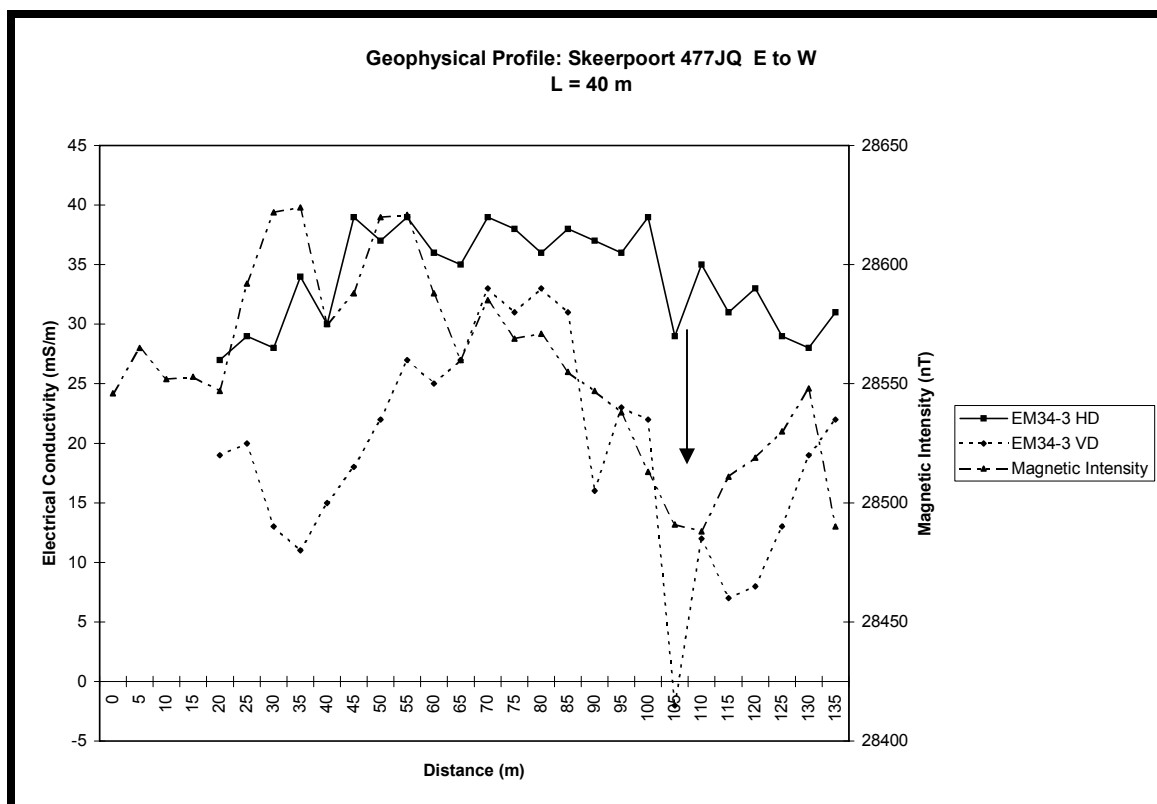


Figure 4.23. Geophysical profile on the farm Skeerpoort 477JQ.

These higher values indicate favourable conditions for vegetation establishment and growth demarcated by the growth of more unique vegetation species in this veld type. The remaining sites, such as the one at station 80 m, are also covered with some vegetation species but these species are common all over the farm and neighbouring areas and appear to be similar in size and extent. From the land-type map (annexure), it is interesting to note that the areas underlain by shale are covered by Shortlands soil series and the areas underlain by andesite are covered by Hutton soil series. From this it is evident that the mafic intrusions such as diabase (lineaments) will also weather to Hutton soil series in contrast with the surrounding Shortlands soil series and give rise to the establishment of different vegetation owing to the changing availability of nutrients, such as calcium (see annexure).

***Acacia karroo*, *Clerodendrum glabrum* and *Rhus lancea* are the geobotanic indicators in this case study. The weathered, water-bearing contact zones of the lineament are vegetated by this species. In the absence of lineaments or mafic intrusions on this farm, the species mentioned are not observed.**

4.5.1 Remarks

The sediments of the Pretoria Group, specifically the Silverton Formation, are intruded by numerous diabase dykes and sills in the area in the region of Pretoria, thus creating probable aquifers. The occurrence of diabase is also common amongst rocks belonging to the Rayton Formation. Owing to the differences in the magnetic intensity of the various rocks and the electrical conductivity of weathered versus unweathered zones, the magnetic and electromagnetic methods can be employed in this geological setting with ease and satisfying results. Zones of weathering are easily identified where $HD > VD$, especially if these could be correlated with intrusions. The areas covered form part of veld types rich in botanic diversity (Bushveld), but frequency mapping and isolation of out-of-the-ordinary botanic specimens lead to the identification of geobotanic indicators that could be used with confidence. The illustrated case containing *Euclea crispa*, Kameelfontein 297JR, indicates that the mapping of the frequency of occurrence of a tree species is extremely important in order not to create a pitfall. Even if a tree or shrub is generally listed as a geobotanic indicator, every geobotanic survey must be accompanied by frequency mapping and the identification of remarkable specimens of such an indicator. If a geobotanic species occurs too frequent on a site, its suitability to be a geobotanic indicator has to be questioned. The association of the tree *Pappea capensis* with aquifers must be studied further.

The three geobotanic sites sampled exhibit higher CEC and Fe values in common, compared to the sites sampled where no geobotanic indicator could be observed. A tendency towards higher values in pH, Mg, Na, K, conductivity, Mn, S, C and N in the geobotanic community is obvious from the results of the soil analysis. The conspicuous higher Fe values present in geobotanic communities may be attributed to the fact that weathering of iron-rich intrusive rocks, for example diabase that are detected by the magnetic technique, releases available iron to the soil contrasted with iron-poor country-rock, such as quartzite. The increased presence of other cations and heavy metals may be attributed to the same origin.

The case studies listed are different, regarding their hydrogeological properties, from the properties published by Frommurze (1937). Although some improved aquifer yields were obtained, the depth drilled and depth of water strike was nevertheless deeper than the

average results published by Frommurze. One reason could be the over-exploitation of aquifers in the Pretoria region by smallholdings, which forces one to drill deeper, while finding groundwater is only probable if the borehole is drilled at a well-selected point. A summary of the soil characteristics and geobotanic indicators is indicated in Table 4.5.

Table 4.5. Comparisons between the soil characteristics of geobotanical indicators and their surroundings.

Parameter	Geobotanical community (A)	Surroundings (B)
pH	5.31-8.03	4.62-7.02
P (mg/kg)	1.26-3.79	1.26-4.95
Ca (mg/kg)	195-1256	128-928
Mg (mg/kg)	100-685	54-174
K (mg/kg)	46-137	20-117
Na (mg/kg)	0-471	1-19
Fe (mg/kg)	38.44-286.46	9.28-47.68
Mn (mg/kg)	67.11-586.34	8.71-280.63
Zn (mg/kg)	0.18-2.63	0-0.54
Al (cmol _c /kg)	0-0.255	0-0.614
Resistance (Ω)	540-4970	3000-5900
%C	0.39-1.41	0.06-0.63
Total N%	0.023-0.087	0.009-0.049
S (mg/kg)	11.82-39.88	1.75-20.08
CEC (cmol _c /kg)	3.64-63.26	2.421-7.31
Geobotanical indicator species under column A	<i>Acacia karroo</i> (sweet thorn) <i>Clerodendrum glabrum</i> (tinderwood) <i>Rhus lancea</i> (karee) <i>Ximenia caffra</i> (sourplum) <i>Zanthoxylum capense</i> (small knobwood) <i>Ziziphus mucronata</i> (buffalo-thorn)	
Geology	Diabase intrusions in sediments of the Pretoria Group	Quartzite and shale, (Pretoria Group)
Aquifer yield (l/h)	2 500 – 12 000	Not applicable

4.6 VAALIUM EONOTHEM: SHALE AND QUARTZITE OF THE PRETORIA GROUP IN THE LYDENBURG AREA

Information pertaining to the case study area regarding its geographic locality, climate, veld types, geology, geohydrology, geophysics, geobotany, soil sampling is tabled (see annexure).

16. Badfontein 114JT

Although the geological map of the area of Barberton (1986) indicates surficial deposits and alluvium over vast areas of the farm Badfontein, outcrops of diabase, shale and hornfels of the Silverton Formation, Boven Member, can be easily observed. The alteration of the different lithologies gives rise to various weathering patterns that could act as confined aquifers. Such a typical aquifer will be a weathered contact zone between diabase and shale. However, the surficial deposits may host an unconfined or semi-confined aquifer since these deposits cover old drainage systems with a high porosity and permeability. The geological map correlates well with the land type map, since deeper soils (Glenrosa and Hutton) are associated with the alluvium, as well as shallow soil and even rocky outcrops are associated with the mapable geological units.

The distinct growth of *Combretum erythrophyllum* (river bushwillow) is observed on the lower slopes of the mountain ridge. This specie is encountered on the riparian border of many streams in the study area. It is not found removed from watercourses in the veld. Hence, the occurrence of such a species in the veld must indicate the presence of groundwater at a reasonably shallow depth. Meulenbeld (1998) identified this tree specie as a phreatophyte. Case studies to follow will also focus on *Combretum erythrophyllum*. The occurrence of shallow groundwater may point to the presence of palaeo-channels and therefore, direct current soundings with the Schlumberger technique were conducted. The borehole, in association with *Combretum erythrophyllum*, yielded 4 800 ℓ/h and groundwater was struck at a depth of 17 m. During the last 15 years this borehole has never dried up nor has its yield ever declined, according to the owner. The borehole log indicated the presence of quartzite pebbles and shale.

The magnetic profile and Schlumberger sounding, as measured on the farm, are indicated in Figures 4.24 & 4.25 respectively. The magnetic profile indicates the presence of a small magnetic anomaly of approximately 20 nT over approximately 60 metres. This anomaly is of low importance if compared to the results of the depth sounding. Furthermore, the aerial photograph does not indicate the presence of major lineaments in this area. The direction of the profile is based on the general strike of the diabase intrusions in this area (southwest-northeast) (see the geological map). Of more importance is the depth sounding model that indicates a significant deep basin of lower resistivity in the sub-surface; a typical H-curve. This depth sounding was measured at station 150 m; see the arrow in Figure 4.24 that represents the position of the borehole mentioned. The position of the traverse was selected on the basis of the general strike of the strata in the region. According to this model it is quite possible to strike water at a depth of only 17 m. Overall, the resistivity of the rocks is low to intermediate. The first layer represents dry overburden and loose gravel. The resistivity decreases according to the depth which may be attributable to the presence of a palaeo-channel filled with scree and surficial deposits (quartzite pebbles) and quantities of water. This palaeo-channel forms the aquifer and geohydrological target. The mountainous character of the area under investigation gives rise to various buried channels and other groundwater conducting features. The deep weathered basin and possible loose structure of the sub-surface may support the growth and propagation of *Combretum erythrophyllum* and also deeper rooting. These trees were present at the time of the building of the Kwena dam in the early 1990s. The last layer that was identified by the depth-sounding model does not indicate resistive non-weathered bedrock, but is in line with the resistivity of shale and mudstone as measured in other parts of the country.

Soil nutrient sampling occurred at the site of the borehole, indicated by the arrow in Figure 4.24 (see Table A1.13a) and one at station 100 m, Figure 4.24 (see Table A1.13b). High values in free lime (Ca) are obvious and can be attributed to the high lime content of weathered andesite and the presence of weathered carbonate layers (Silverton Formation, Boven Member). All the cations are higher for the site with the borehole and where the *Combretum erythrophyllum* occurs. The humus content for this site is also higher, as represented by C, N, S and CEC-values. The debris of the palaeo-channels may include eroded rock from the elevated areas surrounding the site and especially some carbonate material. Station 100 m is not surrounded by species of

Combretum erythrophyllum, but rather those of *Acacia caffra* and *Ziziphus mucronata*. The latter can be used as a geobotanic indicator in certain circumstances but not in this case since they are abundant and no difference in size or circumference can be noticed. The importance of *Combretum erythrophyllum* as a geobotanic indicator is based on its general association with surface water bodies and its classification as a phreatophyte. Such plants prefer their root system to be located in water bodies and therefore the occurrence of such a species in the absence of surface water bodies indicates the presence of groundwater. Depending on the weathering of the rock in the vicinity of an aquifer, the rooting depths of these trees can extend to tens of metres deep.

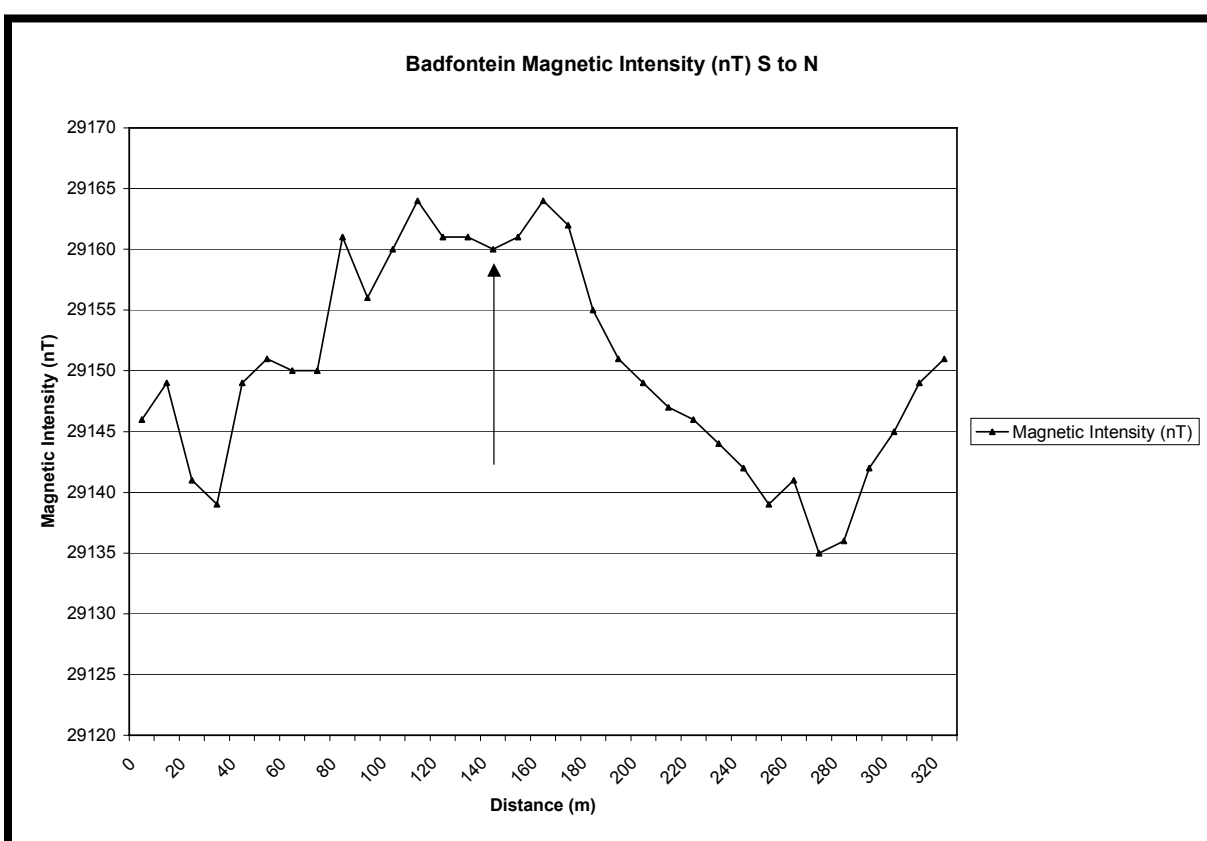
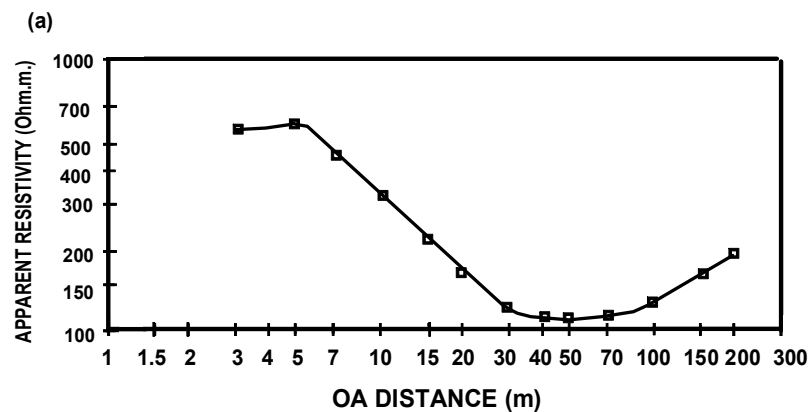


Figure 4.24. Magnetic profile of the farm Badfontein 114J1.



(b)
Depth sounding model:

Layer	1	2	3
ρ (resistivity)	787	72.3	322
h (thickness)	2.9	42.9	

Figure 4.25. Schlumberger depth sounding at the farm Badfontein 114JT.

Combretum erythrophyllum is the geobotanic indicator in this case study. This is based on the fact that this species occurs normally along surface water bodies. Its occurrence in the field indicates the presence of groundwater.

16. Klipspruit 89JT

The geology is almost equivalent to that of Badfontein, but the occurrence of hornfels is predominant especially in the hills. The numerous diabase intrusions in the sediments of the Silverton Formation and quartzite of the Dwaalheuwel and Magaliesberg Formations weather chemically at a much faster rate than the surrounding country rock. These linear diabase intrusions or lineaments can therefore be easily observed on the ground owing to the presence of small, thickly vegetated gorges in the cliffs of the mountains and ridges, see Figure 4.26. These linear features indicate the strike of most lineaments and can be extrapolated on the surface for the purpose of possible aquifer delineation and identification by means of a magnetometer.



Figure 4.26. Linear diabase intrusion in quartzite in the vicinity of Klipspruit 89JT.

A borehole yielding about 1 200 l/h on the farm Klipspruit 89JT was investigated and new borehole positions were sited on the same farm as well as an adjacent one. The location of this borehole yielding this small amount of water was odd to the eye since it was sited in woody surroundings, without any geobotanical indicators. The magnetic

profile around this borehole was investigated and extended to a lonely species of *Combretum erythrophyllum*, close to the footprint of a hill consisting of hornfels. Both positions are indicated in Figure 4.27, where the existing borehole is signified by a dotted arrow and the one associated with a geobotanic indicator by a solid line. A peg was placed at the geobotanic indicator and drilling at the peg yielded 8 400 l/h, about 7 times more than that of the existing borehole. The position of the *Combretum erythrophyllum* species is in accordance with the observed magnetic anomaly at station 130 metres. Furthermore, to stress the importance of *Combretum erythrophyllum* as a geobotanic indicator, a groundwater exploration investigation was conducted on the neighboring farm Kleinfontein 111JT because the current owner was struggling to draw groundwater from a borehole situated close to a dry stream, approximately 55 m deep, with a yield of 1 500 l/h. This borehole is meant to supply the homestead as well as the farming activities. The hills above the *Combretum erythrophyllum* species, occurring on the farm Klipspruit, were investigated for other instances of this tree and/or favourable magnetic profiles, but unfortunately the hornfels did not provide any substantial anomalies. The specie *Hippobromus pauciflorus* (false perdepis) is found frequently on the hornfels. Therefore, the focus was directed to the area of the existing borehole, but only approximately 100 metres east of the banks of a dry stream. Along these banks, in a small valley, some superb specimens of *Combretum erythrophyllum* are found along large boulders of diabase. They do not occur anywhere else in this area. The geophysical data is indicated in Figure 4.28 of this sited borehole. When it was drilled, the borehole yielded about 10 000 l/h. No soil samples were taken from this site.

The arrows in Figure 4.27 denote the high-yielding borehole associated with the geobotanic indicator (solid arrow) and the existing, low-yielding borehole (dotted arrow). Soil samples were obtained at station 120 m (solid arrow) and 280 m (dotted arrow), in order to compare differences in soil quality at the two different borehole sites.

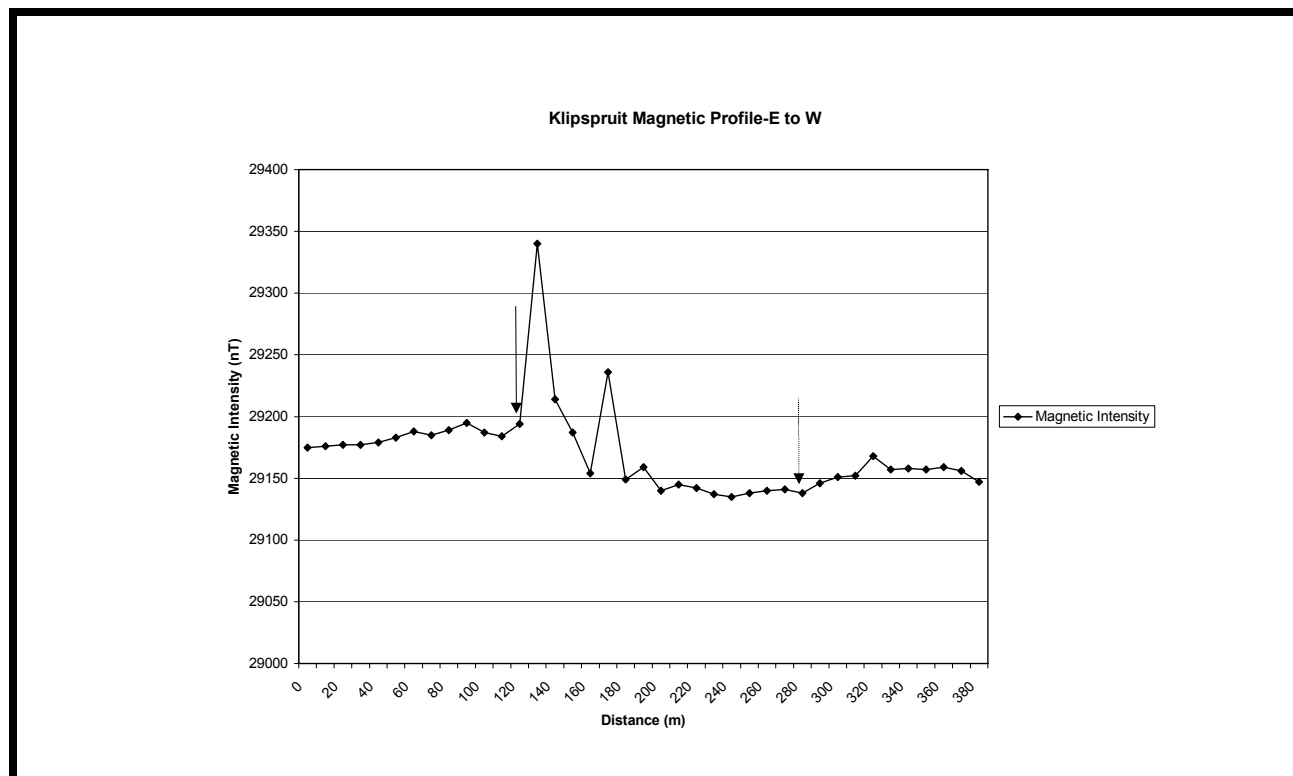


Figure 4.27. Magnetic profile on the farm Klipspruit 89JT.

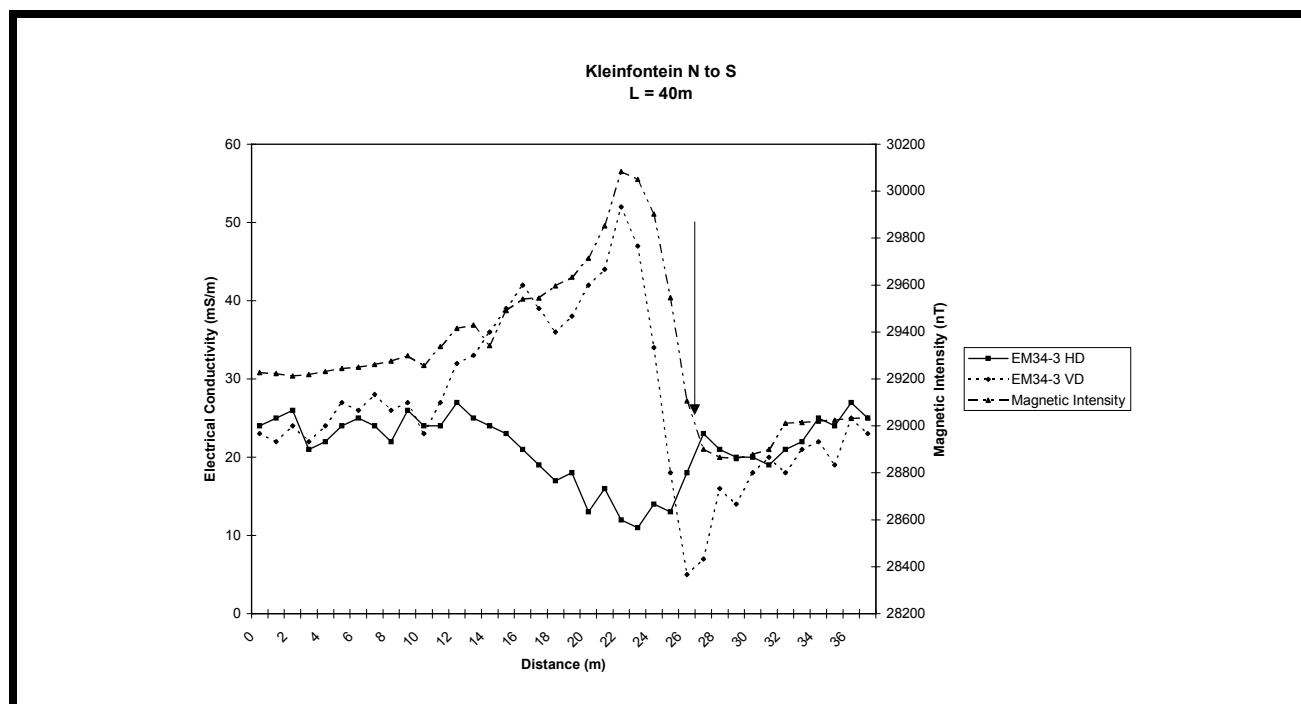


Figure 4.28. Geophysical profiles on the farm Kleinfontein 111JT.

The geophysical results obtained on both farms in association with the geobotanic indicator *Combretum erythrophyllum*, suggest that this species is associated with intrusions, most probably of diabase, on the farm Klipspruit as well as diabase and a dry stream (periodical in flow) on the Kleinfontein farm. Both anomalies depicted in Figures 4.27 & 4.28 indicate significant amplitudes in nano-tesla (nT). The electromagnetic profile, in association with the magnetic profile in Figure 4.28, indicates 'text book' examples of the behaviour of electromagnetic current in the sub-surface in the presence of a conductor. Both dipole components are parallel in the absence of a conductor, but changes occur in electrical conductivity values in the presence of such a conductor. The HD decreases when the conductor is close to the surface, caused by the poorer coupling of the EM-current, but increases on the contact zones of the conductor where the dip, soil-cover and weathering also increase. The opposite is true for the VD. The new borehole is denoted by the arrow, station 27 m. The existing, lower-yielding borehole is situated 100 m west of this profile, but its position on the same anomaly is more or less situated at station 20 m. The limited extent of this profile is attributed to the fact that station 38 m is situated at the dry riverbed and implies a property boundary.

Notable increased levels of humus, consisting of C, N and CEC, are found at the geobotanic indicator site on the farm Klipspruit 89JT. Furthermore, available cations and Fe and Mn are available at increased concentrations. Higher values of iron can be attributed to the geochemical weathering of igneous rock (Table 2.2) that contains higher iron values than the sedimentary and metamorphic rocks in this geological environment. However, phosphorus levels are lower, as is often the case at geobotanic communities, based on the findings of this study. The resistivity of the soil is considerably lower than the other sampled site at the borehole yielding about 1 200 Ω /h.

***Combretum erythrophyllum* is the geobotanic indicator in this case study. This is based on the fact that this species usually occurs along surface water bodies. Its occurrence in the field indicates the presence of groundwater.**

18. Rietfontein 88JT

The geomorphology of this area comprises the broad floodplain of a small stream, the Alexander Spruit, surrounded by steep diabase cliffs, a few metres high, close to its western bank. The occurrence of a *Ficus* species on the cliff is considered a crucial geobotanical or phreatophytical indicator since the *Ficus* species are closely related to water courses in the Lowveld and other parts of Southern Africa. This *Ficus* is situated several metres away from a *Combretum erythrophyllum* (see the two previous case studies relating to *Combretum erythrophyllum*). The appearance of species such as *Acacia caffra* and *Ziziphus mucronata* was taller and more robust than the other species in the surrounding field, which can also be viewed as a hint. A few small specimens of *Zanthoxylum capense* were observed growing under the *Ficus*. The latter species was identified as a geobotanical indicator in other geological settings (Scott & Le Maitre, 1998).

The focus of geophysical exploration fell on these geobotanical indicators. This association of indicators was found to be quite unique on this farm and in the local area. Electromagnetic and magnetic profiling was carried out perpendicular to the strike of the diabase cliff (north-south) and the associated geobotanical indicators so as to intersect any diabase intrusions and other small lineaments. It began close to the stream, continuing to the top of the cliff. The vegetation above the cliff is sparser and more uniform, where only *Acacia* and *Rhus* species with some scattered *Ziziphus mucronata* occur. The profile can be seen in Figure 4.29.

The geophysical profile, as seen in Figure 4.29, indicates a homogenous layered earth (no intrusions that can serve as an aquifer are evident), based on the parallel symmetry between the HD and VD dipoles and also the small amplitude range in the magnetic intensity, except in the proximity of station 20 m, denoted by the arrow. This is the station where the *Combretum erythrophyllum*, *Ficus ingens* and *Zanthoxylum capense* species occur in association with the other aforementioned species. Abrupt changes in the magnetic and electromagnetic fields can be observed, with a magnetic amplitude of approximately 60 nT and HD>>VD. A borehole was drilled in this vicinity (25 m deep), since the cliff made drilling next to the *Ficus* almost impossible, and a yield of 8 000 l/h was obtained, with water being struck at a depth of only 8 metres. The borehole log

consisted of about 2 m of alluvium, 4 m of hornfels and the remaining 19 m, of diabase in various grades of weathering. The aquifers in this case are governed by contact zones of diabase intrusions with the sedimentary rocks of the Pretoria Group.

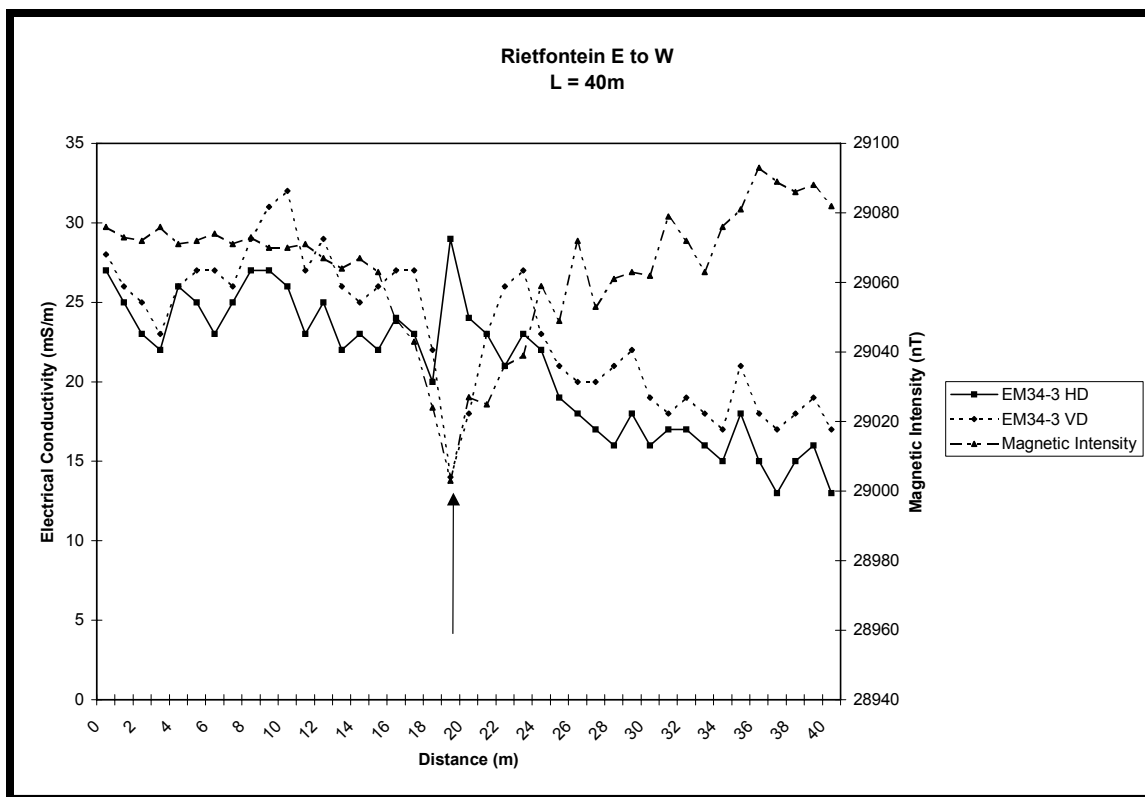


Figure 4.29. Geophysical profiles on the farm Rietfontein 88J1.

Sampling of soil was carried out at station 20 m (borehole, geobotanical indicators) and station 10 m, close to the spruit. The soil in the floodplain of the spruit (not a geobotanic community location) was more enriched with available cations and a lower resistivity than the other, but remarkably the geobotanic community recorded overall higher values of CEC and sulphur, with some variations in the organic carbon content that increased as depth did. The greater CEC content is a crucial parameter with regards to this land type, where the soil consists of Hutton type soil, which is rich in clay. Clay normally exhibits advanced cation, organic carbon and CEC values compared to other soil fractions. A higher CEC value indicates the presence of nutrient-cycling and advanced or different geochemical weathering processes that is in itself a geohydrological target.

Combretum erythrophyllum, *Ficus ingens* and *Zanthoxylum capense* are the geobotanic indicators in this case study. This is based on the fact that the first two mentioned species occur normally along surface water bodies and unconfined aquifers. Their occurrence in the field indicates the presence of groundwater. The specie *Zanthoxylum capense* tends to establish itself in clay soils normally derived from the geochemical weathering of igneous rock. Weathered igneous rock normally acts as an aquifer.

19. Waterval 386KT

In the Magaliesberg Formation of the Pretoria Group, the farm Waterval 386KT is situated between Lydenburg and Burgersfort in the Watervalsrivier Pass. The Watervals River flows through the property. Along the banks and narrow floodplain of the river surficial deposits, alluvium and scree are abundant but rapidly alter to shale layers and mighty quartzite cliffs decorated with waterfalls, which create a local escarpment. The geological map (Pilgrim's Rest, 1986) and field observations do not indicate the presence of major lineaments in the quartzite. Wooded valleys and gorges, such as the one depicted in Figure 4.26, are not obvious and only minute in size. Groundwater abstraction along the river banks is the norm, but boreholes drilled in quartzite are rare. However, to pump water from the river over the cliffs is not economically viable owing to the presence of a head of more than 100 metres, though water is needed on the local escarpment for irrigation and livestock watering. This case study focuses on aquifers associated with geobotanic indicators on the local escarpment. The aforementioned escarpment is covered with species such as *Diospyros lycioides* (bluebush), *Grewia flava* (velvet raisin), *Schotia brachypetala* (weeping boer-bean), *Sclerocarya birrea* subsp *caffra* (marula) and *Terminalia sericea* (silver cluster-leaf), all of which fall into the category of the spine-free species, thus indicating sandy conditions low in nutrients (see Tables A1.13a&b). The appearance of a lonely *Ficus ingens* species on the escarpment attracted attention to this area. A magnetic profile along the *Ficus* indicated the presence of a small dyke, probably a diabase one of a couple of metres in extent, Figure 4.30.

The direction of the profile would lie west to east since the probable diabase dyke strike lies northwest-southeast, as inferred from diabase outcrops 45 m below the *Ficus* species and the aerial photograph (annexure). The measured amplitude of 300 nT

appears erroneous when compared to the other readings. The arrow in Figure 4.30 indicates the drilling spot for the borehole, which yielded 5 500 l/h, where water was struck at a depth of 34 metres. The borehole log consisted of gravel and sand (0 – 1 m), quartzite (1 – 31 m), fractured quartzite and weathered, water-bearing diabase (31 – 36 m), unweathered diabase (36 – 38 m), weathered, water-bearing diabase (38 – 39 m), and quartzite (39 – 75 m).

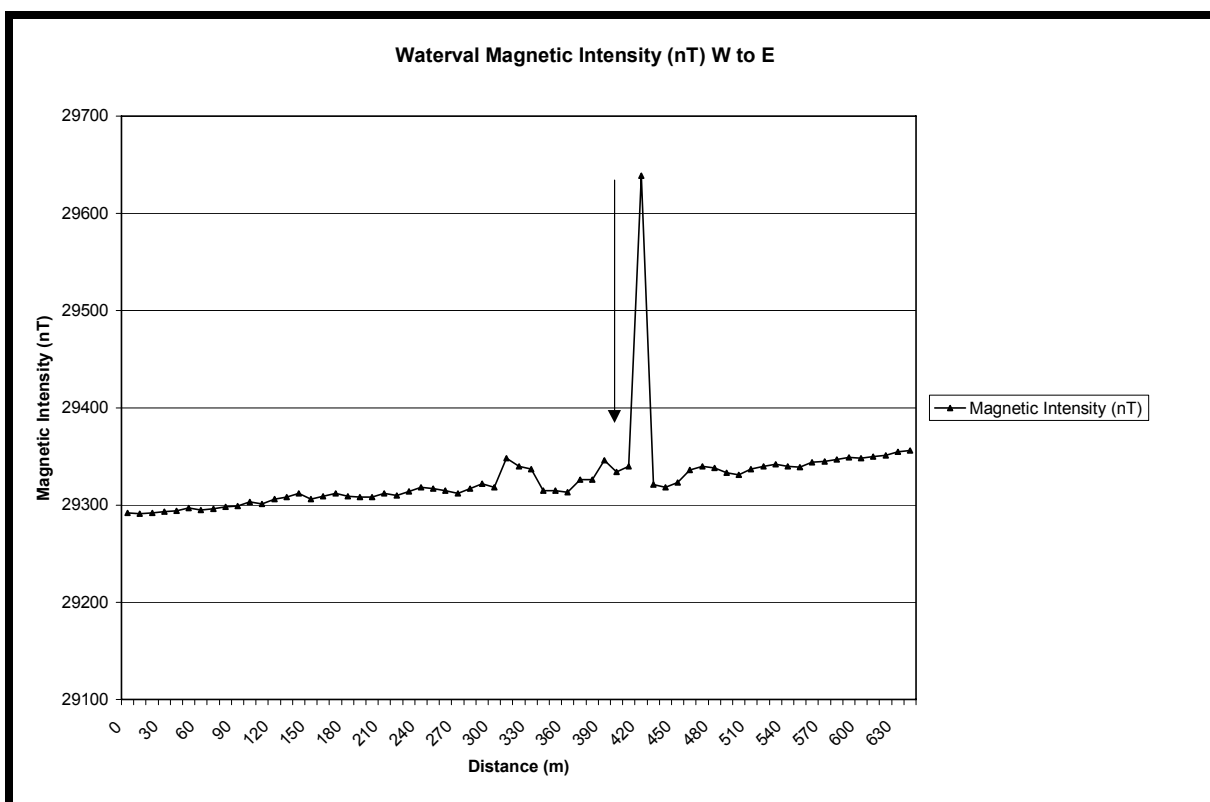


Figure 4.30. Magnetic profile on the farm Waterval 386KT.

Soil sampling was conducted at the borehole in the proximity of 400 m while the remaining sample was obtained at station 370 m. The pH at the borehole site is higher than that of the other site, which is often the case with intrusions since soil with a higher clay content tends to record higher pH-values compared to that which lacks clay. Furthermore, according to the land type map and previous case studies (annexure), the weathered soil of the mafic intrusions tends to be of the Hutton soil series, where the weathered quartzite exhibits a shallow soil profile and is representative of the Mispah soil series; therefore differences in pH and soil nutrients are obvious. The Hutton soil series is more suitable for rooting than that of the Mispah series. Cation availability at the

borehole site is also higher, although the available P-value is lower. The resistance of both samples is quite high, which may indicate the presence of dry silt and sand, while heavy metal concentrations vary. With regard to the humus content, the borehole site is slightly more enriched in nitrogen and indicates an increase in the cation exchange capacity as the depth increases. The surface of the area may also be covered with weathered quartzite material poorly enriched in humus and nutrients, particularly if these values are compared to those obtained in the Kwenya Basin, as previously discussed. Relative to depth, a change in soil chemistry is observed, most probably because erosion and weathering processes did not alter the soil texture.

***Ficus ingens* is the geobotanic indicator in this case study because it is established on the weathered, water-bearing diabase (lineament) contact zone that carries higher concentrations of nutrients when compared to the soil derived from the weathered quartzite.**

4.6.1 Remarks

Intrusions of diabase create numerous opportunities for the development of aquifers in the sediments of the Pretoria Group in the Lydenburg Area. Volcanic events at the time of the Vaalium Eonothem (aged 2 700 Ma) ensured the metamorphosis of the mentioned sediments and it is quite obvious that without these volcanic activities, the water-bearing properties of the sedimentary rocks would be substantially reduced, especially since most of the rocks are shale and mudstone that act as aquitards. Geophysical methods can be employed with ease in a diverse geological environment since this is the weathered product of the different rocks and the strike and dip of these rocks indicate different signatures regarding the obtained geophysical anomalies and profiles. The magnetic method indicated dykes that vary in extent and amplitude. Electromagnetic profiling effectively delineated weathered horizons near the intrusive contacts since $H_D \gg V_D$ in these cases, with electrical conductivity values ranging from 5 to 50 mS/m, depending on the position of the weathered contact. Schlumberger depth sounding results in one case suggest the presence of deep weathering that could be attributed to palaeo-channels. However, in a woody and elevated area such as this, geophysical exploration is somewhat difficult because visibility and the operation of geophysical

instruments with cables are restricted. The identification and presence of geobotanic indicators, indicated in Table 4.6, not only renders geophysical exploration more efficient but also delivers the desired results. This was proven on the farm Waterval 386KT with its luxuriant vegetation cover being characteristic of a sandy environment. The position of a small dyke was betrayed by a *Ficus* species.

Notable higher humus values for all the sites associated with intrusions and successful boreholes are evident in the analyses of the soil samples. Values of CEC and organic carbon are more or less greater than the site sampled without geobotanic indicators in all the cases. Cations, such as Ca, Mg, K and Na are most often abundant or found in higher concentrations at geobotanic sites, characterised by a higher pH-value, and in most cases a higher conductivity of the soil is present. Heavy metal concentrations vary from site to site, but available phosphorus values are in all cases higher for the site associated with no geobotanic or other special features. This may be attributed to the small quantities of P (normally <10 mg/kg) found in the soil, while any available P is taken up by the vegetation, which implies that less P is available in the soil. Since no significant vegetation occurs on the other site sampled, P is not readily extracted from the soil and hence more P is available.

Aquifer characteristics listed in Tables A1.13a&b indicate higher yields for the boreholes investigated than the indicated average yield for the geological formation tabled by Frommurze (1937). Depths to water strike, that of the borehole and the water table vary from case to case, most probably owing to the extreme difference in locations of the various case studies ranging from palaeo-channels to foothills and an escarpment. However, taking the geobotanic features into consideration, all the borehole case studies are relevant and indicate the diverse nature of the occurrence of these species. A summary of the soil characteristics and geobotanic indicators is tabled in Table 4.6.

Table 4.6. Comparisons between soil characteristics of geobotanical indicators and their surroundings.

Parameter	Geobotanical community (A)	Surroundings (B)
pH	5.97-6.69	4.88-6.98
P (mg/kg)	1.37-4.70	1.38-19.60
Ca (mg/kg)	216-1968	97-1734
Mg (mg/kg)	97-987	42-888
K (mg/kg)	26-126	6-200
Na (mg/kg)	6-28	11-51
Fe (mg/kg)	40.57-155.05	15.64-143.97
Mn (mg/kg)	72.06-880.51	25.02-674.63
Zn (mg/kg)	0-1.99	0.12-2.69
Al (cmol _c /kg)	0-0.095	0-1.021
Resistance (Ω)	790-6000	780-5200
%C	0.01-2.32	0.03-2.49
Total N%	0.007-0.107	0.004-0.177
S (mg/kg)	8.95-39.13	9.20-71.90
CEC (cmol _c /kg)	3.831-24.36	3.42-28.83
Geobotanical indicator species under column A	<i>Combretum erythrophyllum</i> (river bushwillow) <i>Ficus ingens</i> (red-leaved fig) <i>Zanthoxylum capense</i> (small knobwood)	
Geology	Diabase intrusions in sediments of the Pretoria Group	Quartzite, shale and hornfels (Pretoria Group)
Aquifer yield (ℓ/h)	5 500 – 10 000	Not applicable

4.7 VAALIUM EONOTHEM: RHYOLITE OF THE ROOIBERG GROUP AND LOSKOP FORMATION IN THE VERENA-MIDDELBURG AREA

Information pertaining to the case study area regarding its geographic locality, climate, veld types, geology, geohydrology, geophysics, geobotany, soil sampling is tabled (see annexure).

20. *Enkeldoornoog 219JR*

The area between Pretoria and Marble Hall is largely covered with rocks of the Bushveld Igneous Complex, including granophyre and granite, although, in certain localities outcrops of rhyolite of the Selonsrivier Formation are evident. The difference in lithology defines geomorphological landscapes such as hills (granophyre), valleys, plains and mountains (rhyolite) and plains (granite). Intrusions of diabase and lineaments cross these rocks, but according to the Pretoria (1978) geological map, the occurrence of these intrusions is limited. The terrain investigated is a flat plain with a low decline towards the north. The plain is scattered with fragments of weathered rhyolite as reflected by the geological and land type maps (annexure), whereas the lower lying area in the dip consists of deep reddish brown soil, which is utilised for subsistence farming purposes. Vegetation, namely trees and shrubs, is only evident in the deep soil with species such as *Clerodendrum glabrum* (tinderwood) and *Rhus lancea* (karee) occupying localised spots. A geophysical investigation of the area was requested in order to supply the farmers with water for irrigation purposes. As hinted by the sporadic growth pattern of the tree species just mentioned, as well as the deep soil, a lower-lying area that can be attributed to a higher degree of weathering than the rock in the surrounding country, the presence of termitaries in this lower lying area and the absence of rhyolite rock fragments in the lower situated area, the investigation was focussed on this locality. The results of the geophysical investigation can be seen in Figure 4.31. The orientation of the geophysical profiles was north-south in order to obtain readings from the shallow soil resulting from weathered rhyolite as well as the deep soil, most probably diabase. The variations in soil and rock types mean that the magnetic and electromagnetic methods are extremely useful due to notable differences in magnetic intensity (diabase: high magnetic intensity and rhyolite: low magnetic intensity) and electrical conductivity (high conductivity for weathered diabase and low conductivity for

weathered rhyolite). These differences make it easy to recognise the geophysical profiles where these rocks occur.

The geophysical profile indicates a small, but significant variation in the magnetic intensity with an amplitude of 20 nT and significant associated fluctuation in electrical conductivity, from about 25 mS/m to –5 mS/m. This indicates the alteration near station 300 m from a highly conductive zone (deep soil) to a highly resistant zone, which is most probably relatively unweathered rhyolite. Readings of around 0 mS/m are characteristic for rhyolite in the Verena-Middelburg area (Meulenbeld, 1998). Hence, electromagnetic profiling is of great assistance in a highly weathered geological area like this since conductors are easily indicated without much confusion and error. Combined with the magnetic method, zones of deeper weathering that act as confined aquifers can be identified with ease. As a result, the proposed borehole was located at station 210 m, Figure 4.31. The arrow also indicates this. This station is linked with the occurrence of the species *Clerodendrum glabrum* and *Rhus lancea* and a termitary. The borehole yielded 7 500 l/h, highly significant for this area. Fragments obtained from drilling indicated the presence of weathered diabase boulders at a depth from 16 to 20 m below the surface. The water strike was at 17 m below the surface. The overburden (0 – 16 m) consists of red soil and weathered diabase. Below 20 m, only unweathered diabase was encountered.

Soil sampling was undertaken at the drilled borehole and geobotanic indicators (station 210 m) and station 330 m, somewhat removed from the geobotanic community but representative of the rhyolite environment. Chemical analysis of the soil samples taken from the geobotanic communities indicates higher values of pH, Ca, Mg, Na, C, N, CEC and S throughout the sampled and analysed soil profile (0.5 and 1.2 m). Variations in P, Fe, Mn, Zn, K and resistivity occur with depth (note the extremely high Zn-value of 47.20 mg/kg at the geobotanic community, depth 0.5 m). Of significance is the higher amount of humus in the soil together with higher levels of available cations at the geobotanic community. Humus in conjunction with clay content is responsible for higher values of C, N and S as a result of organic life in the soil and humus (Brady, 1990). This fact will be investigated during this study at a later stage. Rhyolite is composed mainly of quartz and alkali feldspars K/Na/Ca-aluminum silicate, while diabase consists largely of plagioclase feldspar, Na/Ca-aluminum silicate. One might assume that rhyolite derived soil will be

enriched in potassium. The soil sample analysis indicates that the amount of potassium increases with depth compared to the diabase derived soil. Higher values of Ca, Mg and Na for the latter can be attributed to higher levels of occurrence of these elements in diabase than rhyolite; refer to Table 2.2, Chapter 2, rhyolite and basalt. Diabase is a form of palaeo-basalt (Schumann, 1985).

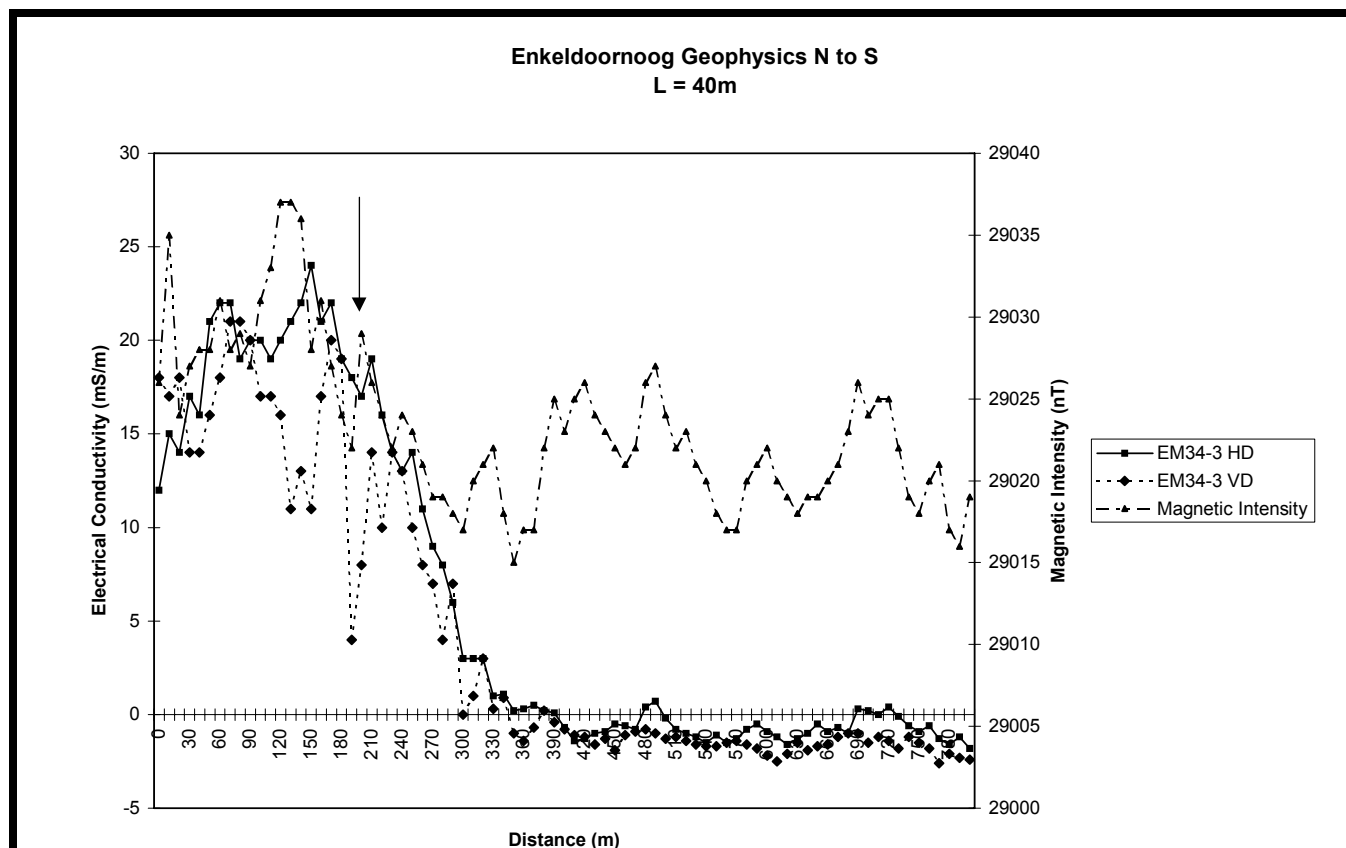


Figure 4.31. Geophysical profile of the farm Enkeldoornoog 219JR.

The higher level of nutrients found at the geobotanic community is representative of weathered diabase (Hutton soil series), compared to the soil sample taken from the relatively nutrient and tree-poor Clovelly soil series (see annexure) resulting from the weathered rhyolite.

***Clerodendrum glabrum* and *Rhus lancea* are the geobotanic indicators in this case study. These trees prefer the deep, nutritious clay soil of the weathered diabase among the shallow, nutrient-poor gravel soil and sparse vegetation of the weathered rhyolite. The weathered diabase acts as an aquifer.**

21. *Kwaggasfontein 460JS*

Rhyolite covered by a thin layer of sandstone and shale belonging to the Vryheid Formation of the Karoo Superground and surrounded by small outcrops of granite porphyry of the Rashoop Granophyre Suite (Bushveld Igneous Complex) can be found on the farm Kwaggasfontein 460JS. Outcrops of rhyolite and granite porphyry occur in stream beds. The thickness of the Vryheid Formation is estimated to be around 20 m, extrapolated from the Pretoria (1978) geological map by contour elevations. Lineaments intersect the rhyolite, with a southwest-northeast strike. Due to this Formation's location, close to the escarpment and elevation, the climate is mild with cold winters. The Bankenveld veld type is characterized only by grass plains and some scattered *Acacia karroo* (sweet thorn) species. No protection from the elements and fire is possible in this flat terrain which therefore restricts the development and establishment of various other shrub and tree species. From the writer's previous experience, the presence of *Acacia karroo* is used as an indicator for variations in soil structure and geology. The land type map (annexure) indicates soil suitable for agricultural purposes and most of the area is cultivated land. The purpose of geophysical groundwater exploration in this area is based on the presence of mine water decanted into the natural surface water regime, and consequently another water source needs to be found to supply water of an improved quality. Rhyolite in itself is a poor aquifer (Frommurze, 1937), Van Schalkwyk *et al.* (1995) and Meulenbeld (1998) and therefore the only alternative is to identify areas of weathered diabase intrusions and also search for a thick overburden cover over the rhyolite, where an elevated water table could possibly be situated. These features may act as confined aquifers. From the geological map and experience gained from groundwater pollution borehole drilling around the surrounding coal mines, it is extrapolated that the entire area is underlain by rhyolite. Areas with an expected thicker Karoo Supergroup (sediments) overburden (around 20 m) were preferred since these sediments can also act as an aquifer, or the Karoo/rhyolite contact zone can do so. The geophysical profile on the farm, as depicted in Figure 4.32, indicates a broad magnetic feature from station 100 m onwards. The direction of the profile, north-south, was chosen in order to intersect with the main lineament as indicated on the geological map. The decision to employ the magnetic and electromagnetic methods was based on their ability to differentiate on the profile between the different rocks encountered in this geological setting, based on differences in measured magnetic intensity and electrical

conductivity. The HD>VD for the section before 100 m and the electrical conductivity here is notably higher than those obtained in the other rhyolite terrains mentioned. This is owing to the overburden of sandstone and shale that is more weathered and consequently holds more moisture. The arrow denotes the position of the borehole. With a depth of 48 m, water was struck at a depth of 21 m in weathered diabase (confined aquifer) with a yield of 4 700 l/h, the same as the average tabled by Frommurze (1937) and in the same range as noted by Meulenbeld (1998) on the farm Luipaardsfontein 444JS, although the latter's aquifers were the result of weathering and joints in the rhyolite. Some *Acacia karroo* trees, quite out of place in this area, adorned the locality of the drilled borehole. Exotic species such as wattle and bluegum are abundant and can easily be observed on the aerial photograph (annexure). The borehole log showed the following lithologies:

- 0 – 2 m: loam
- 2 – 5 m: clay
- 5 – 12 m: shale
- 12 – 19 m: sandstone
- 19 – 22 m: weathered diabase (water strike 21 m)
- 22 – 48 m: unweathered diabase.

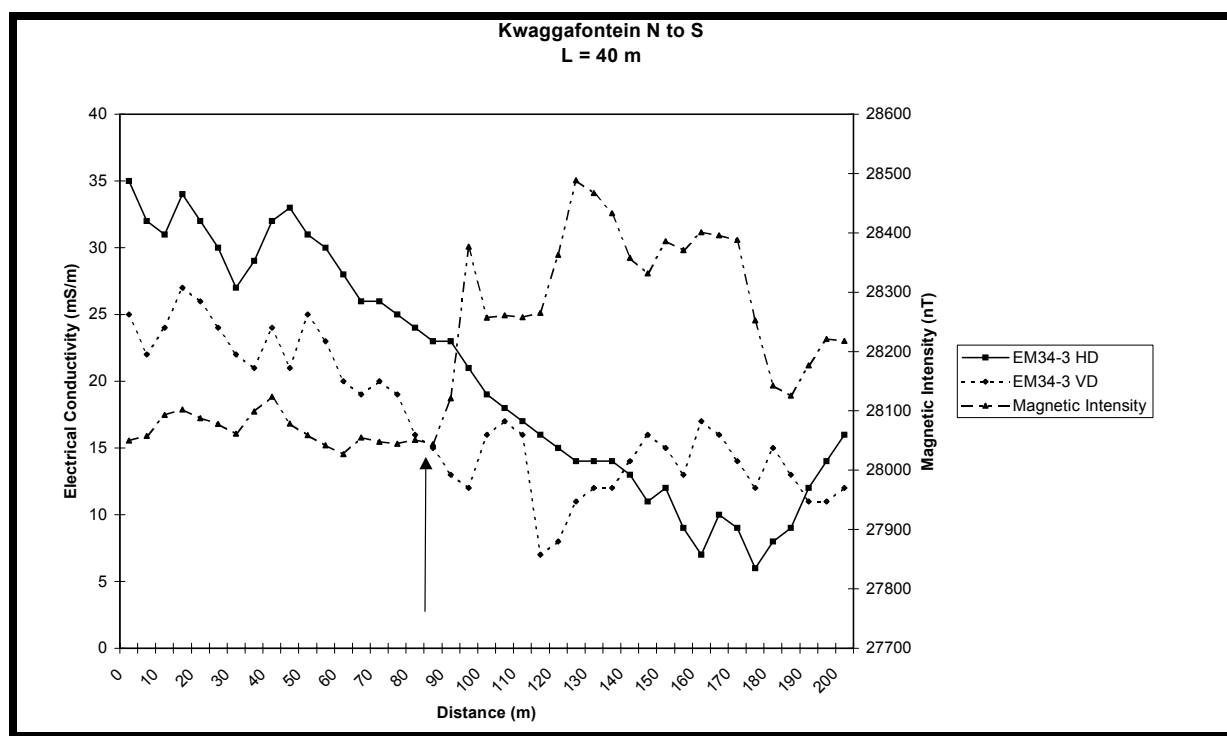


Figure 4.32. Geophysical profile on the farm Kwaggasfontein 460JS.

The geophysical profile indicated in Figure 4.32 perfectly illustrates the transformation from the Karoo overburden to the rhyolite and diabase contact. Note the change in dipole conductivity when both coils move over the broad diabase intrusion (lineament), $VD > HD$.

In line with the other case studies offered, soil samples were taken and analysed. One soil sample (0.5 and 1.2 m) was taken at the *Acacia karroo* (borehole) locality (station 90 m) and the remaining sample at station 110 m. The values of pH, Ca, Mg, conductivity, Mn, Al-toxicity, CEC and S are all higher for the borehole locality. The values correlate in a way with the listed results in Table A1.15 obtained from Land Type Survey Staff (1987), especially P, Mg, Zn, C and CEC values. As remarked earlier, it should be recognised that soil is heterogeneous and varies from place to place and from time to time, depending on climatic events. Important to note are the overall higher values for CEC and S at all the geobotanic communities presented in this section. This indicates the presence of increased clay and humus levels that are crucial for plant life.

The land type map distinguishes between the kinds of soil found on the farm, because the soil derived from the weathered shale and sandstone forms the Avalon soil series, while the weathered rhyolite defines the Hutton soil series.

***Acacia karroo* is the geobotanic indicator in this case study. This species is rooted in the weathered, water-bearing contact zone between the Karoo sediments and the intrusive diabase.**

22. *Rhenosterkop 452JR*

One of the prominent land features around Bronkhorstspuit is Rhenosterkop, reaching an altitude of almost 1700 masl. According to the Pretoria (1978) geological map, this kop is the remnant of a volcano of the Loskop Formation. The volcano has distinct terraces on its eastern side. Pyroclastic rocks and rhyolite can be found. Drainage patterns on this feature are familiar to other pyroclastic sites, where streams disappear into the sub-surface and appear a few metres further away on the surface again. According to Frommurze (1937) it is important to identify zones where the rocks weather into fairly soft rocks along lines of crush where subsequent movement has taken place.

On low ground, too, weathering may be appreciable, and both major and minor jointing comprise a feature that should be looked for. Small springs, a few perennial but mostly annual, issue from joints and fissures in this rock especially after heavy or prolonged rains, and advantage can often be taken of these indications. The case study represents a well excavated in the rhyolite rock close to a spring, where a stream that has disappeared surfaces again. The water flow occurs on joint planes, where this flow is restricted by joint planes that dip at a perpendicular angle to the previous one. Even if the yield of the well is only 2 050 l/h, advantage has been taken of jointing and plausible results obtained at only 2 m of depth. Close to the well, clusters of trees are observed. These latter are the origin of this research.

The aerial photograph (annexure) of Rhenosterkop indicates clusters of trees as small spots scattered on the middle slopes of Rhenosterkop. The slopes are extremely rocky, as the land type series map indicates. Termitaries on these rocky rhyolite slopes are all weak red in colour, except for those growing amidst the tree clusters. These are orange to reddish brown. The tree clusters include species such as *Ximenia caffra* (sourplum), *Acacia karroo* (sweet thorn), *Euclea crispa* (blue guarri) and *Ziziphus mucronata* (buffalo thorn). Other scattered tree species such as *Cussonia paniculata* (highveld cabbage tree) and *Pittosporum viridiflorum* (cheesewood) occupy narrow valleys or small gorges along perennial streams but are not important for this case study, especially as these sites are inaccessible to drilling machines. Geophysical profiling, including magnetic and electromagnetic equipment, along these tree clusters indicates the presence of small intrusions. This explains differences in the colour of the termitaries since the intrusions are most probably formed by diabase that weathers to a red clay. The clay nutrition value must be different to that of the shallow weathered rhyolite and able to support larger botanic species such as trees, compared to the grass cover of the rhyolite. This will be commented on in the discussion of the soil analysis. The association of tree clusters with intrusions is indicated in Figure 4.33, where an arrow denotes the presence of a tree cluster. Five tree clusters all associated with intrusions can be seen over the profile of 565 metres. Lineaments in this area tend to have a northwest-southeast strike. The orientation of the profiles is chosen so as to intersect this lineament (if possible) and to move across various tree clusters.

The highly resistive rhyolite (rock, gravel) distinctively contrasts with the conductive, weathered (clay) diabase on the geophysical profile, with notable $HD \gg VD$ in these zones and corresponding variations in the amplitude of magnetic intensity. The small and low range of electrical conductivity values in general is attributed to the small diabase intrusions surrounded by unweathered rhyolite that are still included in the coil separation of $L = 40$ metres. Thus even over the diabase intrusions, current still passes through the rhyolite and this makes its mark on the overall electrical conductivity values.

The position of the well is 40 m south of the arrow at station 255 m. It is in close proximity to the tree cluster, but too shallow to be linked to a diabase intrusion in depth, especially if it is noted that the water in the well is attributed to the presence of joint planes in the rhyolite. Besides this, soil sampling was undertaken at station 255 m (geobotanic community) and station 285 m (rhyolite rocks on soil). Tree species encountered at the geobotanic community are representative of those mentioned earlier. These tree species are characteristic of all the tree clusters, where *Ximenia caffra* is not present at the last two tree clusters as indicated in the geophysical profile, from station 400 m (Figure 4.33). The depth profile of the well was investigated by a Schlumberger depth sounding, next to the well. The electrodes were laid out north-south for reasons of accessibility. The rhyolite does not possess a strike and therefore it does not matter in which direction the electrodes are laid out. The results are shown in Figure 4.34, representing a HKH-type sounding curve. The sounding indicates a resistive soil overburden with a lower resistivity at a depth of 1.5 m below the surface. The well indicates that this is possible since the water-bearing joint occurs at this depth. Thereafter the sounding indicates an increase in resistance greater depth, most probably unweathered rhyolite. It appears that another possible water bearing feature is present at greater depth (about 15 m below the surface) with a reduction in resistance for a substantial distance. Fortunately other boreholes, drilled in the same locality, indicate that fracturing of the rhyolite about 15-20 m from the surface, yielded groundwater. At times diabase is encountered at greater depth. The bedrock is unweathered rhyolite (high resistance). The yield of the well, considered to be of a shallow depth, is well above the average yield of the formation as noted by Frommurze (1937). Although no diabase is encountered at this well, it is evident from the (electro)-magnetic profiles and surroundings that clay and weathered diabase are present. The latter can be inferred

from the magnetic intensity and electrical conductivity readings because mafic rocks contain considerably more magnetite content than rhyolite (Table 2.2).

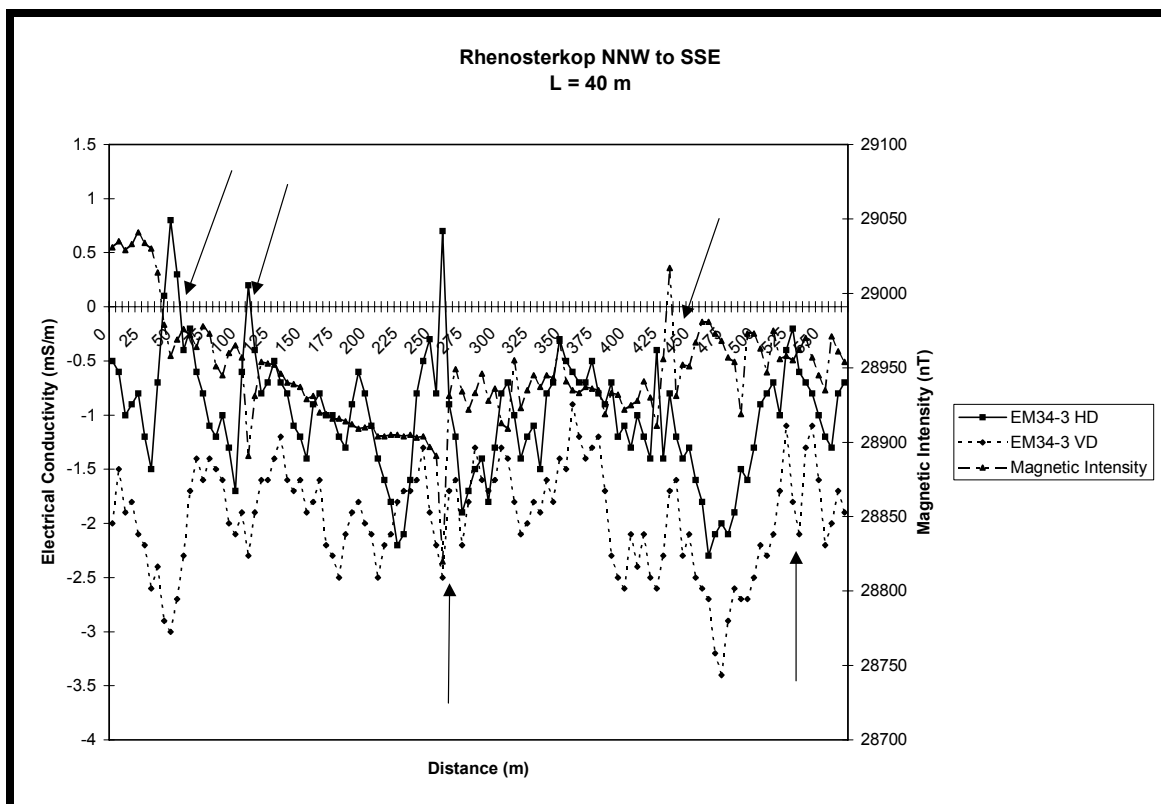


Figure 4.33. Geophysical profile of Rhenosterkop 452JR. Arrows denote tree clusters.

The presence of a geobotanic community on weathered diabase (intrusion) stimulates organic life and nutrient cycling. The soil sampling indicates higher levels of C (in depth), S, N and CEC for the geobotanic community. Other parameters that are notably higher for this community are Ca, K, Na and a lower resistivity. Differences in cation availability can be attributed to differences in the chemical composition of the mother rock. Aluminium toxicity is lower for the geobotanic community. This is significant if the land type (annexure) is considered, which indicates that rock (almost no weathering) is dominant. On a geochemical basis weathered rhyolite is less enriched in cations such as Ca and Mg and contains lower levels of Fe than diabase (compare basalt as it is also a mafic rock) if compared to Table 2.2. The low Fe-content enhances magnetic profiling interpretation as it shows no anomaly. The deficient levels of Ca and Mg are not favourable for vegetation growth, compared to the diabase soil. Therefore, it is easy to spot diabase intrusions on rhyolite owing to denser and more heterogeneous vegetation cover.

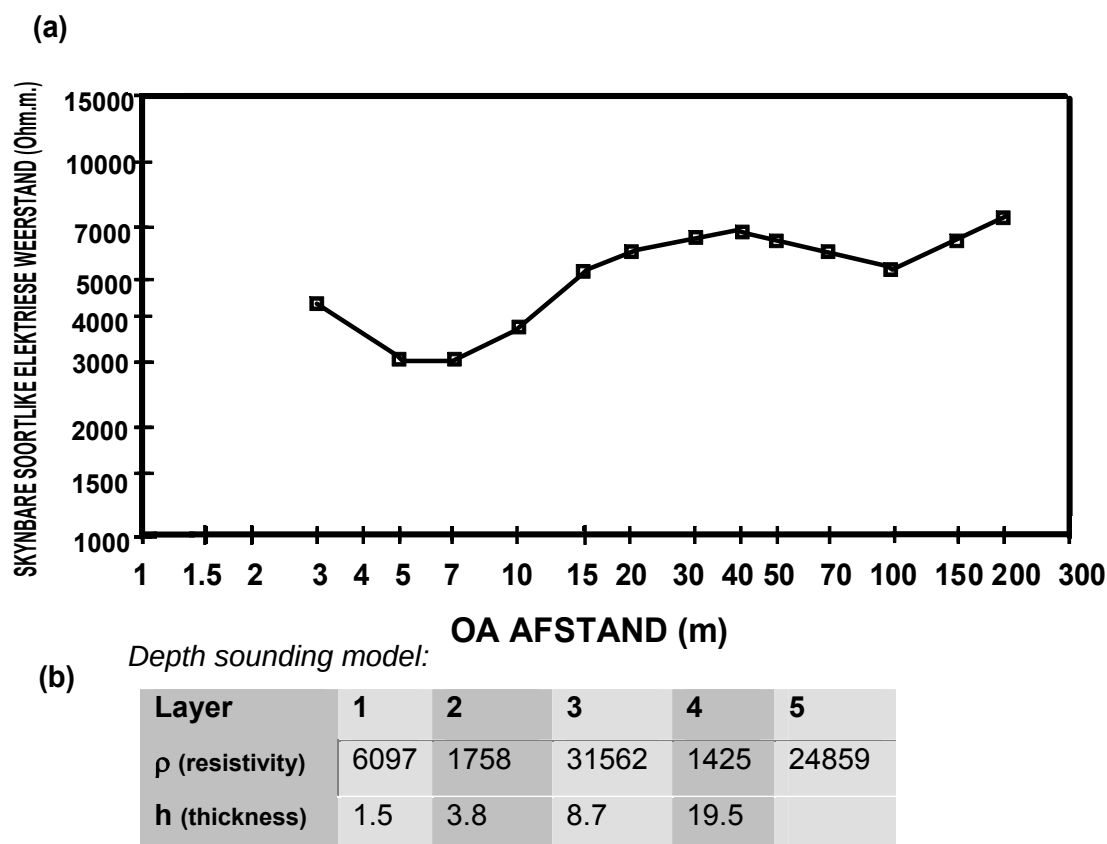


Figure 4.34. Schlumberger depth sounding on the farm Rhenosterkop 452JR.

Acacia karroo, *Euclea crispa*, *Ximenia caffra* and *Ziziphus mucronata* are the geobotanic indicators in this case study. These species prefer the clay soil of the weathered diabase among the gravel soil and sparse vegetation of the weathered rhyolite. The weathered diabase acts as an aquifer. These species also occur on shallow fractured and jointed rhyolite, although this fracturing and jointing arises next to weathered diabase horizons.

4.7.1 Remarks

Although rhyolite is not regarded as the best or the ideal aquifer, contacts with diabase and associated weathered contact zones indicated by botanic communities can improve groundwater exploration results and borehole yield. These botanic communities should be regarded as geobotanic indicators of extreme socio-economic value since they supply a community with valuable groundwater by means of a low cost, yet highly efficient exploration. Results listed in this study (Table A1.15) indicate an increase in the yield compared with that tabled by Frommurze (1937). This is remarkable, especially since the number of boreholes drilled since 1937 had to be increased owing to population growth and a greater demand from aquifers to deliver groundwater for the farming activities which were escalating as a result of economic pressures. The aforementioned scenario has resulted in a stressful impact on these aquifers. Notwithstanding this, geobotanic indicators still have the potential to indicate occurrences of groundwater zones with a greater-than-average yield than that published in literature. A possible explanation could be that geobotanic indicators have never before been studied in detail by groundwater scientists.

The characteristic geophysical signatures of rhyolite discussed in this section are noteworthy. The very low electrical conductivity, or rather, the electrical resistance, of the fairly unweathered rhyolite, contrasts highly with the conductivity of the weathered diabase, with $HD > VD$ in exploitable conditions. This contrast renders the electromagnetic method (EM34-3) extremely useful in this geological setting. Combined with the magnetic method, diabase intrusions are identified with ease and the weathered contact zones are suitable for drilling and are often delineated by geobotanical indicators. Direct current soundings are useful in areas of deep jointing and/or weathering.

Results from the comparison of soil analysis as indicated in Tables A1.15 & 4.7, indicate higher levels of CEC and S throughout the soil profile, with increases evident in C and N at greater depth compared to the soil sampled and analysed at the remaining site. The crucial importance of higher humus values in the soil, implied by the CEC, C, N and S values, will be investigated for all the case studies presented and discussed in the present study. Humus (and clay) are the deliverers of life and can support geobotanic communities in nutritious soil derived from weathered rock, notably diabase. As

indicated in Table 4.7, the communities with geobotanic indicators, and hence associated with diabase intrusions, record higher values of Ca, Mg, Zn, CEC and S with a lower Al-toxicity in common, owing to higher values of pH.

Table 4.7. Comparisons between soil characteristics of geobotanical indicators and their surroundings.

Parameter	Geobotanical community (A)	Surroundings (B)
pH	5.60-6.10	4.86-6.23
P (mg/kg)	0.73-8.52	2.02-8.75
Ca (mg/kg)	466-924	268-653
Mg (mg/kg)	80-508	77-138
K (mg/kg)	0-138	0-111
Na (mg/kg)	40-286	19-153
Fe (mg/kg)	30.88-202.22	40.38-234.13
Mn (mg/kg)	15.58-379.66	26.13-211.64
Zn (mg/kg)	0.26-47.20	0.16-1.84
Al (cmol _e /kg)	0-0.155	0-0.412
Resistance (Ω)	670-3200	1470-4300
%C	0.46-3.02	0.43-2.03
Total N%	0.037-0.118	0.041-0.098
S (mg/kg)	27.26-106.43	18.33-34.06
CEC (cmol _e /kg)	6.605-10.26	1.20-7.15
Geobotanical indicator species under column A	<i>Acacia karroo</i> (sweet thorn) <i>Clerodendrum glabrum</i> (tinderwood) <i>Euclea crispa</i> (blue guarri) <i>Rhus lancea</i> (karee) <i>Ximenia caffra</i> (sourplum) <i>Ziziphus mucronata</i> (buffalo thorn)	
Geology	Diabase intrusions in rhyolite of the Selonsrivier and Loskop Formations	Rhyolite (mostly unweathered) of the Selonsrivier and Loskop Formations
Aquifer yield (ℓ/h)	2 050 – 7 500	Not applicable

4.8 VAALIUM EONOTHEM: SEDIMENTS OF THE LOSKOP FORMATION AND A DIABASE SILL IN THE BRONKHORSTSPRUIT-MIDDELBURG AREA

Information pertaining to the case study regarding its geographic locality, climate, veld types, geology, geohydrology, geophysics, geobotany, soil sampling is tabled, (see annexure).

23. Klikeiland 524JR

The region south of Bronkhorstspuit is predominantly covered with outcrops of diabase sills amongst quartzite of the Rayton Formation. Diabase intrusions are easily spotted in this environment owing to the manifestation mainly of *Acacia caffra* (common hook-thorn) and *A. karroo* (sweet thorn) on diabase-derived soils, compared to the bare appearance of the quartzite. It is remarkable that one often finds *Acacia* bush, resembling Bushveld, in this veld type on diabase-derived clay soils. Climatic factors do not appear to hinder shrub and tree growth on these soils. Large diabase sill outcrops are evident and form prime agricultural lands owing to the deep, clay soil profile. Geophysical profiling (magnetics and electromagnetics) was conducted on the diabase, without intercepting other lithologies. Since the diabase has neither a strike nor gradient, the profiling direction was arbitrarily selected to be north-south. The aim of the profiling was to find deep weathered basins in the diabase that could act as confined aquifers. Weathered basins will be further investigated in this case by direct current (Schlumberger) soundings in order to determine the depth of weathering and drilling depth. The soundings were laid out in a north-south direction since the diabase does not pose a strike direction. Existing boreholes will be included in the profile in order to understand current aquifer conditions and probable yield that would sustain an irrigation pivot system, because this was desired by the landowner. However, based on experience, it is unlikely for the aquifers associated with this kind of geological environment to yield sufficient groundwater at only one borehole to drive an irrigation pivot system. It is wise to drill a few boreholes on the farm and to direct the groundwater to a dam linked to the pivot system. Although a number of geophysical profiles were conducted on the farm, only those associated with geobotanic communities will be included since the remaining profiles were determined on cultivated land with no reference to botany whatsoever. It is interesting to note that the geobotanic community

yielded the highest measured aquifer yield on this farm, 9 000 l/h (Figure 4.35), compared to the average 5 000 l/h of the existing boreholes.

The geophysical profile, as depicted in Figure 4.35, represents a small differences in magnetic intensity amplitude (<50 nT) over the entire profile. The electromagnetic profiling data is of beneficial importance because electrical conductivity values alter dramatically at some stations. The profile commences at the quartzite debris scattered over the soil for the first 40 m, whereafter the profile moves across weathered diabase soil with an increase in the electrical conductivity of the horizontal dipole component in particular. Some diabase boulders are evident on the surface.

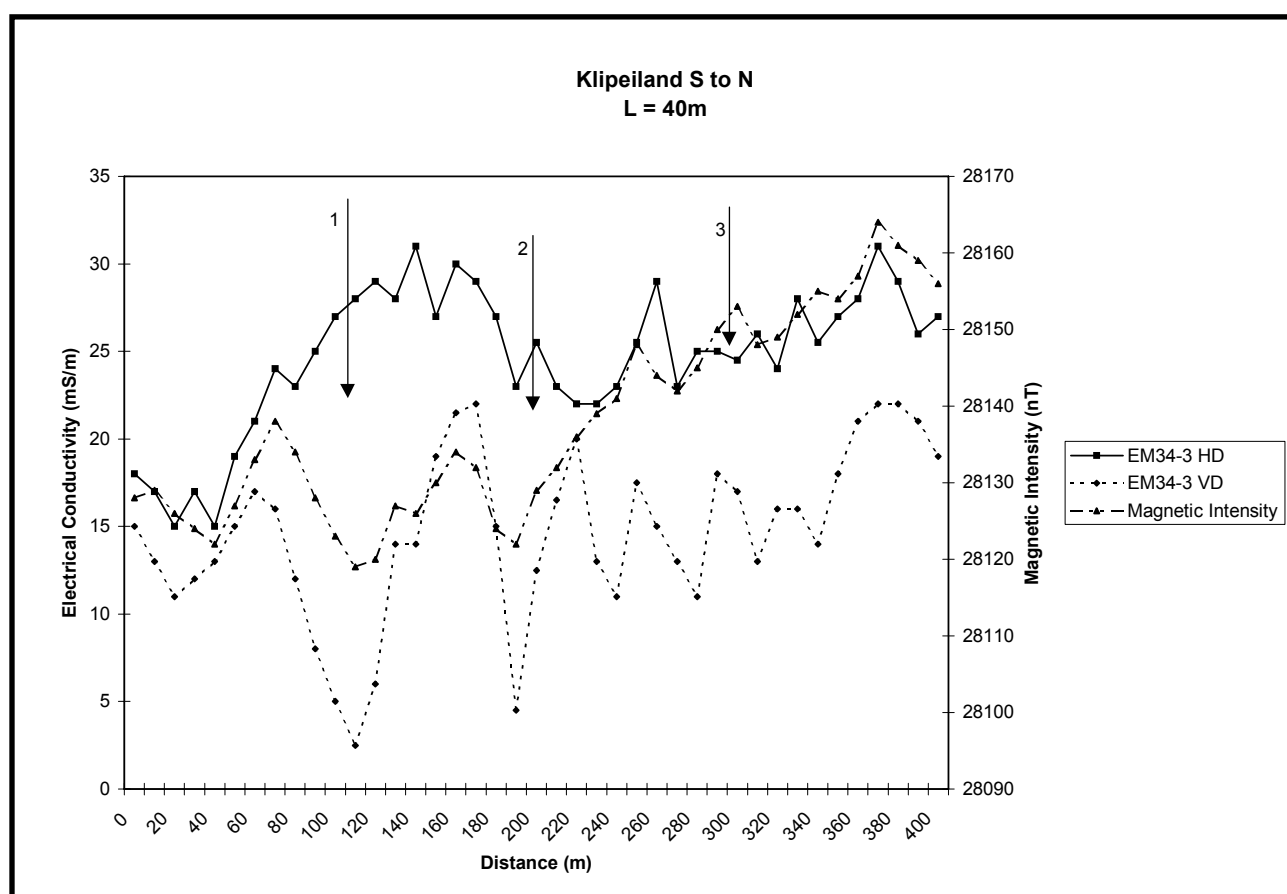


Figure 4.35. Geophysical profile on the farm Klipeiland 524JR.

Three arrows denote positions of newly drilled boreholes (1 & 2) and an existing borehole at number three. Position 1 was selected with confidence because tall *Acacia*

karroo with a large circumference together with *Euclea crispa* (blue guarri) were growing close to this spot. These *Acacia karroo*, compared with most of other *Acacia karroo* in this environment were conspicuous and extraordinary. The frequency of appearance of trees with such dimensions was exceptional on this farm. This is also true for *Euclea crispa*, for which the occurrence frequency was low: only six specimens were found in an area of approximately 15 hectares. The HD>>VD difference at position 1 is approximately 27 mS/m and significant for this profile. Since the area consists of weathered diabase in various phases and at various depths, a weathered basin deeper than that which normally occurs in this setting was expected and investigated by means of Schlumberger soundings, depicted in Figure 4.36. The sounding curve is an H-type, representing lower resistivity (weathering) in depth confined by a highly resistive layer or bedrock in depth. The model can be compared to models of this geological setting included in the work of Meulenbeld (1998).

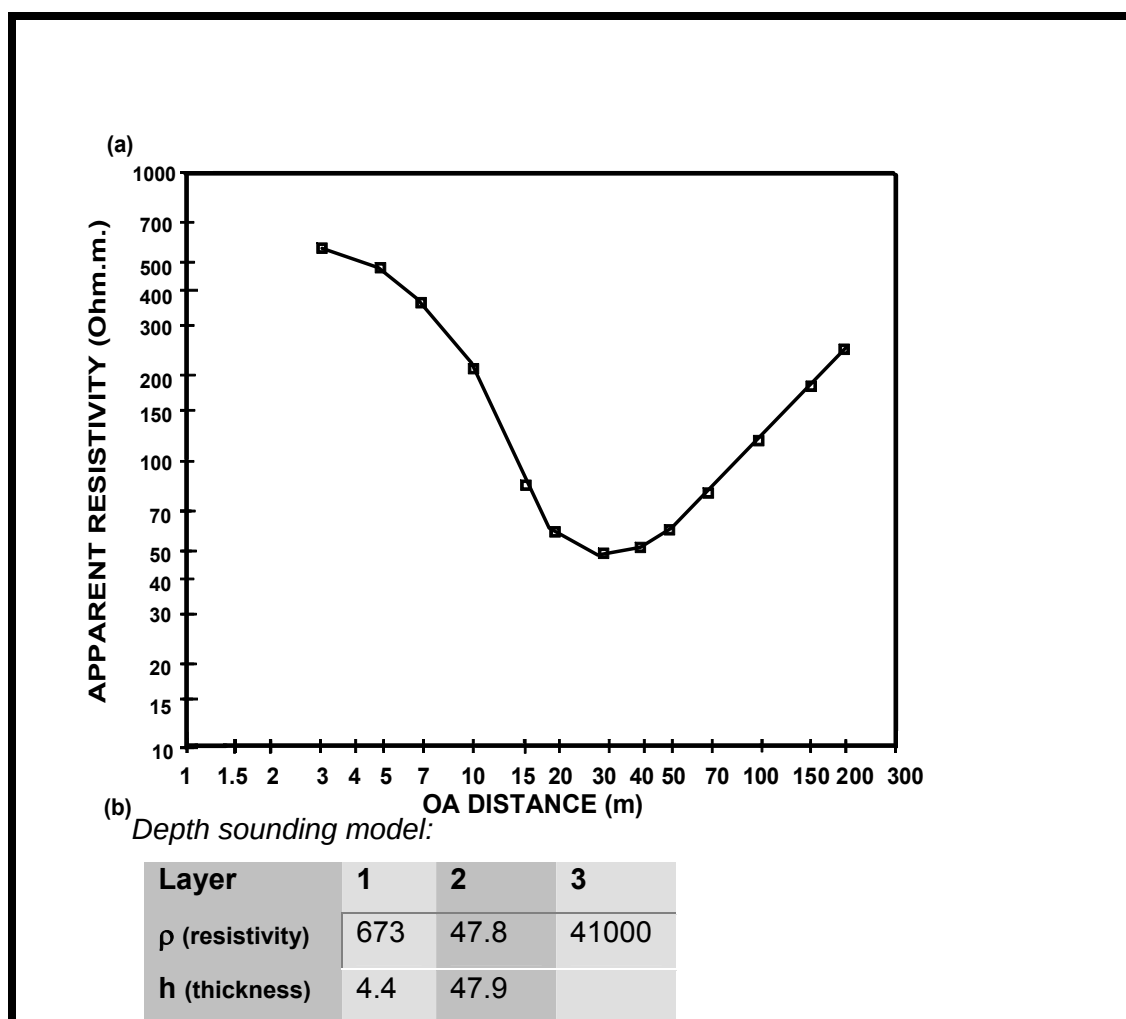


Figure 4.36. Schlumberger sounding at position 1, Klipelland 524JR.

The borehole at position 1 was drilled to a depth of 42 m, not in the indicated bedrock (unweathered diabase), but ended in large diabase boulders because they restricted further easy drilling. However, water was struck at a depth of 18 m. Clay was drilled to a depth of 16 m, whereafter some small boulders and fractured diabase were encountered. The total cumulative yield was 9 000 l/h. Position 2 was also drilled and yielded 6 700 l/h, where water was struck at a depth of 21 m and the total depth of the borehole was 47 m, before large boulders hindered further drilling. A species of *Euclea crispa* is found around position 2. The existing borehole (position 3) yielded 3 200 l/h. No significant anomaly or signature can be seen at this station regarding the geophysical profile. Some *Acacia karroo* shrubs adorn this spot. Compared to the earlier comprehensive study conducted by Frommurze (1937) and the only published results so far, the yield is twice as high as the average for diabase intrusions in this area with a shallower water strike (18 m versus 27 m). The depths of the boreholes are almost the same. All the borehole logs of this case study indicate drilling into weathered and fractured diabase.

At position 1, soil samples were collected at the specified depths of 0.5 m and 1.2 m, whereas the other sample was taken at station 170 m, between positions 1 and 2 and a spot with little weathering, owing to $HD \approx VD$. Some *Acacia karroo* specimens occur at station 170 m. The geobotanic community at position 1 grows on soil with a lower pH and P-content but lower Al-toxicity compared to the other site. Available cations are generally higher. The cation Mg is important for photosynthesis. The resistivity is considerably lower, mainly owing to differences in the degree of weathering. Furthermore, heavy metal content is higher and humus slightly (C, S, N and CEC). Cation exchange capacity is important with regards to water-holding capacity and survival during periods of drought. In addition, more nutrients can be held in suspension and be available to the roots. This might explain the robust growth pattern of the *Acacia karroo* at position 1. The soil sample representation by Land Type Survey Staff (1987) does not compare regarding cation availability at the case study area. In addition, the land type map (annexure) indicates only Hutton soil series for this locality since it represents weathered diabase and therefore is of little use because it does not distinguish between the changes in the geochemistry of the soil.

***Acacia karroo* and *Euclea crispa* are the geobotanic indicators in this case study. Deep, weathered, water-bearing basins in diabase are covered with these species. The *Acacia karroo* is different in its tall shape and large circumference from those encountered on shallow, weathered basins of diabase.**

24. Rietfontein 314JS

A mixed geology is encountered as the Loskop Formation; shale, sandstone and conglomerate; diabase sills and some Karoo Supergroup (Dwyka Formation and Vryheid Formation) occur. The diabase outcrops are defined in areas of dominant ridges where numerous diabase boulders are found. These ridges are populated with some shrubs and trees, mostly *Acacia caffra* (common hook-thorn). Some boreholes had been drilled in these diabase outcrops, but all were dry. Inspection of the drilling chips indicated nothing other than unweathered diabase. These boreholes were not sited by means of geophysics. This geophysical survey was conducted in areas on the farm where outcrops of the Loskop Formation were evident and in order to locate diabase intrusions in these. Patches of Karoo Supergroup overburden might occur, but its thickness is limited to a couple of metres. The Karoo Supergroup reaches a thickness over 40 m to the north (higher elevation) as indicated by an abandoned coal mine. The Loskop Formation in these surroundings does not host any geobotanical indicators, only grass species. The previous case study (Klipleiland 524JR) proved that certain shrubs and trees do grow on weathered diabase-derived soils. Therefore, in a situation such as this, diabase intrusions in the sediments of the Loskop Formation could be indicated by the presence of some indigenous shrubs or trees, which was indeed the case.

The variation in the lithology across the farm justifies the application of the employment of electromagnetic and magnetic methods, based on the different signatures of the various rocks on the geophysical profiles. The profiles were run north-south because the geological map (annexure) indicates that diabase intrusions and lineaments in this area strike east to west. Weathered diabase contacts serve as a confined aquifer and form the exploration target. The first 80 m of the geophysical profile represents fairly homogenous, layered earth since the magnetic intensity does not indicate any particular anomalies and the HD=VD for the EM34-3 (Figure 4.37). A coil separation of 40 m (L = 40 m) was used in order to search for the maximum possible depth in an area of

resistive overburden (relatively unweathered shale and sandstone with a silt-sand soil). At station 90 m the situation changes, with $HD \gg VD$, before the magnetic intensity increases over 100 nT. At this station (90 m), species of *Acacia karroo* and *Rhus lancea* are found, the only ones encountered in an area of 200 hectares. Although these were small, a size probably caused by fire and wind damage, significant indicators of a difference were encountered in the soil and geological properties, such as a diabase intrusion encountered at station 120 m. The existence of diabase is based on the geology and behaviour of the geophysical profile such as that at this station. An increase in the magnetic intensity and a shift in the dipole dominance, $VD \geq HD$, denotes the presence of diabase. Station 90 m (position of arrow) is located above a weathered contact of Loskop sediments, shale and the diabase sill, as indicated by the borehole log. This position was drilled to a depth of 60 m, with the water strike at 23 m and a yield of 7 500 l/h. The drilling results compare favourably with the published Loskop Formation geohydrological information by Meulenbeld (1998). The yield is exceptional for this case, but the study by Meulenbeld (1998) indicated that sediments of the Loskop Formation could yield reasonable quantities of groundwater ($>7\ 000$ l/h) if associated with intrusions. The borehole log consists of:

0 – 2 m: loam

2 – 21 m: shale

21 – 24 m: weathered diabase (water strike 23 m)

24 – 60 m: unweathered diabase.

Subsequent to determining the geophysical profile as depicted in Figure 4.37, soil samples were taken at two localities. The first locality represents the occurrence of *Acacia karroo* and *Rhus lancea* and the borehole and the other locality is situated at station 120 m, representing the diabase intrusion environment. The geobotanic community at the borehole evidences a lower pH-value and the results indicate some Al-toxicity. The resistivity values do not differ much at both localities. Overall, the geobotanic community shows higher values for Mg, K, P, Fe, C, S, N and CEC, especially in the shallow sample (0.5 m). The higher values in pH, Ca and Na at station 120 m might be due to the weathering of clay/silt rich diabase. The profile, as sampled and described by Land Type Survey Staff (1987), is more representative of slightly weathered diabase, owing to the high values of Ca and high resistivity at a shallow

depth. Unfortunately, both soil samples are derived from Hutton soil series and no classification can be made based on this (see land type map, annexure).

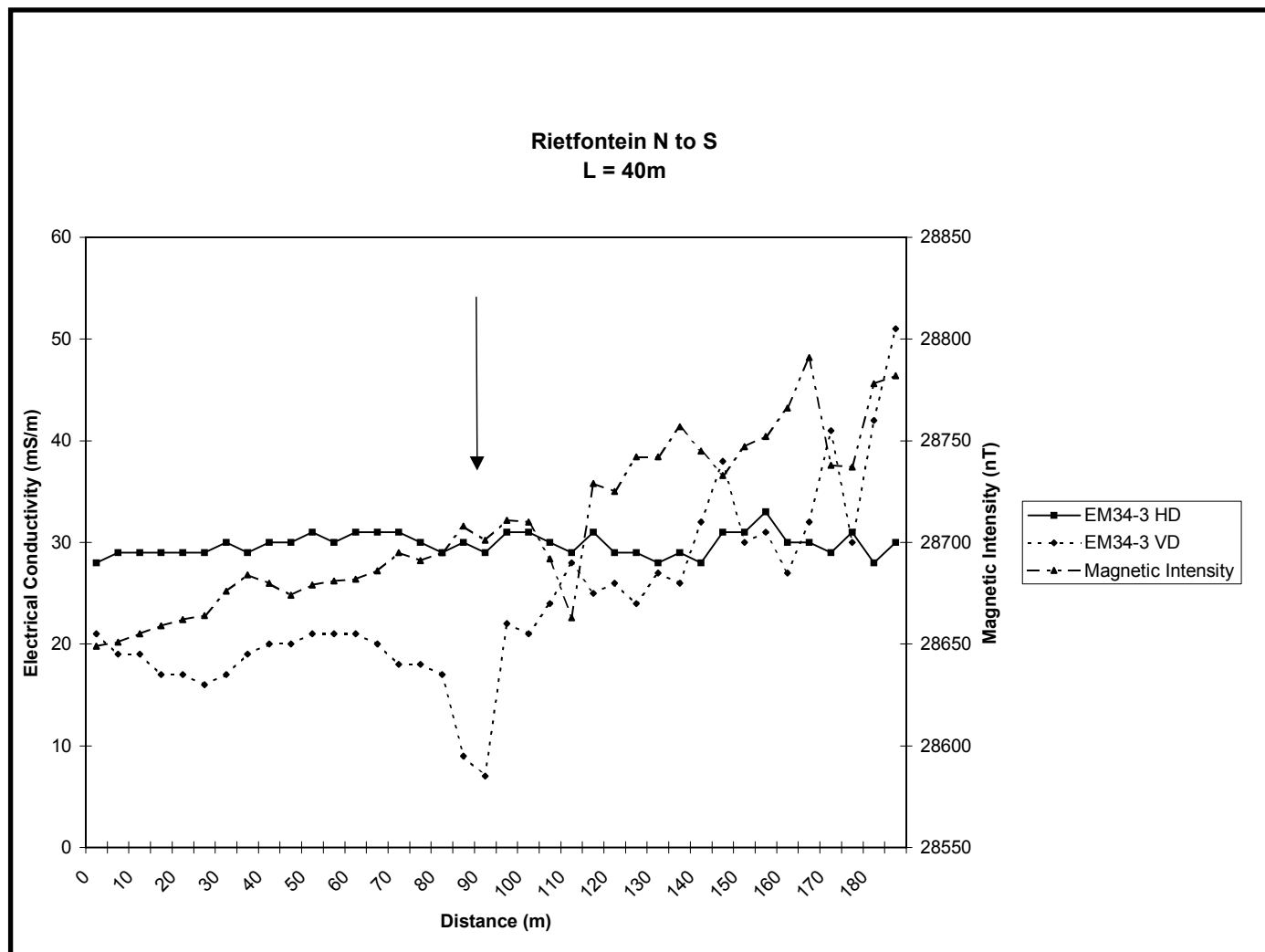


Figure 4.37. Geophysical profile on Rietfontein 314JS.

Acacia karroo and *Rhus lancea* are the geobotanic indicators in this case study. Both species are associated with a weathered, water-bearing diabase sill in contact with sedimentary rock. The geobotanic community possesses higher nutrient and CEC levels compared to the non-geobotanic community. Both soil samples (geobotanic and non-geobotanic) are representative of Hutton soil series.

4.8.1 Remarks

Geobotanic communities, although restricted in species composition owing to the colder and exposed Highveld conditions, indicated zones of deeper, intense weathering associated with diabase intrusions. Aquifer yield was above average as referred to elsewhere. Geophysical methods such as magnetics and electromagnetics accurately indicate zones of deeper, intense weathering associated with diabase intrusions in conjunction with the geobotanic communities. Therefore, the geobotanic communities act as reference points in the field for sound aquifer exploration. Direct current soundings increase knowledge regarding the sub-surface geological conditions. The chemical soil-sampling analysis indicated higher pH-values for the sites sampled with no reference to the geobotanic communities. One reason might be that all these samples were taken from a diabase environment that tends to exhibit higher pH-values. Generally, the geobotanic communities of the two case studies mentioned indicate higher values of Mg, K, conductivity, Fe, C, S, N and CEC, see also Table 4.8. The higher availability of Mg, C, S, N and CEC is supportive of plant development and growth, which might be the reason for the establishment of a specific geobotanic community.

Table 4.8. Comparisons between soil characteristics of geobotanical indicators and their surroundings.

Parameter	Geobotanical community (A)	Surroundings (B)
pH	4.97-6.06	5.67-7.35
P (mg/kg)	1.30-2.37	1.53-2.10
Ca (mg/kg)	340-1001	282-2381
Mg (mg/kg)	164-355	112-198
K (mg/kg)	83-160	54-110
Na (mg/kg)	0-29	5-35
Fe (mg/kg)	45.98-79.49	29.19-57.83
Mn (mg/kg)	178.90-343.15	74.72-443.12
Zn (mg/kg)	0.24-25.31	0.12-0.89
Al (cmol _c /kg)	0-0.041	0-0.062
Resistance (Ω)	900-3040	940-4650
%C	0.46-1.18	0.14-0.80
Total N%	0.027-0.059	0.013-0.058
S (mg/kg)	15.61-60.81	4.81-15.71
CEC (cmol _c /kg)	6.77-17.75	5.26-21.54
Geobotanical indicator species under column A	<i>Acacia karroo</i> (sweet thorn) <i>Euclea crispa</i> (blue guarri) <i>Rhus lancea</i> (karee)	
Geology	Diabase intrusions in sediments of Loskop Formation and weathered basins in diabase intrusions associated with the Pretoria Group	Sediments and unweathered diabase of the Loskop Formation and diabase intrusions in the Pretoria Group
Aquifer yield (ℓ/h)	7 500 – 9 000	Not applicable

4.9 MOGOLIAN EONOTHEM: GRANITE OF THE NEBO GRANITE IN THE ROOIBERG-WARMBATHS AND VERENA AREAS

Information pertaining to the case study area regarding its geographic locality, climate, veld types, geology, geohydrology, geophysics, geobotany, soil sampling is tabled, (see annexure).

25. Droogekloof 471KR

The farm is situated along the Boschpoort Fault between the Zwartkloof Anticline and Droogekloof Thrust. Some lineaments are also indicated on the Nylstroom map (1978). The strike of these structural entities is northwest to southeast. The Zwartkloof Anticline and Droogekloof Thrust are responsible for the thrust of the Waterberg sediments (Swaershoek Formation, Nylstroom Subgroup, Waterberg Group) and the rhyolite of the Schrikkloof Formation (Rooiberg Group) along the Nebo Granite (granite) (Lebowa Granite Suite, Bushveld Igneous Complex). Therefore, the Droogekloof valley hosts a variety of outcrops belonging to other geological formations that occur on a wider scale to the north of Droogekloof. A small band of dolomite (Malmani Subgroup) outcrops to the south (section 4.2). This high structural energy case study hosts a *Ficus* species that acts as a geobotanic indicator. Numerous boreholes has been previously drilled in the red granite to a depth of 120 m, with frequently discouraging results, although most of the successful boreholes show a water strike at approximately 120 m owing to deep fracturing of the granite resulting from the structural deformations that occurred in this valley. These boreholes were sited by the owner who relied on layman's methods, namely wires. Governed by the geological map, groundwater exploration was focused on the Boschpoort Fault that cuts through the farm on its southern border. Some interesting rooting patterns along the fault zone are depicted in Figures 4.38 and 4.39. The fault zone is characterised by rock fragments of the Schrikkloof Formation (sandstone). The geobotanical indicators of the fault zone are *Ficus ingens* (roots) and a tall *Acacia karroo* species with an above average circumference (right corner of Figure 4.38). The electromagnetic profile of the fault zone is indicated in Figure 4.40. The short length of the profile results from the following: this profile was generated on the southern border of the farm, which offered difficult undulating terrain, a dry riverbed with steep walls and intersections with powerlines, fences and the main road of the valley (noise).

The geophysical profiles of the dry boreholes are not presented since no significant anomalies can be observed and because the EM-34-3 has a maximum exploration depth of 60 m and therefore is not suitable to identify aquifers at a depth of >100 m, especially in this geological setting. No magnetic anomalies were identified. Schlumberger soundings were not performed owing to the difficulty of the terrain (undulating Bushveld with unweathered granite in places that restricts ground penetration by the electrodes). Nevertheless, drilling in the granite implies drilling in the Zwartkloof Anticline, which is not recommended on the basis of structural geology, owing to diverging groundwater flow patterns.



Figure 4.38. The Boschpoort Fault, characterised by sandstone fragments. Note the tall *Acacia* species on the right side of the picture.



Figure 4.39. Conspicuous rooting of *Ficus ingens* along the fault zone.

The electromagnetic profile (Figure 4.40) was laid out from north to south in order to cross the fault zone that runs east-west. The profile indicates significant differences in electrical conductivity of the profile for the HD and VD, with notable $HD \gg VD$ along stations 83-89 m. The borehole was placed at station 86 m, where $HD \gg VD$ is at the maximum and probably denotes the position of the deepest weathering, and in the close vicinity of the geobotanic indicators. The borehole and aquifer characteristics are presented in Table A1.19a(i). The yield of 17 000 l/h can be attributed to the porosity and transitivity of the fault and structural deformation of the area, since the anticline directs groundwater and surface run-off towards this fault (groundwater convergence zone). The recharge of the fault could possibly be linked to the dolomite aquifers, that outcrop approximately 3 km towards the southeast. A concern regarding the water quality could be fluorite concentrations since this mineral was previously mined in this area. Upon drilling of the borehole, the first 10 m consisted of sandstone (Waterberg Group) which was followed by coarse-grained granite in contrast to the finer grained granite of the surroundings.

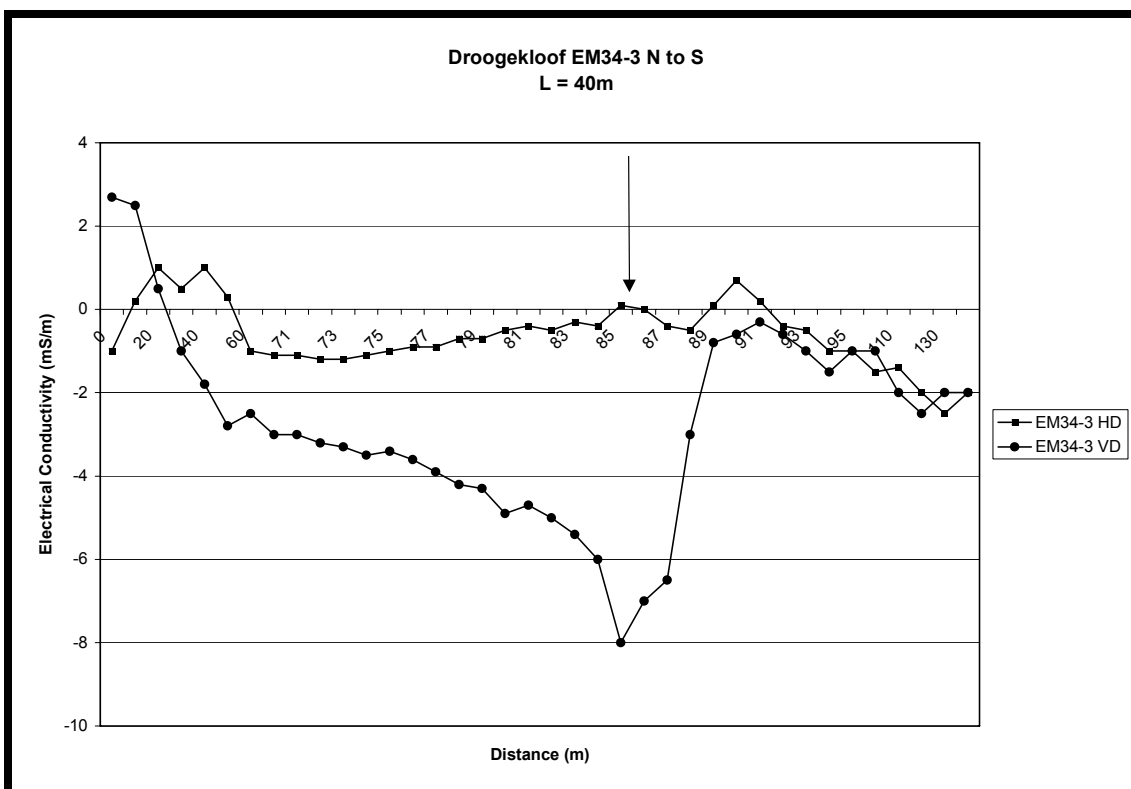


Figure 4.40. Electromagnetic profile of the Boschpoort Fault at Droogekloof 471KR.

The soil samples, collected at stations 86 m (weathered fault zone) and 93 m (close proximity to the rhyolite ridge), indicate higher pH, cations (Ca, Mg, K, Na), Mn, conductivity and CEC-values with increases of N and S in depth: refer to Tables A1.19(a&b)(i). The higher values of Mg and CEC are crucial for photosynthesis and water-holding capacity, which is important to sustain vegetation (Brady, 1990 & Rasmussen & Collins, 1991). Higher cation values may be derived from weathered diabase enriched in these minerals, compared to granite (Brownlow, 1975 & Hurlbut & Klein, 1977). The nutrient composition at the geobotanic community is impressive compared to the general nutrient characteristics of the Glenrosa and Mispah soil series (see annexure).

***Acacia karroo* and *Ficus ingens* are the geobotanic indicators in this case study. They occupy the spot with the deepest weathering and elevated nutritional status, where the weathering is visible on the electromagnetic profile as HD>>VD. The deepest weathering forms an excellent groundwater basin. With regards to the *Acacia karroo*, it is important to identify tall specimens with a large circumference.**

26. Kareefontein 432KR

Plains of granite intersected by some lineaments and dry riverbeds that cut through these plains give rise to a hilly environment. The granite plains are covered with trees that do not bear thorns, whereas the valleys and dry riverbeds do have some thorn trees on their banks together with termitaries. Thorn trees can provide a hint that a buried lineament is present, whereas the presence of a termitary may also indicate a hidden lineament. Eugène Marais studied termites in depth and one of his observations was that termites build a nest in the presence of a magnetic field (Marais, 1990 & Walker & Bothma, 2005). Granite is very often poor in magnetic minerals, while lineaments are rich in such minerals and are very easily detected by magnetometers. Kareefontein, between Mabula and Alma, some 35 km to the northwest of Warmbaths, is situated on a plain of granite intersected by a dry river bed (Monyagole stream) with some *Acacia karroo* trees along its banks and termitaries surrounded by broad-leafed trees that do not bear thorns (typical Sour Bushveld vegetation). Most farms in this region are dedicated to game-farming and lodges. The presence of *Acacia karroo* and termitaries amongst *Burkea africana*, *Combretum molle*, *C. apiculatum*, *C. zeyheri*, *Euclea crispa*, *Faurea saligna* and *Ochna pulchra* is conspicuous and triggered the decision to consider the thorn bearing trees and termitary as geobotanic/groundwater indicators. Observations on the farm revealed no other presence of the latter. A few of profiles were laid out perpendicular to the dry riverbed, implying a southwest to northeast profile direction. The position and bed of the Monyagole stream lies in the same direction as that of the indicated lineaments on the Nylstroom map (1978), but no lineaments are indicated in the vicinity of the said stream on the map. The aerial photograph (annexure) indicates the presence of a small lineament close to the river bed. The strike of the lineament is southeast-northwest and therefore the geophysical traverses were run north to south in order to cross the lineament conveniently. The best geophysical profile obtained is depicted in Figure 4.41. The geobotanical species that occur include *Acacia karroo*, *Ximenia caffra* and *Zanthoxylum capense*. The geophysical profile indicates the centre of a magnetic structure around station 430 m. Whereas the HD=VD for the profile runs on top of the granite, the weathered edges of the structure are indicated by HD>>VD and the unweathered structure by VD>>HD. The magnetic profile as measured on the granite indicates no magnetic anomalies. This kind of homogenous magnetic reading is often found in the absence of magnetic, intrusive bodies in the granite. The arrow near

station 330 m indicates the position of the drilled borehole. The borehole yielded 5 500 l/h and water was struck at a depth of 52 m, in the weathered zone of the intrusion (representing a confined aquifer). At 68 m unweathered diabase was encountered. The borehole was drilled to a depth of 75 m in order to cater for a sump (Table A1.19a(i)). The overburden consists of granite.

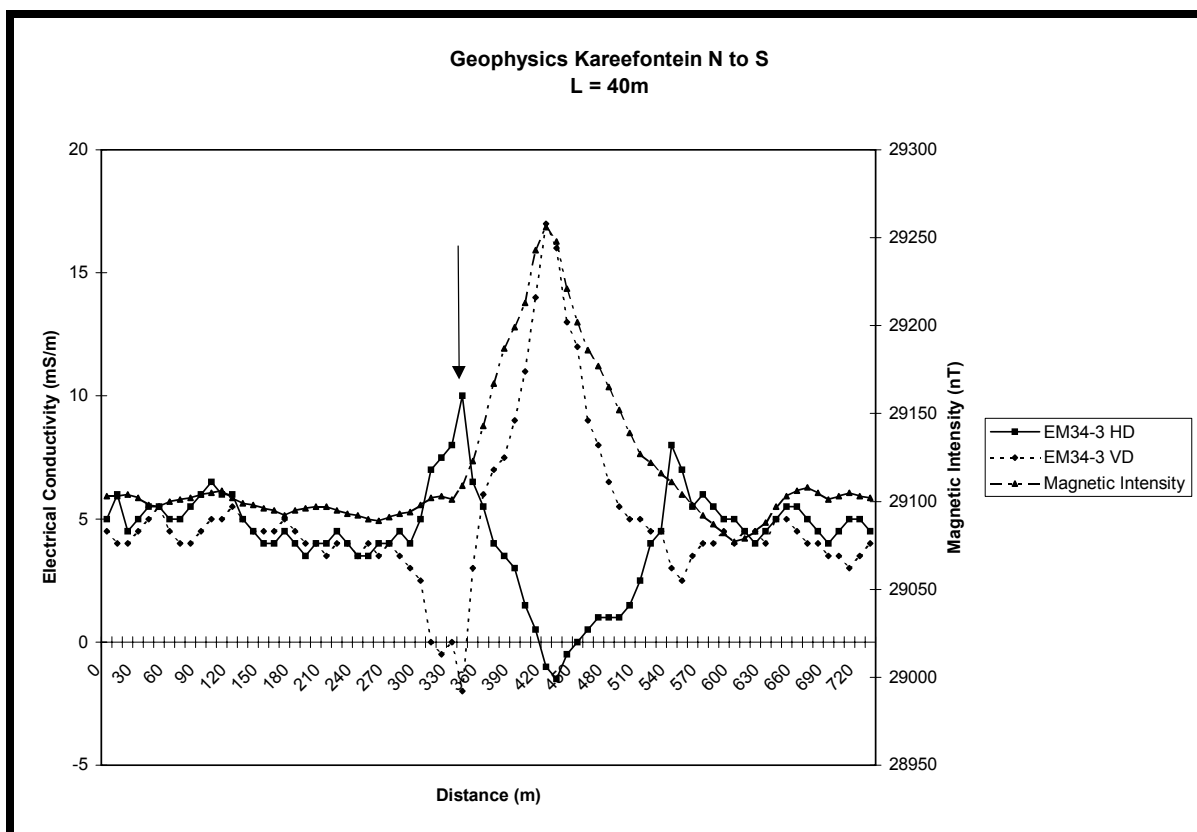


Figure 4.41. Geophysical profile along the Monyagole stream, Kareefontein 432KR.

Soil samples were taken at station 330 m and 270 m (granite). The samples associated with the intrusion and borehole (330 m) indicate a higher value in pH, Ca, Mg & Na, conductivity and CEC-values (Table A1.19(a&b)(i)). According to Bronlow (1975), diabase contains a higher proportion of Ca and Mg compared to granite, but is lower in K. This is reflected in the soil sample analysis. The land type map (annexure) indicates only Clovelly soil series, which is representative of the weathered granite in this area. Notably, the geobotanic community does not conform with the said soil series, since it is more representative of the Hutton soil series.

***Acacia karroo*, *Ximenia caffra* and *Zanthoxylum capense* are the geobotanic indicators in this case study since they are associated with the water-bearing lineament and a soil profile rich in nutrients compared to that of the surroundings.**

27. Zandfontein 476KQ

Approximately 48 km east of Thabazimbi is the farm Zandfontein 476KQ, situated in a broad valley between the Elandsberg and Swaershoekberge. The Zand River flows through this valley, which is densely overgrown by shrubs and trees. The valley consists of Nebo Granite with some diabase intrusions (strike east-west) and quartz veins. The diabase intrusions or lineaments are visible on the aerial photograph (annexure). This borehole was sited for domestic purposes because the farm had been recently purchased and a new homestead was to be built. In such terrain that is densely overgrown, it is quite difficult to distinguish between different trees and shrubs from a distance. A geobotanic survey would take some time. Guided by the Thabazimbi geological map (1974), the area on the map denoted by the diabase intrusion was investigated. The following geobotanic indicators were found: *Acacia karroo*, *Ximenia caffra* and *Zanthoxylum capense*. They compare favourably with the geobotanic indicators seen on the farm Kareefontein 432KR. These geobotanic indicators are quite different entities in this habitat compared to the characteristic vegetation types of the listed Sourish Mixed Bushveld/Sour Bushveld veld types. When *Acacia karroo* occurs, its presence is always measured against the frequency of occurrence, the circumference of the tree/stem and obvious differences in growth patterns (height, robustness). The presence of such an intrusion must be viewed as a possible exploitable confined aquifer since most other boreholes in the area penetrate granite in different stages of weathering with a yield of about 2 500 l/h, according to local information. The electromagnetic profile of the survey across the interpreted position of the diabase intrusion is indicated in Figure 4.42. The profile was run along a bush-clearing in a north to south direction so that the lineament/intrusion would be crossed. No magnetic data is available owing to difficulties encountered with the magnetometer at the time of the survey, although the electromagnetic instrument would be able to differentiate between the weathered and unweathered zones in the sub-surface based on differences in soil moisture, and hence electrical conductivity. The proposed borehole position was based

only on the profile as illustrated in Figure 4.42. In a broad sense, it seems that the electromagnetic profile indicates a homogeneous, layered earth as $HD \approx VD$. On closer observation of the data, some distinguishing features can be observed, since at stations 240-280 m, the $VD > HD$ and probably indicates the position of the unweathered diabase intrusion. Its flanges indicate $HD > VD$ or weathered conditions, more definite at its northern side, station 225 m. The borehole was placed at this station, which hosts the geobotanic indicators mentioned (*Acacia karroo*, *Ximenia caffra* and *Zanthoxylum capense*). The borehole's water strike was at 54 m and the final depth of the borehole is 80 m, with a yield of 4 250 l/h. The depth of water strike (54 m) could be the cause of the poor response on the EM-34-3 because its maximum exploration depth is 60 metres, and deeper buried conductors display a smaller anomaly. The borehole log showed the following: sand (0 – 1 m), weathered granite (1 – 11 m), unweathered granite (11 – 52 m), weathered, water-bearing diabase (52 – 56 m), unweathered diabase (56 – 65 m), fractured granite (no water) (65 – 69 m), unweathered granite (69 – 80 m). Soil samples were gathered at stations 225 m and 260 m (see Table A1.19(a&b)(i)). From the results it is clear that the soil above the intrusion has a higher pH, but regarding the other chemical parameters (P, Ca, Mg, K, Na, Fe, Mn, Zn, C, N and S) as well as the conductivity and CEC-values, the values of the geobotanic community are in some cases significantly higher, thus indicating nutrient-rich soil derived from the weathered mafic intrusion, in contrast with the generally poor nutrient-retaining Clovelly soil series derived from the weathered granite (land type map, annexure). The contribution of the geobotanic community to higher humus values can be considered as a factor for tree development in this Bushveld environment.

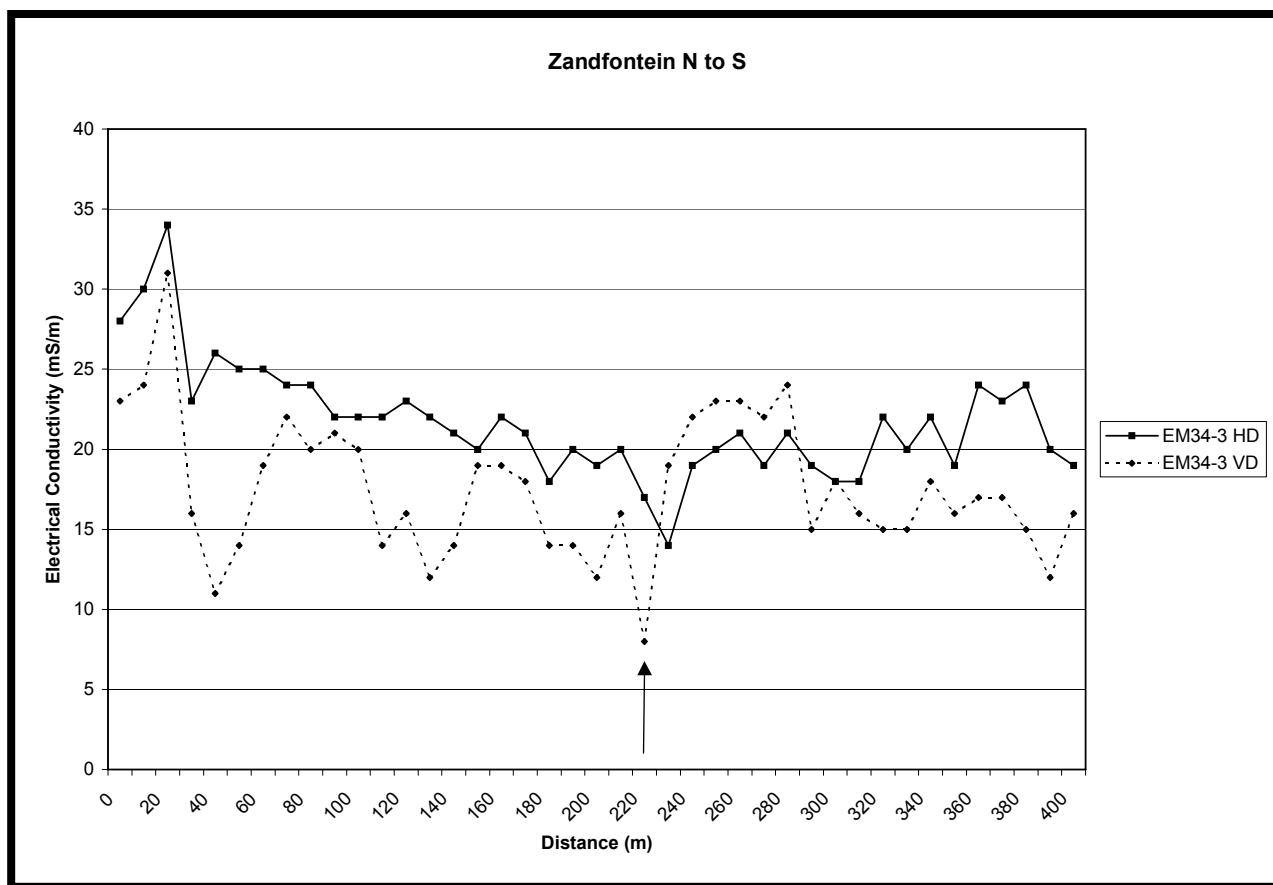


Figure 4.42. Electromagnetic profile on the farm Zandfontein 476KQ.

***Acacia karroo*, *Ximenia caffra* and *Zanthoxylum capense* are the geobotanic indicators in this case study because they are associated with the water-bearing lineament and a soil profile rich in nutrients compared to that of the surrounding area.**

28. Klipfontein 256JS

Apart from the outcrops of the Nebo Granite in the Warmbaths area, outcrops of this granite are found in the Verena area, between Bronkhorstspuit and Groblersdal. The case studies presented are situated in a plain bordering the Wilge River and the local sandstone escarpment of the Wilgerivier Formation (Waterberg Group). Some small diabase dykes cut through the granite. Owing to the proximity of the river and deep weathering profiles in the granite, agricultural practices requiring intensive irrigation are found. The plain is mostly covered with grass species, although on rocky granite

outcrops, called tors, tree and shrub species such as *Burkea africana* (wild syringa) and *Cussonia paniculata* (Highveld cabbage tree) are encountered. At some places, well away from the river, *Combretum erythrophyllum* (river bushwillow) species grow. This botanic species is recognised as a geobotanic indicator in the previous listed case studies. The occurrence of this species, found at places removed from the current position and the banks of the Wilge River, may indicate palaeo-channels. Owing to the presence of diabase dykes, palaeo-channels and/or deep weathering profiles, the geophysical methods utilised include the magnetic, electromagnetic and Schlumberger sounding methods. The (electro)magnetic profiles are indicated in Figure 4.43, while the sounding is illustrated in Figure 4.44. The traverse orientation of the (electro)-magnetic profiles is based on the strike of the diabase intrusions as indicated on the geological map of the area (annexure). The Schlumberger sounding was laid out east-west because the granite does not have a strike direction and therefore electrode effects are not likely to arise.

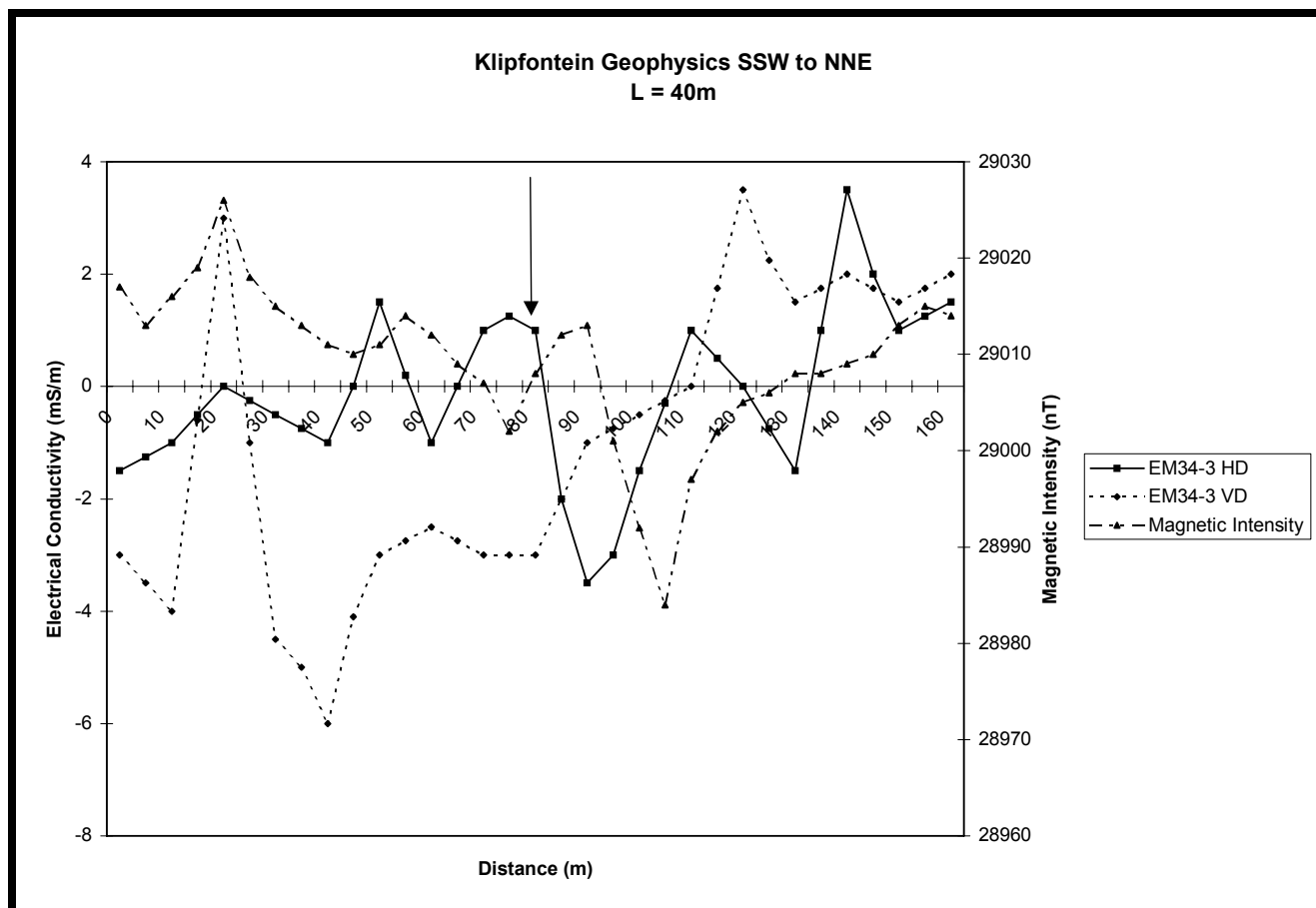


Figure 4.43. Geophysical profiles on the farm Klipfontein 256JS.

From Figure 4.43 it is obvious that the geophysical profiles measured do not indicate a significant increase in magnetic intensity nor distinct electromagnetic profiles since both dipoles alter in maximum conductivity values. The existing borehole is situated at station 80 m (arrow in Figure 4.43) and is shaded by some *Combretum erythrophyllum* species. Since the profiles did not indicate favourable aquifer conditions, it was decided to conduct a Schlumberger depth sounding at the spot. Furthermore, according to a local drill operator, the borehole struck water at a depth of about 18 m in weathered or loose granite soil and boulders. The yield of this borehole is 55 000 l/h and it is one of the strongest in the area. The sounding as depicted in Figure 4.44 indicates favourable possible aquifer conditions in depth (KH-type curve). The modelling of the sounding curve indicates an extensive zone of lower conductivity between 5.5 and 24.2 m, overlain by a resistive overburden, quite typical of the land type (see annexure). In this conductive zone, groundwater was apparently struck at a depth of 18 m, quite possible according to the sounding model. The conductive zone can be seen as a palaeo-channel in this environment in the vicinity of an intrusion of limited extent. It might be that, owing to the different mechanical, chemical and weathering resistance properties of diabase compared to those of granite, the diabase-defined palaeo-channels of the Wilge River in the past. Palaeo-channels are excellent geohydrological conduits.

Soil samples taken at this site are represented in the second table of this section, Table A1.19(a&b)(ii). The soil sample obtained at the borehole position (station 80 m) is, surprisingly, considerably lower in CEC and S-values, while the organic carbon value is higher with almost comparable nitrogen values for both positions sampled, stations 80 m and 100 m. The reason for this is unclear since any interaction with agricultural fertilisers is not suspected in the surroundings of these positions. There are variations in pH, Mg, Fe and Mn at greater depth, a tendency for higher values of these elements with increased depth at the borehole position. Notably higher P, Ca, Mg and Zn values occur at the geobotanic/borehole position. The resistivity of the soil is also lower.

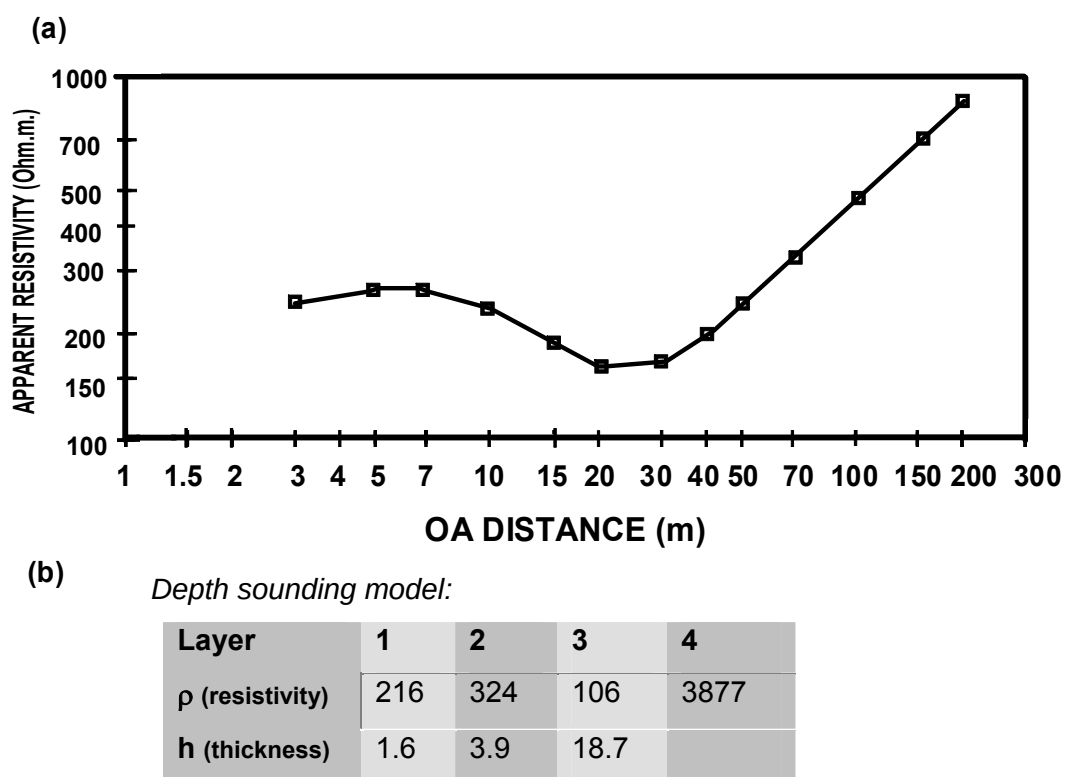


Figure 4.44. Schlumberger depth sounding at Klipfontein 256JS.

Combretum erythrophyllum is the geobotanic indicator in this case study since it hints at the position of palaeo-channels, which can be considered as semi-confined aquifers owing to their relatively shallow presence in old channels covered with hardened alluvium in places. These trees can easily tap into these palaeo-channels that act as groundwater conduits.

29. Zusterstroom 447JR

The borehole drilled on the farm furnishes sufficient water (18 000 l/h) to supply a couple of greenhouses there. The borehole log (NGDB, 1996) indicates the presence of granite in various stages of weathering to a depth of 22 m, with a water strike at 15 m. Deeper, only unweathered granite is indicated. No diabase is logged. The geomorphology of the farm comprises a vast plain underlain by granite of the Nebo Granite. The soil on the surface is, remarkably, a silt-sand mixture (characteristic of the representative land type) containing a large amount of quartz particles, indicating weathered granite. Owing to the presence of some small diabase dykes in the area, profiling methods were utilised. The origin of these diabase dykes can be attributed to the severe faulting that took place along the edges of the Waterberg basin in this area and subsequently, cracks in the bedrock were filled with mafic rocks (diabase). One such diabase intrusion in contact with the fault zone yields thermal water in the vicinity. The geophysical profile as depicted in Figure 4.45 indicates a small increase in the magnetic intensity from stations 200 to 240 m. The borehole is denoted by the arrow, station 210 m. The increase in magnetic intensity can be attributed to a small buried, diabase dyke, because the tree species identified at the spot are *Combretum erythrophyllum* and *Acacia karroo*. The latter is renowned for its association with clay soils derived from weathered diabase or other mafic intrusions. The former, a phreatophyte, indicates spots of deeper weathering or positions of palaeo-channels. Therefore, depth soundings were conducted as well. The magnetic and electromagnetic profiles combined are depicted in Figure 4.45 and it is interesting to observe the more or less constant readings of the horizontal dipole compared to the alternating readings of the vertical dipole. In the zone of the intrusion, $HD > VD$ occurs and is a fair indicator of possible aquifer conditions. Note that the layout of the (electro)-magnetic traverses was carried out so as to cross the diabase intrusions indicated on the geological map (annexure). The Schlumberger depth sounding (east-west orientation), Figure 4.46, at the borehole and geobotanic indicator position indicates a KQH-type curve, a resistive overburden and bedrock layer with an intermediate conductive layer, most possibly a palaeo-channel in this environment, in close proximity to the small diabase dyke interpreted as being present. The possibility of a wider weathering zone along the flanges of the diabase intrusion is not expected since sounding techniques are not able to plot zones of conductivity in regions of a structural dip greater than 45° : therefore the palaeo-channel model is the most plausible.

According to the interpretation of the depth sounding and borehole log it is possible to strike water at a depth of 15 metres, since the layer of lowest resistivity is situated at a depth of 5.0 – 24.8 metres, in the weathered granite or palaeo-channel filled with weathered material. The bedrock is undoubtedly unweathered granite, indicated by the resistivity of this final indicated layer.

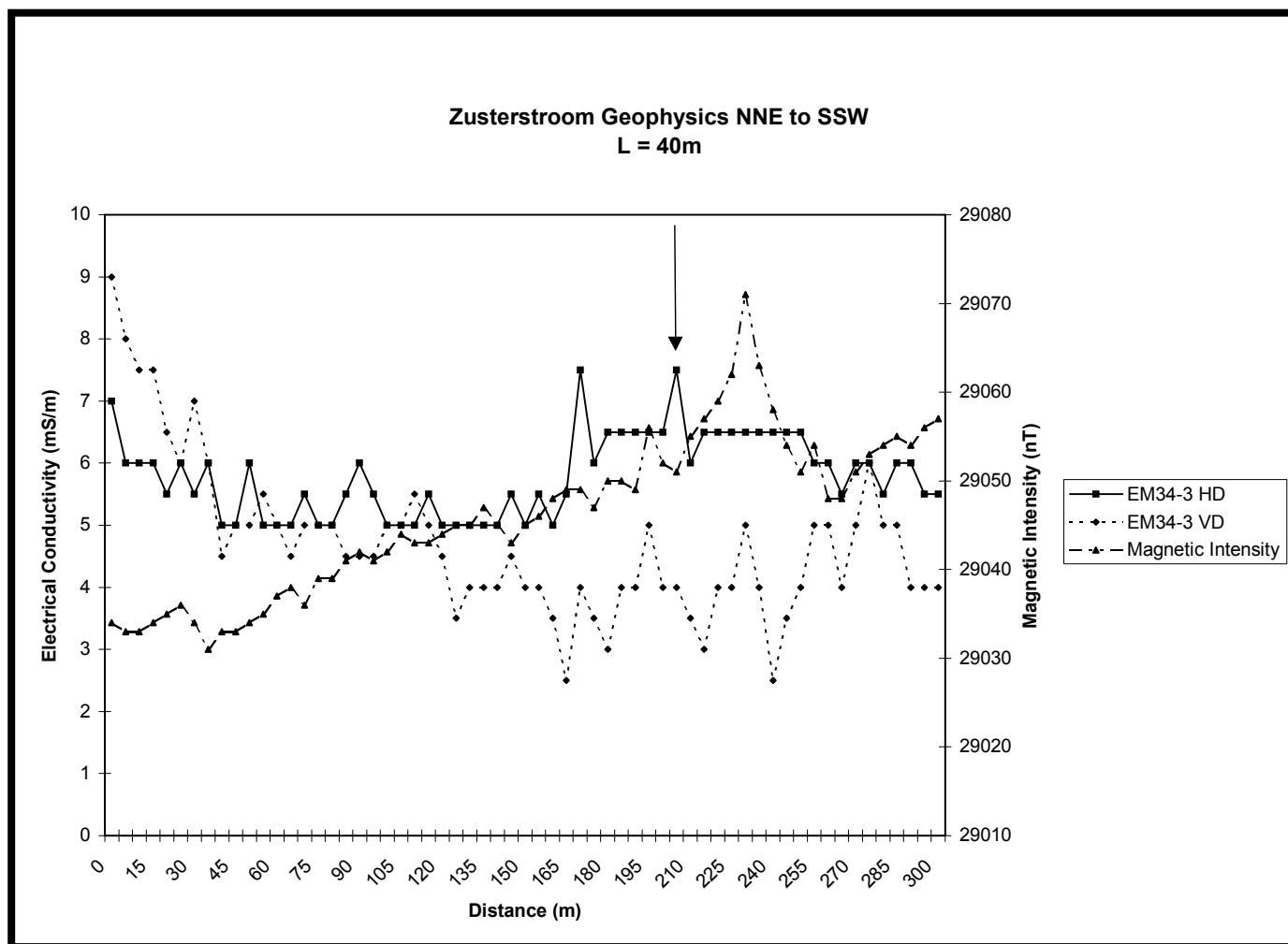
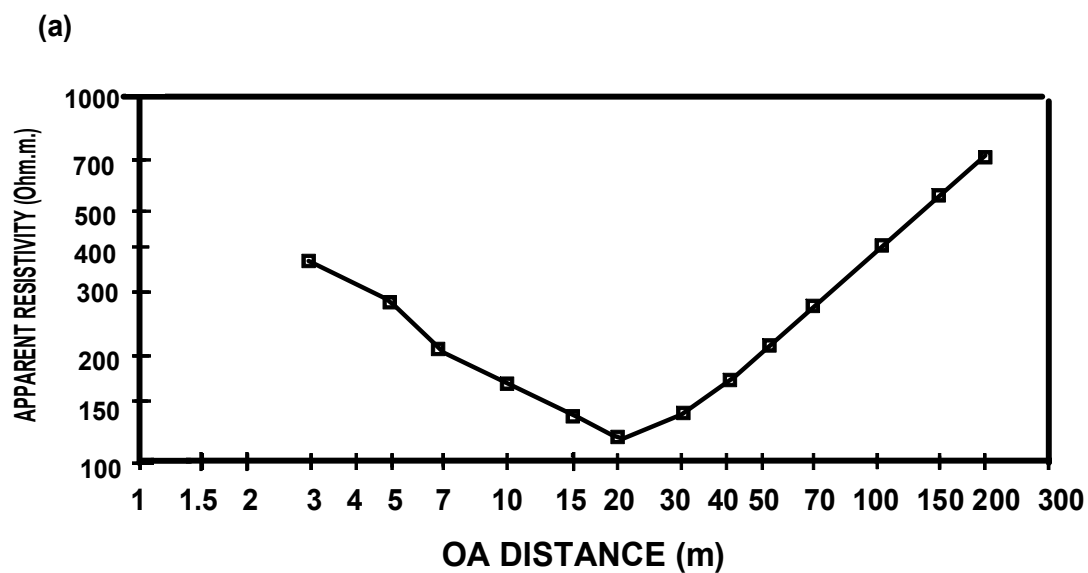


Figure 4.45. Geophysical profile on the farm Zusterstroom 447JR.



(b) *Depth sounding model:*

Layer	1	2	3	4	5
ρ (resistivity)	343	511	215	78.4	10504
h (thickness)	0.4	0.8	3.8	19.8	

Figure 4.46. Schlumberger depth sounding on the farm Zusterstroom 447JR.

The soil samples and soil analysis, as tabled in Table A1.19(a&b)(ii) and taken at station 210 m (borehole) and 180 m, illustrate a remarkably conductive soil, a factor ten less than the resistivity of the soil some 30 m to the north. In addition, the pH of the soil, cation values, heavy metal content and humus values only relating to CEC and S, are higher than those of the site sampled without any geobotanical indicators or identified

geophysical anomalies linked to aquifer conditions (Figure 4.45). The remarkably higher Ca, Mg, Na, Fe, Mn and Zn values may be derived from the weathering of the mafic rocks rich in these elements compared to the weathered state of the nutrient-poor granite. The higher nutrient levels at the borehole or geobotanic indicators support tree growth. It is strange that the C and N values are lower at the geobotanical site, considering the high resistivity of the other site sampled, thus indicating dry soil conditions that do not aid the formation of humus and resultant C and N development or their availability in the soil matrix.

***Acacia karroo* and *Combretum erythrophyllum* are the geobotanic indicators in this case study. The former represents clay soil and the latter indicates the position of palaeo-channels. The occurrence of these indicators is restricted to this locality.**

4.9.1 Remarks

The Nebo Granite, as investigated in the Warmbaths, Verena and other areas, is generally a poor aquifer, as indicated in the literature (Frommurze (1937), Meulenbeld (1998) and Botha *et al.* (2001)). However, with the aid of geobotanic indicator species that suggest the existence of deeper situated weathered mafic intrusions, reasonable quantities of groundwater can be struck. The geobotanic indicator species will be referred to in Table 4.9. Aquifers of interest in the Nebo Granite, as indicated in the present study, include weathered contact zones between the granite and diabase, zones of faulting and palaeo-channels. The point must be stressed that geobotanic indicators constitute an extremely useful tool in the field of groundwater exploration as indicated by unsuccessful and lower yielding boreholes according to the statistics. Geophysical groundwater exploration is strengthened by the application of various geophysical methods that are at hand at a reasonable cost and are time efficient. The inter-connecting cable of the EM-34-3 and electrode layout of the Schlumberger apparatus could be a hindrance in the Bushveld environment. Most of the encountered anomalies of the magnetic profiles are at reasonably small magnetic intensity amplitudes, except the one measured at Kareefontein 432KR. Electrical conductivity values vary between -10 to over 10 mS/m, depending on the sub-surface conditions, but these values indicate

rather resistive sub-surface conditions. Increased electrical conductivity values indicate normally weathered diabase (clay/water rich) in this environment. Zones of deeper weathering can, at times be easily spotted by means of the electromagnetic method, according to amplitude variations between the HD and VD. At sites such as Klipfontein 256JS, Zandfontein 476KQ and Zusterstroom 447JR for instance, magnetic and electromagnetic responses are not well-defined regarding the clear definition of anomalies. Geobotanic indicators cause a lack of trust in other readings or geological conditions observed on the surface. These indicators rather focus the intentions of the groundwater prospector on the spot by yielding satisfactory results when drilled. It must be remembered that intrusions of mafic rocks in the granite are often limited in extent and therefore a small anomaly will be observed that is of significance when taking the background readings into account. The modelling of Schlumberger depth soundings indicated palaeo-channels (resistivity of 100 Ωm) in association with intrusions of diabase (as interpreted from the profiles) in the Verena area, denoted on the surface by species of *Combretum erythrophyllum*.

The results of the soil sampling exercise are listed in Table 4.9. The Warmbaths area geobotanical sites display higher values of Ca, Na and Zn with distinctive high values of Mg and CEC. These values are important for photosynthesis and water-holding capacity in the dry Bushveld (Brady, 1990 & Rasmussen & Collins, 1991). In the Verena area, notably higher values of Ca and Na are distinguished in the soil chemical analysis of soil samples analysed at the geobotanic community/indicators. Other high values include P, Mg, Mn, Zn and the lower resistivity of the soil. Combined, it is obvious that the sites with geobotanic indicators display higher overall values of Ca, Mg, Na and Zn, although the high sodium content does not limit the establishment of vegetation. This can be linked to the weathering of the diabase that enriches the soil in these elements compared to the weathering of the plagioclase rich granite, which weathers more slowly and releases these elements in lower concentrations to the soil owing to the fact that granite is less enriched in these elements, notably Ca and Mg (Brownlow, 1975 & Hurlbut & Klein, 1977). The fact that potassium is present in more or less equal amounts in the soil samples taken at geobotanic positions and other sites may refer to a higher amount of potassium rich minerals in the granite, such as perthite (Nylstroom, 1978), adularia and leucite. It is interesting to observe that available iron is not abundant at the geobotanic communities associated with mafic (diabase) intrusions, since mafic rocks such as

diabase possess a higher percentage of iron in their mean chemical composition (Brownlow, 1975 & Hurlbut & Klein, 1977).

Table 4.9. Comparisons between soil characteristics of geobotanical indicators and their surroundings.

Parameter	Geobotanical community (A)	Surroundings (B)	Geobotanical community (A)	Surroundings (B)	Geobotanical community (A)	Surroundings (B)
	Warmbaths area		Verena area		Combined	
pH	5.49-6.37	4.78-6.67	5.80-6.76	5.12-7.00	5.49-6.76	4.78-7.00
P (mg/kg)	0.88-15.81	0.85-27.92	10.28-16.27	0.88-15.08	0.88-16.27	0.85-27.92
Ca (mg/kg)	282-1091	130-389	681-1488	107-493	282-1488	107-493
Mg (mg/kg)	113-361	47-108	136-1593	42-234	113-1593	42-234
K (mg/kg)	27-101	25-68	39-131	16-153	27-131	16-153
Na (mg/kg)	18-230	3-34	72-533	12-43	18-533	3-43
Fe (mg/kg)	18.18-73.19	12.56-75.72	34.35-221.43	7.98-137.99	18.18-221.43	7.98-137.99
Mn (mg/kg)	4.90-130.74	0.69-142.31	50.58-857.58	1.85-141.77	4.90-857.58	0.69-142.31
Zn (mg/kg)	0.23-3.23	0.13-1.14	0.25-3.47	0.17-0.44	0.23-3.47	0.13-1.14
Al (cmol _c /kg)	0-1.775	0-2.630	0-1.080	0-0.950	0-1.775	0-2.630
Resistance (Ω)	1800-6000	3800-9800	1300-3400	3000-30000	1300-6000	3000-30000
%C	0.06-0.70	0.18-0.84	0.03-0.29	0.09-0.29	0.03-0.70	0.09-0.84
Total N%	0.010-0.065	0.017-0.080	0.008-0.027	0.020-0.024	0.008-0.065	0.017-0.080
S (mg/kg)	1.63-17.76	4.40-23.23	9.01-48.11	12.92-79.75	1.63-48.11	4.40-79.75
CEC (cmol _c /kg)	5.183-10.93	2.334-4.95	5.503-22.096	8.464-29.25	5.183-22.096	2.334-29.25

Geobotanical indicator species under column A	<i>Acacia karroo</i> (sweet thorn) <i>Ficus ingens</i> (red-leaved fig) <i>Ximenia caffra</i> (sourplum) <i>Zanthoxylum capense</i> (small knobwood)		<i>Acacia karroo</i> (sweet thorn) <i>Combretum erythrophyllum</i> (river bushwillow)		<i>Acacia karroo</i> (sweet thorn) <i>Combretum erythrophyllum</i> (river bushwillow) <i>Ficus ingens</i> (red-leaved fig) <i>Ximenia caffra</i> (sourplum) <i>Zanthoxylum capense</i> (small knobwood)	
Geology	Diabase intrusions and structural deformation in the Nebo Granite	Unweathered Nebo Granite	Diabase intrusions and palaeo-channels in the Nebo Granite	Unweathered Nebo Granite	Diabase intrusions, palaeo-channels and structural deformation in the Nebo Granite	Unweathered Nebo Granite
Aquifer yield (ℓ/h)	4 250 – 17 000	Not applicable	18 000 – 55 000	Not applicable	4 250 – 55 000	Not applicable

4.10 MOGOLIAN EONOTHEM: THE WATERBERG GROUP IN THE WATERBERG AND MIDDELBURG AREAS

Information pertaining to the case study area regarding its geographic locality, climate, veld types, geology, geohydrology, geophysics, geobotany, soil sampling is tabled (see annexure).

The following case studies are representative of the Waterberg Group in the Waterberg area: see also Table A1.21(a&b)(i).

30. Hartbeesfontein 394KR

Hartbeesfontein 394KR is situated on sandstone plains and ridges, south of the Waterberg massif. The lithology is predominantly sandstone with inclusions of grit, conglomerate, shale and siltstone belonging to the Alma and Schilpadkop Formations of the Waterberg Group. Structurally, the formations were folded in the geological past and hence the axis of the Loubad Syncline lies to the south of the farm. Numerous lineaments cross the farm in various strikes, but the main strike direction of the structural phenomena is east-west. Outcrops of diabase sills are prominently covered with *Acacia* species, such as those on the farm Doornkop 357KR, between Alma and Rankin's Pass. Diabase intrusions can at times be easily identified in the field owing to its susceptibility to weathering and erosion since these create negative (lower) topography and are more densely covered with vegetation, see Figure 4.47. This photograph depicts the hills around the farm and the prominent sandstone cliffs can be seen in the middle of the photograph, while the diabase intrusion can be observed in the left corner of the photo, marked by the dense vegetation growth and the developed saddle on the ridge.

Geobotanical indicators, especially amongst various types of shrub and tree vegetation in the savanna biome, aided geophysical groundwater exploration on this farm. The primary exploration target was the possible weathered southern contact zone of the lineament. The inferred groundwater flows towards the axis of the Loubad Syncline in the sandstone beds, which was earmarked as the secondary target since it creates a basic sump between the folded sandstone beds. Geobotanical indicators identified

include *Acacia karroo*, *Rhus lancea*, *Strychnos pungens* (spine-leafed monkey orange) and *Ximenia caffra*. The occurrence of the *Acacia* species was limited to one count in approximately 2 hectares. The other species displayed a particular linear distribution pattern and were quite abundant in this linear zone. 'No-grow' positions of these species were noted outside the linear zone (only associated with other lineaments as indicated on the aerial photograph, see the annexure). The linear zone is approximately 500 m long and only a few metres wide in the absence of any fencing. The geophysical profile was conducted from northeast to southeast, enabling proper perpendicular crossing over the lineament. Both the magnetic and electromagnetic methods were employed: see Figure 4.48.



Figure 4.47. Identification of diabase intrusions among the sandstone of the Waterberg Group.

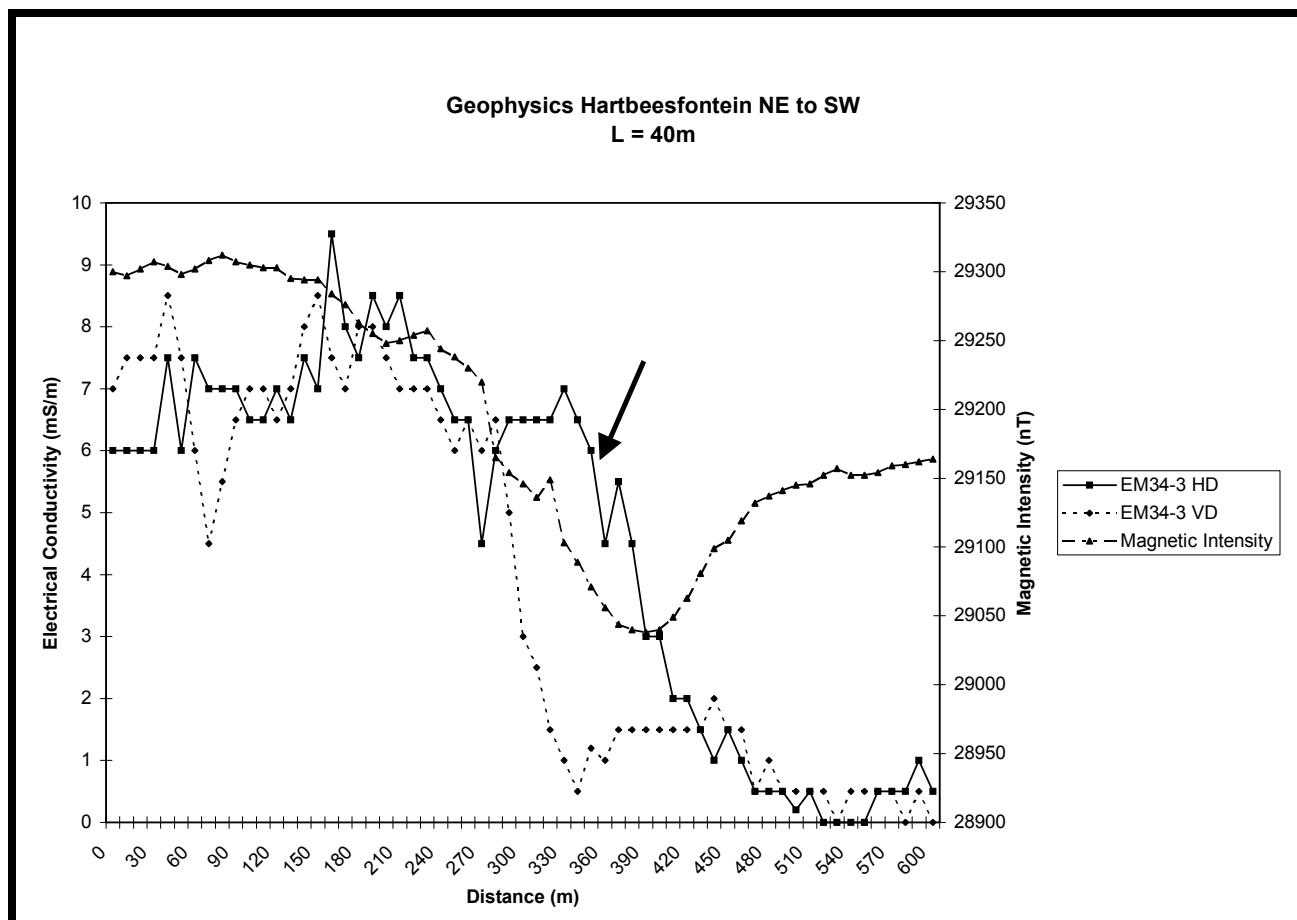


Figure 4.48. Geophysical profile across a lineament on the farm Hartbeesfontein 394KR.

The geophysical profile as indicated in Figure 4.48 defines a clearly shaped magnetic anomaly since the magnetic intensity varies above 250 nT. In addition to this magnetic anomaly, the electromagnetic conductivity response is clearly and definitely anomalous between stations 300 to 450 m. Of importance is $HD \gg VD$, while for the remaining portion of the profile $HD \approx VD$. Of interest is the alteration in electromagnetic conductivity; in the first part of the profile from station 0 to 300 m the instrument measures the response over the extent of the lineament, whereas between stations 300 to 450 m, the response obtained is representative of a weathered dipping contact zone. The dip of this lineament is indicated by the response of the magnetic intensity which drops gradually. Thereafter, (from station 450 m), the response measured is less conductive and rather represents unweathered sandstone. The arrow at station 360 m denotes the position of the borehole. The borehole was drilled to a depth of 64 m, because it is slightly beyond

the threshold of the maximum exploration depth of the electromagnetic instrument: therefore the electromagnetic profile represents the upper 60 m of the sub-surface. To drill deeper would not be justified by the obtained electromagnetic results. The borehole yielded 15 000 l/h because it was drilled in the primary exploration target aquifer. The borehole log indicated sandstone till a depth of about 30 m, whereafter diabase boulders were encountered till a depth of 36 m (water was struck at 34 m). The rest of the borehole rests in weathered to unweathered diabase. The depth of drilling, water strike (34 m) and static water level depth (18 m) compare favourably with the results as presented by Frommurze (1937), see Table A1.21(a&b)(i). The reason why the borehole was not placed at the intersection of the two lineaments (red lines), as indicated in the aerial photograph (annexure), is that at such an intersection, possibly less fracturing and weathering, takes place owing to the increased heat of the igneous event. A borehole is too costly to warrant such a chance being adopted.

The soil samples were collected at the geobotanic community, next to the drilled borehole at station 360 m and the other one at station 390 m, where no geobotanical indicators could be observed. The results of the analysis reveal lower pH, Al and cation values for the geobotanic community, but overall higher values in P, conductivity, Fe, C, N, S and CEC, all of which are parameters essential for plant life. Higher cation values for the non-geobotanic community can be attributed to the weathering of feldspathic sandstone. The soil series of the various land types, as found on this farm, are indicative of the geochemical weathering of sandstone.

***Acacia karroo*, *Rhus lancea*, *Strychnos pungens* *Ximenia caffra* are the geobotanic indicators present. These species are associated with the weathered zones (aquifer) of the lineament. They do not occur elsewhere, except on other lineaments or diabase intrusions on this farm.**

31. Pennsylvania 336LR

The northern parts of the Limpopo Province are primarily dedicated to extensive livestock farming or game-farming practices. Along river courses and irrigation schemes linked to regional dams, intensive irrigation agricultural practices are often found. If one finds irrigation schemes in the middle of the Bushveld, quite some distance away from the nearest river or dam, then these must be related to possible aquifer conditions that might yield an abundant quantity of groundwater in the area of concern. This is the case in the area of the farm Pennsylvania 336LR, approximately 10km northeast of the small village of Baltimore, close to the Botswana border. A prominent fault, known as the Melinda Fault (Pietersburg, 1985), crosses the area in a southwest-northeast direction. Lineaments associated with the Mogalakwena Formation (Waterberg Group) intrude the arenaceous sediments (coarse-grained purplish brown sandstone and conglomerate). The strike of these lineaments varies considerably in the area, but in the present study area, it lies predominantly southwest-northeast, alongside the fault structure. The lineaments and smaller dykes were doubtful for groundwater exploration since the fault lay more to the north of the farm, crossing farm boundaries. In addition, the owner of the farm was not interested in developing the game farm into an intensive farming enterprise. According to Brandl (1986), the Waterberg rocks were downthrown to the south in pre-Karoo times along the Melinda Fault. Vertical displacement was about 1 000 m. In post-Karoo times the fault was reactivated with a downthrow to the north. The throw was at least several hundred metres. According to the geological map (Pietersburg, 1985), the farm Pennsylvania is covered with alluvium (sand) over the Mogalakwena Formation and some diabase intrusions are also evident. To the north of the fault, Swazian-age rock outcrops (see section 4.1) and some Karoo-age formations are apparent.

The purpose of groundwater exploration in this set-up was to supply game with drinking water as well as to furnish additional water for domestic purposes. Therefore, one was restricted to a portion of the farm where this water was needed in order to save infrastructure development costs after drilling a successful borehole. The farm covers the Arid Sweet Bushveld and Mixed Bushveld veld types (Acocks, 1988). The abundance of *Grewia flava* (velvet raisin) and occurrence of *Combretum imberbe* (leadwood) is a reflection of the occurrence of the veld types mentioned. The species

Combretum imberbe was used as a geobotanic indicator, particularly since some large trees were evident on the farm. These trees measure about 15 m in height and display a linear distribution pattern, close to one another. The frequency of these trees on the farm was restricted to this one spot. The species *Commiphora mollis* (velvet corkwood) and *Lonchocarpus capassa* (apple-leaf) were also visible among the *Combretum* species. The former was identified as a geobotanic indicator on the farm Command, section 4.1, while the latter is normally associated with low altitudes along river courses (Van Wyk & Van Wyk, 1997). No river courses are evident on this farm; hence the occurrence of *Lonchocarpus capassa* is conspicuous. A little further on, in the absence of the said *Combretum* species, a superb specimen of the Savanna gardenia (*Gardenia volkensii*) was located, the only one observed on the farm which exceeded 3 000 ha in extent. The association of this *Gardenia* species with groundwater conditions still needs to be established in further research on this topic. Furthermore, the growth of Tamboti (*Spirostachys africana*) on heavy soils that may indicate the presence of weathered mafic intrusions and hence aquifers, needs to be established, since this was the case in the Rooiberg area (section 4.2) as well. Tamboti grows in clusters and has a tendency to grow in a linear pattern amongst other Bushveld vegetation. In this Bushveld environment, numerous other botanic species occur but will not be mentioned here since their link to geobotany-groundwater could not be clearly proven or established.

Groundwater exploration was merely based on data obtained from the magnetic method along the said geobotanic indicators, because this instrument was the best choice in this woody environment. The Schlumberger sounding and electromagnetic profiling methods have the disadvantage of cables that can easily be hooked and damaged by thorns, stems, branches, twigs, etcetera and imply earth leakage that gives erroneous readings on the display panel of the instrument. The magnetic profile is illustrated in Figure 4.49. The orientation of the magnetic profile was set to cross the linear growth pattern of the observed geobotanic indicators, northwest-southeast. The profile indicates a possible sill contact zone as indicated by the magnetic intensity high at station 180 m towards the magnetic North Pole and the magnetic intensity low at station 530 m towards the magnetic South Pole, the position denoted by the arrow and the position of the drilled borehole. The borehole was drilled to a depth of 70 m, with a water strike at 41 m in a weathered sandstone/diabase zone that serves as a confined aquifer. The borehole is situated between two *Combretum imberbe* species. The borehole yield at the time was 8

000 l/h, well above the average for this area as indicated by Frommurze (1937), and quite possible according to the hydrogeological Polokwane (2003) map. The complete borehole log is:

0 – 3 m: sand

3 – 7 m: weathered, loose sandstone

7 – 39 m: unweathered sandstone

39 – 42 m: fractured sandstone and weathered diabase (water strike 41 m)

42 – 70 m: unweathered diabase.

Soil samples were gathered at stations 530 m (borehole and geobotanic indicator position) and 570 m. Analysis of the soil samples indicates higher values in pH, cations, conductivity, heavy metals and CEC-values for the geobotanic community. According to the land type map (annexure), the Hutton soil series covers the portion of the farm investigated. Nevertheless, the higher values measured at the geobotanic community is significant since it indicates the presence of weathered mafic rock compared to the general poor soil-nutrient content of weathered sandstone.

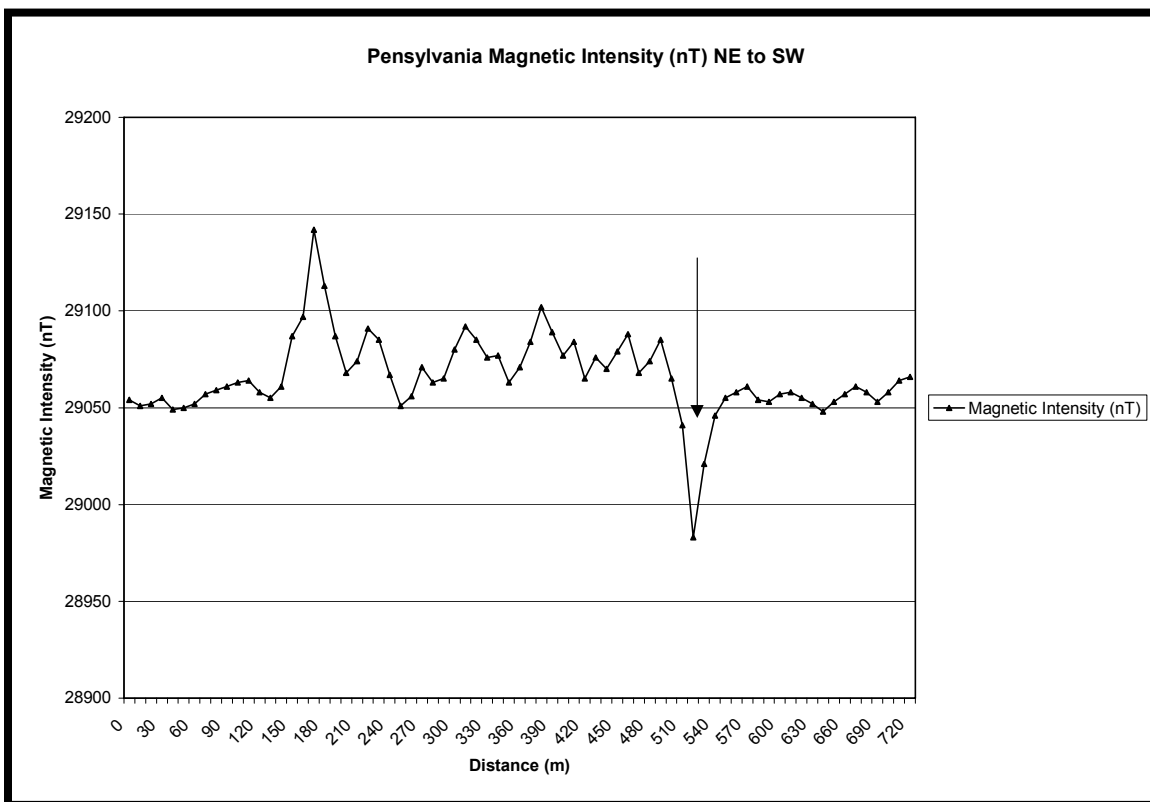


Figure 4.49. Magnetic profile on the farm Pennsylvania 336LR.

***Combretum imberbe* is the geobotanic indicator present since it demarcates the buried water-bearing mafic intrusion. The geobotanic importance of the following tree species requires further attention: *Commiphora mollis*, *Gardenia volkensii*, *Lonchocarpus capassa* and *Spirostachys Africana*.**

The following case studies are representative of the Waterberg Group in the Bronkhorstspuit area: see also Tables A1.21(a&b)(ii,iii).

32. Elandsfontein 493JR

A cluster of *Combretum erythrophyllum* (river bushwillow) species on the farm Elandsfontein 493JR triggered interest in this area regarding suitable groundwater exploration. The species *Combretum erythrophyllum* is linked to some excellent aquifer yield characteristics among various geological lithologies and formations as previously discussed. The most abundant formation on the farm Elandsfontein 493JR is the Wilgerivier Formation of the Waterberg Group. Diabase intrusions in the said formation are characterised by *Acacia caffra* (common hook-thorn). An existing borehole on the farm is situated among *Acacia caffra* trees with some conspicuous growth of *Zanthoxylum capense* (small knobwood). However, this case was not included because it is situated in the lodge area with a high ambient noise level from water pipes, electrical cables and steel objects. The soil formations are also disturbed in places.

The area studied is covered with some *Combretum erythrophyllum* species, mentioned earlier. This can be referred to a shallow depth to groundwater owing to the presence of a palaeo-channel or shallow weathering of a diabase sill, but still deep enough to be below the static water level of the region. The weathering of a diabase sill is a favourable option owing to the fact that no sandstone outcrops were observed in the *Combretum erythrophyllum* cluster, but in its surroundings. If the zones without any sandstone outcrops are followed, this ends at the cluster of *Acacia* species at the lodge mentioned. Approximately 75 m east of the *Combretum erythrophyllum* cluster some other geobotanic indicators are present, including some superb tall *Acacia karroo* specimens, *Euclea crispa* and *Zanthoxylum capense* where no sandstone outcrops are noticeable. The presence of the shallow weathering of a diabase sill or of a palaeo-channel

motivated the employment of only the Schlumberger depth sounding method, with the model indicated in Figure 4.50, owing to the horizontal nature of the expected aquifer.

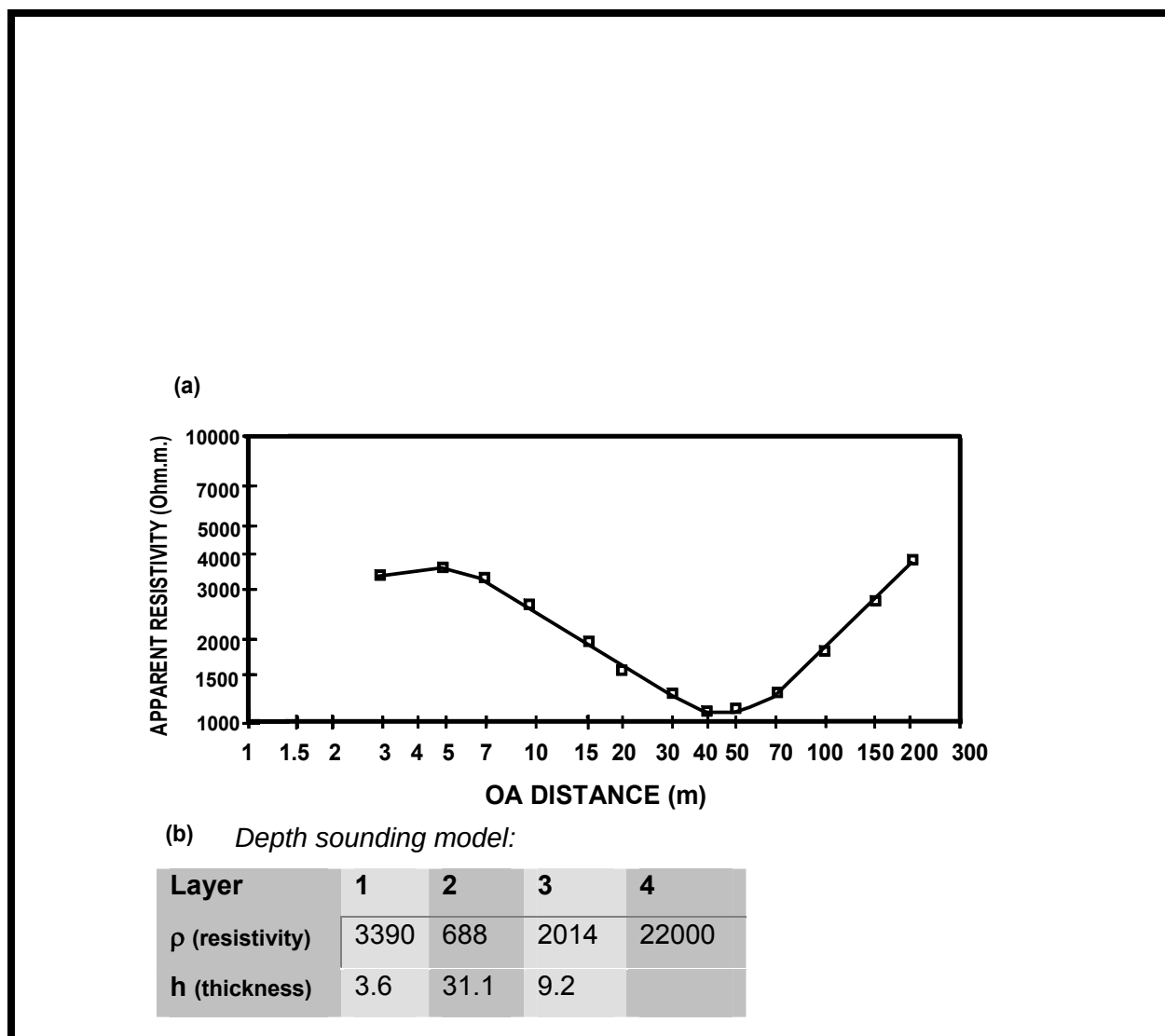


Figure 4.50. Schlumberger depth-sounding on the farm Elandsfontein 493JR.

The Schlumberger depth-sounding model as represented in Figure 4.50 indicates a HA-type curve. The traverse was laid out parallel to the strike of the sandstone (east-west) and its position defined by the strike of the linear vegetated feature as indicated on the aerial photograph. The model indicates some resistive overburden (Mispah soil type), but a thick intermediate layer of lower resistivity till a depth of about 35 m, whereafter it progresses into unweathered diabase bedrock. The groundwater will be situated in layer 2 or in the transgression zone between zones 2 and 3. The borehole drilled at this spot

among the *Combretum erythrophyllum* species yielded 11 000 l/h and was drilled to a depth of 45 m, resulting from the model as tabled in Figure 4.50. The water strike was at 23 m, representing layer 2 and consisted of consolidated sand, diabase boulders and some interlayered sandstone and diabase as interpreted from the resulting borehole log. The first couple of metres was drilled merely in loose sand obliged correct borehole construction by placing a larger diameter casing into the sand to prevent the drilled borehole from being continuously filled with sand. The end of the borehole rests in a relatively unweathered diabase. This fact indicates that the *Combretum erythrophyllum* species grows in this case, on top of a weathered diabase sill covered with sand with a low clay content (probably alluvium). Thorn trees normally grow in clay conditions (Bonsma, 1976). If compared to the studies of Frommurze (1937) and Meulenbeld (1998), this case study represents an aquifer yield well above the average yield obtained in the Wilgerivier Formation. The depth of drilling and groundwater interception is comparable to the average results of this region.

Soil samples taken at the borehole and among the *Combretum erythrophyllum* shrubs indicate higher pH, Ca, Mg, K, heavy metal, conductivity, C, N and CEC-values, resembling a clay soil. The remaining sample was obtained near some sandstone ridges, about 30 m away from the geobotanic site. The organic part of the geobotanic community's soil samples (C, N and CEC) are a couple of times (factor 3) higher than that of the other site (sandy soil) and signify the importance of humus, indicating life and availability of water, in this sandy, dry and leaching habitat (Table A1.21(a&b)(ii)). The sand records a lower pH and hence considerable Al toxicity values that restrict plant growth and development. The differences in soil composition and underlying geological conditions give rise to conspicuous tree growth.

***Combretum erythrophyllum* is the primary geobotanic indicator in this case study. With the aid of the geobotanic species *Acacia karroo*, *Euclea crispa* and *Zanthoxylum capense*, the differences in soil type and geology could be mapped. The *Combretum erythrophyllum* indicates sandy soil and shallow groundwater (almost unconfined) conditions, whereupon *Acacia karroo*, *Euclea crispa* and *Zanthoxylum capense* indicate clay soil and deeper, confined groundwater conditions.**

33. Leeuwfontein 492JR

This farm possesses a conspicuous feature in that a prominent *Acacia* community occupies a small hill on its northern border. The boreholes on this farm were already in existence, but the area was studied regarding geobotanic indicators close to successful boreholes. According to the owner, the borehole logs consisted mainly of 'blouklip' (a local name for diabase). The farm is used for cattle farming on the dry and sandy soil derived from weathered Wilgerivier Formation sandstone and cultivation practices on the loam soil, derived from the weathered diabase sill as indicated on the Pretoria geological map (1978). Part of the Bankenveld veld type, plains covered with grass are characteristic and some tree or shrub cover on loam and clay soils, and also between rocky shelters and valleys, is common. The growth of the *Acacia* species on soils derived from weathered diabase is obvious in the Wilgerivier Formation (Meulenbeld & Hattingh, 1999). The *Acacia* community was visited and two boreholes were studied, one successful (Figure 4.51) and one dry (Figure 4.52). Notes on geobotanic indicators were made together with soil samples from both sides. A magnetic profile was also run along these boreholes (Figure 4.53).

The borehole, as represented by the model in Figure 4.51, indicates a depth profile with decreasing apparent resistivity to a depth of 32 metres. The borehole is 60 m deep, water was struck at a depth of 25 m and the static water level is approximately 7 m from the surface. The yield of the borehole is 5 000 l/h, considerably higher than the average for this formation (Frommurze, 1937, Meulenbeld, 1998 & Johannesburg, 1999). The model as represented in Figure 4.51 is a typical HA-type curve, the same shape as derived on the neighbouring Elandsfontein 493JR property. The interpretation of the model leads one to suspect the presence of a resistive overburden since the surface is scattered with sandstone boulders and some sandstone outcrops. The weathered contact zone of the diabase sill is measured in depth, and is represented by a decrease in apparent resistivity. The bedrock of the model is not very resistive, but will be representative of diabase in a certain state of weathering. Geobotanic indicators observed around this successful borehole are limited to *Acacia karroo* (sweet thorn) and some *Gymnosporia buxifolia* (common spike-thorn) species. The *Acacia karroo* can be regarded as a geobotanic indicator in this rather treeless environment. Since all the *Acacia* trees in the community are representative of *Acacia karroo*, one must identify tall

and robust trees with a noteworthy circumference. This was the case at the successful borehole, whereas at the dry borehole, *Acacia karroo* is abundant, but the robustness and circumference of the specimens are somewhat lacking.

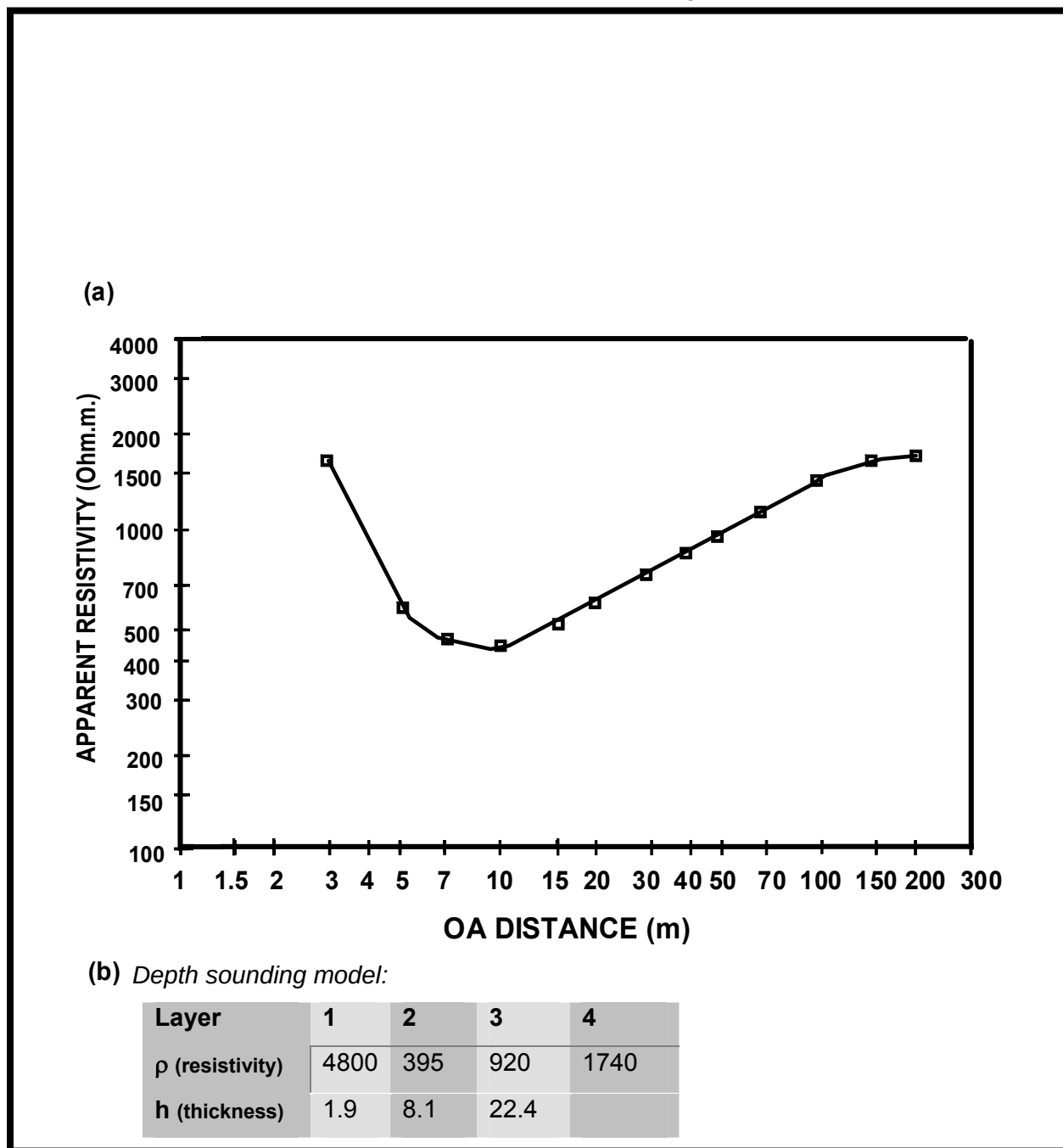


Figure 4.51. Schlumberger depth-sounding at the successful borehole on the farm Leeuwfontein 492JR.

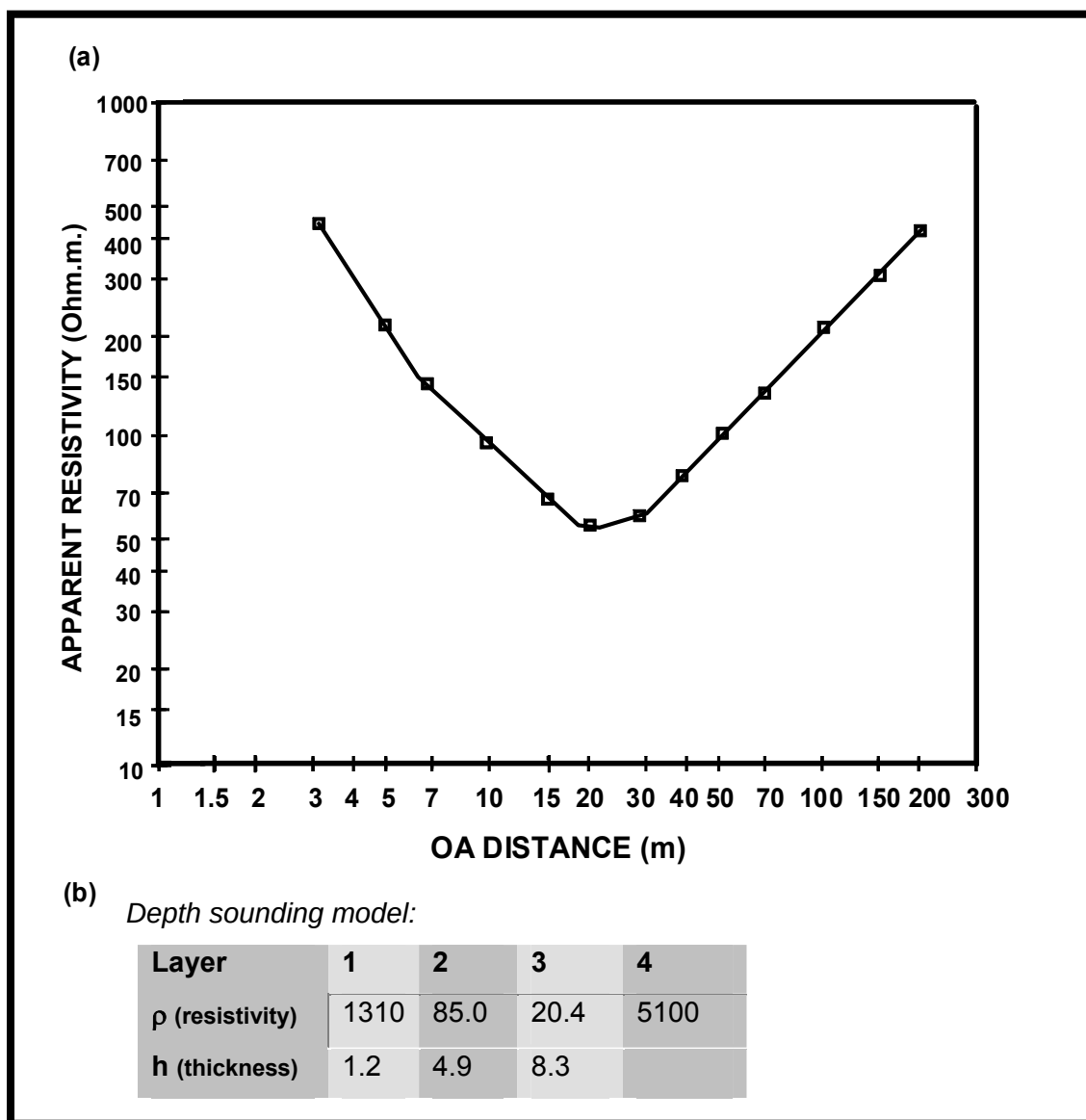


Figure 4.52. Schlumberger depth-sounding at the dry borehole on the farm Leeuwfontein 492JR.

The measured apparent resistivity signature of the sub-surface at the dry borehole is illustrated in Figure 4.52. The model indicates the same type curve as tabled in Figure 4.51, namely a HA-type curve. But note the different shape and shallow weathering profile, since only a 14 m weathered profile covers the relatively unweathered diabase bedrock (higher resistivity). The parameters of the successful borehole indicated that

groundwater was struck at a depth of 25 m, too deep in this case because at a depth of 25 m relatively unweathered diabase is present. Aquifers in this environment are situated in the weathered diabase-unweathered diabase transgression zone. In order to achieve a successful borehole, it is essential that the weathering depth must be sufficient. The successful and dry boreholes are approximately 120 m apart. This borehole is also 60 m deep. Both soundings were laid out east-west so as to capture only the diabase sill and not to cross the sandstone layers since these can impose electrode effects. The magnetic profile as indicated in Figure 4.53 indicates the transgression from sandstone beds to an intrusive diabase sill. The transgression can only be defined if the profile is run in a north-south direction.

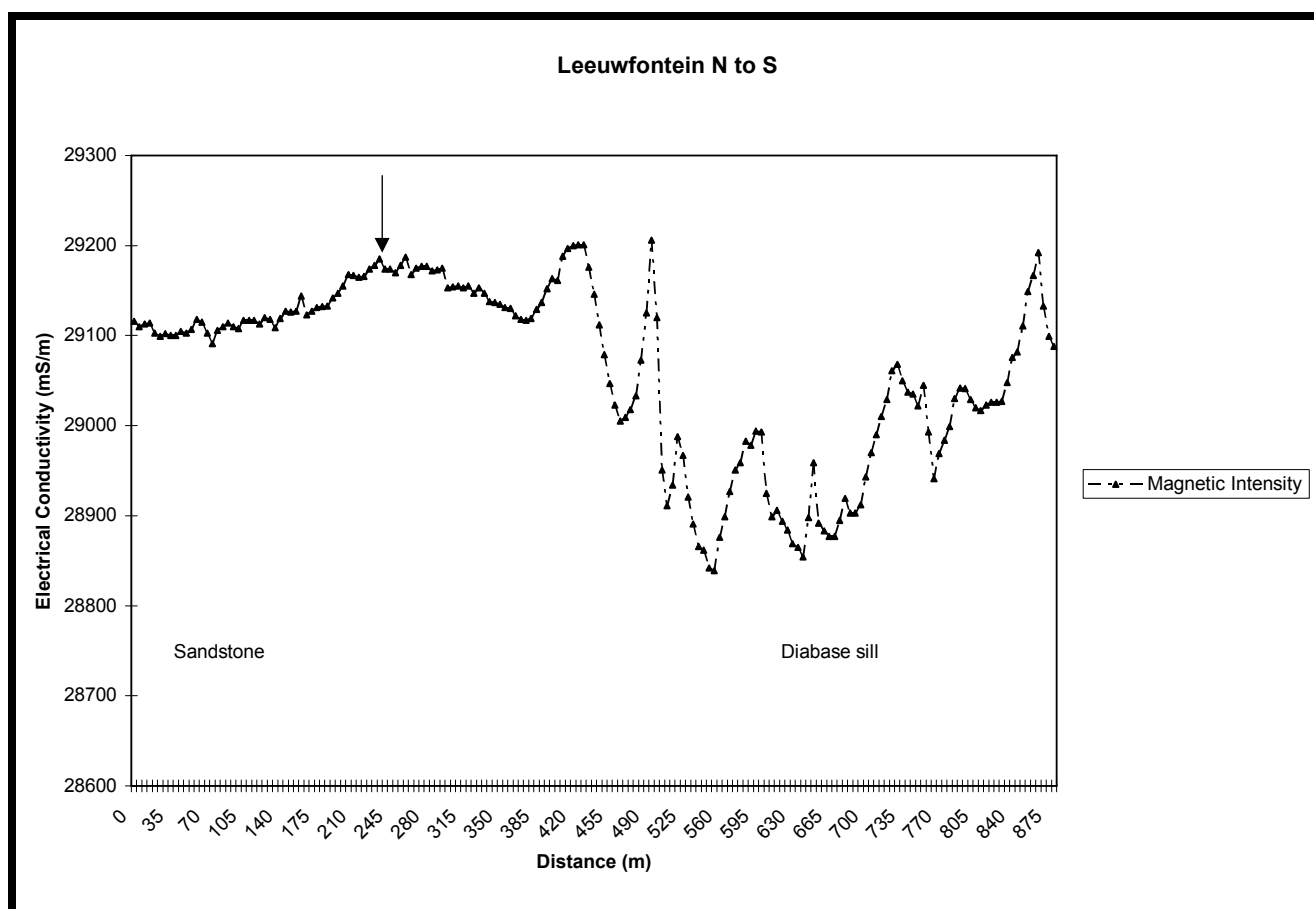


Figure 4.53. Magnetic profile on the farm Leeuwfontein 492JR.

The profile over the sandstone overburden is basically minimally disturbed in its magnetic intensity readings, whereas the profile readings over the weathered diabase sill are erratic. According to the Schlumberger depth sounding models, the diabase is

covered by sandstone in certain areas. The profile, as measured from north to south, experiences a decline in altitude from north to south. The diabase covered by sandstone is about 15 m higher than the exposed diabase. The difference in altitude, the sandstone cover and the significant weathering of the diabase represent important contributors to the development of the confined aquifer in this case. Where the sandstone cover is absent and the depth of the weathering profile is quite shallow, aquifer conditions are absent. Altitude might be another important factor when considering drilling into weathered intrusions since altitude and the weathered horizon govern the depth of the static water table as well as the probability of encountering the water when drilling.

At the site of the yielding borehole (representing the geobotanic indicators) and at the dry borehole, soil samples were taken at the indicated depths, see Tables A1.21(a&b)(ii,iii). The geobotanic community records higher pH, Ca, Mg, K, Na, Fe, Mn, C, N, conductivity and CEC values with a decrease in S with depth (Table A1.21(a&b)(ii)). Since the higher values represent the higher availability of these elements in the soil for plant life and enhance more favourable growth conditions, being protected against drought stress (considerably higher CEC values that indicate higher water availability and content), it is not far fetched to associate the successful borehole with the pronounced *Acacia karroo* species.

***Acacia karroo* is the only geobotanic indicator present. A pitfall arises at this locality since the entire diabase intrusion is covered with this species. It is crucial to identify trees that are robust with a remarkably large circumference.**

34. Onspoed 500JR

The use of aerial photographs when studying borehole siting on this farm is extremely helpful since the sandstone (Wilgerivier Formation) cliffs and ridges are crossed and intersected by numerous lineaments, most probably diabase intrusions, that are remarkably clearly evident on these aerial photographs; see annexure. Geophysical exploration can be directed by these observed and identified lineaments because they can be extrapolated from the sandstone outcrops to the grassy, sandy plains.

The borehole in question is situated along such a lineament. The borehole is 180 m deep, but the British Engineering Corps, according to the previous landowner, the late Mr J van Ryneveld, does not base its depth on geological conditions, but rather, as an exercise. It is the deepest borehole in the Wilgerivier Formation known to the present author. The borehole yields 22 000 l/h, water was struck at a depth of 18 m and the measured static water table resides at a depth of 5 m below the surface (the static water table elevation can be attributed to the closeness of the Wilge River). Around the borehole some growth of *Acacia karroo* (sweet thorn) and *Burkea africana* (wild syringa) together with *Dichapetalum cymosum* (gifblaar) is evident. These species are regarded as geobotanic indicators in the Wilgerivier Formation, according to Meulenbeld & Hattingh (1999). The occurrence of these species in clusters on other portions of the farm is limited and mostly in line with inferred lineaments from the aerial photograph. Geophysical methods implemented on the farm include the magnetic and electromagnetic methods as well as Schlumberger depth soundings owing to the presence of numerous lineaments and the gentle elevation of the plain. The results are presented in Figures 4.54 and 4.55.

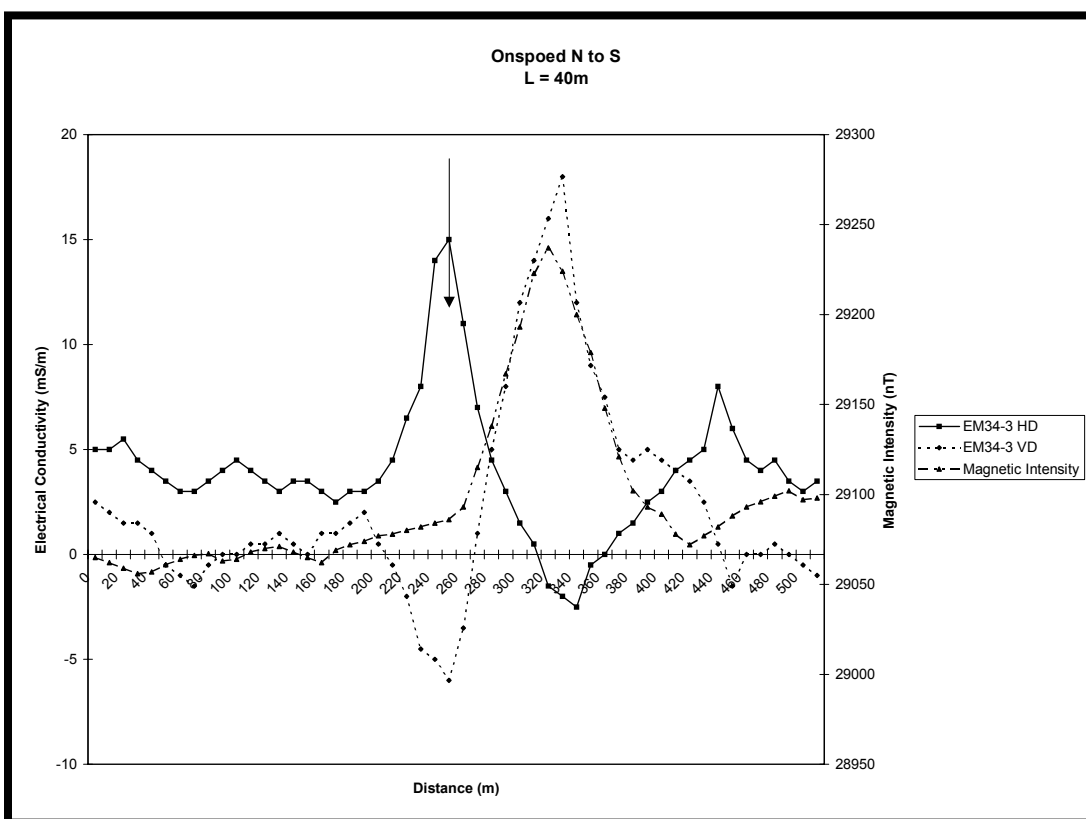


Figure 4.54. Geophysical profile on the farm Onspoed 500JR.

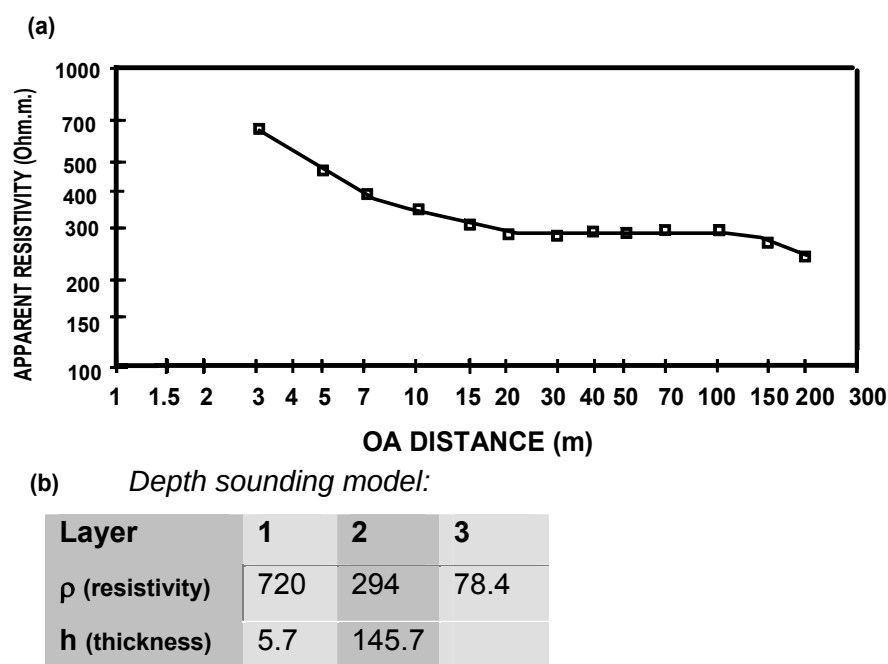


Figure 4.55. Schlumberger depth sounding on the farm Onspood 500JR.

The geophysical profile as indicated in Figure 4.54 was measured from north to south, almost perpendicular to the strike of the identified lineaments. Although the electrical conductivity is low, some significant anomalies arise for both dipole components. The magnetic profile indicates a magnetic anomaly (diabase intrusion/lineament) from station 260 m to 400 m that is well defined by the signature of the HD and VD components. A significant anomaly around station 250 m arises, where $HD \gg VD$ (weathered diabase). The arrow denotes the position of the borehole. Thereafter the $VD \gg HD$ over the lineament (unweathered diabase) and drops towards the edge of the lineament, as indicated by the drop in magnetic intensity. The rest of the profile indicates parallel

readings between HD and VD and a lower conductivity. These values represent the sand overburden and sandstone bedrock. A Schlumberger depth sounding near station 250 m was measured and its results are presented in Figure 4.55. The sounding direction was east-west, parallel to the strike of the sandstone so as to minimise electrode effects.

The model depicted in Figure 4.55 indicates an extremely deep weathered profile that extends into the measured bedrock. This might be the reason for the remarkably deep borehole, and to posit the location of a deeper confined aquifer might be reasonable. Since this depth sounding was located at station 250 m in close proximity to the lineament, it might be argued that the lineament is extensively weathered and its dip is not in excess of 45° because the sounding curve would rather be of an A-type than the measured Q-type.

The soil samples were taken at the borehole with the few geobotanic indicators (*Acacia karroo* (sweet thorn), *Burkea africana* (wild syringa) and *Dichapetalum cymosum* (gifblaar)), at station 250 m and also station 220 m on the sandy plain. The results indicate that the borehole/geobotanic site displays higher values of pH, Ca, Mg, Na, Fe, Mn, C, N and CEC. This must be attributed to the geochemical deep weathering of the diabase since sandstone is deficient in these kind of nutrients and tends to have acid soil (low pH) with minimal weathering, especially in the environment of this land type (rock, Mispah soil series) that generally indicates less weathering and shallow soil. The obtained results are quite similar to those presented previously in the preceding case studies. Lower resistivities are measured at both stations and may represent the findings of the depth sounding; an extremely well-weathered lineament.

***Acacia karroo*, *Burkea africana* and *Dichapetalum cymosum* (a weed) are the geobotanic indicators in this case study. This is based on the fact that these species normally occur along lineaments and clay-rich soil. The land type and weathering of the sandstone does not permit the soil profile to contain a large clay content. Hence, weathered igneous rock is expected in the clayey areas. The sandstone/igneous rock contact acts as the aquifer.**

The southern edge of the Wilgerivier Formation is in contact with shale and hornfels belonging to the Silverton Formation of the Pretoria Group (see annexure). The weathering of these rocks contributed to the formation of Avalon, Clovelly and Glencoe type soils with a characteristic high sand content. The strike of the Wilgerivier Formation extends east-west with a gentle dip towards the north; therefore depth soundings can be performed. As illustrated in the geological map (annexure), numerous diabase intrusions occur in this locality. Such intrusions are visible as lineaments (red lines) on the aerial photograph. Owing to the presence of diabase, it is feasible to employ the magnetic method as an additional geophysical technique.

The existing borehole is situated along a lineament, although not visible on the aerial photograph, with an east-west strike between sandstone outcrops. It can be interpreted that linear areas with almost no sandstone outcrops form a lineament. This borehole yield of 3 000 l/h, is quite average for this area (Frommurze, 1937, Meulenbeld, 1998 and Johannesburg, 1999). But this must not be taken for granted, because a dry borehole is evident on this farm, where the borehole drilling chips reveal sandstone and diabase having been drilled. The borehole with a yield of 3 000 l/h is 40 m deep, water was struck at a depth of 23 m and the static water level is 12 m from the surface, as indicated in Table A1.21(a&b)(iii).

The magnetic profile was run perpendicular to the expected strike of the diabase intrusion (the strike was expected to lie east-west owing to the shape of terraces in the sandstone beds). The Schlumberger sounding was laid out parallel to the strike of the sandstone (east-west). The magnetic profile as shown in Figure 4.56 clearly demarcates an anomaly since the magnetic intensity increases to a maximum value of about 29060 nT from station 120 m. Since the magnetic intensity does not flatten or decrease sharply after the peak value, it can be assumed that the intrusion dips gently to the south and is covered by sandstone. No diabase outcrops were visible, only some large coarse-grained diabase rocks with a yellow iron-oxide coating tilled from the lands in the past. The arrow marks the position of the borehole at station 80 m and the position of the soil sample and geobotanic indicators (*Acacia karroo*, *Euclea crispa* and *Strychnos pungens*) in the linear zone. The remaining soil sample was collected at station 55 m. A Schlumberger depth sounding was performed at the borehole position since the

expected gentle dip of the lineament still made depth soundings still possible. The extent of weathering can also favour Schlumberger depth soundings as indicated in case study number 34. The Schlumberger QQH-type curve and model, Figure 4.57, indicate a resistive sandstone overburden (high sand content as indicated in the land type map as well) that decreases gradually in depth to a conductive layer, highly weathered diabase with a clay content, approximately 17 m thick at a depth of 14 metre. According to the borehole information, groundwater was struck in the 17 m thick layer, or layer number 4 of the model. The last layer or bedrock will most probably be relatively weathered diabase. Since the borehole is only 40 m deep, it is expected that the end of the borehole rests in diabase. This kind of sounding curve is a trustworthy curved shape that indicates groundwater in this formation, according to Meulenbeld (1998). Groundwater in the Wilgerivier Formation normally occurs in weathered diabase contact zones as encountered here.

The sour and sandy environment is illustrated by the low pH-values of both soil samples taken at the site of the geobotanic community and the other one some distance from it. However, the pH-value of the geobotanic community is higher. Although the Ca and Mg values are overall higher at the geobotanic community, only the available K and Na values increase with depth. Since the Mn, conductivity, C, N, S and CEC values are also higher for the geobotanic community, these values represent a suitable environment to host plant life in this hostile, sandy and sour (high Al toxicity) habitat owing to a higher soil moisture content (CEC), organic life indicators (C, N) and Mg-values required for photosynthesis. The presence of the abovementioned geobotanic indicators is not clearly visible on the aerial photograph, and therefore it is important to spot tree species that can act as geobotanic indicators depending on the zone of occurrence, during site investigations. The geobotanic indicators are established between the linear sandstone terraces where no sandstone outcrops are visible and the placement of the borehole, thus in the area underlain by weathered diabase. The linear zone records higher C, N, Mg and CEC-values. The dry borehole is drilled among the outcrops of sandstone.

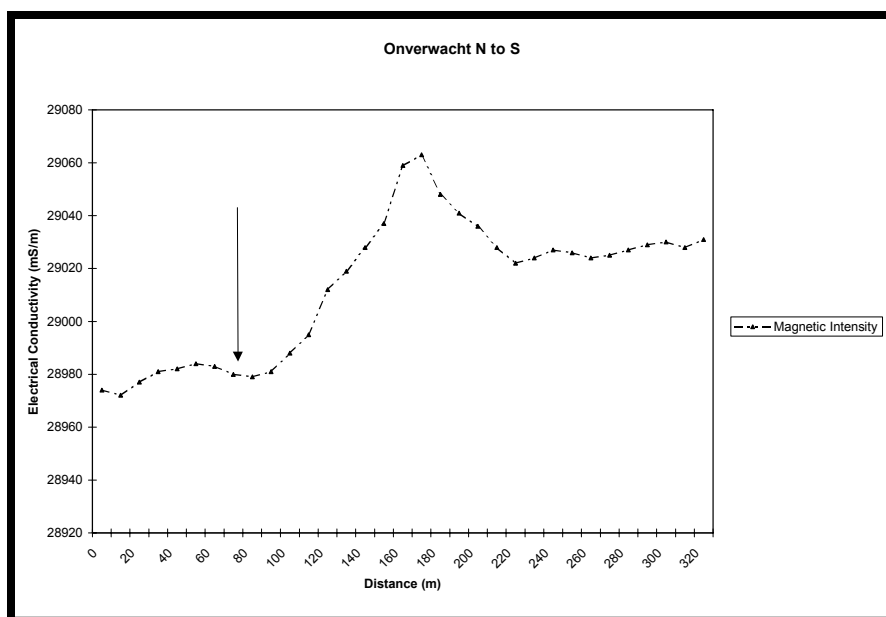
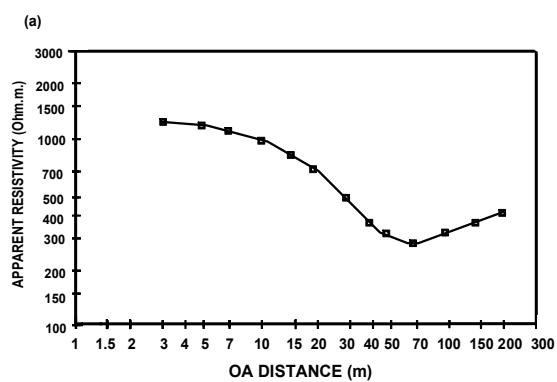


Figure 4.56. Magnetic profile on the farm Onverwacht 532JR.



(b) *Depth sounding model:*

Layer	1	2	3	4	5
ρ (resistivity)	1360	1019	348	170	521
h (thickness)	1.9	8.2	4.3	17.2	

Figure 4.57. Schlumberger depth sounding on the farm Onverwacht 532JR.

Acacia karroo, *Euclea crispa* and *Strychnos pungens* are the geobotanic indicators in this case study. This is based on the fact that these species normally occur along lineaments and clay-rich soil. The land type and weathering of the sandstone does not permit the soil profile to contain a large clay content. Hence, weathered igneous rock is expected in the clayey areas. The sandstone/igneous rock contact acts as the aquifer.

36. Trigaardspoort 451JR

The Wilgerivier Formation is, at places, covered with weathered sediments of the Dwyka Formation, Karoo Supergroup, although the thickness of the Dwyka sediments is restricted to approximately a few of metres (Visser, 1989). The Wilgerivier Formation basin in this area is quite flat without any conspicuous outcrops and therefore only limited protection can be granted to indigenous vegetation, which presents difficulties in geobotanical-geophysical groundwater exploration. Since this farm borders closely on outcrops of rhyolite and granite belonging to the Loskop Formation and Nebo Granite Suite respectively, which are covered with more abundant indigenous vegetation, some of this vegetation is encountered on this farm. The only problem associated with it is the lack of protection the indigenous vegetation usually obtains from the outcrops with regards to frost, wind, fire and invasion of the land by large *Eucalyptus* species or bluegums that absorb large quantities of water on a daily basis and tend to destroy life around their stem base. Fortunately, a small *Euclea crispa* (blue guarri) specimen was located on the farm, close to a spring, rooting in clay. The presence of clay suggests the presence of weathered diabase in this geological setting. The land types and representative soil series (Mispah and Clovelly) are poor in clay. This geobotanic specimen was used as a geobotanic indicator and the geophysical methods were applied in its surroundings in order to locate a favourable drilling spot. The geophysical profile and sounding are indicated in Figures 4.58 and 4.59. The arrow in Figure 4.58 denotes the position of the drilled borehole around station 240 m and the location of the blue guarri (*Euclea crispa*) species. Both (electro) magnetic traverses were conducted north-south in order to limit the influence of noise. A poor magnetic anomaly can be observed, but the electromagnetic profile indicates favourable weathering positions in the vicinity of stations 220 – 260 m, due to HD>>VD (weathered diabase). Although the

electrical conductivity is distinctly low, in the range of 3 mS/m, the differences in conductivity are still significant if compared to the overall scale of readings obtained over the profile. The low electrical conductivity represents an indication that the conductive weathered diabase structure is considerably covered by resistive sandstone. A Schlumberger depth sounding (east-west orientation, parallel to the strike of the sandstone) was conducted at the borehole/geobotanic indicator site because the presence of a mafic intrusion is not clearly defined on the magnetic profile. The obtained H-curve is represented in Figure 4.59.

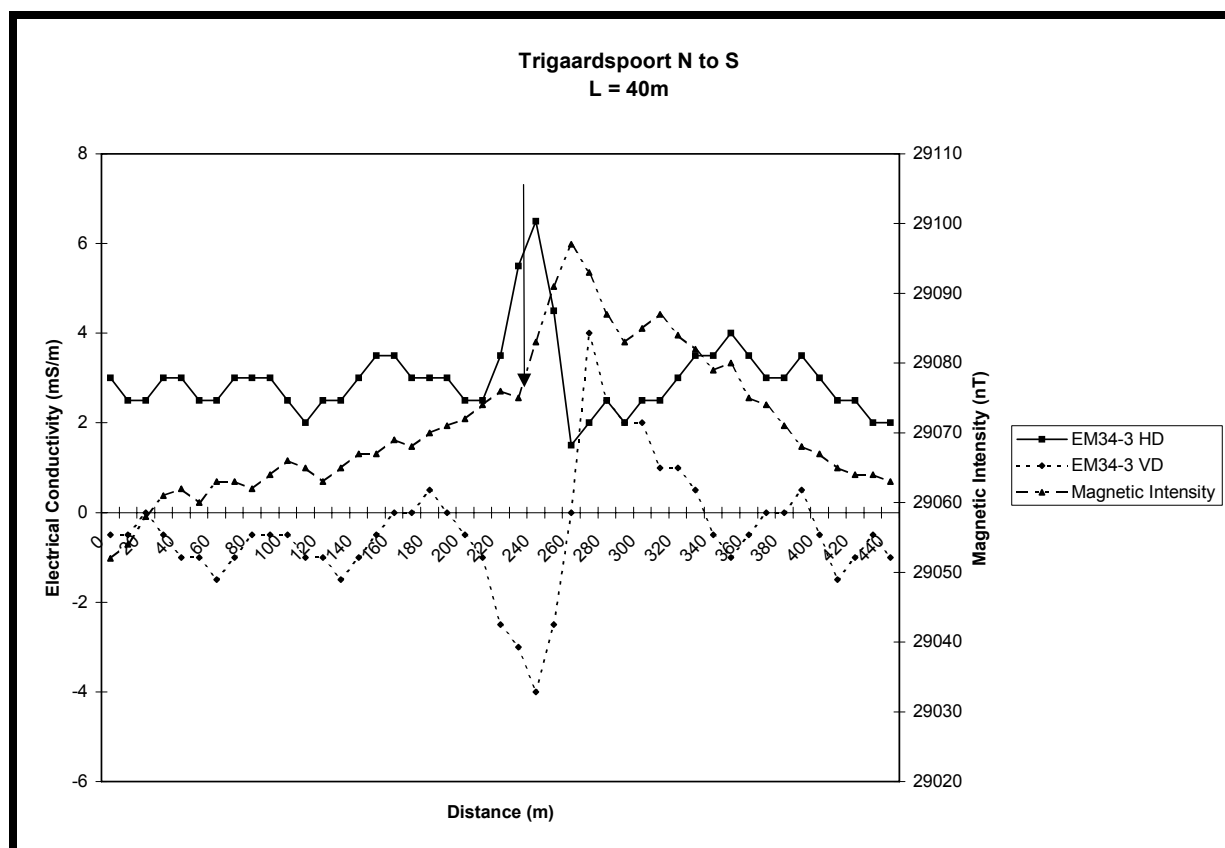


Figure 4.58. Geophysical profile on the farm Trigaardspoort 451JR.

The modelled depth sounding represents a three layered earth with a small and electrical conductive zone close to the surface, layer 2. One can deduce that the first layer is competent sandstone since numerous outcrops occur in the locality of the sounding. The second layer represents water-bearing features such as joints or fissures in the rock, because these features carry water due to their proximity to a spring and a stream. The rising segment of the curve features the bedrock, and sandstone with a gradual transgression to diabase (mafic rock) in depth, in accordance with the borehole

log. The diabase intrusion is poorly defined on the sounding curve owing to its steep incline, inferred from the magnetic traverse. According to the borehole log it is evident that at a depth of 28 m a sandstone/diabase contact arises, which acts as an aquifer. The presence of diabase in the area is indicated by the Pretoria geological map (1978), by the presence of the closely situated spring and the shape of the linear streams (lineaments) as seen on the aerial photograph (annexure). Normally springs originate owing to the presence of a confined layer in the sub-surface (Fetter, 1994).

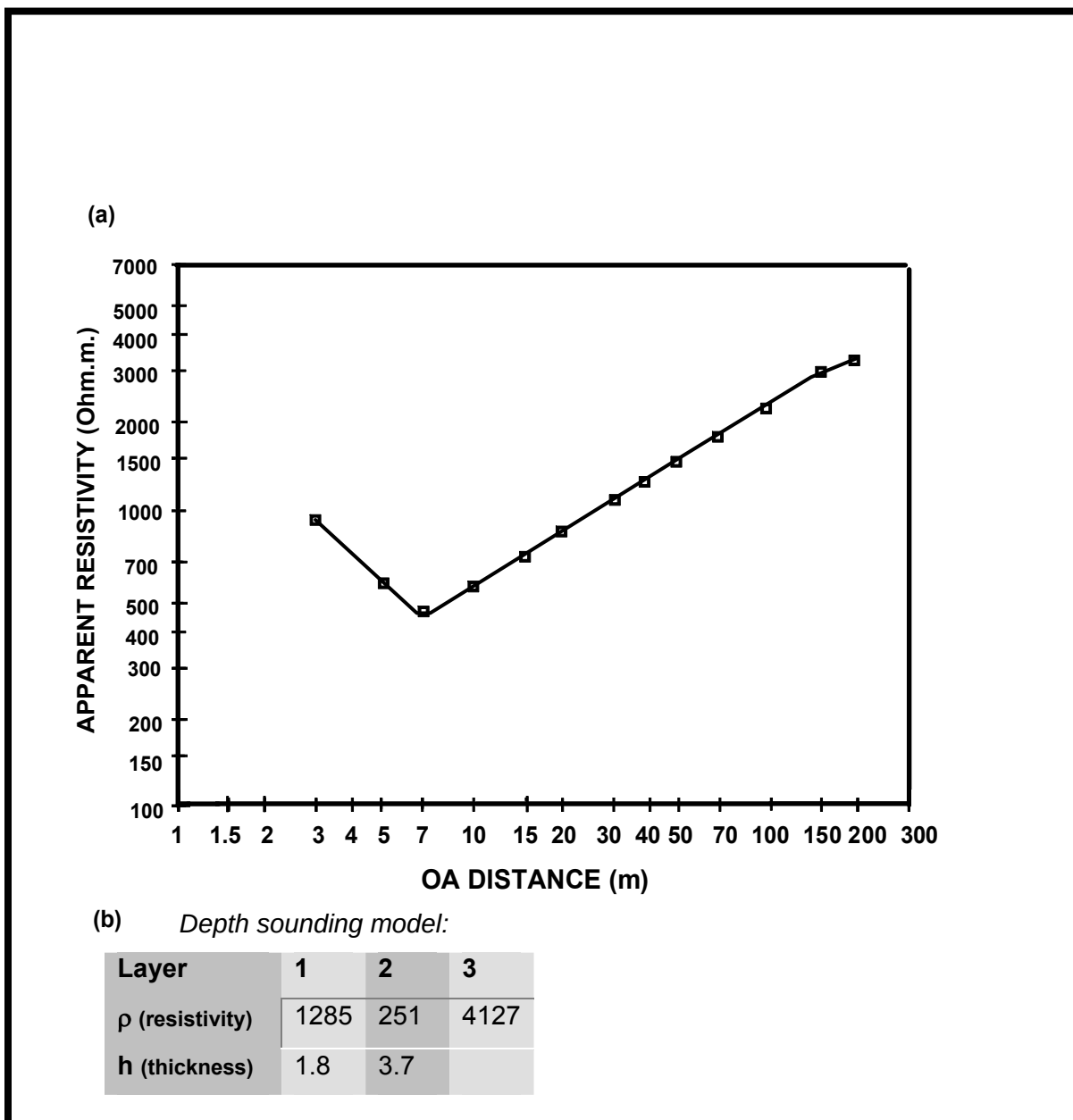


Figure 4.59. Schlumberger depth sounding and model on the farm Trigaardspoor 451JR.

As indicated in Table A1.21(a&b)(iii), the borehole has a yield of 3 500 l/h and a depth of 70 metres, with water strikes at depths of 3 and 28 metres. The static water table is situated 2 m from the surface (close to the surface of the water-bodies). The deeper water strike represents a small contact zone, not indicated by the curve owing to lateral effects (incline of intrusion $>45^\circ$) and the principle of suppression (small conductive layer between thicker resistive beds) (Van Zijl, 1987). In this case the geobotanic indicator, the presence of a spring and favourable electromagnetic profile eased the decision to drill a borehole at the spot since the magnetic profile and Schlumberger depth sounding did not appear to be promising alone. The yield of the borehole is above average for this environment, as indicated earlier. The borehole was drilled to 70 m because it creates a comfortable water sump below the surface, with a capacity of 14.5 m³.

Soil samples were subsequently collected at the location of the borehole/geobotanic indicator, at station 250 m and the remaining location at station 270 m, an indicated geophysical anomaly owing to a maximum magnetic intensity reading and $HD \approx VD$. The former indicated a higher pH-value, overall higher Ca, Mg, K, Fe, Mn, C, N, CEC and conductivity values. For the soil series representative of this environment (Mispah and Clovelly), a clay deficient soil is normal. The presence of some clay at the geobotanic indicator suggests the presence of diabase. The higher clay content at the geobotanic site results in elevated nutrient levels that support tree growth and rooting. Previously discussed case studies with respect to the Wilgerivier Formation have indicated that the higher values of available nutrients support plant life, although not remarkably present at this spot, owing to climatic and protection factors. The fact must be stressed that the difference in available nutrients between the geobotanic indicator and the other site sampled is almost as much as ten times at certain levels.

***Euclea crispa* is the geobotanic indicator in this case study. Higher concentrations of clay and nutrients are indicators of weathered diabase, whereas the clay and nutrient-poor Mispah and Clovelly soil series are derived from weathered sandstone. Aquifer conditions are created by weathered diabase in the sandstone owing to its higher porosity and permeability in the weathered and fractured zones.**

37. Vlakfontein 453JR

Various geological outcrops occur on the farm Vlakfontein 453JR, approximately 15 km north of Bronkhorstspuit. The Wilgerivier Formation basin was intruded by a huge diabase sill and owing to the weight of the intrusion, the sandstone strata dip about 25° to the southwest, whereas the normal dip of the strata is 5°-10° to the southeast in the same area (Pretoria, 1978). The Pretoria geological map (1978) indicates a lineament with an east-west strike on the farm. The southwestern parts of the farm are covered with weathered shale belonging to the Dwyka Formation of the Karoo Supergroup. A prominent hill west of the farm, called Vlooi kop, consists of sandstone, grit and coal of the Eccu Group, Karoo Supergroup. Geophysical groundwater exploration on this farm was entirely based on a geobotanic indicator, namely a giant *Combretum erythrophyllum* (river bushwillow) species. This specimen is situated approximately 5 km from the nearest surface water body. It grows in a small local, linear depression that is not cultivated, on a neighbouring farm (150 m to the west). The depression is also occupied by some *Acacia caffra* (common hook-thorn) species, although they appear quite frequently on diabase intrusions in the Wilgerivier Formation in the vicinity of Bronkhorstspuit. A study of aerial photographs of the farm, in association with the geological map, indicated the presence of a lineament next to the *Combretum erythrophyllum* species. The contact zones of a lineament act as groundwater pockets and consequently act as preferable geohydrologic targets. The location of this lineament was traced by means of geophysical profiling methods, including the magnetic and electromagnetic ones. The measured profile, illustrated in Figure 4.60, was run from north to south because the strike of the lineament lies east-west.

The first 300 m of the profile represents a homogenous layered earth, with some areas of deeper weathering, indicated by local HD-VD variations. The high electrical conductivity of the sub-surface is considerably higher (a factor of ten) than the measured electrical conductivity of the Wilgerivier Formation sandstone as determined in other case studies presented and indicates higher concentrations of soil moisture and clay. From station 300 m a decline in magnetic intensity and electrical conductivity is experienced, whereafter a rise in the magnetic intensity and the vertical dipole component of the electromagnetic apparatus is observed. This can be ascribed to the presence of the vertical orientation of lineament in the sub-surface. The arrow in Figure

4.60 denotes the position of the drilled borehole; since it is on the side of the lineament, it represents the lowest magnetic intensity value for the profile and HD>VD (weathered contact zone). When the 60 m deep borehole was drilled, it had a yield of 18 000 l/h and water strike at 18 m. The static water level is 12 m from the surface in the borehole. The borehole log indicated: 0-2.5 m loam overburden; 2.5-12 m sandstone; 12-22 m weathered diabase; 22-34 m less weathered diabase; 34-60 m unweathered diabase. The depth of the borehole is based on the maximum exploration depth of the EM-34-3 as stated by the manufacturer of the instrument, Geonics.

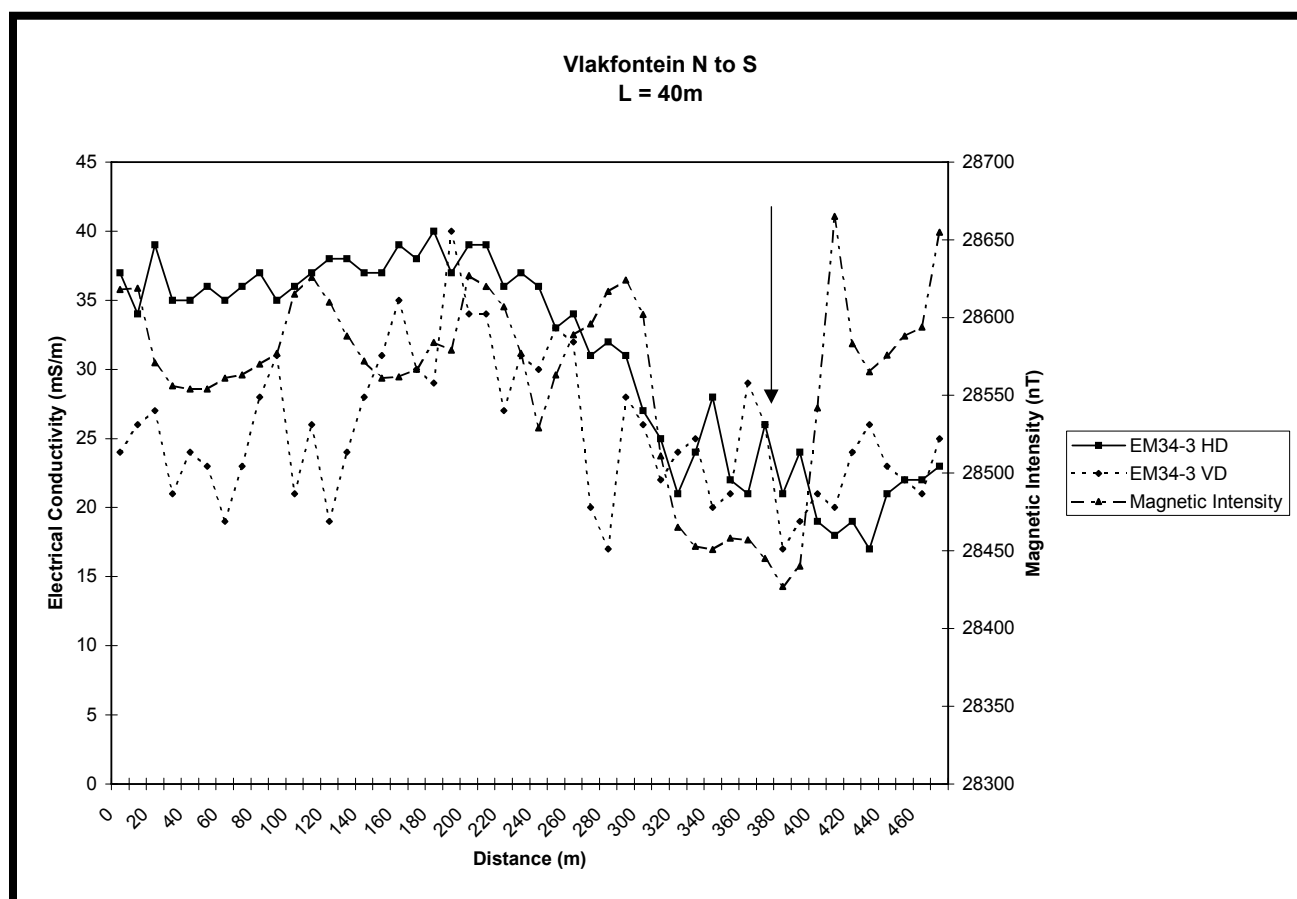


Figure 4.60. Geophysical profile on the farm Vlaktefontein 453JR.

The geophysical profile in Figure 4.60 therefore represents only the upper 60 m of the sub-surface or less. Even if the geobotanic indicator is not situated next to the drilled borehole in this instance, the geobotanic indicator was the cause of the initial geophysical investigation in this area because this indicator is rooted on the same geological structure. This is a convenient tool where certain areas are cultivated. The

original vegetation can be traced to surrounding areas that are still intact, as long as the areas are geologically connected or homogenous.

The soil samples presented in Table A1.21(a&b)(iii) were sampled at station 380 m (borehole) and 340 m. The borehole site indicates an elevated pH, higher N, P, K-values close to the surface, and overall higher values in Ca, Mg, Fe, C, N and CEC. These values are once again favourable for plant life. Such values indicate a different geochemical weathering process and the presence of weathered diabase. The Hutton soil series contains lower levels of the stated nutrients.

***Combretum erythrophyllum* is the geobotanic indicator in this case study. Since the rooting system of this species is normally found in close contact with water, its presence indicates shallow groundwater. *Combretum erythrophyllum* usually grows well on sandy alluvium, and its presence indicates a higher sand content in the soil. Its roots can easily penetrate a weathered diabase contact zone to a depth of 18 m.**

The following case studies are representative of the Waterberg Group in the Middelburg area (see Table A1.21(a&b)(iv)).

38. Bankfontein 264JS

The geobotanic indicators linked to the Wilgerivier Formation in this area include *Acacia karroo* and *Euclea crispa* (blue guarri) and indicate possible weathered diabase intrusions that manifest themselves as lineaments and deeper soil profiles in a rocky land type. An area where these species grow was identified, and geophysical profiling and a sounding indicated the presence of such a lineament: see Figures 4.61 and 4.62. The geophysical profile, as indicated in Figure 4.61, was conducted north to south in order to cross possible lineaments as seen in the aerial photograph of the farm (annexure).

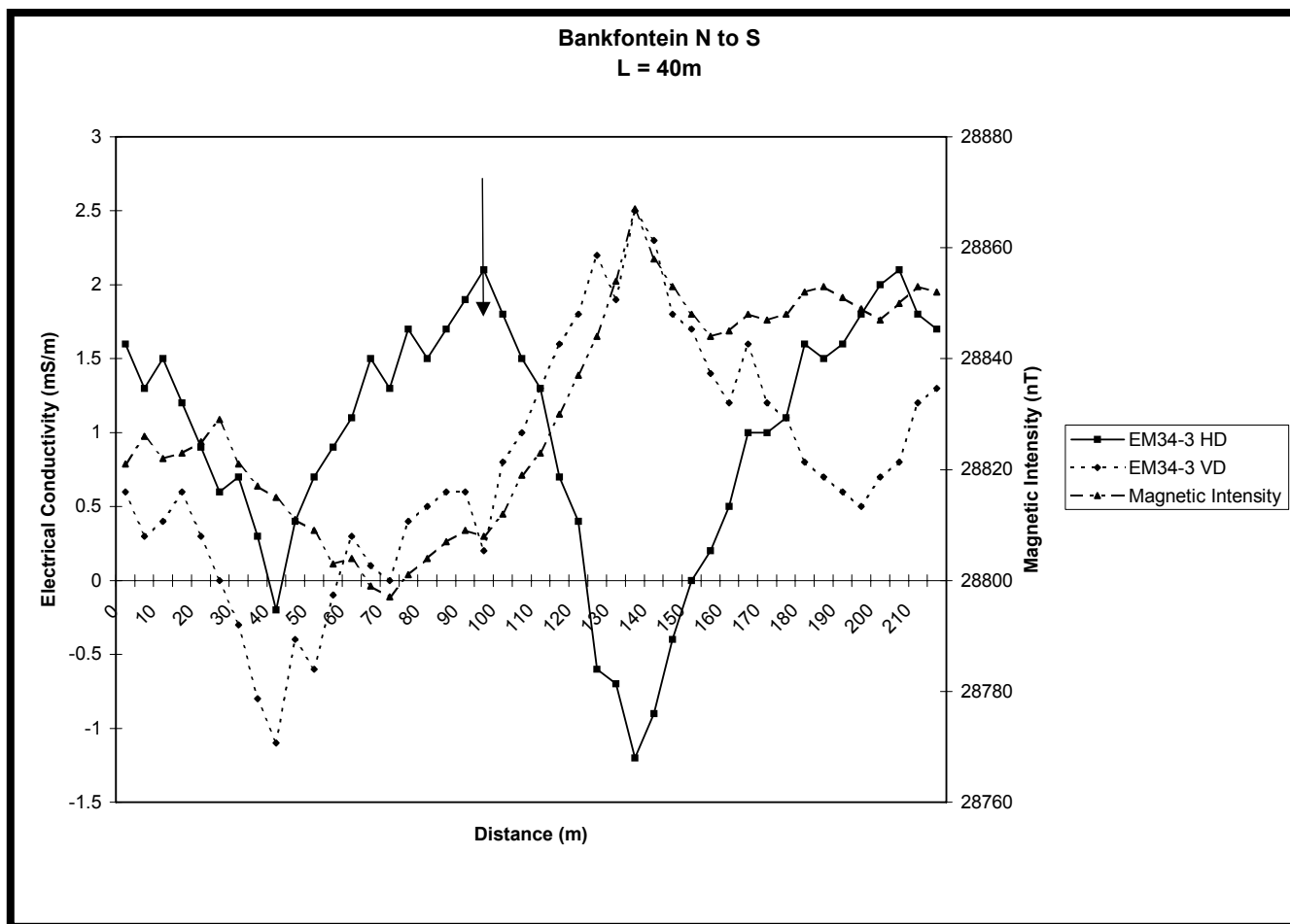


Figure 4.61. Geophysical profile on the farm Bankfontein 264JS.

The geophysical profile (Figure 4.61) indicates an environment low in electrical conductivity: even over the interpreted diabase intrusion (station 140 m), the electrical conductivity does not increase much. The possibility of an intrusion is signified by the increase in magnetic intensity and dipole signatures of the electromagnetic instrument over the entire profile. From station 120 m till station 170 m a distinct alteration in dipole configuration is noticed on the profile as $VD \gg HD$ (diabase intrusion). The amplitude of the magnetic intensity is approximately 60 nT. The shape of the magnetic anomaly is poorly defined to the south, implying that a rapid decrease in magnetic intensity values is not measured in contrast with the northern flank. Therefore it can be assumed that the anomaly gradually dips towards the south and can be regarded as a combination between a dyke and sill, owing to its gradient (dip). Weathered intrusive contact zones in the sandstone act as confined aquifers. Since the gradient is less than 1:1 or a 45° dip,

the Schlumberger depth soundings are appropriate, and therefore these were performed at station 95 m, as indicated by the arrow in Figure 4.61. The arrow also denotes the position of the drilled borehole and position of the geobotanic indicators. The borehole log indicated the following:

- 0 – 1 m: sand
- 1 – 4 m: conglomerate sandstone
- 4 – 11 m: jointed/fractured sandstone
- 11 – 17 m: sandstone
- 17 – 25 m: weathered diabase
- > 25 m: unweathered diabase.

The sounding curve and model, as indicated in Figure 4.62, represents a KHKH-type curve because a 6-layered earth was modelled. The sounding (as in every case) was laid out parallel to the strike of the Wilgerivier Formation so as to diminish the electrode effects. The first layer is conductive (moist), unconsolidated sand that transgresses into conglomerate sandstone, which outcrops in the area. Layer three is once again a conductor and is interpreted as a confined layered, jointed and water bearing sandstone. Layer four is a competent sandstone layer: thereafter the weathered contact zone of the sandstone/diabase contact is measured. The bedrock is unweathered diabase. The drilling results of the borehole (Table A1.21(a&b)(iv)) indicate that groundwater was struck at depths of 10 m and 24 m, with a total borehole depth of 65 metres. The final depth of the borehole was decided by the landowner. The yield of the borehole is 3 800 l/h and the static water level rests at 8 m from the surface. The yield is well above the average yield for this formation as listed in Table A1.21(a&b)(iv).

Soil samples were gathered at the borehole site (station 95 m) where the said two geobotanic indicators are situated and at station 80 m, a sandy and grassy habitat. The chemical analysis of the soil samples indicated a higher pH, soil conductivity, P, cation, Fe, C, N and CEC-values, with decreasing concentrations of Mn, Zn and S with depth (1.2 m) at the geobotanic community, which is indicative of weathered diabase and to be expected since the borehole is situated next to a lineament (aerial photograph, annexure).

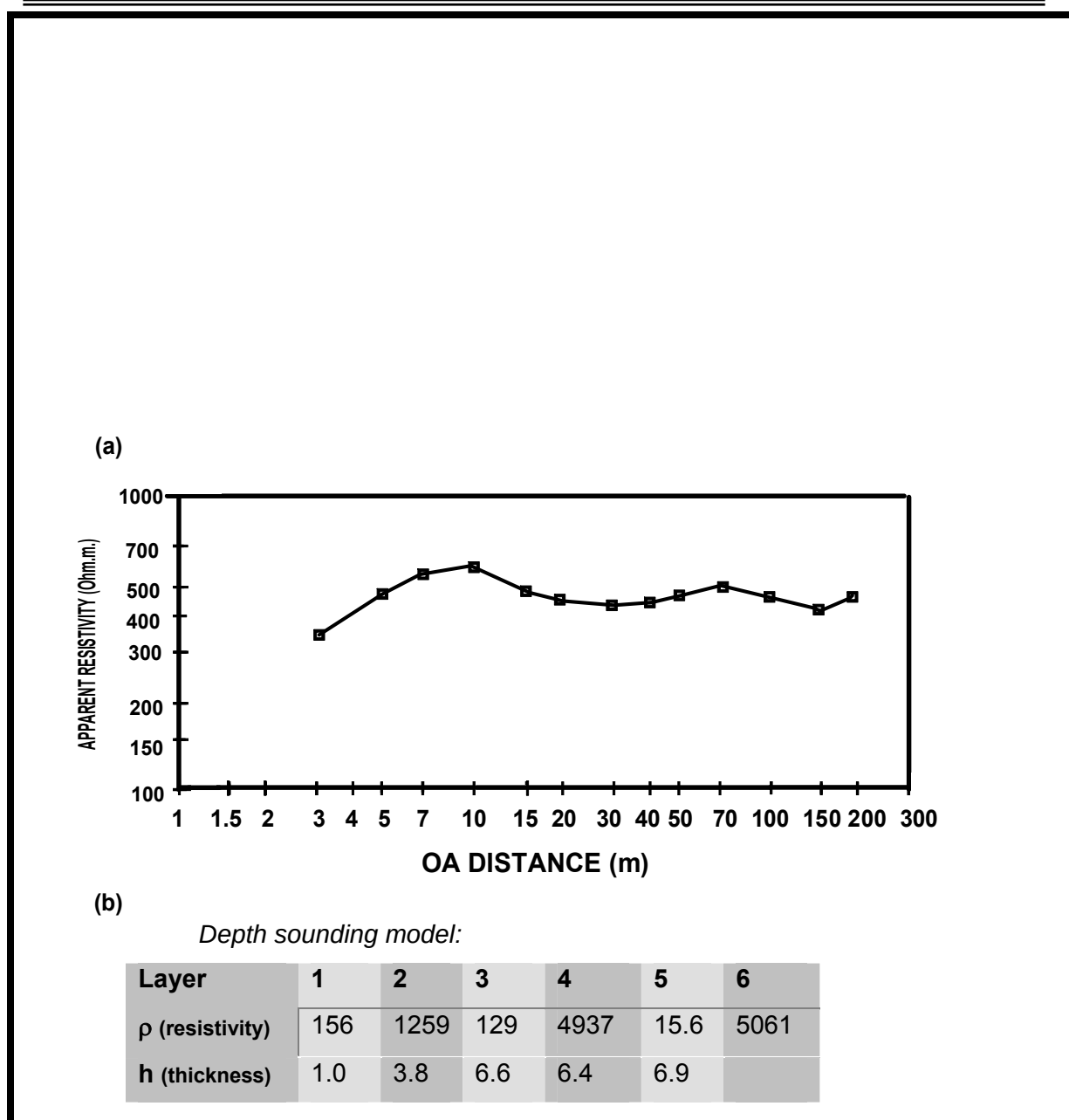


Figure 4.62. Schlumberger depth sounding on Bankfontein 264JS.

Acacia karroo and *Euclea crispa* are the geobotanic indicators in this case study. They occur on the weathered, clayey edge of the lineament, which is the confined aquifer. The land type and geology consists of unweathered rock and the presence of trees such as these indicates weathering conditions and moisture that provides nutrients, water and a rooting medium.

39. Bankplaas 239JS

Locally the sandstone of the Wilgerivier Formation dips 6° to the southeast. Diabase intrusions intersect the sandstone and outcrops of diabase are frequently found along streams and wetlands. Diabase intrusions are further recognised from the occupation, by *Acacia* species, of weathered, clay-rich, diabase soils and the human desire to utilise these soils for agricultural cultivation practices: diabase boulders on the land are evidence of tilling practices. The Bankplaas area is populated at a low density per square kilometre, which may be attributed to the remoteness of the area, difficult terrain and low groundwater yield (on average 2 500 l/h) that restricts major land developments which require water. A few dry boreholes on the farm are reflectors of poor aquifer conditions and/or bad selection of drilling, since the people responsible were fooled by the presence of the *Acacia* shrubs and trees. Nevertheless, geophysical groundwater exploration on this farm was guided by the *Acacia* species and therefore the geophysical survey was directed towards the weathered, clay-rich soil derived from the numerous diabase intrusions, most probably sills owing to the extent of these. The *Acacia* cover of the weathered diabase intrusion was crossed and the frequency of species observed was noted as well as the circumference and visual appearance of the species. Numerous *Acacia caffra* and *Acacia karroo* and also some *Aloe marlothii* (mountain aloe) were noted, although a locality was identified with two large *Acacia karroo* specimens in association with one *Euclea crispa* species. The frequency of occurrence of the *Acacia* species on the weathered diabase is approximately 140 per hectare. *Euclea crispa* was found only in this spot, although more were found 500 m from it, but it was too far away to be investigated owing to later infrastructure expenses when the borehole would be drilled; thus such an option was considered to be of little value. Geophysical exploration combined the magnetic and electromagnetic methods (east-west direction to cover the diabase sill) with a concluding Schlumberger depth sounding at the locality of the borehole to be drilled. Depth soundings are feasible because of the sill-like nature of the diabase intrusion as inferred from the Pretoria geological map (1978), field observations and the extent of the clay soil covered with luxurious *Acacia* growth. As indicated in Figure 4.63, a very conductive sub-surface is measured with large variations in the measured magnetic intensity, although no clear defined magnetic anomaly can be identified, as it depends on the state of weathering of the diabase. Variations in the electromagnetic dipole components are evident, most probably due to

the extent of weathering of the diabase sill. Areas of little or no weathering are most frequently recognised by $VD > HD$, and areas of weathering, by $HD > VD$. Profound aquifer conditions may be located where $HD \gg VD$, for example around station 330 m, which is the locality where the larger *Acacia karroo* and *Euclea crispa* species were located.

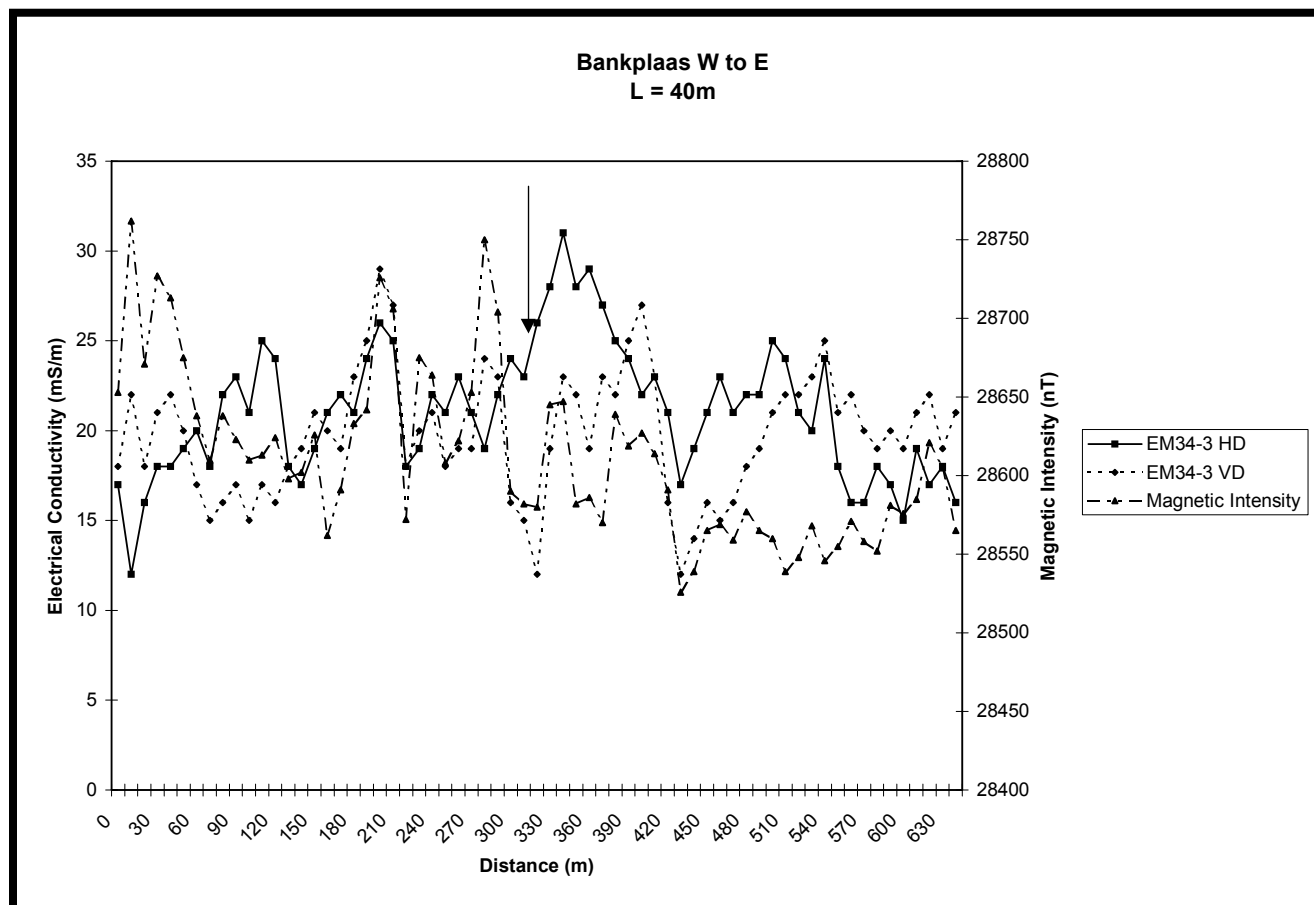


Figure 4.63. Geophysical profile of a portion of the farm Bankplaas 239JS.

The arrow in Figure 4.63 denotes the position of the drilled borehole, geobotanical indicators and where the soil samples were gathered. The other soil sample was taken at station 300 m, where $VD > HD$ and a higher resistance and less weathering are anticipated. It is not evident that the borehole is in line with the lineament, as indicated with a red line on the aerial photograph (annexure). The position at 330 m was further investigated by means of a Schlumberger depth sounding: Figure 4.64.

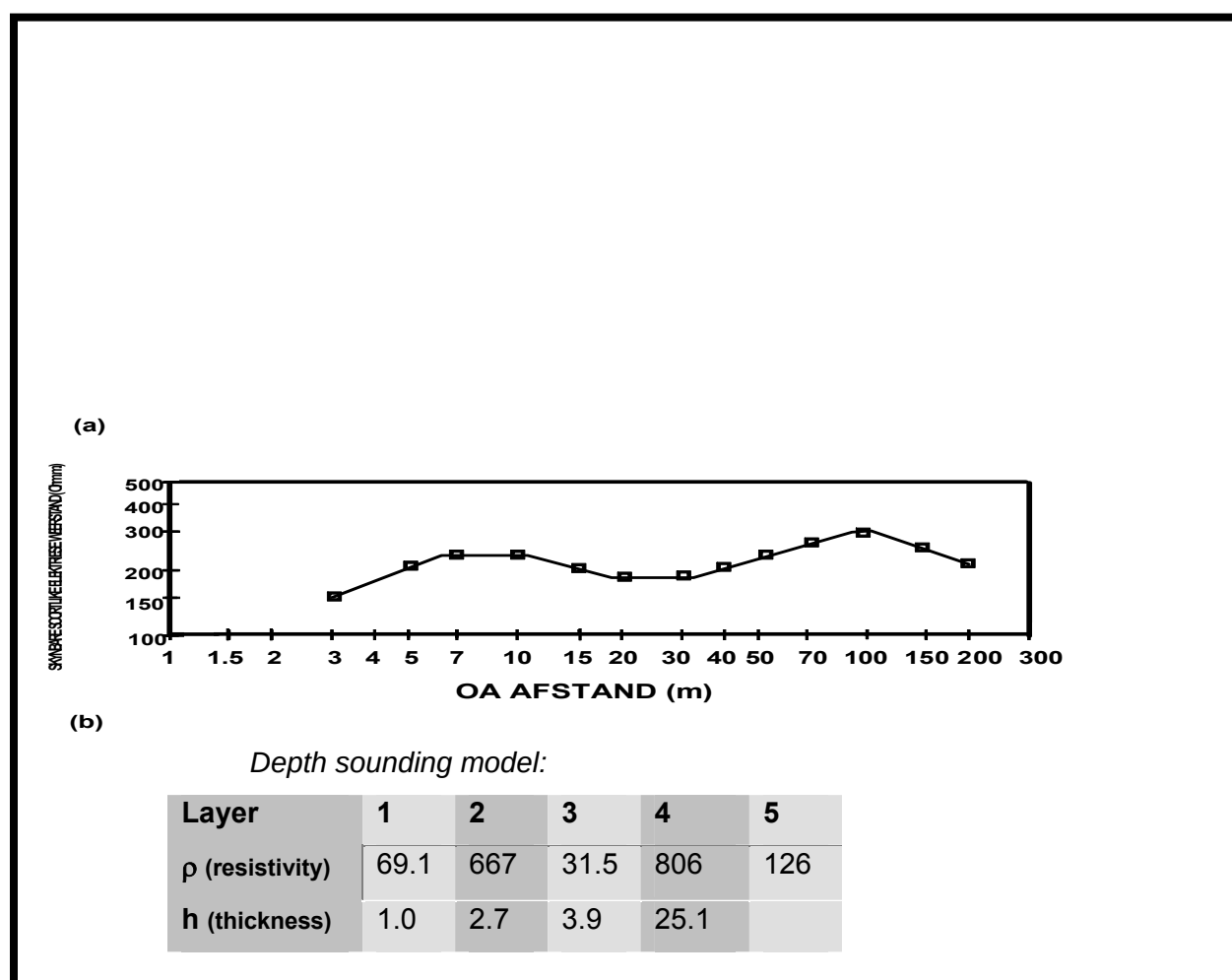


Figure 4.64. Schlumberger depth sounding on Bankplaas 239JS.

A northeast-southwest electrode direction was used for the sounding in order to minimise electrode effects because it is parallel to the strike of the Wilgerivier Formation. The depth sounding as indicated in Figure 4.64 represents a KHK-type curve. The first layer is a thin conductive layer of clay, although 1 m thick which is remarkable in this arenaceous environment and is supportive of agricultural cultivation. The resistive second layer is most probably ferricrete because it was evident from the soil sampling process that ferricrete is present in the soil sample fragments and small pieces of ferricrete rock were encountered. Layers 3 and 4 indicate various weathering horizons associated with the weathered diabase intrusion in depth. Layer 3 is most probably clay and acts as an aquiclude, whereas the fourth layer is higher in resistivity, but its extent and resistivity may refer to the presence of large boulders and fragmented diabase. The

low resistivity of the last layer is surprising since no groundwater was intersected in this layer, which may indicate the presence of conductive minerals in this rather somewhat unweathered diabase. The fact is that the borehole, when drilled, reached a depth of 59 m where the last 30 m was drilled in unweathered diabase according to the borehole log (NGDB, 1996). The 30 m penetration of the diabase was only undertaken to create a sump. Water was struck at a depth of 26 m (layer 4), yielding 3 250 ℓ/h, and the static water level rested at 14 m from the surface. The yield of the borehole is acceptably high for this environment, measured against the existing dry boreholes and published values of aquifers belonging to the Wilgerivier Formation in this setting (Frommurze, 1937, Meulenbeld, 1998 and Johannesburg, 1999).

The location of the borehole/geobotanic indicator possesses overall increased levels of pH, Ca, Mg, K, Na, soil conductivity, C, N and CEC throughout the soil profile (0.5 and 1.2 m), although higher concentrations of Fe, Mn and Zn only occur in the upper layer. Sulphur levels are notably lower at the geobotanic site. The elevated levels of elements at the geobotanic community are significant since both sample locations were situated in the weathered, clayey diabase sill.

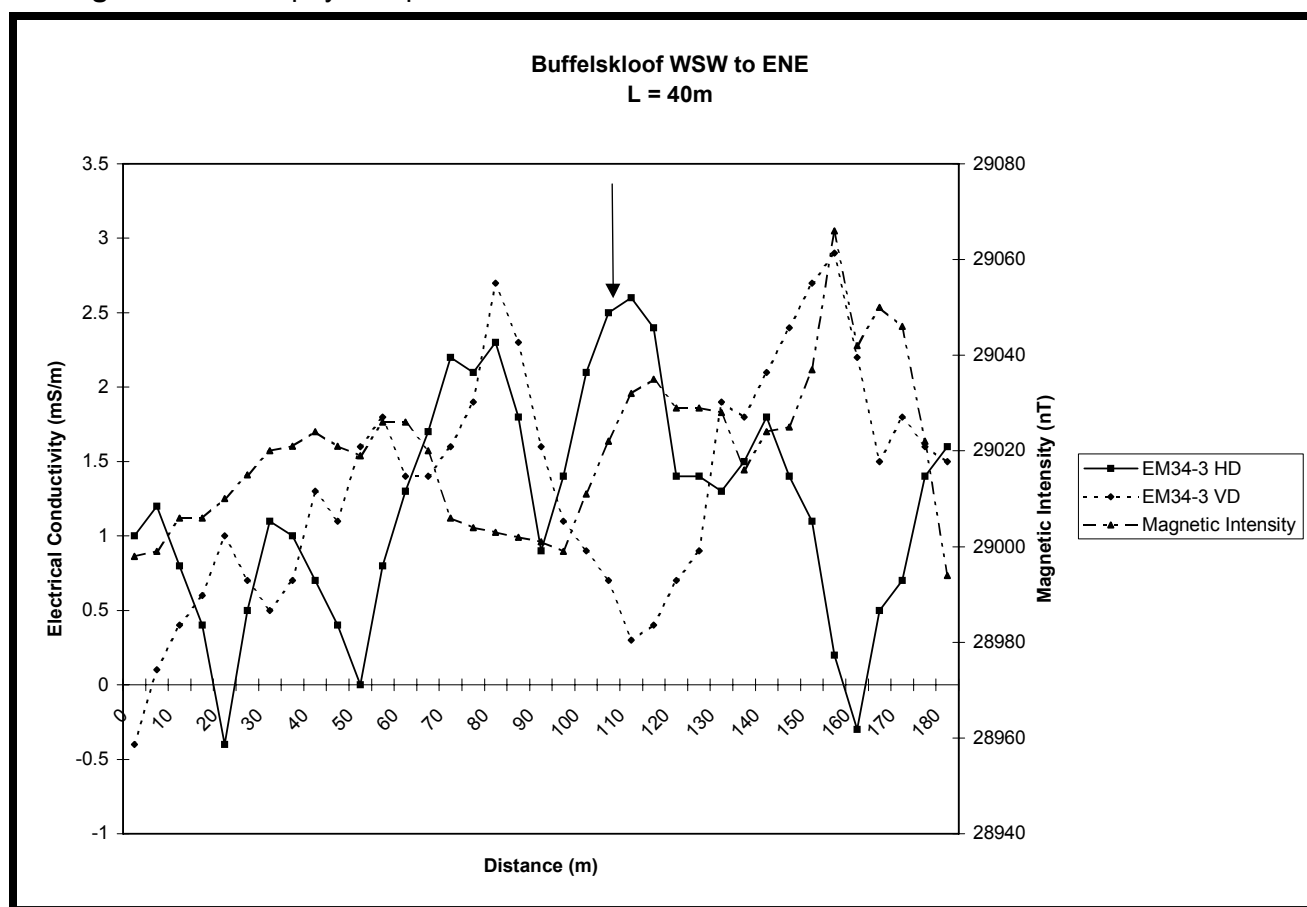
***Acacia karroo* and *Euclea crispa* are the geobotanic indicators in this case study. They occur on the weathered, clayey surface of the diabase sill. Zones of deeper weathering and groundwater basins are represented by the abovementioned species that are distinctive in their size (tall, large circumference) and uniqueness compared to the surrounding, otherwise homogenous, vegetation cover.**

40. Buffelskloof 342JS

Buffelskloof 342JS is situated in close proximity to the abrupt contact between the Wilgerivier and the Loskop Formations, on the eastern edge of the Wilgerivier Formation. This contact can be easily observed in the field since the Wilgerivier Formation towers above the Loskop Formation. Owing to the variation in geology, namely sandstone of the Wilgerivier Formation with an intrusive diabase sill at varying depths underneath the sandstone and ultimately outcropping, variations in botany and agricultural practices are noticeable. The following geobotanic indicators indicate the contact zone between the sandstone and diabase: *Acacia karroo*, *Burkea africana* (wild

syringa) and *Euclea crispa*. Meulenbeld & Hattingh (1999) list the *Burkea africana* as a geobotanic indicator. The species *Dichapetalum cymosum* (gifblaar) is associated with *Burkea africana* on this farm. The magnetic and electromagnetic profiles as presented in Figure 4.65, indicate the transgression from a sandstone environment to a diabase sub-surface owing to the increases in the magnetic intensity, measured in nano-Tesla (nT), and the relative rise in electrical conductivity of both dipole components. The traverse was laid out in order to cross the sandstone/diabase transgression and the geobotanic indicators.

Figure 4.65. Geophysical profile on the farm Buffelskloof 342JS.



The signatures of the electromagnetic dipoles are significant for one to be able to distinguish between the dominant sandstone and diabase sub-surfaces. For the sandstone sub-surface the HD and VD dipoles alternate and are more or less parallel, considering the minute variations in electrical conductivity (-0.5 to 2.5 mS/m), with regards to stations 0 to 100 m. Stations 100 to 135 m represent the sandstone and diabase contact as HD>>VD and the magnetic intensity increases by at least 30 nT. The

arrow at station 110 m denotes the position of the drilled borehole and locality of the geobotanic indicators (*Acacia karroo*, *Burkea africana* and *Euclea crispa*). From station 135 m the diabase sill is prominent since the magnetic intensity maintains its higher value and $VD \gg HD$, indicating low possibilities for aquifer conditions. After 180 m the signature alters, since $HD > VD$, which could indicate the edge of the intrusion. It is deduced from chips from the the borehole drill and NGDB (1996) that the intrusion is a sill-type, wedged into the sandstone of the Waterberg Group, since the diabase intrusion is encountered 30 m below the surface. Water was struck on the upper contact zone of the sandstone/diabase contact. A Schlumberger depth sounding at the position of the arrow measured a conductive layer near the surface (Figure 4.66). The modelled curve represents a KH-type curve, with a sharp contrast between conductive and resistive layers. The first layer indicates loose, unconsolidated topsoil with a resistive, competent sandstone second layer of a minute thickness of approximately 1.7 metres. The presence of this sandstone is evident in the numerous sandstone outcrops in the immediate sounding environment. The thick third layer (47.3) constitutes the weathered zone between the sandstone, particularly the diabase. The weathered zone is surprisingly thick. It is important to conduct the sounding parallel to the strike of the sandstone in order to avoid electrode effects. The bedrock comprises unweathered diabase and is not conductive at all, in contrast with the modelled diabase bedrock at Bankplaas 239JS, although this bedrock is situated much deeper than the latter. The drilled borehole is 50 m deep, water strike at 21 m (layer 3), yields 3 500 l/h and the static water level is 8 m from the surface. One would expect a larger quantity of groundwater to be available under such extreme weathering conditions in the sub-surface, but it may be that groundwater recharge in the Wilgerivier Formation basin is complicated by alternating competent layers of sandstone and diabase. In addition, the alternating sedimentary and igneous layers that define a fine Bankenveld habitat create numerous springs in the vicinity and actually discharge aquifers.

Similar to the previous soil analysis results of the Wilgerivier Formation, the borehole and geobotanic site record elevated values of pH, Ca, Mg, K, Na, conductivity, Fe, Mn and Zn with depth, C, N, S and CEC that are quite different from the average Hutton soil series characteristics, which is an indication of the presence of weathered diabase. Weathered sandstone is nutrient poor with a higher resistivity. The soil sample

representing the site not covered by geobotanic indicators is station 70 m, where $HD > VD$ in Figure 4.65.

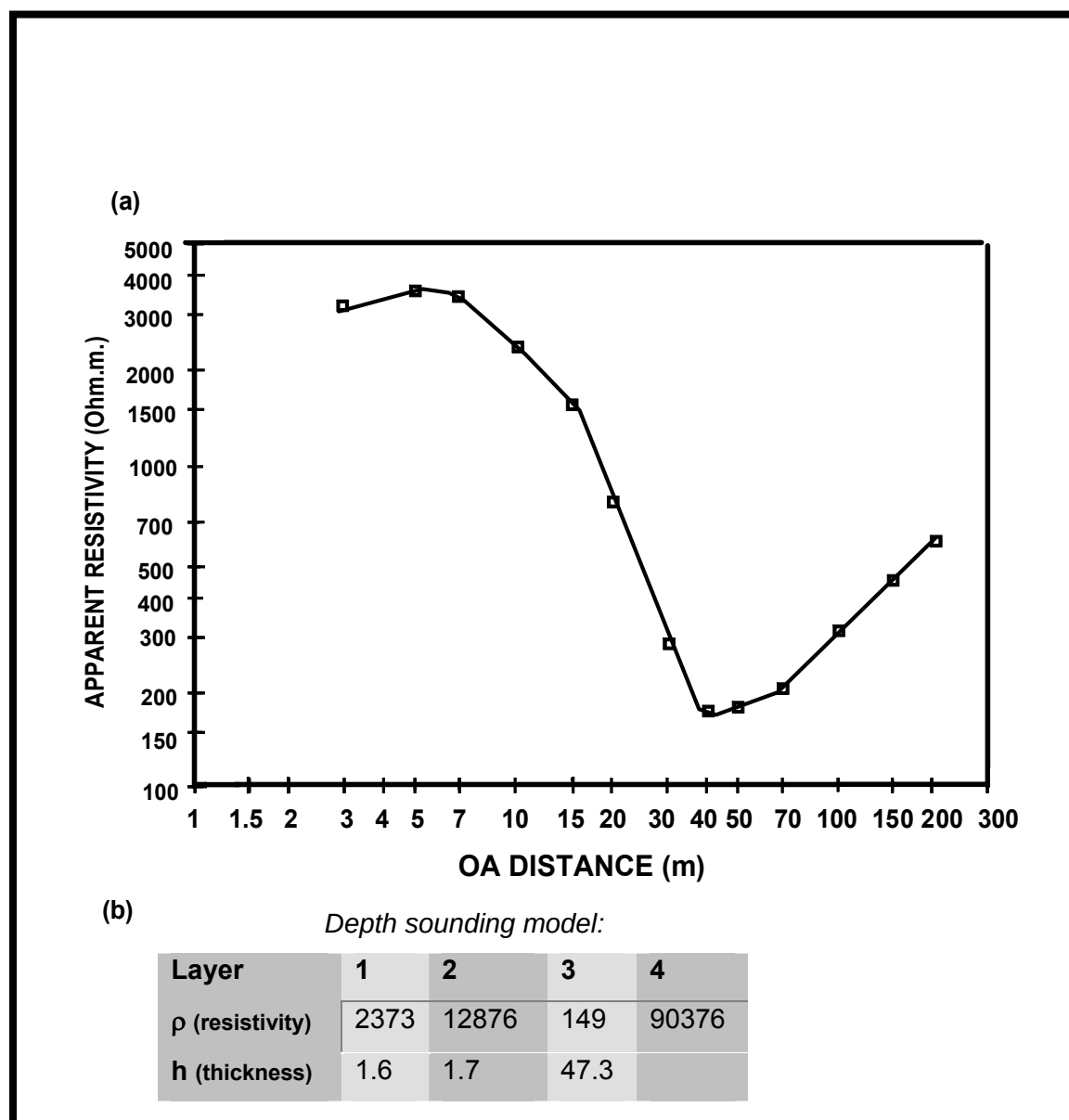


Figure 4.66. Schlumberger depth sounding near the sandstone/diabase contact on the farm Buffelskloof 342JS.

Acacia karroo, *Burkea africana* and *Dichapetalum cymosum* (weed) are the geobotanic indicators in this case study. These species occupy the transgression zone from the sandstone to the diabase. This zone acts as an aquifer and hence supports tree growth.

41. Goedehoop 244JS

Centred in the Wilgerivier Formation basin, the farm Goedehoop 244JS is characterised by an extensive diabase sill of circular proportions (Pretoria, 1978) and is covered by the Hutton soil series. Although no new borehole siting by means of geophysical-geobotanical methods was carried out on this property, the farm was included as it posed an interesting geobotanical case study and borehole log information was available (NGDB, 1996). The farm stands out among the grassy plains of the Wilgerivier Formation owing to its luxuriant vegetation canopy. The vegetation is mainly *Acacia karroo*. Numerous outcrops of diabase are encountered on the farm and the soil displays a clayey texture. Two boreholes were studied, a dry and a yielding borehole. No geophysical profiles were laid out due to the presence of numerous noise factors around the existing borehole positions. The sounding lines took an arbitrary east-west direction as the diabase sill does not possess a strike. The first borehole, Figure 4.67, represents the dry borehole. Both sounding curves represent a H-type model, being an intermediate conductive layer confined by resistive rock. The crucial difference between the two sounding curves is to be found in the depth to the unweathered diabase, since the contact zone is the aquifer in this case. According to the landowner and NGDB water was struck at a depth of 15 m. This depth correlates favourably with the results as presented in Figure 4.68. The first borehole is dry (Figure 4.67) because the depth of weathering is too shallow (only about a metre too shallow). The modelled bedrock values indicate a higher resistive diabase at the dry borehole position, compared to the bedrock value of the successful borehole. A lower value might imply greater weathering and an increasing opportunity to locate an aquifer. Geobotanic indicators include *Acacia karroo* and *Euclea crispa*. This was the only spot where the latter was found. The *Acacia karroo* were on average 2 m higher at this spot compared with those of the surrounding community.

As indicated in Table A1.21(a&b)(iv), the successful borehole yielded 2 700 l/h which is average for this formation, but under the circumstances (limited depth to aquifer and weathering zone) the yield is considered reasonably good. The dry borehole was drilled to a depth of 82 m, and only unweathered diabase was encountered. The successful borehole was drilled till a depth of 32 m and intersected weathered and unweathered diabase. No sandstone was drilled.

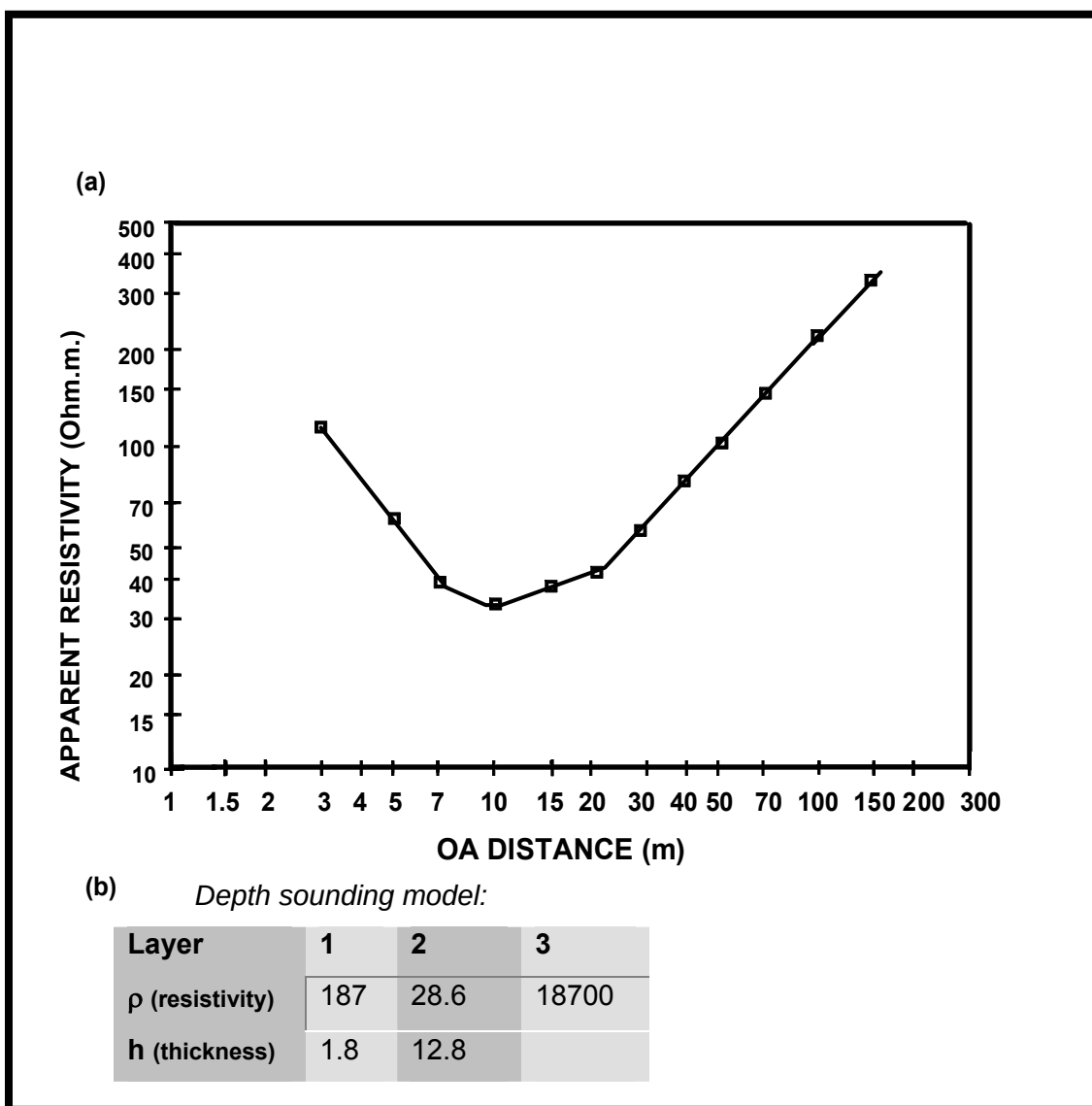


Figure 4.67. Schlumberger depth sounding of the dry borehole on Goedehoop 244JS.

Soil samples were collected at the successful borehole (higher *Acacia karroo* and *Euclea crispa*) and the dry borehole (common *Acacia karroo*). The former revealed higher levels of pH, Ca, Mg, K, Mn, Zn, S and CEC as well as increasing levels of Fe, C and N with increasing depth compared to the other sample.

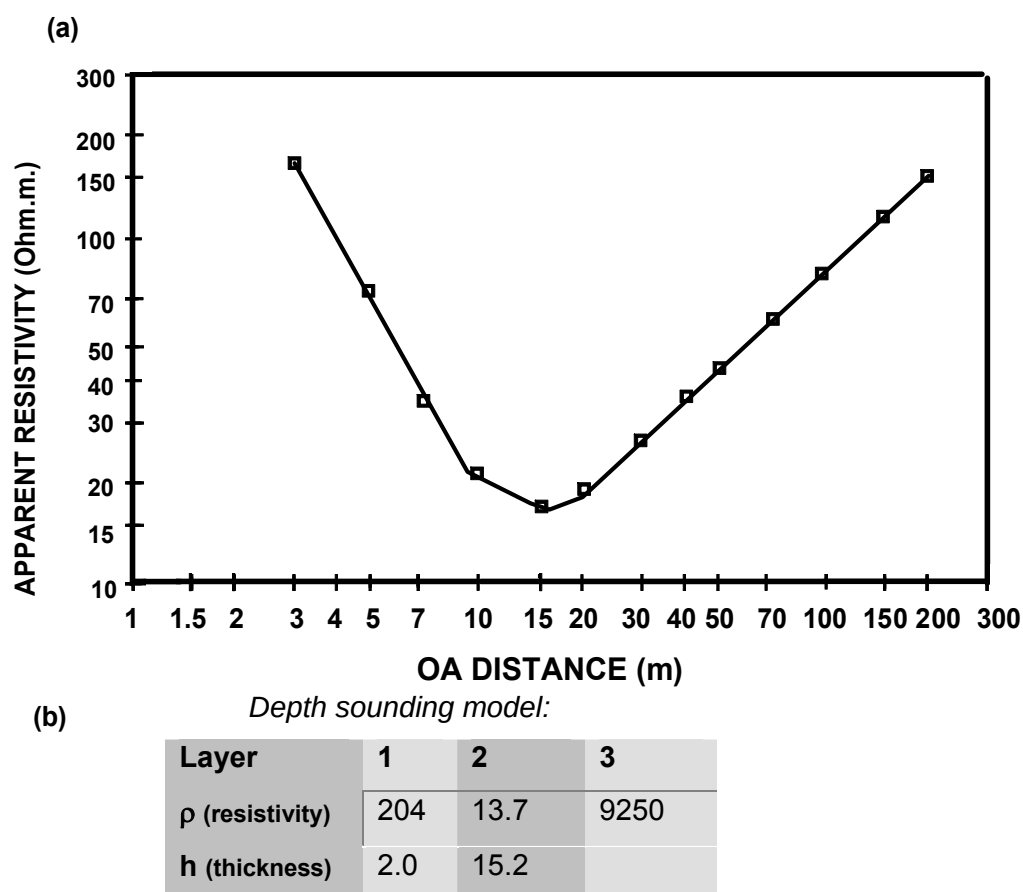


Figure 4.68. Schlumberger depth sounding at the successful borehole, Goedehoop 244JS.

***Acacia karroo* and *Euclea crispa* are the geobotanic indicators in this case study. They occur on the weathered, clayey surface of the diabase sill. Zones of deeper weathering and groundwater basins are represented by the abovementioned species that are distinctive in their size (tall, large circumference) and uniqueness compared to the surrounding, otherwise homogenous, vegetation cover.**

4.10.1 Remarks

A predominantly arenaceous geological group, the sediments of the Waterberg Group exhibit a definite unique character compared to the intrusive mafic (diabase) rocks that intersect these sediments in numerous places. The chemical weathering of the sediment is less than that of its counterpart, the diabase, and as a result, a distinct geomorphological landscape is created. This landscape consists of outcrops, cliffs, ridges and sand plains underlain mostly by sandstone. The botanical characteristics of the sandstone features include species such as *Combretum apiculatum* (red bushwillow), *Combretum molle* (velvet bushwillow), *Combretum zeyheri* (large-fruited bushwillow), *Faurea saligna* (Transvaal beech), *Grewia flava* (velvet raisin), *Mundulea sericea* (cork bush), *Ochna pulchra* (peeling plane), *Pappea capensis* (jacket-plum), *Peltophorum africanum* (weeping wattle), *Protea caffra* (common sugarbush) and *Rhus gueinzii* (thorny karee). These represent broad-leafed species without thorns. Thorny species are associated with the diabase intrusions and usually occur in valleys, near wetlands, gorges and clay plains. These species include *Acacia caffra* (common hook-thorn), *Acacia karroo* (sweet thorn), *Aloe marlothii* (mountain aloe), *Burkea africana* (wild syringa-not thorn bearing), *Combretum imberbe* (leadwood-not thorn bearing), *Euclea crispa* (blue guarri-not thorn bearing) and *Strychnos pungens* (spine-leafed monkey orange). The occurrence of *Aloe* species is recognised on mafic outcrops in the north-eastern parts of South Africa since *Aloe marlothii* grows on diabase derived soils, such as those at Bankplaats 239JS. In other parts of South Africa, Karoo-age dolerite in parts of Southern Kwazulu-Natal, *Aloe Ferox* (bitter aloe) is especially common.

In addition to the abovementioned, geophysical methods can differentiate between sandstone and diabase rocks and soils with ease, owing to a higher resistance for competent sandstone, $>10\ 000\ \Omega\text{m}$ for sounding interpretation and -10 to $1\ \text{mS/m}$ for

profiling interpretation (lower conductivity), and lower magnetic intensity for sandstone bodies in the sub-surface. Geophysical groundwater exploration, with the aid of geobotanical indicators in the Waterberg Group, resulted in higher aquifer yields than the average yield for these arenaceous rocks as displayed on various maps and in literature: see Frommurze (1937), Johannesburg (1999) and Polokwane (2003). It is important to take care in the layout of geophysical profiles (perpendicular to strike) and geophysical soundings (parallel to strike) in order to obtain reliable readings. Since the case studies listed in the present research stretch from the Limpopo area towards the Highveld in the region of Bronkhorstspuit-Middelburg, noticeable differences in the distribution of the botanic species occur but, nevertheless, identified geobotanical indicators for the Waterberg Group compare to those listed in the previous case studies.

The cation exchange values (CEC) associated with geobotanical indicators and aquifers, throughout the case studies, are higher compared to the values of samples from the sites without any noticeable geobotanic indicators: see Table 4.10. This indicates that the geobotanic sites possess a higher water and therefore organic life (humus) content. A higher water content is crucial for enduring drought stress since humus and clay can hold greater quantities of water and available nutrients. The summary of the soil sampling exercise is presented in Table 4.10, with a separation between the three different localities of the Waterberg Group and a joint representation of values of the soil quality of the geobotanic/borehole site and the remaining sites with no distinct geobotanical indicators.

Of importance, and clearly reflected in the soil chemical analysis, are the differences in soil chemistry between the soils derived from the Waterberg Group sediments and the diabase intrusions. The Waterberg Group in the Waterberg area consists of feldspathic (Ca, K, Na silicate) sandstone (Nylstroom, 1978). Diabase is rich in dark minerals, containing plagioclase feldspar $n\text{Na}[\text{AlSi}_3\text{O}_8] + n\text{Ca}[\text{Al}_2\text{Si}_2\text{O}_8]$ and hornblende $\text{Ca}_2\text{Na}(\text{Mg,Fe})_4(\text{Al,Fe})[(\text{Si,Al})_4\text{O}_{11}]_2[\text{OH}]_2$, where n denotes the percentage of Na or Ca (chemical formulas according to Schumann, 1985). The soil analysis of the Waterberg area indicates fewer deficiencies in cation values between the soils derived from the arenaceous sediments and diabase intrusions compared to those from the Wilgerivier Formation. This can be attributed to the fact that in the Waterberg area, soils derived from the arenaceous sediments and diabase intrusions are both rich in cations owing to

the chemical composition and weathering of the parent rocks. The Wilgerivier Formation sandstone is notably poor in Ca and Mg, compared to the soils derived from the intrusive diabase, which is richer in Ca and Mg owing to the presence of minerals such as hornblende. The low pH and consequently higher Al-toxicity of the sandy soil of the Wilgerivier Formation contrasts with the higher pH-values of the clay soil of the weathered diabase. In general, the diabase soil (at the geobotanic communities) displays higher values of organic carbon, available nitrogen and CEC. All these nutrients and values are essential in order to sustain plant communities. Therefore, it is not unusual to encounter trees, shrubs and associated geobotanic indicators on clay soil, derived from weathered diabase and aquifers caused by the underlying hydrogeological conditions.

The soil chemical analysis as presented by Land Type Survey Staff (1987), does not compare favourably with the results of the listed case studies as presented in this study (see Tables A1.21(a&b)(ii-iv)). This emphasises the complex composition of soils that differ spatially and over time.

Table 4.10. Comparisons between the soil characteristics of the geobotanical indicators and their surroundings.

Parameter	Geobotanical community (A)	Surroundings (B)	Geobotanical community (A)	Surroundings (B)	Geobotanical community (A)	Surroundings (B)
	Waterberg area		Bronkhorstspuit area		Middelburg area	
pH	5.06-6.24	4.85-6.02	5.65-6.63	4.62-5.90	5.37-6.37	4.50-5.38
P (mg/kg)	2.19-3.07	1.94-5.24	0.84-29.32	0.92-30.32	0.96-3.19	1.41-2.85
Ca (mg/kg)	111-282	82-190	535-1940	128-481	263-1363	126-176
Mg (mg/kg)	40-104	31-76	152-755	49-147	84-1454	46-87
K (mg/kg)	31-47	10-44	48-218	17-175	33-264	13-103
Na (mg/kg)	4-32	5-48	10-59	0-70	12-58	0-29
Fe (mg/kg)	11.00-31.44	7.95-54.53	41.59-131.49	8.07-71.12	35.77-72.92	20.16-74.79
Mn (mg/kg)	25.68-197.53	0.77-59.19	49.24-478.92	1.79-182.65	76.36-229.04	1.40-233.06
Zn (mg/kg)	0.28-0.39	0.18-0.46	0.29-3.63	0.34-5.49	0.11-0.82	0.20-0.50
Al (cmol _c /kg)	0-0.559	0-0.936	0-0.164	0.114-1.064	0-0.321	0.237-1.471
Resistance (Ω)	7000-16000	18000-24000	900-2800	920-30000	740-3400	2000-18000
%C	0.06-0.31	0.06-0.55	0.84-1.98	0.12-0.89	0.37-2.01	0.17-1.02
Total N%	0.008-0.029	0.009-0.023	0.068-0.133	0.016-0.067	0.038-0.128	0.020-0.086
S (mg/kg)	7.21-23.28	8.46-16.67	6.08-71.53	5.78-150.19	10.15-28.41	5.85-45.09
CEC (cmol _c /kg)	2.620-4.433	1.673-2.799	6.635-20.83	2.12-7.53	6.36-22.54	2.62-6.50

Geobotanical indicator species under column A	<i>Acacia karroo</i> (sweet thorn) <i>Combretum imberbe</i> (leadwood) <i>Rhus lancea</i> (karee) <i>Strychnos pungens</i> (spine-leaved monkey orange) <i>Ximenia caffra</i> (sourplum)		<i>Acacia karroo</i> (sweet thorn) <i>Burkea africana</i> (wild syringa) <i>Combretum erythrophyllum</i> (river bushwillow) <i>Euclea crispa</i> (blue guarri) <i>Strychnos pungens</i> (spine-leaved monkey orange) <i>Zanthoxylum capense</i> (small knobwood)		<i>Acacia karroo</i> (sweet thorn) <i>Burkea africana</i> (wild syringa) <i>Euclea crispa</i> (blue guarri)	
Geology	Diabase intrusions in the Waterberg Group sediments	Unweathered and competent Waterberg Group sediments	Diabase intrusions in the Wilgerivier Formation	Unweathered and competent Wilgerivier Formation	Diabase intrusions in the Wilgerivier Formation	Unweathered and competent Wilgerivier Formation
Aquifer yield (ℓ/h)	8 000 - 15 000	Not applicable	3 000 – 22 500	Not applicable	2 700 – 3 800	Not applicable

Parameter	Geobotanical community (A)	Surroundings (B)
	Combined	
pH	5.06-6.63	4.50-6.02
P (mg/kg)	0.84-29.32	0.92-30.32
Ca (mg/kg)	111-1940	82-481
Mg (mg/kg)	40-1454	31-147
K (mg/kg)	31-264	10-175
Na (mg/kg)	4-59	0-70
Fe (mg/kg)	11.00-131.49	7.95-74.79
Mn (mg/kg)	25.68-478.92	0.77-233.06
Zn (mg/kg)	0.11-3.63	0.18-5.49
Al (cmol _c /kg)	0-0.559	0-1.471
Resistance (Ω)	740-16000	920-30000
%C	0.06-2.01	0.06-1.02
Total N%	0.008-0.133	0.009-0.086
S (mg/kg)	6.08-71.53	5.78-150.19
CEC (cmol _c /kg)	2.620-22.54	1.673-7.53
Geobotanical indicator species under column A	<i>Acacia karroo</i> (sweet thorn) <i>Burkea africana</i> (wild syringa) <i>Combretum erythrophyllum</i> (river bushwillow) <i>Combretum imberbe</i> (leadwood) <i>Euclea crispa</i> (blue guarri) <i>Rhus lancea</i> (karee) <i>Strychnos pungens</i> (spine-leaved monkey orange) <i>Ximenia caffra</i> (sourplum) <i>Zanthoxylum capense</i> (small knobwood)	
Geology	Intruded (diabase) Waterberg Group sediments	Arenaceous Waterberg Group sediments
Aquifer yield (ℓ/h)	2 700 – 22 500	Not applicable

4.11 CARBONIFEROUS – PERMIAN EONOTHEMS: SANDSTONE AND SHALE OF THE VRYHEID FORMATION IN THE NIGEL AREA

Information pertaining to the case study area regarding its geographic locality, climate, veld types, geology, geohydrology, geophysics, geobotany and soil sampling, is tabled (see annexure).

42. Holgatfontein 326IR

The topography of the area is predominantly flat with some local, small and broad depressions that host wetlands. Positive landmarks, such as hills, are caused by rocks of the Randerium Eonothem, namely shale, quartzite and banded ironstone of the Hospital Hill Formation, West Rand Group, Witwatersrand Supergroup. Most parts of the farm are underlain by sandstone and shale of the Vryheid Formation, Ecca Group, Karoo Supergroup. Dolerite sills are common, manifested as intrusions between the sedimentary layers. A lineament with a northwest-southeast strike crosses through the farm, according to the East Rand (1986) geological map.

Most of the natural veld of the farm has been converted to agricultural lands and pastures. Along some of the farm roads, rock outcrops and patches of indigenous grassland and shrubs occur. Common shrub species found include *Acacia karroo* (sweet thorn), *Diospyros lycioides* (bluebush) and *Rhus pyroides* (common wild currant). The first named species is the only one considered to be of value as a geobotanic indicator, which has been frequently indicated in the previous case studies. The other two species occur frequently along outcrops and fences caused by bird-droppings rich in the fleshy seed of the *Diospyros* and *Rhus* species. Geophysical exploration on the farm utilised the magnetic and electromagnetic profiling methods, because of the existence of intrusive dolerite features (lineament and sills) and the speed and coverage of the combined methods since a few traverses of several kilometres could be carried out. The significant stations of the traverse, or profile, selected for borehole drilling purposes, based on the occurrence of geobotanic indicators, are depicted in Figure 4.69. Owing to the length of the traverse, it mainly followed the farm roads, but with the intention of crossing the strike of the lineament. The geobotanic indicators were a couple of *Acacia karroo* shrubs since the occurrence of indigenous trees and shrubs is limited and confined on the Highveld.

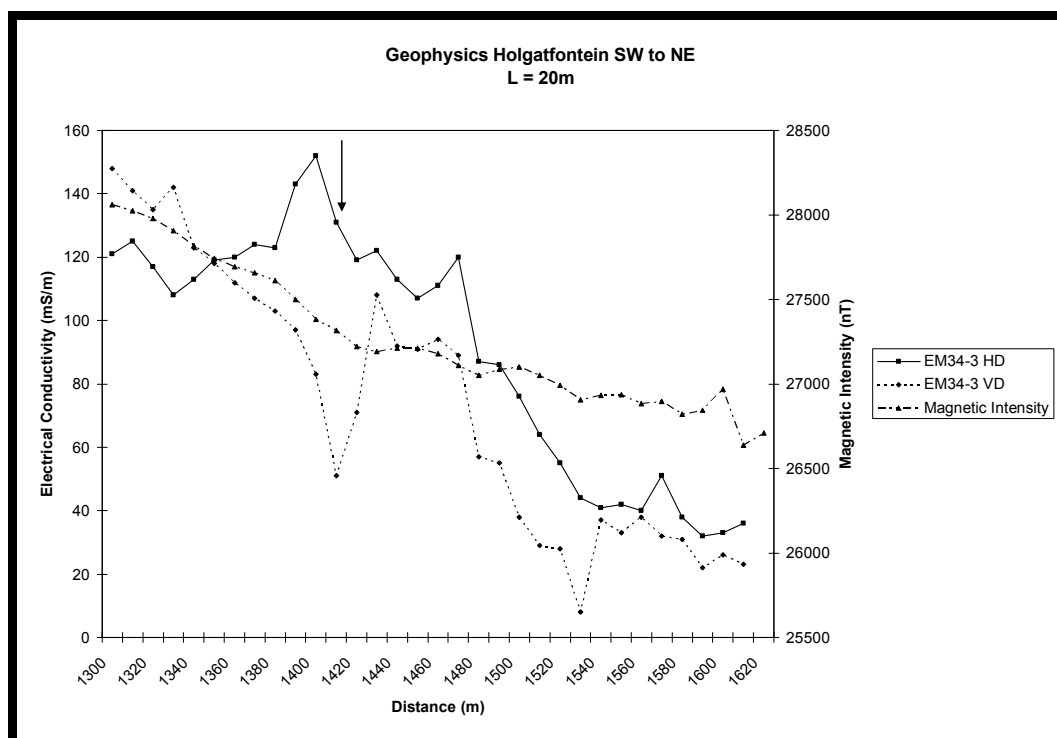


Figure 4.69. Segment of a geophysical profile on the farm Holgatfontein 326IR.

The geophysical profile as outlined in Figure 4.69, indicates the descending northeastern limb of a lineament (note the station numbers: 1300 – 1620 m). Of interest is the signature of the electromagnetic dipoles, notably $HD \gg VD$, since at station 1410 m an amplitude of up to 100 mS/m is observed, which indicates significant weathering on the lineament contact zone. The electrical conductivity of the soil is very high, mostly owing to the presence of clay soil. The arrow at station 1410 m indicates the position of the drilled borehole, one of the spots where the *Acacia karroo* features, although this species does not occur frequently on the farm. Soil samples, at a depth of 0.5 m and 1.2 m respectively, were collected here. The other sample was taken at station 1440 m, where $HD \approx VD$, indicative of less and shallower weathering of the lineament. The drilled borehole yielded 7 000 l/h, water strike at 26 m and a total borehole depth of 60 m (Table A1.23), guided by the maximum exploration depth of the EM-34-3 and the signature obtained. The borehole log indicated:

Loam: 0-3 m

Sandstone: 3-8 m

Quartzitic sandstone: 8-10 m

Weathered diabase and boulders: 10-28 m (water strike at 26 m)

Less weathered diabase: 28-35 m

Unweathered diabase: 35-60 m.

The geobotanic indicator (*Acacia karroo*) and associated borehole soil characteristics indicate a higher pH, increased levels of cations (Ca, Mg, K, Na) and P (anion), Mn, conductivity and CEC values compared to the other site. A lower value for C, N and S at the geobotanic community is seen in the results (Table A1.23). Higher CEC-values (humus) indicate the presence of more available cations (as is the case), although C, N and S fixation occurs by means of the process of photosynthesis and microorganism activity at the geobotanic site. Rensburg soil series occur at the geobotanic community (land type Ea15a, see annexure), which contain a high percentage of clay (up to 40%) and are typical turf soils resulting from weathered dolerite. Compared to the surrounding Avalon soil series, the occurrence of *Acacia karroo* on the Rensburg soil series is, surprising since this soil series possesses higher levels of CEC, pH and cations.

***Acacia karroo* is the geobotanic indicator in this case study. It prefers Rensburg soil series that are derived from weathered dolerite sills and dykes (lineaments). The weathered contact between the sedimentary and igneous rocks forms the aquifer in this geohydrological setting.**

43. Leeuwkraal 517IR

The existence of different geological lithologies on the farm Leeuwkraal 517IR defines two different veld types caused by the variation in geology and topography. Turf Highveld and Bankenveld (Acocks, 1988) occur on the farm, where Turf Highveld predominantly occupies the dolerite outcrops, the sedimentary rocks (Karoo Supergroup) and the Bankenveld on the outcrops of the Klipriviersberg Group (Ventersdorp Supergroup). The presence of mafic and ultramafic rocks (andesite/basaltic lava and dolerite) among the sedimentary rocks of the Karoo Supergroup justifies the utilisation of geophysical profiling methods, such as magnetics and electromagnetics. The mafic and ultramafic rocks, especially those belonging to the Klipriviersberg Group, give rise to hills and ridges, such as the prominent Klein van Collerskop in the vicinity. These hills and ridges host a variety of tree and shrub species, including *Acacia karroo* (sweet thorn), *Buddleja salviifolia* (sagewood), *Celtis africana* (white stinkwood), *Cussonia paniculata* (Highveld cabbage tree) and *Euclea crispa* (blue guarri). The grass species *Themeda triandra* (rooigras) predominantly grows in the indigenous, undisturbed natural veld areas.

As in the previous case study, a long geophysical profile (>3 km) was conducted on the farm in order to identify possible aquifer conditions due to weathering (HD>>VD), intrusive contact zones (magnetic intensity) and the presence of geobotanic indicators. The direction of the geophysical profiles was north to south. The direction was arbitrarily selected because the geological map (annexure) does not portray any particular linear intrusions. The flat nature of the farm, combined with the absence of numerous bushes, eases the operation of both the said geophysical methods. As mentioned in the above paragraph, certain tree and shrub species occur on the farm, but the frequency of occurrence of the tree species was mapped and if these occurred frequently, the differences in their circumference or height were recorded (especially *Acacia karroo*). The alteration of sedimentary rocks with intrusive/extrusive (dolerite/lava) bodies is ideal in order to obtain feasible geophysical signatures in areas of significance, implying aquifer conditions in contact zones. The geophysical profile obtained (Figure 4.70) indicates at least three dyke-type structures, in the vicinity of stations 900, 1600 & 3000 m. The increase in magnetic intensity at these stations is significant compared to the ambient or background readings. The variation in electromagnetic dipole readings, referring to the HD/VD ratio and electrical conductivity, indicates poor weathering profiles owing to VD>>HD and the presence of vertical structures in the sub-surface. The entire profile was not covered by the electromagnetic method, owing to time constraints. Only the stations indicating the presence of geobotanic indicators and intrusive bodies (where magnetic intensity increases) were covered. The purpose and objective of the geophysical prospecting was to identify a drilling position based on reliable geophysical information backed by the presence of geobotanical indicators.

Around station 2450 m, a notable decrease in the VD-component is observed, where HD>VD for some stations is manifested, thereafter VD>>HD. In combination with the magnetic intensity plot, it can be observed that this station is placed on the one flange of the intrusive dyke/lineament-type body. Furthermore, it is the only station on this profile of over 3000 m that indicates noteworthy HD>VD and significant electrical conductivity readings (>100 mS/m), whereas the rest of the electromagnetic readings prior to this station are below 100 mS/m. This signifies the presence of material with a greater conductivity, like water, clay and sub-surface fracturing and weathering.

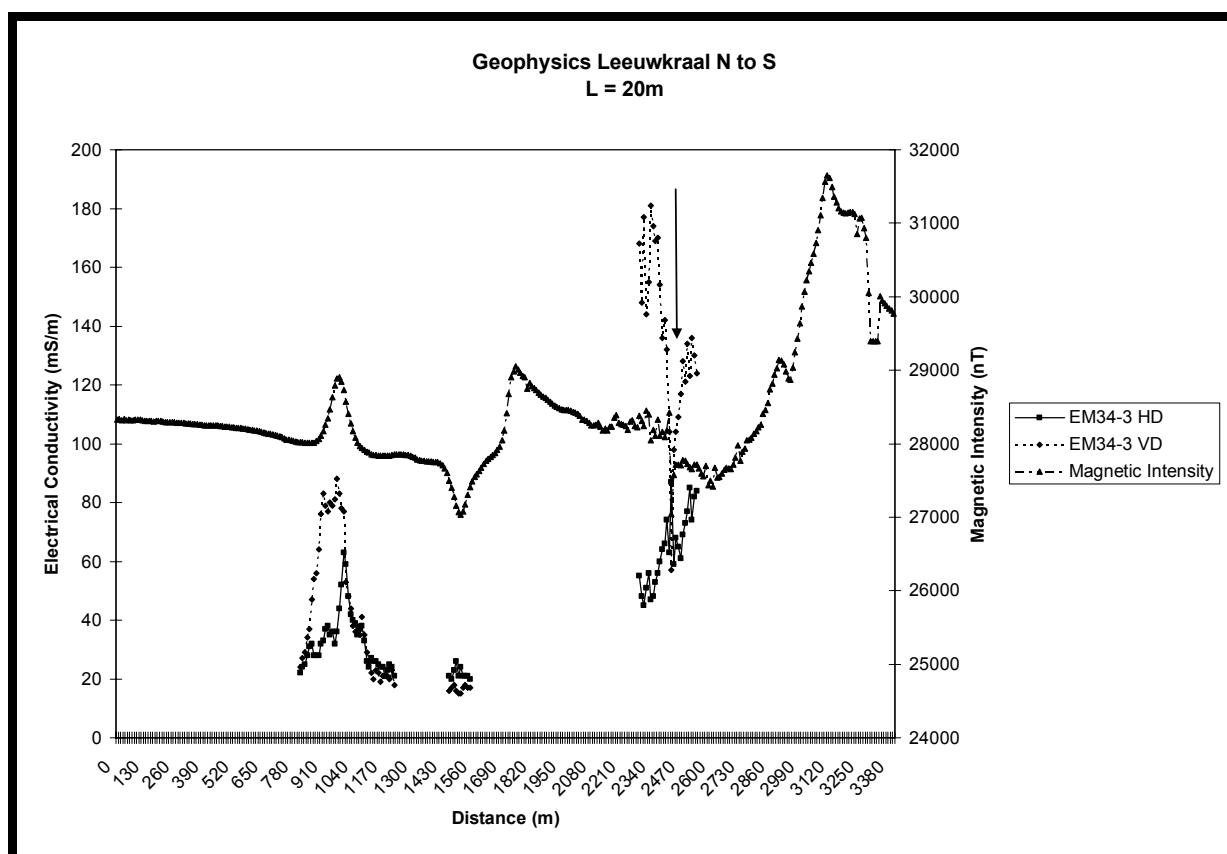


Figure 4.70. Geophysical profile on the farm Leeuwkraal 517IR.

Geobotanic indicators found at station 2450 m include *Acacia karroo* (tall specimens) and *Euclea crispa*. The frequency of sightings of the former occurs at approximately 45 species per hectare near the station 2450 m and diminishes towards the north. Since station 2450 m hosts some extraordinary *Acacia* species (compared to the other *Acacia karroo*) on the farm, it can be considered a geobotanical indicator. The occurrence of *Euclea crispa* is low and occurs at an interval of approximately 2 species per hectare. The geophysical profile crossed only one of them, at station 2450 m. The species *Celtis africana* was previously referred to as a possible geobotanical indicator (dolomite of the Malmani Subgroup-section 4.3). Although some *Celtis africana* species occur near the station 2450 m and at a frequency of 8 trees per hectare, its relevance as a geobotanic indicator could be further investigated. That this species occupies spots of deeper weathering, is likely to be true in this setting since it can be seen growing in areas of weathered outcrops and some depressions. The arrow in Figure 4.70 denotes the position of the drilled borehole, for which the properties are: yield 6 800 l/h, depth 65 m and water strike 23 m. The yield is well above the average yield of the region (2 400 l/h) and the water

strike corresponds favourably with other published results related to the region, 29 m (Vegter & Ellis, 1968). The encountered water-bearing feature is a typical confined aquifer. The borehole log indicates:

0 – 2 m: loam

2 – 7 m: weathered shale and breccia

7 – 17 m: shale and breccia

17 – 21 m: very weathered (clay) lava

21 – 29 m: weathered lava/andesite and boulders (water strike 23 m)

29 – 65 m: unweathered andesite.

Soil sampling, once again, was performed at the geobotanic/borehole position (2450 m) and at a locality with no notable geobotanic indicators, except in this instance one with a small *Acacia karroo* species (1 m in height) at station 2530 m. The soil of the geobotanic community records increased levels of pH, cations, heavy metals (Fe, Mn, Zn), soil conductivity, C, N and CEC. The combination of the weathered clay soil derived from the mafic and ultramafic rocks and decomposing botanic litter contributes favourably to elevated levels of CEC, cations, organic carbon and nitrogen. This is confirmed by the soil series (land type map, annexure) since the geobotanic community is representative of the Arcadia soil series, which is a dark, clay soil derived from weathered mafic rocks compared to the non-geobotanic community's lighter, loam soil (Avalon soil series) derived from weathered sedimentary rock.

***Acacia karroo*, *Celtis africana* and *Euclea crispa* are the geobotanic indicators in this case study. They are established on the Arcadia soil series, which is representative of weathered mafic rocks. The Avalon soil series, derived from weathered sedimentary rocks, does not support geobotanic indicators in this environment. The soil samples indicated that the geobotanic community contains higher levels of rich nutrients and CEC. The weathered mafic rock is a confined aquifer.**

44. Schoongezicht 225IR

The northern edge of the Karoo basin covers some rocks belonging to the Pretoria Group on the farm Schoongezicht 225IR and creates difficulties in the layout and interpretation of Schlumberger soundings as presented in this case study. The grass species *Fingerhuthia sesleriiformis* (thimble grass) was previously identified by Meulenbeld (1998) on this farm and is recognised as a geobotanic indicator by Kent & Enslin (1965) and Vegter & Ellis (1968). Based on the findings previously published by Meulenbeld (1998), further investigations relating to geobotany were conducted on this farm. According to the East Rand (1986) geological map, the farm is predominantly covered by rocks of the Vryheid Formation: shale and sandstone. These rocks are underlain by those belonging to the Pretoria Group (Transvaal Sequence), notably andesite of the Hekpoort Formation, shale and quartzite of the Silverton, Daspoort and Timeball Hill Formations with a northwest-southeast strike and 15-20° dip towards the northeast. The Vryheid Formation rocks do not display any structural features such as an inclination gradient. Groundwater prospecting includes the application of profiling methods (magnetics and electromagnetics) and a sounding method (Schlumberger). The profiling plot is shown in Figure 4.71.

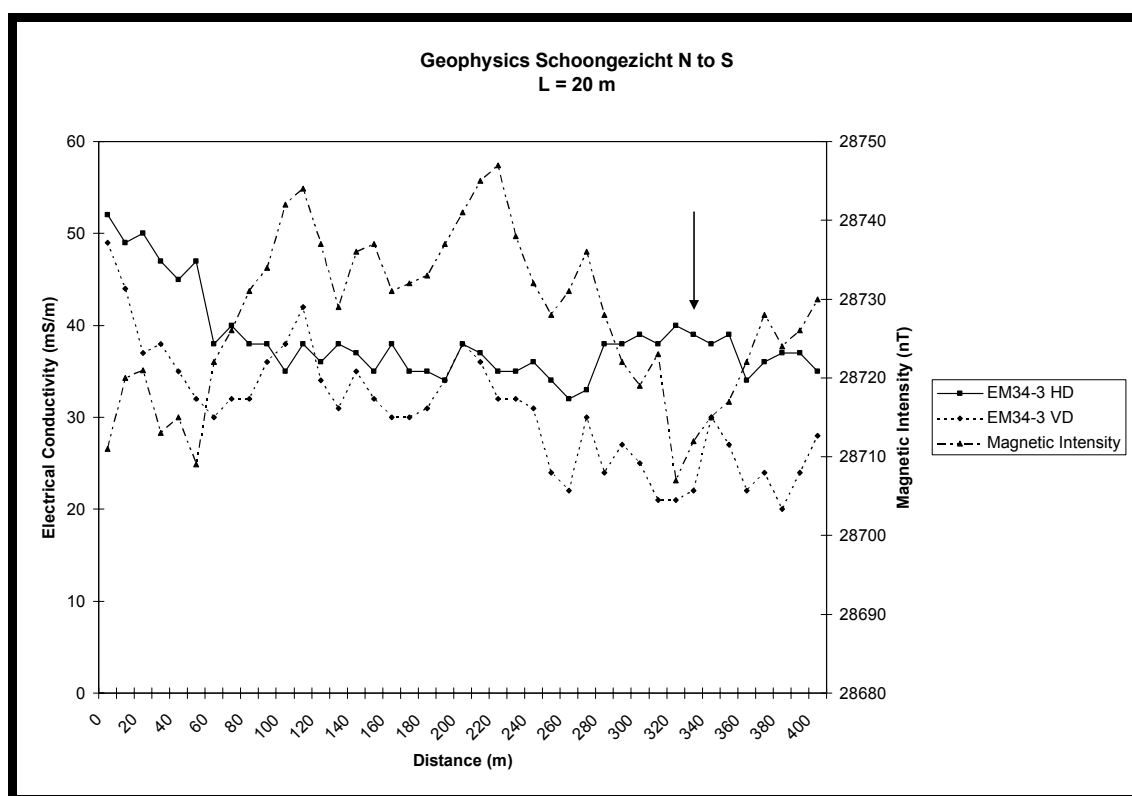


Figure 4.71. Geophysical profile on the farm Schoongezicht 225IR.

The geophysical profile, as indicated in Figure 4.71, does not identify the presence of any significant intrusive body close to the surface since the magnetic intensity values do not indicate any considerable increases (amplitude values <50 nT). The electromagnetic dipoles indicate a fairly homogenous layered earth since $HD \approx VD$ in a conductive environment and hence do not suggest the presence of an intrusive body. At station 330 m, $HD > VD$ which may indicate a deeper weathering profile. The arrow at station 330 m indicates the position of the existing borehole, with a yield of 9 000 l/h, a depth of 90 m and water strike of 65 m according to the NGDB (1996). The yield is well above the average yield of the region (Table A1.23). The depth of the borehole (90 m) may indicate different geological conditions in depth and therefore Schlumberger soundings were performed at the borehole because the maximum exploration depth of the electromagnetic methods is 60 m and too shallow to identify the cause of the existing aquifer conditions. Although the borehole is only surrounded by the geobotanic indicator grass specie *Fingerhuthia sesleriiformis*, the specie *Acacia karroo* grows in a linear pattern on outcrops of andesite/diabase (mafic rocks). Diabase is present as shown on the geological map (East Rand, 1986). *Acacia karroo* occupies the northwestern parts of the farm and no other tree species are evident. Some boreholes were drilled along the *Acacia karroo* tree line with a substantial yield (>5 000 l/h) according to the land owner. However, no access could be arranged to visit these. The paradox of anisotropy (see Van Zijl, 1987) is illustrated by the two Schlumberger soundings included: Figures 4.72 and 4.73. The first sounding (Figure 4.72) was conducted perpendicular to the strike of the underlying Pretoria Group rocks (northeast-southwest), whereas Figure 4.73 indicates the model obtained by conducting the sounding parallel to the strike of the underlain Pretoria Group rocks (northwest-southeast). Note the difference in shape and modelling depths, although the basic curve type, KH, is similar for both soundings. Notable differences in modelled conductivity and the thickness of the layer occur between both sounding models, with only the layout of electrodes in opposite directions. The third layer is extremely thick and conductive and is a succession of argillaceous and arenaceous rocks with interlayered small dolerite sills that are less than 2 m thick (NGDB, 1996). A discordant contact zone between the Pretoria Group rocks and the rocks belonging to the Vryheid Formation is anticipated between layers three and four. The nature of the Pretoria Group rocks is unclear owing to the small spatial extent of the outcrops in the area. A distinct aquifer (and the small intrusive sills) is not noticeable on the sounding curve and model (Figure

4.73) owing to the principle of equivalence (Van Zijl, 1987). The aquifer is situated in this thick layer. Resistant bedrock is measured at a depth of about 115 m, which could be unweathered andesite or quartzite.

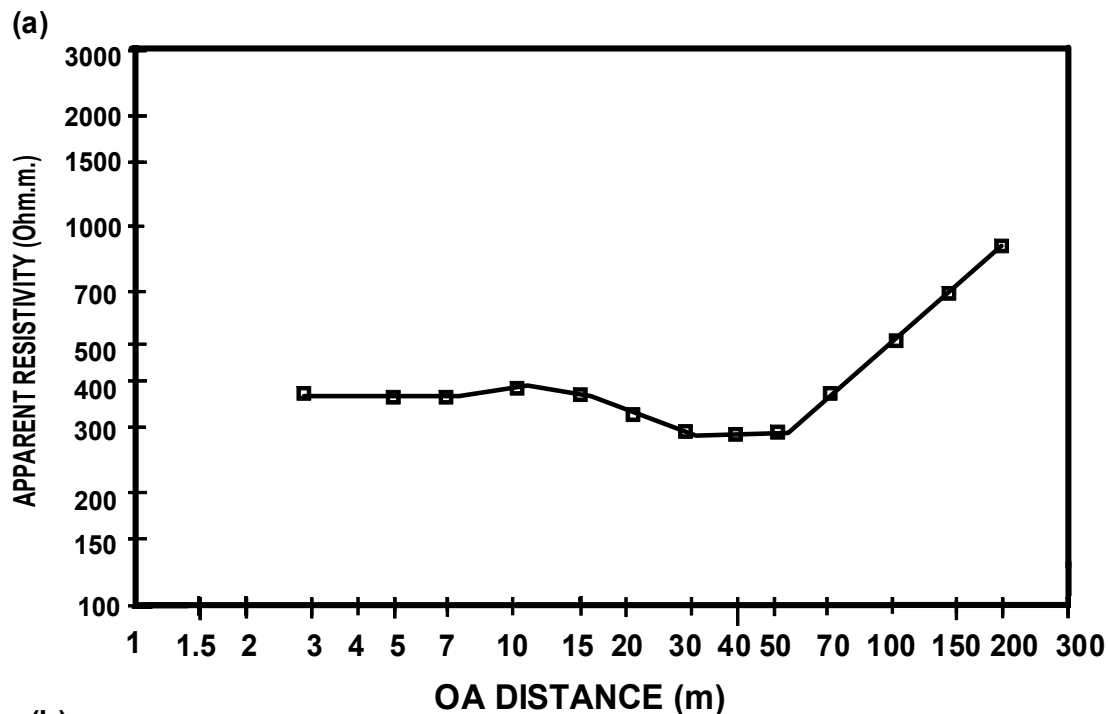
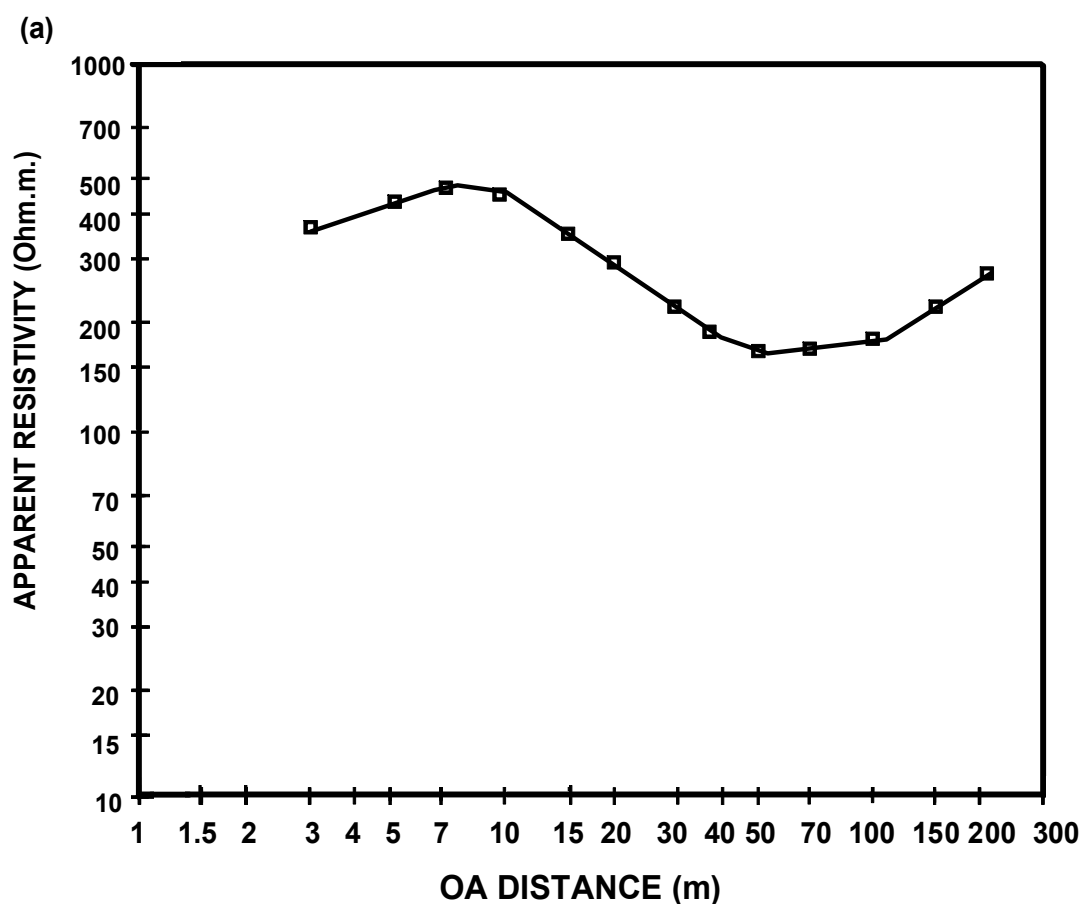


Figure 4.72. Schlumberger sounding perpendicular to the strike of underlain Pretoria Group rocks, Schoongezicht 225IR.

Quite similar to the chemical soil analysis of the geobotanic spot (station 330 m) and the other sampled site (station 360 m) in the previous case study, the present case study's geobotanic indicator (*Fingerhuthia sesleriiformis*) records values of a higher pH, cations, heavy metals in the deeper soil (1.2 m), conductivity, N, S and CEC. Station 360 m was selected because an increase in the magnetic intensity is observed and also because it is occupied by the more common grass of the area, namely *Themeda triandra* (rooigras). Unfortunately, of all the case studies presented, this farm was the only place where the species *Fingerhuthia sesleriiformis* was found,

although the said species occurs widely in the study area (Van Oudtshoorn, 1994). The locality where *Fingerhuthia sesleriiformis* and *Acacia karroo* grows is more representative of weathered mafic rocks (andesite: see annexure) and of the Hutton soil series. The latter contains more clay (higher pH) than the Avalon soil series. *Themeda triandra* is a climax species and establishes itself on both the Hutton and Avalon soil series and cannot be used as a geobotanic indicator.



(b) Depth sounding model:

Layer	1	2	3	4
ρ (resistivity)	305	986	176	2055
h (thickness)	1.8	3.2	111.8	

Figure 4.73. Schlumberger sounding parallel to the strike of underlain Pretoria Group rocks, Schoongezicht 225IR.

Geobotanical-geophysical groundwater exploration based on grass species is greatly more difficult than on tree or shrub species since grasses appear to be similar and can at times only be easily identified by their seed or inflorescence: burning destroys the appearance of grass species while overgrazing and other bad farming practices eliminate these grass species; they are mostly overtaken by invader grass species. Therefore, indigenous tree and shrub species are preferred as indicators because they are less severely affected by the above-mentioned practices.

***Acacia karroo* and *Fingerhuthia sesleriiformis* are the geobotanic indicators in this case study. These species grow on Hutton soil series, which are higher in clay content in contrast with the Avalon soil series. The higher clay content is derived from the geochemical weathering of mafic rocks. The weathered mafic rock defines aquifer conditions.**

4.11.1 Remarks

The case studies of this part of the Karoo Supergroup indicated the presence of geobotanical indicators, although these were restricted to only three species, namely *Acacia karroo*, *Euclea crispa* and *Fingerhuthia sesleriiformis*. The latter is a grass species that could be useful on the tufted grassy plains of the South African Highveld. Poor farming practices may lead to the extinction of this grass species, particularly since it favours depressions and wetlands, while overgrazing or regular burning might alter the composition of the species to the common invader *Eragrostis plana* (tough love grass). The yield of the boreholes associated with the listed geobotanical indicators is well above the average yield of 2 400 l/h for this region as indicated in Table A1.23. The use of special geophysical profiling methods such as the magnetic and electromagnetic EM-34-3 ones, is valuable since sedimentary rocks are intruded by numerous mafic and ultramafic rocks that exhibit different signatures from the profiles. The signature of an intrusion on the profile is a rise in the magnetic intensity and conductivity (>60 mS/m), in particular the horizontal dipole component. Soundings are useful in the case of weathered basins and areas underlain by older rocks that define a discordant contact zone.

The results of the soil samples obtained at the geobotanic site and the remaining site are indicated in Table 4.11. Of interest is the overwhelming availability of Ca, Mg and Mn at the geobotanic sites, most probably owing to the enrichment of the soil by the

weathered mafic and ultramafic rocks that are richer in these elements than the arenaceous and argillaceous rocks of the Vryheid Formation (see Chapter 2, Tables 2.1 & 2.2) and the ability of humus to hold and exchange cations in abundance, compared to clay (Rehm, 1994). The soil is also more conductive with pH-values that are not destructive to plant growth and development, compared to the lower pH-values of sites with no geobotanical indicators and higher Al-toxicity levels. The higher CEC-values of the geobotanical communities, in some cases, can be attributed to wetter conditions, soil differences, microorganism activity and therefore a situation rich in rotting plant material (anaerobic conditions) and the building up of humus underneath and in the vicinity of such communities.

Table 4.11. Comparisons between the geobotanical indicators' soil characteristics and their surroundings.

Parameter	Geobotanical community (A)	Surroundings (B)
pH	5.62-6.79	4.54-6.27
P (mg/kg)	0.48-8.33	2.36-6.45
Ca (mg/kg)	1320-2302	148-667
Mg (mg/kg)	521-1368	52-292
K (mg/kg)	89-186	29-192
Na (mg/kg)	17-62	10-58
Fe (mg/kg)	104.27-329.13	14.80-225.18
Mn (mg/kg)	246.87-407.54	7.77-204.81
Zn (mg/kg)	0.41-2.33	0.34-1.55
Al (cmol _c /kg)	0-0.198	0.100-1.106
Resistance (Ω)	1400-2000	2000-5200
%C	0.23-1.48	0.27-2.66
Total N%	0.029-0.088	0.018-0.181
S (mg/kg)	6.70-144.78	9.23-88.36
CEC (cmol _c /kg)	14.510-28.691	5.452-19.19
Geobotanical indicator species under column A	<i>Acacia karroo</i> (sweet thorn) <i>Euclea crispa</i> (blue guarri) <i>(Fingerhuthia sesleriiformis)</i> (thimble grass)	
Geology	Dolerite, andesite and basaltic lava in contact with sediments of the Vryheid Formation	Sandstone and shale of the Vryheid Formation
Aquifer yield (l/h)	6 800 – 9 000	Not applicable

4.12 PERMIAN – TRIASSIC EONOTHEMS: ARENACEOUS AND ARGILLACEOUS ROCKS OF THE IRRIGASIE, LISBON AND CLARENS FORMATIONS OF THE KAROO SUPERGROUP IN THE MABULA-WATERBERG AREA

Information pertaining to the case study area regarding its geographic locality, climate, veld types, geology, geohydrology, geophysics, geobotany, soil sampling is tabled (see annexure).

45. Droogesloot 476KR

The non-perennial stream, Karee Spruit, cuts through the farm Droogesloot 476KR, approximately 25 km west-southwest of Warmbaths and 12km south-southeast of Mabula. Large parts of the farm are covered with deposits belonging to the Clarens Formation of the Karoo Supergroup. Visible outcrops are scarce while the surface is usually covered with sand. A small portion of the farm is covered with basaltic rocks (Letaba Formation), but falls outside the scope of the geophysical investigation on this farm. The entire farm is covered with dense bush and only portions made available for intensive agricultural practices have been cleared. On the farm, the need existed for a groundwater supply for a new homestead as well as a water supply for cattle in the area near the homestead. The Karoo Supergroup in this area, which is intersected by intrusive bodies, is neither indicated on the geological map (Nylstroom, 1978), nor are the contact zones with these bodies recognised as aquifers on the hydrogeological map (Polokwane, 2003). The aquifers associated with the arenaceous rocks of the Clarens Formation in this area are linked to intergranular conditions and fractures. The absence of intrusive structures is the reason behind the elimination of the magnetic method from this case study. The electromagnetic method (EM-34-3) was utilised for the identification of fracture zones, backed by geobotanical indicators, on this farm. It is expected that these fracture zones will be evident on the aerial photograph (annexure) by the presence of denser bush cover when compared to the surrounding veld. The direction of the profile was set from west to east so that it would cross some surface water courses in the hope that these features are underlain by fractured rocks. Although the utilisation of the electromagnetic method on the farm is made difficult by the presence of dense bush, the method is useful and is required in the absence of intrusive magnetic bodies. Schlumberger depth soundings were not laid out because of the dense bush conditions. If one employs the electromagnetic method a possible pitfall arises in this arenaceous and possibly argillaceous environment because the weathered clay rock,

close to the surface, clouds the penetration of the electromagnetic current into the deeper situated layers and thus, the possible exploration depth is restricted. Therefore, geobotanic indicators are extremely important in the positioning of a borehole owing to the difficult, misleading geological-geophysical conductive conditions.

The electromagnetic profile, measured on the farm, is indicated in Figure 4.74. Of importance are the high conductivities of the sub-surface, mostly triggered by the nature of the weathered sedimentary rocks. A variation in the electromagnetic dipoles over the length of the profile of 450 m can be attributed to changing conditions in the state of weathering of the rock and fracturing. If $HD > VD$, one can assume that more fracturing is present, but if the fractures or weathering are filled with clay material, then an aquiclude arises instead of an aquifer.

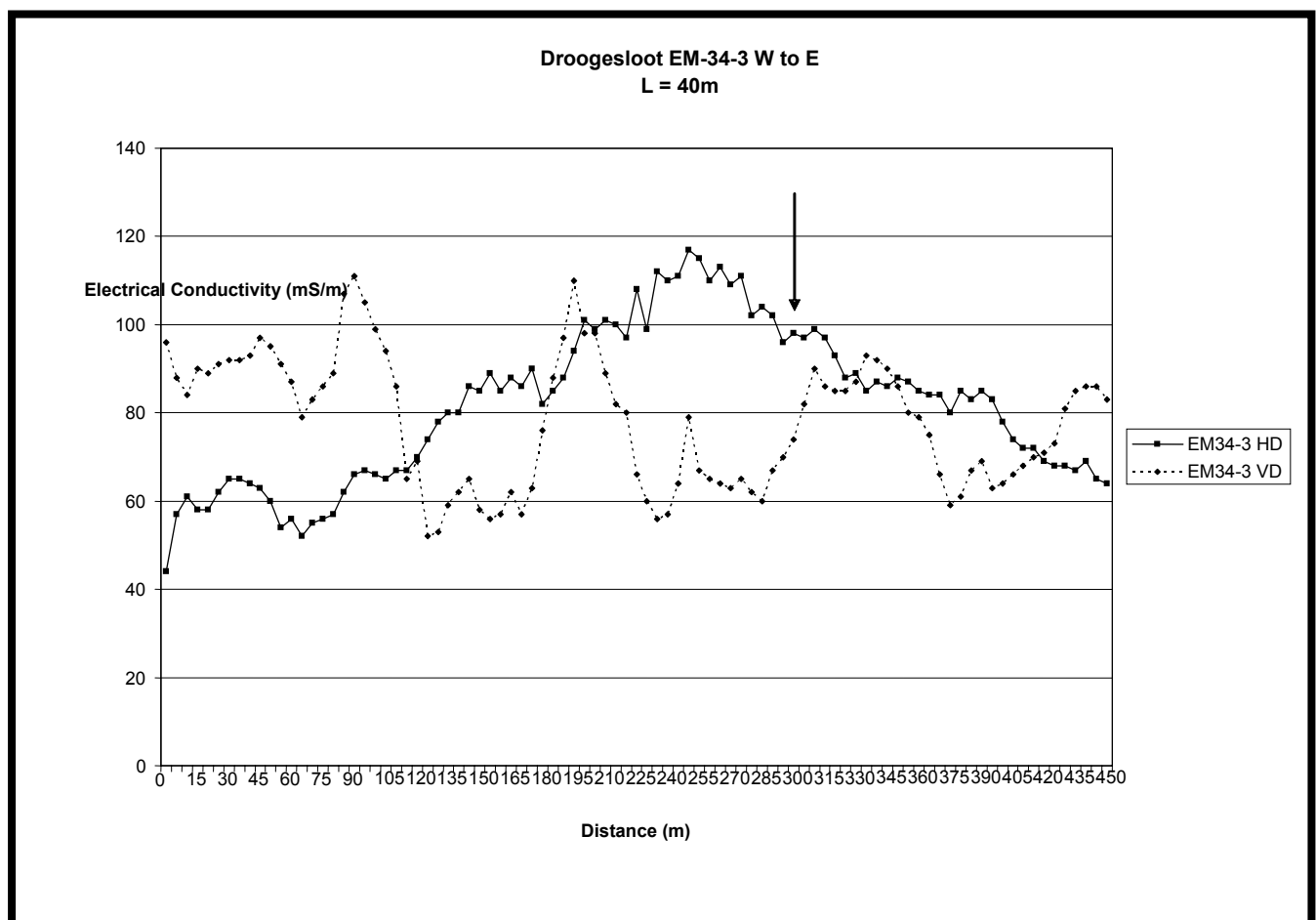


Figure 4.74. Electromagnetic profile on the farm Droogesloot 476KR.

Based on the writer's previous experience in the Bushveld areas of the northern parts of South Africa, geobotanical indicators were identified on the farm by means of a

distribution list of the frequency of encountered species in the surroundings of the geophysical profile and where $HD > VD$. It was found that two species occur irregularly and have a linear distribution pattern along station 300 m. Three more, short, profiles were run parallel to the one displayed in Figure 4.74 in line with station 300 m and it was found that $HD > VD$ in these areas as well and that the same type of geobotanic indicators occurs at these stations, namely *Rhus lancea* (karee) and *Strychnos pungens* (spine-leafed monkey orange). The arrow, at station 300 m (Figure 4.74) indicates the position of the drilled borehole. The yield of the borehole is 6 000 l/h, the depth 75 m, water strike 33 m, while the static water level in the borehole after drilling is 17 m from the surface, see Table A1.25. The borehole encountered water in fractured sandstone. The borehole log indicates the presence of sand (0 – 2 m), loam (2 – 4 m), weathered sandstone (4 – 8 m), sandstone (8 – 32 m), fractured sandstone (32 – 33 m) and sandstone (33 – 75m). The borehole is deeper than the exploration depth of the EM-34-3, even with a coil separation of 40 m, but since the average borehole depth is 60 m in this area (Frommurze, 1937), drilling beyond 60 m on this spot with geobotanic indicators was found to be justified. The yield of the borehole is almost twice as much as the average for this region (Frommurze, 1937). Of further interest are the chemical properties of the soil near the geobotanic indicators as sampled at station 300 m ($HD > VD$) and 330 m ($HD = VD$). The soil properties of the geobotanic indicator indicate increased levels of P, K, Mn, Zn, C, N and S with increasing depth (1.2 m) and overall higher values for CEC. The values of pH at both stations signify alkaline soils ($pH > 8$) with no Al-toxicity. The soil is rich in Ca at both stations ($Ca > 4300$ mg/kg). According to the land-type map (annexure), the geobotanic community forms part of the Hutton soil series as does the non-geobotanic community. The differences in the geochemical properties of the soil can be attributed to the nutrient recycling by the geobotanic indicators taking place (leaves, branches, roots) in the fractured zone. These trees are able to extract different nutrients from the fractured aquifer from those nutrients available in the surroundings.

***Rhus lancea* and *Strychnos pungens* are the geobotanic indicators in this case study. Both species grow along the linear fracture zone in the sandstone. It is most probable that these trees extract nutrients from the fractured aquifer to support their growth. The geochemical properties of the soil at the geobotanic community indicate higher levels of nutrients and CEC compared to the other site sampled. Both sampled localities are located in the Hutton soil series.**

46. Grootfontein 528KQ

The Irrigasie Formation underlies the farm and makes geophysical prospecting more difficult since the lithology of this formation is predominantly that of argillaceous rocks, such as siltstone, mudstone and shale. The pitfalls with regards to the electromagnetic method, as mentioned in the previous case study, are greater in this case. Dense bush covers the surface, although large areas have been cleared as a result of agricultural practices. A small sandstone outcrop gives rise to the prominent Slypsteenkop. The Irrigasie Formation is abruptly displaced along a fault on the northern part of the farm, but this area could not be investigated because of the farm boundaries and the location of the provincial road. Some Hematite (Fe_2O_3) veins occur on the farm, north of the fault zone in granite (Bushveld Complex age), and are problematic because this causes an extremely conductive electromagnetic field as well as erroneous magnetic intensity readings on the magnetometer, and therefore obscures any associated aquifers.

During the geophysical exploration, consideration was given to the existence of Slypsteenkop since it defines a band of sandstone in the Irrigasie Formation and geobotanic indicators such as *Rhus lancea* (karee) and *Strychnos pungens* (spine-leaved monkey orange) that were listed in the previous case study, where the same geological and climatological area is represented. Such fracture zones can be identified by the use of the electromagnetic method, and exploring for groundwater in the vicinity of sandstone will reduce the likelihood that the said pitfalls would occur. The relatively undisturbed nature of these rocks, by intrusive bodies, renders profiling with the magnetic method useless, as seen in Figure 4.75, where no magnetic anomaly can be observed since the total magnetic intensity amplitude is only 20 nT. The aerial photograph (annexure) indicates linear vegetated patterns on the farm with a southwest-northeast strike in the vicinity of the sandstone outcrop. The geophysical profiles were laid out east-west in order to cross these linear patterns, and it was easier to operate the electromagnetic instrument in this direction because of the open roads.

The electromagnetic profile illustrates a very conductive vertical dipole component, while the horizontal dipole component depicts stable electrical conductivity readings of about 40 mS/m. The arrow at station 110 m indicates the location of the drilled borehole. The reason for $\text{VD} > \text{HD}$, and especially at station 110 m where $\text{VD} \gg \text{HD}$ for the entire profile, can be attributed to the presence of an inclined sandstone layer since this profile is in the vicinity of Slypsteenkop. Station 110 m was selected on the

basis of the anomaly in the electromagnetic dipole readings, because it indicates a change in sub-surface weathering and inclination conditions.

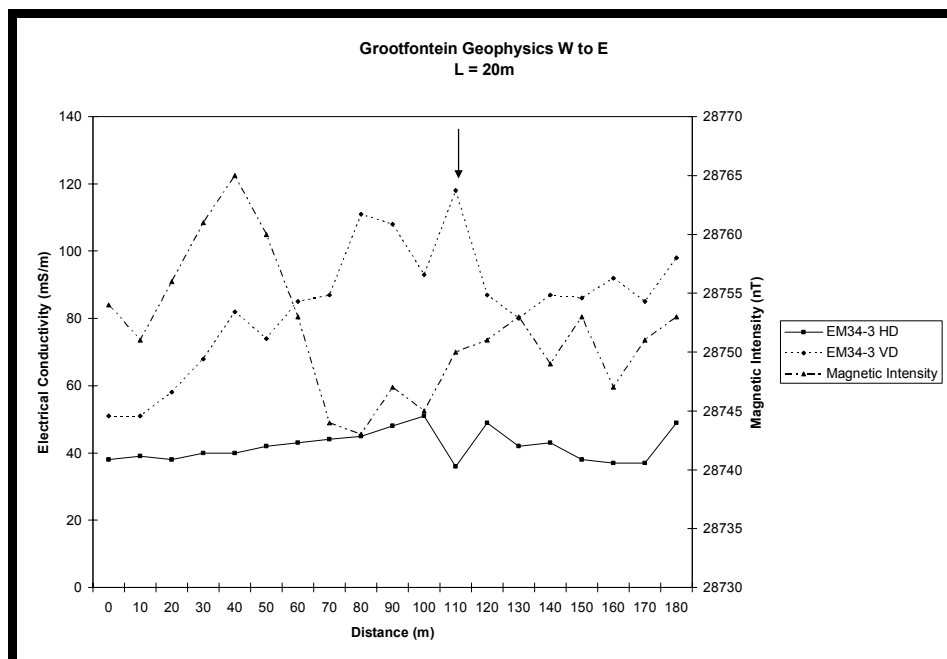


Figure 4.75. Geophysical profile on the farm Grootfontein 528KQ.

Furthermore, the botanic species *Rhus lancea* and *Strychnos pungens* occur at station 110 m. The borehole drilled at station 110 m was drilled to a depth of 65 m and water was struck at a depth of 30 m in a small band of fractured sandstone. The yield of the borehole is 5 000 l/h, above the average of 3 300 l/h as indicated by Frommurze (1937). The borehole log consists of soil (0 – 3 m), shale (3 – 22 m) and sandstone (22 – 65 m) with the confined aquifer at 30 m. Soil samples taken at stations 110 m and 90 m indicate alkaline soil conditions (pH > 7.9), high Ca values (Ca > 5100 mg/kg), increased levels of Mg, K, conductivity, Fe, Mn, Zn and CEC at deeper levels (1.2 m) at the geobotanic community of station 110 m. These values compare favourably with the chemical soil analysis of the previous case study, which is located in close proximity, and the Hutton soil series on the land type map.

***Rhus lancea* and *Strychnos pungens* are the geobotanic indicators in this case study. Both species grow on the linear fracture zone in the sandstone. It is most probable that these trees extract nutrients from the fractured aquifer to support their growth. The geochemical properties of the soil at the geobotanic community indicate higher levels of nutrients and CEC compared to those of the other sampled site. Both sampled localities are located in the Hutton soil series.**

47. Newcastle 202LQ

A localised Karoo Supergroup outcrop is situated in the northwestern part of Limpopo Province, close to the coal-mining town of Ellisras. On the farm Newcastle 202LQ, outcrops of the Lisbon and Clarens Formations occur, the former being unique to this geological environment. Both formations were deposited during the Triassic Eonothem, with the Lisbon Formation being the oldest of the two. The Lisbon Formation is composed of argillaceous rocks, whereas the Clarens Formation is a fine-grained arenaceous unit. On the farm Newcastle 202LQ, a localised fault zone, with an east-west strike, abruptly divides the two formations. The aerial photograph (annexure) reveals some north-south striking features along the fault. The Karoo Supergroup rocks are frequently intersected by fault zones in this area (Ellisras, 1993).

Most farms in this area are dedicated to game farming: consequently bush clearing is not practised as a rule which, therefore, hinders the application of line-coupled geophysical methods such as the EM-34-3 profiling and Schlumberger soundings. The electromagnetic and magnetic profiling techniques were used on this farm, despite the luxurious vegetation cover: however, the profiles were laid out along vehicle tracks in the bush in order to overcome the hindrance of the vegetation and to cross the identified features on the aerial photograph perpendicularly. The fault zone and associated structures are recognised on the surface by the linear (east-west and sometimes north-south) growth of *Combretum imberbe* (leadwood) and *Ficus ingens* (red-leafed fig) trees associated with the Mixed Bushveld veld type (Acocks, 1988). The importance of *Combretum imberbe* was discussed in Chapter 2. The associated aquifer with the fault zone constitutes a fractured aquifer, but the average indicated yield of these Karoo formations are low, approximately 2 000 l/h (Frommurze, 1937 & Polokwane, 2003). The fault zone is characterised by the increase in electrical conductivity of the horizontal dipole component of the EM-34-3, with a distinct $HD > VD$ over the fault zone (stations 260-320 m), whereas at the other stations $HD = VD$ or $VD > HD$. The magnetic intensity does not indicate any magnetic anomalies: therefore one can assume that these faults are not filled by mafic or ultramafic rocks (Figure 4.76). The spike in the magnetic intensity value at station 380 m is caused by some steel material lying nearby and can be referred to as noise. The arrow at station 320 m denotes the position of the drilled borehole, with a yield of 4 500 l/h, well above the average yield of 2 000 l/h, especially taking into consideration that the highest percentage of unsuccessful boreholes drilled in the

northern beds of the Karoo Supergroup are drilled in this area: 11% of all boreholes drilled in the Karoo beds in this area are unsuccessful or dry according to Frommurze (1937). The borehole log indicated the following: 0-3 m fine sand; 3-34 m siltstone; 34-38 m brecciated rock (water strike 36m); 38-70 m silt- and mudstone.

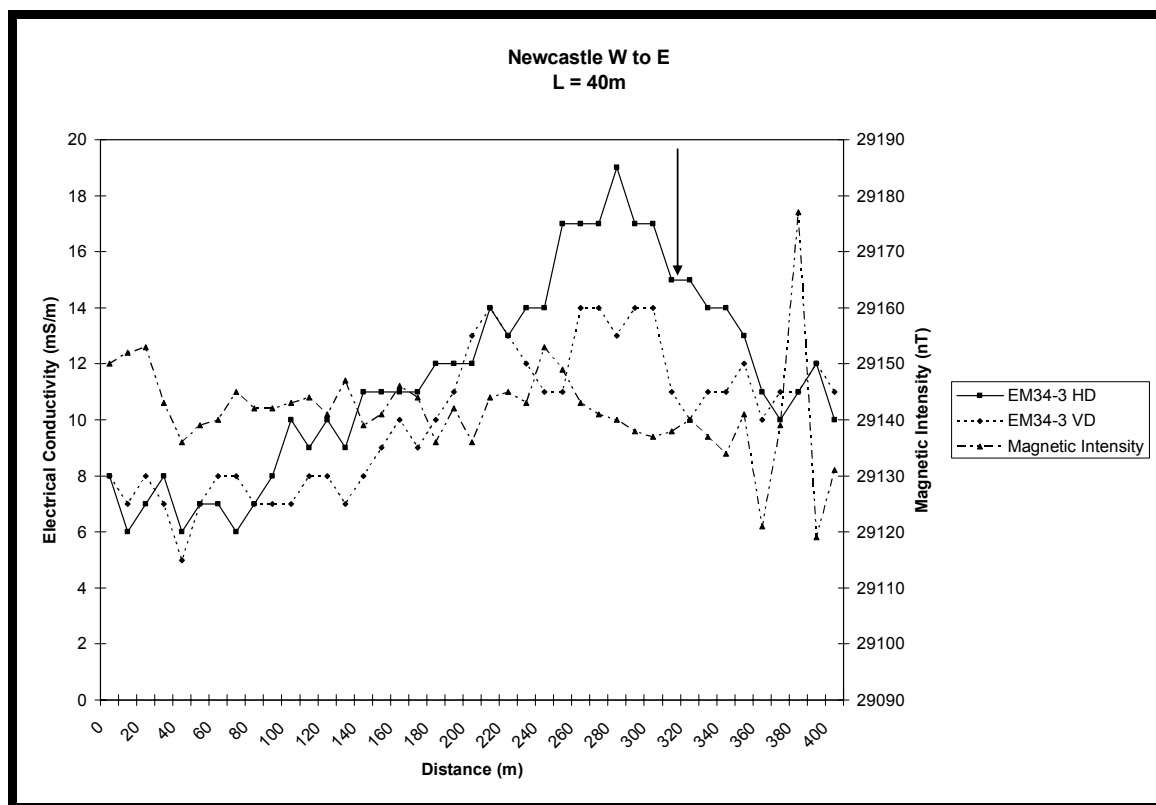


Figure 4.76. Geophysical profile on the farm Newcastle 202LQ.

The depth of the borehole (70 m) corresponds with the average depth of boreholes in the Karoo beds in this area (69 m), Table A1.25(a&b). Other geohydrological parameters are indicated in Table A1.25(a&b). Alkaline soils are characteristic of the soils derived from the Karoo Supergroup in the northern parts of South Africa. These alkaline soils are superb hosts of vegetation since Al-toxicity is non-existent and, combined with the lower average rainfall of the area, create a sweet grass-veld vegetation type. The geobotanic community at the borehole (*Combretum imberbe* and *Ficus ingens*), station 320 m, possesses increased levels of available K, Zn, C, N and CEC compared to the site that was sampled with no significant geobotanical indicators and geophysical anomalies (station 360 m). This can be based on the land type Ah85a (see annexure). The geobotanic community is most probably rooted in the Hutton soil series while the other site resembles the Clovelly soil series, a sandy type.

***Combretum imberbe* and *Ficus ingens* are the geobotanic indicators in this case study. These species prefer the richer clay Hutton soil series compared to the sandy Clovelly soil series. Furthermore, *Ficus* species such as this one are normally associated with surface water bodies and their occurrence in the field indicates shallow groundwater conditions or feasible rooting conditions (fracturing and faulting). *Combretum imberbe* is well known to indicate groundwater in the drier parts of Southern Africa.**

4.12.1 Remarks

In the absence of mafic and ultramafic intrusions, associated aquifers with the argillaceous and arenaceous rocks of the Irrigasie, Lisbon and Clarens Formations of the Karoo Supergroup are predominantly caused through fracturing of the rock by tectonic stresses and intergranular spacing and openings. Weathering of these rocks, particularly the silt and clay rich argillaceous rocks such as siltstone, mudstone and shale, prohibits the propagation of electromagnetic waves in the deeper layers of the sub-surface and obscures deeper conductors since the clay is a conductor itself and governs the flow of the electromagnetic current. This is a potential pitfall when the electromagnetic method is utilised in such an argillaceous and arenaceous rock environment with a scarce frequency of intrusions: it is of little use. It is difficult to list electrical conductivity values for aquifers in this region owing to the generally highly conductive properties of the earth. Every case should be treated on its own, being guided by geobotanical indicators. Schlumberger soundings can be performed, but the large areas covered by farms and the dense bush limit the proper application of this method since a misalignment of the current electrode spacing (AB) caused by poor operator visibility at large electrode spacings, creates erroneous apparent resistivity readings. This is one of the reasons why Schlumberger soundings were not utilised in this environment. The yield of boreholes is not such that it permits large abstraction of water in order to sustain agricultural pivot irrigation systems, otherwise larger areas of land would have been cleared of bush. Although sound geophysical groundwater exploration in this environment is restricted by the type of rock and vegetation conditions, the latter can be employed as an opportunity in the sense of geobotanic indicators that could suggest where to search for aquifer conditions in the sub-surface. Identified geobotanic indicators for this area are listed in Table 4.12. Soil sampling at geobotanic sites, compared with the soil characteristics of the surrounding veld, indicates an alkaline pH environment where aluminium toxicity is

absent and which subsequently favours root and plant growth. The soil is rich in available calcium, mostly due to the formation and weathering of calcrete nodules (CaCO_3) in this dryer climatic environment (increased N-value). Overall, the soil is low in resistivity and poor in organic carbon and subsequently also deficient in sulphur and nitrogen (Table 4.12). The results, as presented in Table 4.12, indicate the results gathered from soils derived from the Permian-Triassic deposited Karoo Supergroup in the savanna biome (section 4.12) and those obtained from the earlier deposited Karoo Supergroup rocks in the grassland biome (section 4.11). It is quite easy to observe the difference in geobotanic indicators of the two indicated biomes owing to differences in the type of aquifer (sedimentary rock fractures vs. intrusive contact zones).

Table 4.12. Comparisons between soil characteristics of the geobotanical indicators and their surroundings.

	Irrigasie, Lisbon & Clarens Formations (Savanna Biome)		Vryheid Formation (Grassland Biome)	
Parameter	Geobotanical community (A)	Surroundings (B)	Geobotanical community (A)	Surroundings (B)
pH	7.46-8.60	7.62-8.57	5.62-6.79	4.54-6.27
P (mg/kg)	1.30-12.61	0.99-16.66	0.48-8.33	2.36-6.45
Ca (mg/kg)	2688-6747	2785-7043	1320-2302	148-667
Mg (mg/kg)	129-879	211-684	521-1368	52-292
K (mg/kg)	113-323	92-282	89-186	29-192
Na (mg/kg)	16-59	20-101	17-62	10-58
Fe (mg/kg)	2.35-69.36	1.06-51.07	104.27-329.13	14.80-225.18
Mn (mg/kg)	36.08-224.29	25.37-202.25	246.87-407.54	7.77-204.81
Zn (mg/kg)	0.31-0.84	0.22-0.59	0.41-2.33	0.34-1.55
Al (cmol _c /kg)	0-0	0-0	0-0.198	0.100-1.106
Resistance (Ω)	800-2400	780-3000	1400-2000	2000-5200
%C	0.13-0.48	0.07-0.75	0.23-1.48	0.27-2.66
Total N%	0.014-0.077	0.007-0.059	0.029-0.088	0.018-0.181
S (mg/kg)	5.34-9.57	4.13-12.43	6.70-144.78	9.23-88.36
CEC (cmol _c /kg)	10.39-23.116	5.53-22.931	14.510-28.691	5.452-19.19

Geobotanical indicator species under column A	<i>Combretum imberbe</i> (leadwood) <i>Ficus ingens</i> (red-leaved fig) <i>Rhus lancea</i> (karee) <i>Strychnos pungens</i> (spine-leaved monkey orange)		<i>Acacia karroo</i> (sweet thorn) <i>Euclea crispa</i> (blue guarri) <i>(Fingerhuthia sesleriiformis)</i> (thimble grass)	
Geology	Fractures and faulting in argillaceous and arenaceous rocks of the Irrigasie, Lisbon and Clarens Formations	Unfractured argillaceous and arenaceous rocks of the Irrigasie, Lisbon and Clarens Formations	Dolerite, andesite and basaltic lava in contact with sediments of the Vryheid Formation	Dolerite, andesite and basaltic lava in contact with sediments of the Vryheid Formation
Aquifer yield (ℓ/h)	4 500 – 6 000	4 500 – 6 000	6 800 – 9 000	6 800 – 9 000

4.13 NOTE ON *Boscia foetida* subsp. *rehmanniana*

The area northwest of Marble Hall, and in particular the farm Loskop Noord 12JS, is covered by rocks belonging to the Eccra Group of the Karoo Supergroup. The lithology includes shale, shaly sandstone, grit, sandstone, conglomerate and some minor coal deposits. In some places, the Eccra Group overlies dolomite and chert of the Deutschland Formation and Malmani Subgroup (Chuniespoort Group, Transvaal Sequence) and granite belonging to the Lebowa Granite Suite (Bushveld Complex) (Nylstroom, 1978). The sedimentary rocks are predominantly overgrown with *Combretum apiculatum* (red bushwillow), *Mundulea sericea* (cork bush) and *Peltophorum africanum* (weeping wattle). Some localities are underlain by intrusive diabase and such localities can be identified by the following thorn-bearing tree species: *Acacia karroo* (sweet thorn), *A. robusta* (brack thorn), *A. tortillis* subsp. *heteracantha* (umbrella thorn) and *Dichrostachys cinerea* (sickle bush). The tree species *Boscia foetida* subsp. *rehmanniana* (Figure 4.77) (stink shepherd's tree) occupies places where conspicuous transgression zones between thorn-bearing species (diabase derived soil) and non-thorn-bearing species (sedimentary rock derived soil) are noticeable: Figure 4.78. These zones are defined by dipping grit outcrops and termitaries in a linear pattern along these outcrops: Figure 4.79. Furthermore, the geobotanic indicator *Ximenia caffra* (sourplum), listed earlier, is prominent along the transgression zone. The magnetic profile (Figure 4.80), as measured on the farm Loskop Noord 12JS, indicates a small, but significant amplitude (12 nT) in close proximity to the occurrence of *Boscia foetida* subsp. *rehmanniana* and *Ximenia caffra* (arrow) in association with a transgression from *Acacia karroo*, *A. robusta*, *A. tortillis* subsp. *heteracantha* and *Dichrostachys cinerea* veld towards veld occupied by *Combretum apiculatum*, *Mundulea sericea* and *Peltophorum africanum*. Termitaries are observed in this transgression zone. From these specific observations regarding *Boscia foetida* subsp. *rehmanniana* it can be assumed that this species (and also probably *Boscia albitrunca* (shepherd's tree)) can be regarded as a geobotanic indicator if other phenomena are taken into account such as transgression zones of tree characteristics (thorns vs. no-thorns, outcrops, other geobotanic indicators). The rooting depth of this species extends up to 68 m deep (Canadell et al., 1996). More case studies and drilling results reflecting groundwater parameters regarding the mentioned species will be clearly advantageous because this case was not drilled but merely investigated by geobotanical-geophysical means. Note that in certain areas *Boscia albitrunca*

(shepherd's tree) can replace in for *Boscia foetida* subsp. *rehmanniana* since the latter species is less widespread. The species *Boscia albitrunca* is also used in mineral exploration (Mshumi, 2006).



Figure 4.77. A superb specimen of *Boscia foetida* subsp. *rehmanniana* in association with a termitary.



Figure 4.78. Transgression zone from thorn-bearing tree species (foreground tree with small, dark green leaves) to non-thorn-bearing tree species in the background (tree with large, light green leaves).



Figure 4.79. *Boscia foetida* subsp. *rehmanniana* along a dipping grit outcrop next to a transgression zone as depicted in Figure 4.80.

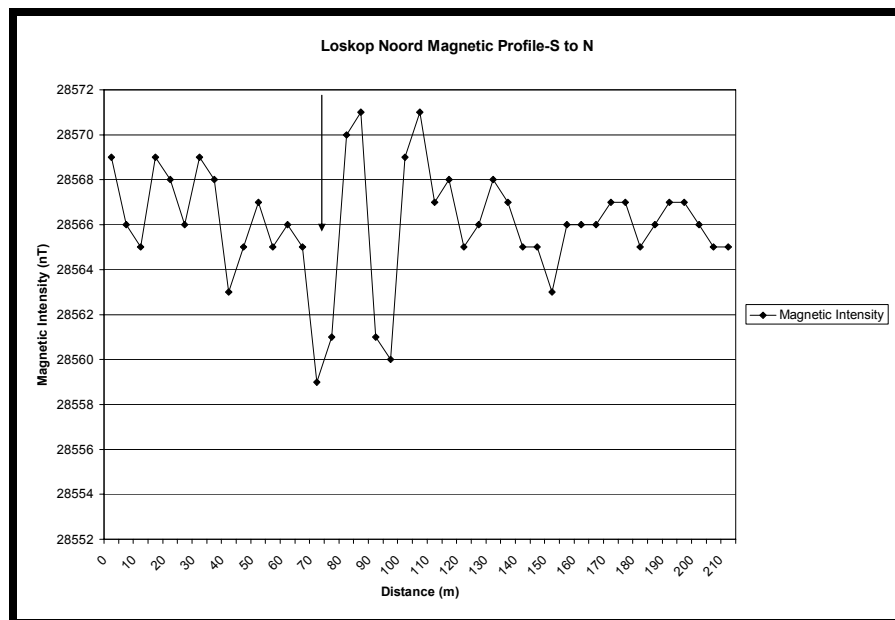


Figure 4.80. Magnetic profile on the farm Loskop Noord 12JS.

4.14 JURASSIC EONOTHEM: BASALT ROCK OF THE LETABA FORMATION AND DOLERITE INTRUSIONS OF THE KAROO SUPERGROUP IN THE SPRINGBOK FLATS AREA

Information pertaining to the case study area regarding its geographic locality, climate, veld types, geology, geohydrology, geophysics, geobotany, and soil sampling is tabled (see the annexure).

48. Kalkheuvel 73JR

A local, unique outcrop of Karoo-age dolerite east of the village of Pienaarsrivier, approximately 50 km north of Pretoria, on the farm Kalkheuvel 73JR is studied. The weathered dolerite soil is rich in lime nodules; therefore this locality was mined for lime aggregates used in the cement industry (Pretoria Portland Cement). Mining has subsequently ceased. A groundwater supply for game was requested. The geobotanical phenomena on this farm are quite interesting and of great value. The areas underlain by dolerite are more or less clayey in texture and host thorn-bearing botanic species such as *Acacia erioloba* (camel thorn), *A. luederitzii* (false umbrella thorn), *A. mellifera* (black thorn) and *A. tortillis* subsp. *heteracantha* (umbrella thorn). Terrain underlain by dolerite is further demarcated by the aloe *Aloe greatheadii* var. *davyana* as mentioned by Acocks (1988) (see also Van Wyk & Smith, 1996 for an update of aloe classification). Since the dolerite outcrop is limited in extent, weathered argillaceous rocks of the Irrigasie Formation (Karoo Supergroup) are found on the eastern and northern boundaries of the farm, contributing to a silt and sand soil texture. Characteristically these soils do not host thorn-bearing botanic species, but, rather, broad-leafed tree species such as *Grewia flava* (velvet raisin), *Lannea discolor* (live-long), *Peltophorum africanum* (weeping wattle), *Sclerocarya birrea* subsp. *caffra* (marula) and *Tarchonanthus camphoratus* (wild camphor bush), representing Kalahari Thornveld and Mixed Bushveld vegetation. The species *Boscia albitrunca* was not obvious locally.

During the geophysical groundwater exploration the existence of the dolerite sill covering argillaceous rock of the Irrigasie Formation was taken into account. The differences in magnetic and electrical conductivity responses render the magnetic and electromagnetic methods outstanding for use in this geological setting. The use of Schlumberger soundings is extremely difficult in this terrain owing to thorn bushes (leakage) and

possible electrode effects as a result of ground disturbance caused by mining activities. The argillaceous rock was not regarded as an aquifer but rather as an aquitard because of the low permeability of silt and the absence of intrusive bodies or structural deformation in this rock as denoted by the Pretoria (1978) geological map. The aerial photograph did not indicate any structures caused by the impact of mining on the surface vegetation (see annexure). Geophysical profiling on the argillaceous rock and across the dolerite sill did not reveal any particular geophysical anomalies of interest but indicated a somewhat homogenous layered earth as $HD \approx VD$, with no magnetic intensity anomalies. The profiles were run east-west in order to cross the different rock types as mentioned. Dolerite, in this area, could contain several aquifers, notably (i) a deep weathered basin on the top of the sill, (ii) weathered contact zones on the edges of the sill, (iii) deeper dolerite/argillaceous contact zones and (iv) jointing in the dolerite rock. Case (ii) was considered to represent a feasible groundwater exploration target. With the aid of geobotanic indicators (*Acacia karroo* (sweet thorn) and *Rhus lancea* (karee)), the position at station 110 m (Figure 4.81) was selected as the drilling target, represented by a north-western contact zone between the sill and Irrigasie Formation. The geophysical signatures in Figure 4.81 illustrate a transgression of electrical conductivity, from a dolerite sill, stations 0-110 m, $VD \gg HD$ to $HD \gg VD$ (argillaceous rock) with a significant decline in magnetic intensity (50 nT). The spot at station 110 m was covered by the geobotanic indicators *Acacia karroo* and *Rhus lancea*. Both species occur on this portion of the farm at a low frequency, implying less than one species per hectare. The borehole was drilled till 60 m, because this is the maximum exploration depth of the EM-34-3.

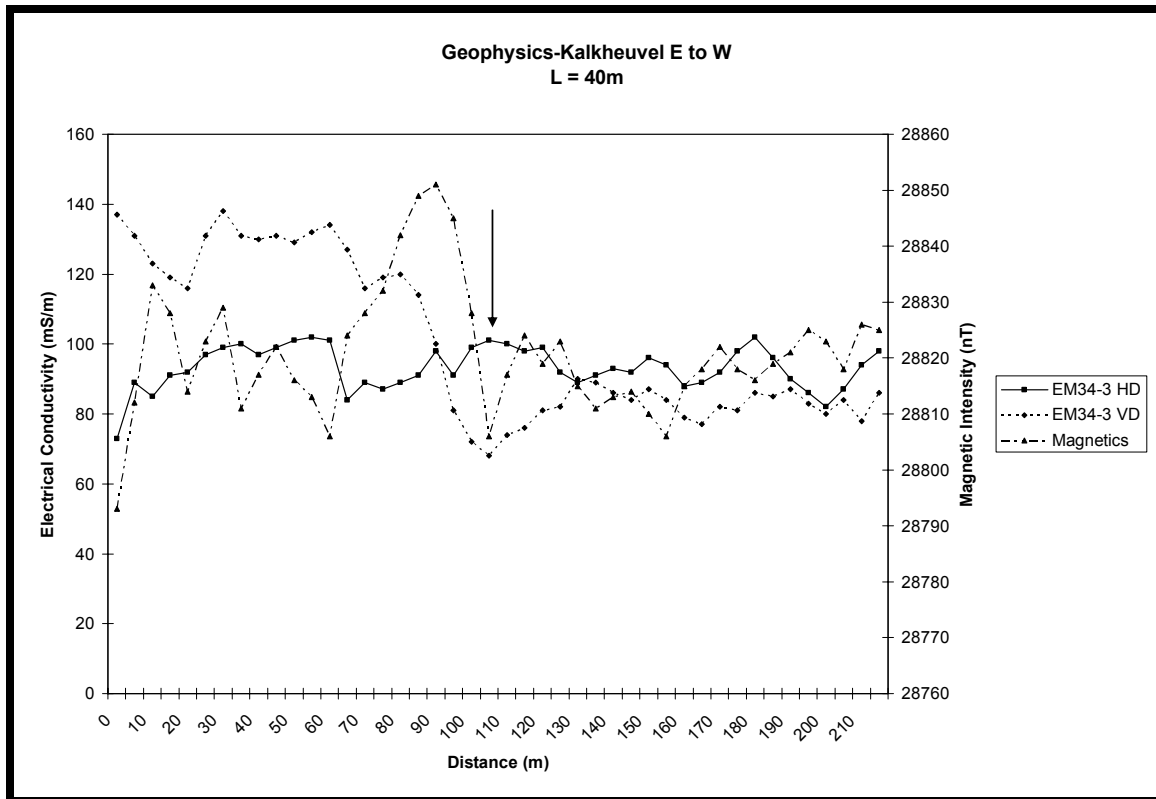


Figure 4.81. Geophysical profile on the farm Kalkheuvel 73JR.

Water was struck at a depth of 24 m and a yield of 5 500 l/h was measured. The borehole log indicated that the first 19 m were drilled in siltstone: after this weathered dolerite was encountered in which the confined aquifer is situated. From a depth of 27 m, unweathered dolerite is found. Soil samples were taken at depths of 0.5 and 1.2 m at station 110 m (geobotanic indicators) and station 90 m (less weathered dolerite), for which the chemical analysis indicates a large amount of free, available lime present in the soil. The geobotanic community (dolerite/argillaceous rock contact) records overall higher levels of pH, Ca, Mg, Na with an increase of CEC-values in depth. The less weathered dolerite soil indicates higher levels of heavy metals (Fe, Mn and Zn), owing to the weathering of the dolerite compared to the weathered argillaceous rock mixed with some weathered dolerite at the geobotanic community, since sedimentary rocks are poorer in heavy metals than igneous rock such as dolerite (see Chapter 2). The land type map (annexure) does not discriminate against the two lithologies, namely dolerite and siltstone, since both lithologies are part of the Hutton soil series.

A potential geobotanic pitfall on this farm is represented by the camel thorn (*Acacia erioloba*) since this tree species occurs locally and its locality is quite unique compared to the botanic composition of the surrounding veld types. However, the camel thorn is a characteristic tree species of the Kalahari Thornveld veld type, as listed by Acocks (1988). This veld type occupies a very limited spatial extent in this area and is confined to the dolerite outcrops and immediate vicinity of the banks of the Pienaars River.

***Acacia karroo* and *Rhus lancea* are the geobotanic indicators in this case study. These species demarcate the weathered edge of the dolerite sill in contact with the sedimentary rocks. The weathered edge of this sill defines a confined aquifer in depth. Higher levels of nutrients and CEC are noticed on the soil profile of the geobotanic community.**

49. Langkuil 13JR

Situated about 10 km northwest of Radium on the Springbok Flats, the farm Langkuil 13JR is entirely underlain by basalt of the Letaba Formation, Karoo Supergroup. The turf soil observed in the area possesses a distinct red or black colour (Arcadia soil series: see land type in the annexure). A non-perennial stream, the Plat River, runs through the farm. The landscape is a plain, where the only land marks are occasional large trees such as *Acacia erioloba* (camel thorn), *Combretum erythrophyllum* (river bushwillow) and *Olea europaea* subsp. *africana* (wild olive). The *Combretum* species frequently occupies the banks of the Plat River and the latter is a stand-alone robust tree in the plains of the veld between the ordinary vegetation of the Springbok Flats Turf Thornveld veld type. The occurrence of *Combretum erythrophyllum* in the veld, not close to any existing streams or channel beds, may indicate the location of palaeo-channels above weathered basalt. This species was selected as a geobotanic indicator for this farm. Although the *Olea europaea* subsp. *africana* and some *Acacia erioloba* species can be regarded as geobotanic indicators, based on their robust growth and low frequency of occurrence, the landowner did not display any interest in these sites for drilling purposes.

The definition of palaeo-channels was obtained by utilising Schlumberger depth soundings, which were laid out north-south in order to be parallel to the current stream and possible palaeo-channels. This was done in order to minimise possible electrode effects by conducting the soundings over the old channels instead of crossing them. Profiling along the geobotanic indicator was also performed in order to establish the existence of other possible structures that could give rise to an accumulation of groundwater in the sub-surface, as indicated by previous case studies. The aerial photograph (annexure) indicates many linear features with an east-west strike. Therefore, the profiles were orientated north-south in order to intersect these. For calibration purposes, a dry borehole in the immediate vicinity was also studied for its apparent resistivity characteristics. The dry borehole was not placed in close proximity to any *Combretum erythrophyllum* species. The Schlumberger depth soundings are presented in Figures 4.82 (dry borehole) and 4.83 (successful borehole).

The interpretation of the Schlumberger sounding models indicates that two types of sounding curves are obtained: HK in the case of the dry borehole, implying low resistive bedrock with a resistive, confining layer between conductive layers. The successful borehole sounding is defined by a KH-type sounding curve, which indicates an increase in resistivity with depth. However, the resistivity values for the modelled layers in Figure 4.83 (successful borehole) are lower for the conductive layers and higher for the resistive layers compared to the model in Figure 4.82, and hence a sharper benchmark exists between the conductive and resistive layers in the model presented in Figure 4.83. The dry borehole's geo-electric definition of the sub-surface, in accordance with its borehole log, indicates shallow weathering of basalt close to the surface (about 5 m deep), whereafter a thick resistive, confining layer of basalt follows (27 m thick). Although the sandstone bedrock records a lower resistivity (174 $\Omega\cdot\text{m.}$), it is probably too deep and too low in electrical conductivity to act as an aquifer if compared to other favourable results of this farm (water strike in the upper 25 m). The difference in the geo-electrical properties of the sub-surface is clearly indicated by the model of Figure 4.83 and borehole log, where this borehole yielded 8 000 l/h. Underneath a thin resistive and confining layer of pebbles, gravel and sand at a depth of 1.6 to 7.8 m, a conductive zone of more gravel and sand is present to a depth of 22.4 m, whereafter unweathered basalt continues. Apparently, according to local information obtained from farmers, diviners and drillers, in this basalt environment, groundwater is present at a shallow depth and must

be struck not deeper than about 25 m, since after this depth, the chance of striking groundwater diminishes to basically zero percent. This rule, if applied to Figures 4.82 & 4.83, indicates clearly why the latter is successful and the former not. The species *Combretum erythrophyllum* indicated, with some accuracy, the presence of palaeo-channels at the successful borehole. Without the aid of this tree species, mapping the presence of such palaeo-channels would be time- and cost-consuming.

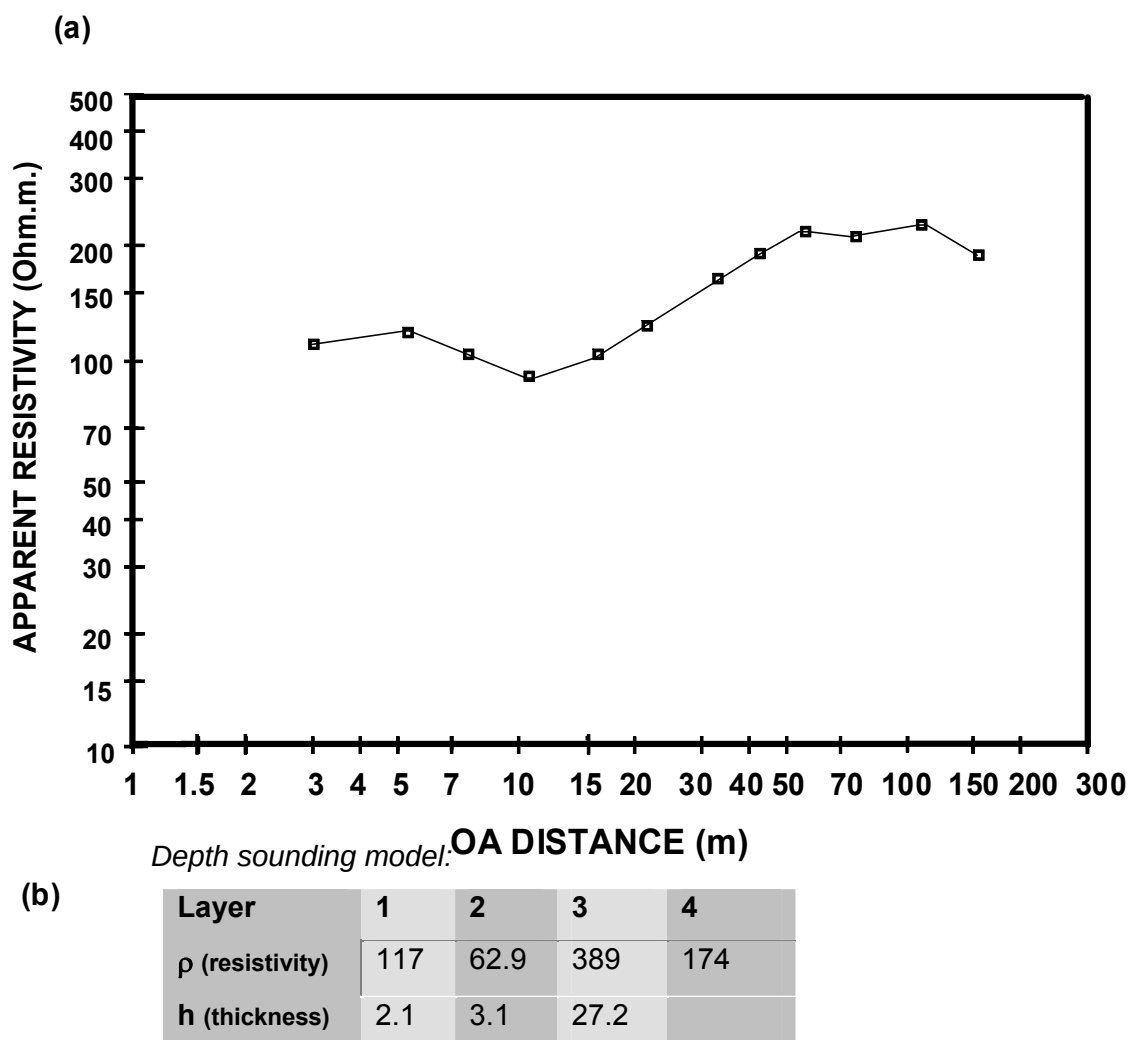


Figure 4.82. Schlumberger sounding along the dry borehole on the farm Langkuil 13JR.

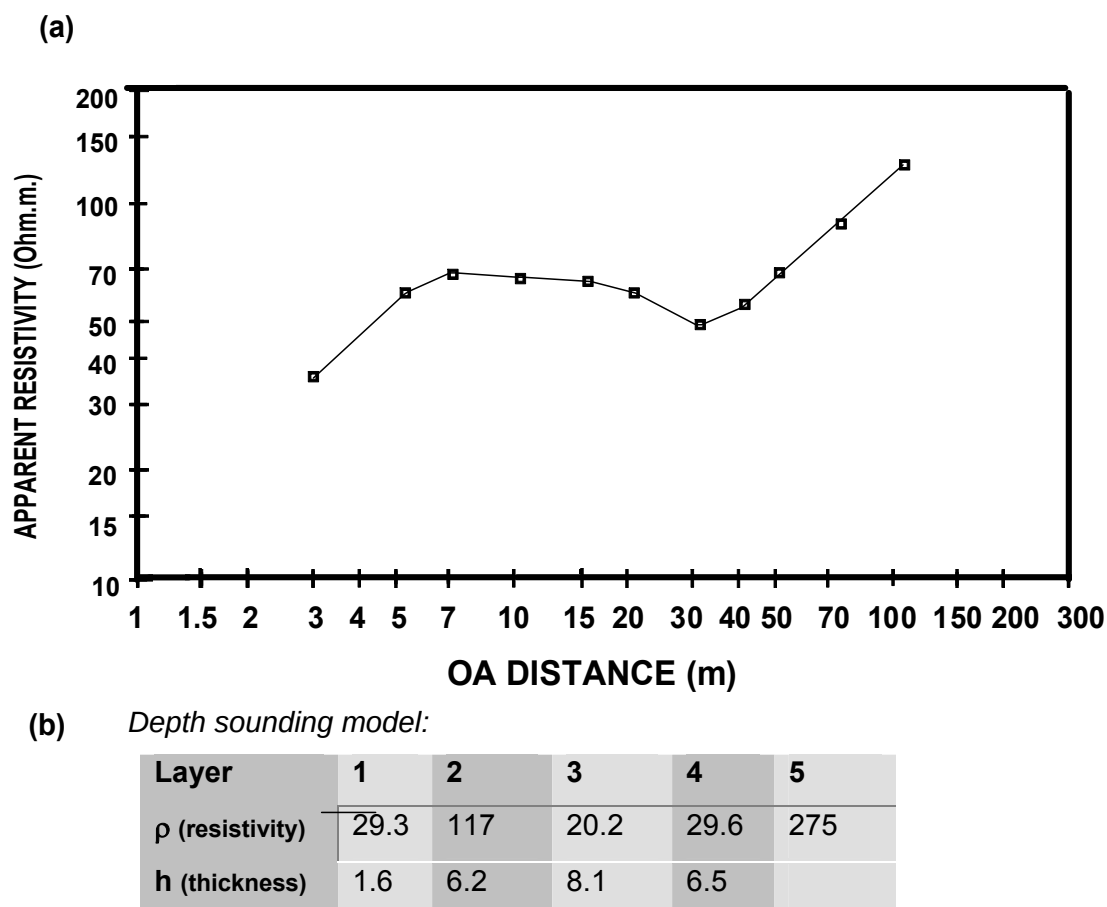


Figure 4.83. Schlumberger sounding along the successful borehole on the farm Langkuil 13JR.

The geophysical profile, run along the expected palaeo-channel, is indicated in Figure 4.84. The arrow at 120 m indicates the position of the drilled borehole/sounding position and it seems that to the south of this borehole an increase in magnetic intensity is observed (station 90 m). This increase can be attributed to unweathered, competent

basalt that acts as a barrier, which may have served as a palaeo-bank for the palaeo-river. The behaviour of the electromagnetic dipoles indicates a conductive environment (also see the low resistivity values for the sub-surface as depicted in the Schlumberger soundings), where the different dipole behaviour indicates possible drilling positions owing to $HD \gg VD$, as at station 120 m. In cases where $VD > HD$, this can be the effect of unweathered basalt close to the surface. According to this interpretation, the only possible drilling spots along the profile would be at stations 75 and 120 m.

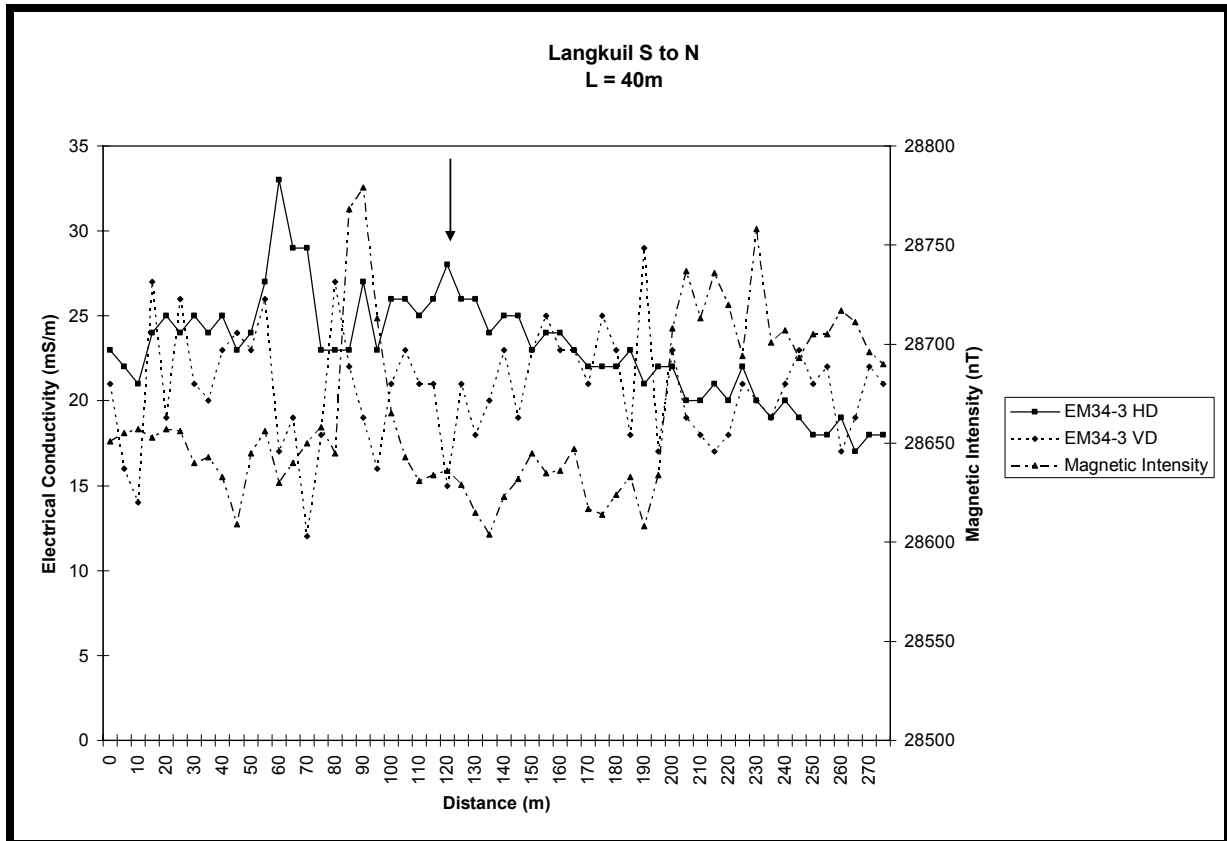


Figure 4.84. Geophysical profile along the successful borehole on the farm Langkuil 13JR.

An analysis of the results of the soil sampling at station 120 m and station 90 m (barrier) indicates the presence of large quantities of free-lime in the palaeo-channel and weathered basalt soil compared to the soil sample taken at the barrier. The large amount of free lime in this environment can be ascribed to a change in the N-value owing to the dryer conditions that favour the formation of calcrete formations in contrast to the formation of ferricrete layers. In addition to this, basalt as a mafic rock contains higher concentrations of CaO compared to other rocks and therefore weathered basalt acts as

a source of free lime (see Table 2.2). The palaeo-channel/geobotanic community possesses even higher levels of soil conductivity, other cations (Mg, K, Na), Mn and CEC. The soil samples, similarly to those mentioned in the memoirs of the Land Type Survey Staff (1987), indicate high levels of cations present in the soil when compared to the chemical analysis of other soils, published in the said memoirs and referred to in the present study. Although the magnitude of soil samples included in the current study does not correspond to the same extent as those published in the said memoirs, nonetheless the high levels of cations present are significant compared to the other samples analysed for the present study. The organic carbon and CEC-values of the samples referred to in the memoirs are excessive compared to the values of the samples taken from various other farms. Once again, this fact emphasises that soil chemical and physical properties vary and change over a period of time and space.

***Combretum erythrophyllum* is the geobotanic indicator in this case study since it indicates the presence of palaeo-channels in the basalt that host an aquifer. The soil in which it grows is furthermore rich in nutrients and CEC when compared to the other sampled non-geobotanic sites.**

50. Vlakplaats 483KR

The farm Vlakplaats 483KR is situated on the western edge of the Letaba Formation in the Springbok Flats, between Radium and Mabula. On the surrounding farms, and towards the south (Vogelstruispan), sandstone outcrops of the Clarens Formation are evident in a few localities. Areas underlain by sandstone display a sandy soil texture, whereas the areas underlain by basalt exhibit a characteristic clay and turf texture. Hence, the owners of farms situated on basalt practise agricultural irrigation in contrast to farms on the sandstone that are predominantly developed as game farms and extensive beef cattle ranches. The purpose of groundwater exploration on this farm was to locate another aquifer in order to supply a new irrigation development on this farm. As indicated in the previous case study (Langkuil 13JR), the electromagnetic technique is a versatile tool with which to explore weathered basins and/or palaeo-channels in the basalt. The EM-34-3 was utilised on this farm (Figure 4.85) and the signature of the horizontal dipole is more or less constant, which is in sharp contrast to the signature displayed by the vertical dipole, indicating abrupt variations. The electrical conductivity of

the sub-surface is exceptionally high, but a conductive sub-surface restricts deep exploration (60 m). If local advice is taken into account (case study 49), groundwater should be struck not deeper than 25 m from the surface, while the EM-34-3 is able to display these sub-surface conditions with a coil separation of 40 m in this conductive environment. The arrow at station 130 m denotes the position of the drilled borehole (yield 15 400 l/h and water strike 22 m below the surface in weathered/fractured basalt in a confined aquifer). The aim when laying the direction of the profile was to cross the east-west nonconformity between the sandstone and basalt, as indicated on the geological map (annexure). Of interest at station 130 m, is that HD>>VD with a local decrease in magnetic intensity whereas the magnetic amplitude over the entire profile is a mere 30 nT. At station 130 m HD>>VD amplitude is excessive compared to the other stations plotted on the profile (35 mS/m difference between HD and VD). The amplitude is attributed to a weathered basin in the basalt which is further indicated by the small decrease in the magnetic intensity that denies the existence of any intrusive bodies in the basalt. Geobotanic indicators at station 130 m include a tall and robust (unique for this immediate locality) *Acacia karroo* (sweet thorn), *Ximenia caffra* (sourplum) and *Zanthoxylum capense* (small knobwood). The latter two species mentioned have an extremely low frequency of occurrence on the farm, about 1 count per three hectares.

Because a weathered basin in basalt is anticipated, according to the interpretation of the geophysical profile, it was appropriate to conduct a Schlumberger depth sounding (Figure 4.86) at station 130 m in order to establish water-bearing properties to a depth of 25 m. The layout of the electrodes was north-south because the basalt does not possess a strike direction. The sounding curve represents a three-layered earth with a conductive intermediate layer: hence the curve is of a H-type. The conductive zone stretches to a depth of 19.5 m (weathered basalt), under which resistive, unweathered basalt rests. According to the borehole log, the following sequence was drilled:

0 – 2 m: loam, turf

2 – 20 m: very weathered basalt

20 – 24 m: weathered and fractured basalt (water strike at 22 m deep)

24 – 60 m: unweathered basalt.

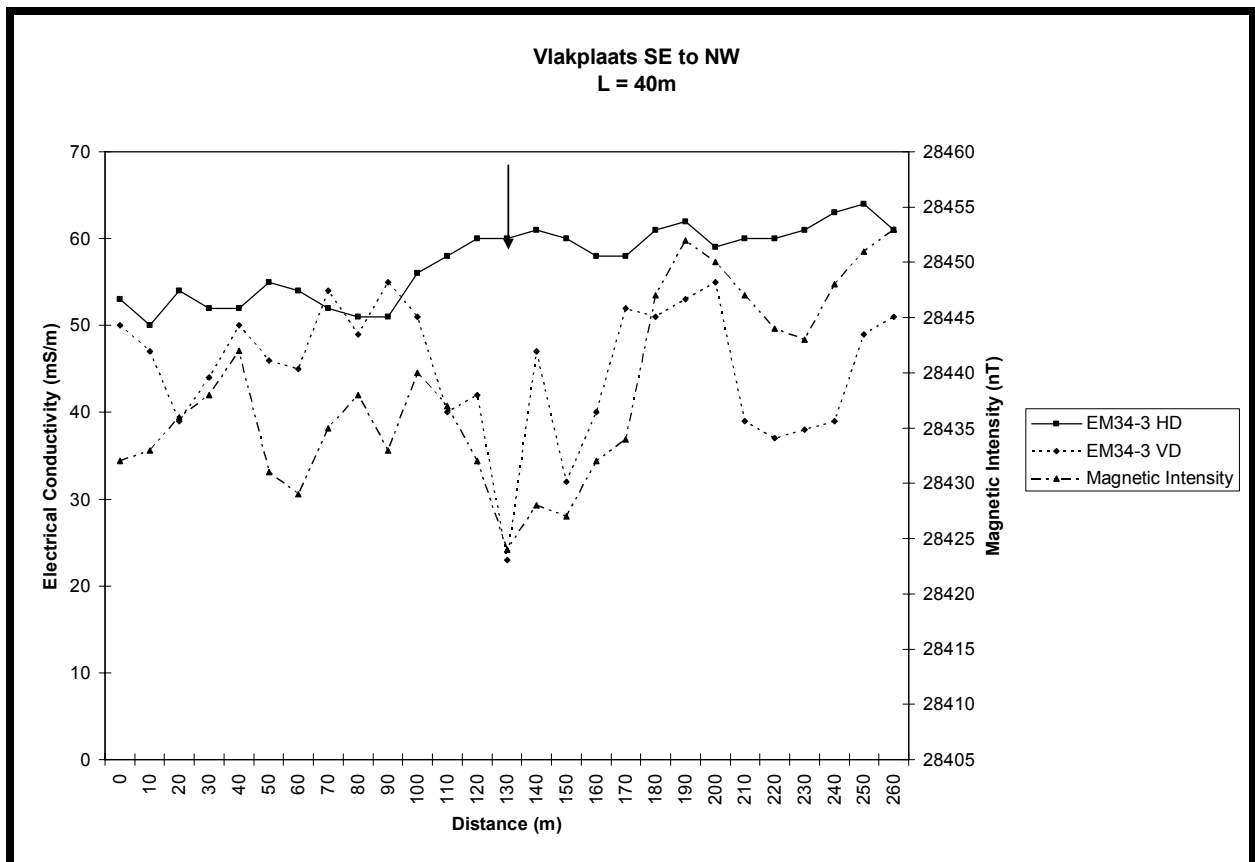


Figure 4.85. Geophysical profile on the farm Vlakplaats 483KR.

Soil samples taken at station 130 m (the geobotanic community) and station 170 m (where the increase in the vertical dipole component is probably due to less weathering in the sub-surface) reveal that the geobotanic community, overall, has higher levels of pH and CEC-values only, in the analysed soil sample results. The increased levels of CEC once again offer an indication of the greater amount of available water and humus in the sub-surface, which is beneficial to vegetation growth and establishment. Once again in this environment, freely available calcium is present in the soil (lime nodules). Both soil samples are representative of the Hutton soil series (land type map, annexure).

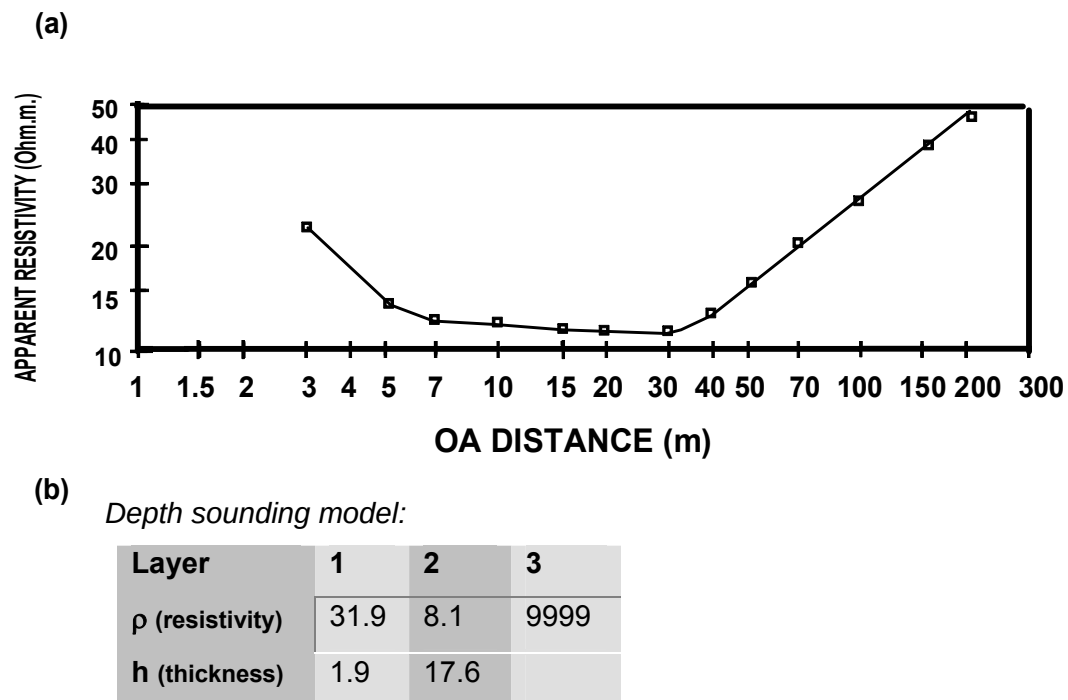


Figure 4.86. Schlumberger depth sounding at station 130 m, Vlakplaats 483KR.

Acacia karroo, *Ximenia caffra* and *Zanthoxylum capense* are the geobotanic indicators in this case study, where the soil they grow upon is enriched in CEC. These species denote weathered/fractured areas that serve as confined aquifers in the basalt.

4.14.1 Remarks

The geophysical properties of the mafic and ultramafic rocks (basalt and dolerite) of the Karoo Supergroup in the Springbok Flats area, present a sharp contrast to those evident in the sedimentary rocks of the Karoo Supergroup. These contrasts regarding the mafic and ultramafic rocks that yield significant amounts of water, are visible in abrupt magnetic intensity readings, higher conductivity and lower resistivity readings (and sounding curve shapes) and shallow weathering. The EM-34-3 is an extraordinary geophysical exploration tool in this basalt and dolerite environment. Schlumberger depth soundings are crucial since their interpretation indicates significant weathering in the sub-surface, essential to drill a successful borehole in this geological environment with weathered basalt resistivities ranging between 10-200 $\Omega\cdot\text{m}$. According to the results in Table A1.27, it is clear that the geohydrological characteristics of all the case studies are overwhelming compared to those published in the extensive work of Frommurze (1937). Geophysical and geohydrological success can be attributed to the signposts of the veld, the various geobotanical indicators, particularly those that repeatedly occur in other case studies situated on other lithologies, veld types, climatic regions and veld types. The geobotanical indicators for the Letaba Formation and dolerite presented in the three case studies are listed in Table 4.13.

The chemical properties of the soil listed in Table 4.13 indicate the range of geochemical properties for both geobotanic communities (A) and the sampled positions with no obvious or significant geobotanic communities (B). The values in both columns correspond well with one another and it is obvious that, in general, the geobotanic communities do not affect geochemical soil qualities beyond the area surrounding them. However, throughout the case studies listed, it was indicated that the CEC-values for those presented are on average higher compared to the soil samples of the surrounding localities that were sampled. In a number of instances, available cations were present at increased levels, in particular, the available calcium or free lime partly caused by the chemical composition of the weathered rocks and the increased N-value are beneficial for lime formation. The dolerite locality (Kalkheuvel 73JR) contains excessive levels of available phosphorous, potassium, zinc and organic carbon, but is poor in free iron compared to the localities with a basalt derived soil (compare results in Table A1.27a&b).

Table 4.13. Comparisons between the soil characteristics of the geobotanical indicators and those of their surroundings.

Parameter	Geobotanical community (A)	Surroundings (B)
pH	6.79-8.13	6.70-7.52
P (mg/kg)	0.84-8.79	0.8814.87
Ca (mg/kg)	2786-5758	1530-4493
Mg (mg/kg)	444-2061	321-1511
K (mg/kg)	100-486	104-470
Na (mg/kg)	27-104	9-61
Fe (mg/kg)	4.81-86.99	29.55-136.35
Mn (mg/kg)	77.46-531.08	226.23-300.13
Zn (mg/kg)	0.31-1.16	0.33-2.02
Al (cmol _c /kg)	0	0
Resistance (Ω)	1600-2800	440-2400
%C	0.01-1.02	0.03-1.38
Total N%	0.005-0.097	0.001-0.127
S (mg/kg)	3.88-7.88	3.84-16.99
CEC (cmol _c /kg)	9.27-46.47	7.52-31.40
Geobotanical indicator species under column A	<i>Acacia karroo</i> (sweet thorn) <i>Combretum erythrophyllum</i> (river bushwillow) <i>Rhus lancea</i> (karee) <i>Ximenia caffra</i> (sourplum) <i>Zanthoxylum capense</i> (small knobwood)	
Geology	Dolerite and basalt (Letaba Formation) contact and weathering zones plus palaeo-channels	Unweathered basalt, dolerite or sedimentary rock at contact zones
Aquifer yield (l/h)	5 500 – 15 400	Not applicable

CHAPTER 5 DISCUSSION AND GUIDELINES

The objective and aim of the study is to investigate and prove that certain geophysical-geobotanical relationships occur in the north-eastern parts of South Africa. The tools employed to establish whether such proof exists, comprised geophysical data, geological features, soil sample chemical analysis of geobotanical communities next to a borehole and soil samples from locations removed from any significant geobotanical indicators, and geohydrological information. Therefore, it is important to list all the various geobotanical indicators identified across various geological formations as well as the geochemical properties of the soil in which these geobotanical indicators are rooted. Of interest is the brief comparison of the yield of boreholes drilled along geobotanical indicators and the average yield of the geological strata, in order to establish the socio-economic benefit of geobotanical indicators.

5.1 GEOBOTANICAL INDICATORS

Certain geobotanical indicators occur in various geological formations and climatic conditions, but more or less indicate the same sub-surface aquifer conditions owing to similar conditions of weathering, rooting depth and erosion (soil nutrient status). The identified geobotanical indicators referred to in the present study, their association with certain geological formations, climatic factors and aquifer conditions are listed in Table 5.1.

From the results depicted in Table 5.1, it is obvious that the species *Acacia karroo* enjoys the widest distribution and listings. This corresponds favourably with the natural distribution list of the mentioned species as indicated by the work of Van Wyk & Van Wyk (1997). Basically, all the indicated geobotanical indicators are associated with mafic or ultramafic rock intrusions (basalt, diabase and dolerite) and stress the point that sedimentary rocks are inherently poor shrub or tree hosts. A few exceptions are linked to fractures, weathered basins, palaeo-channels and fault zones. Notably, the species *Combretum erythrophyllum* is preferably situated on weathered basins that could, at times, be directly coupled with palaeo-channels. Weathered basins are also demarcated by the species *Celtis Africana*, however, more case studies are required in order to establish its preferred growth environment. The role of climate and particularly frost must

be treated with care because certain areas are prone to frost during the winter season, but shelter provided by rocks, gorges, hardy vegetation, structures and depressions limit the damaging effects of frost on natural, indigenous vegetation and therefore certain more common species in the savanna biome can also occur in the grassland biome. The 15 identified geobotanical indicators represent only less than 2% of all identified, representative shrub, tree and some grass species that occur in South Africa. The value of geobotanical indicators is represented in the last column of Table 5.1 since most of the obtained aquifer yields in the presence of a geobotanical indicator are well above the average of those of the particular geological formation. In cases where both yields are the same or even less than the indicated average, this is indicative of a difficult groundwater environment. A few of the species listed in Table 5.1 warrant further study and research regarding their value as geobotanical indicators, merely based on the fact that only a few locations and case studies are linked to these botanical species or no boreholes are associated with them.

5.2 SOIL NUTRIENTS

All the geobotanical communities of the case studies situated next to a borehole indicated in this study, were sampled for the purpose of soil geochemical analysis. Soil samples were taken at depths of 0.5 m and 1.2 m throughout the study to ensure uniformity. Soil samples were all taken at the same representative depths at locations away from these geobotanical communities at spots where less vegetation and/or geophysical activity (anomalies on the geophysical profile) occurred, yet within a distance of about 35 m, if possible, from the other sampled locality. The soil nutrient status of the geobotanical community versus that of the other locality will be portrayed in this section. The soil nutrient status could be a reason why a geobotanical species grows at a particular spot. Therefore, the geochemical analysis of soil could indicate differences in a particular soil series as indicated on the land type maps. The weathering of various lithologies can cause these differences. The status of the soil nutrients would thus be able to indicate drilling positions in the absence of geobotanical indicators, if these do not exist because of natural factors or human impacts. It is important to isolate soil quality parameters that could be used as drilling position indicators in association with, or in the absence of geobotanical indicators. Such soil quality parameters will be identified in this chapter. Firstly, a brief overview of the importance of the various

geochemical parameters to vegetation will be given. Some of these parameters are closely associated with sub-surface moisture content that could be a result of *in situ* aquifer conditions.

Table 5.1. Summary of geobotanical indicators as indicated in this study.

Botanical Specie	Occurrence	Geology	Rainfall (mm/year)	Evaporation (mm/year)	Frost	Elevation (masl)	Aquifer Type	Yield (ℓ/h): A-geobotanical community; B-average
<i>Acacia karroo</i> (sweet thorn)	Bankfontein 264JS	Wilgerivier Formation	600-800	1750-2250	Yes	1200-1600	Diabase contact	A-3 800; B-3 000
	Bankplaas 239JS	Wilgerivier Formation	600-800	1750-2250	Yes	1200-1600	Diabase contact	A-3 250; B-3 000
	Blokdriif 512KQ	Leeuwoort Formation	500-800	2000-2250	No	800-1600	Diabase/fault structure	A-60 000; B-2 500
	Buffelskloof 342JS	Wilgerivier Formation	600-800	1750-2250	Yes	1200-1600	Diabase contact	A-3 500; B-3 000
	Droogekloof 471KR	Nebo Granite	600-800	2000-2250	No	1200-1600	Diabase/fault structure	A-17 000; B-1 800
	Elandsfontein 412JR	Malmani Subgroup	600-800	2000-2250	Yes	1500-1700	Diabase and cavities	A-45 000; B-25 000
	Elandsfontein 493JR	Wilgerivier Formation	600-800	1750-2250	Yes	1200-1600	Weathered basin	A-11 000; B-3 000
	Goedehoop 244JS	Wilgerivier Formation	600-800	1750-2250	Yes	1200-1700	Diabase contact	A-2 700; B-3 000
	Hartbeesfontein 394KR	Schilpadkop Formation	400-800	2250-2500	Yes	800-1600	Lineament contact	A-15 000; B-2 600
	Holgatfontein 326IR	Vryheid Formation	600-800	2000-2250	Yes	1200-2000	Dolerite contact	A-7 000; B-2 400
	Kalkheuvel 73JR	Dolerite/Irrigasie Formation	400-600	2000-2250	Yes	800-1200	Dolerite contact	A-5 500; B-5 500
	Kameeldrift 313JR	Silverton Formation	600-800	2000-2250	Yes	1500-1700	Diabase contact	A-12 000; B-3 375
	Kareefontein 432KR	Nebo Granite	600-800	2000-2250	No	1200-1600	Diabase contact	A-5 500; B-1 800
	Klipleiland 524JR	Diabase	600-800	2000-2250	Yes	1200-1600	Weathered basin	A-9 000; B-4 600
	Kwaggasfontein 460JS	Selonsrivier Formation	600-800	1750-2000	Yes	1600-2000	Diabase contact	A-4 700; B-4 700
	Leeuwfontein 492JR	Wilgerivier Formation	600-800	1750-2250	Yes	1200-1600	Diabase contact	A-5 000; B-3 000
	Leeuwkraal 517IR	Vryheid Formation	600-800	2000-2250	Yes	1200-2000	Basalt/dolerite contact	A-6 800; B-2 400
	Onspoed 500JR	Wilgerivier Formation	600-800	1750-2250	Yes	1200-1600	Diabase contact	A-22 500; B-3 000
	Onverwacht 532JR	Wilgerivier Formation	600-800	1750-2250	Yes	1200-1600	Diabase contact	A-3 000; B-3 000
	Rhenosterkop 452JR	Loskop Formation	600-800	2000-2250	Yes	1400-1700	Diabase and fractures	A-2 050; B-1 770
	Rietfontein 314JS	Loskop Formation	600-800	2000-2250	Yes	1200-1600	Diabase contact	A-7 500; B-5 000
	Schoongezicht 225IR	Vryheid Formation	600-800	2000-2250	Yes	1200-2000	Diabase contact	A-9 000; B-2 400
	Skeerpoort 477JQ	Silverton Formation	600-800	2000-2250	Yes	1500-1700	Diabase contact	A-2 500; B-3 375
	Vaalfontein 491KQ	Leeuwoort Formation	500-800	2000-2250	No	800-1600	Diabase contact	A-1 500; B-500
	Vlakplaats 483KR	Letaba Formation	400-600	2000-2250	Yes	800-1200	Fractures	A-15 400; B-5 500

<i>Acacia karroo</i> (Continued)	Zandfontein 476KQ	Nebo Granite	600-800	2000-2250	No	1200-1600	Diabase contact	A-4 250; B-1 800
	Zusterstroom 447JR	Nebo Granite	600-800	2000-2250	Yes	1200-1600	Diabase contact	A-18 000; B-3 750
<i>Adansonia digitata</i> (baobab)	Beck 568MS	Beit Bridge Complex	300-400	2250-2500	No	400-800	Diabase contact	A-650; B-360
	Command 588MS	Beit Bridge Complex	300-400	2250-2500	No	400-800	Diabase contact	A-500; B-360
	Wolvedans 68MR	Beit Bridge Complex	400-600	2250-2500	No	800-1200	Basic rock contact	A-770; B-360
	Zoetfontein 154MQ	Mount Dowe Group	400-600	2250-2500	No	800-1200	Diabase contact	A-650; B-360
<i>Burkea africana</i> (wild syringa) Normally associated with <i>Dichapetalum</i> <i>cymosum</i> (gifblaar)	Buffelskloof 342JS	Wilgerivier Formation	600-800	1750-2250	Yes	1200-1600	Diabase contact	A-3 500; B-3 000
	Onspoed 500JR	Wilgerivier Formation	600-800	1750-2250	Yes	1200-1600	Diabase contact	A-22 500; B-3 000
<i>Celtis Africana</i> (white stinkwood)- deeper weathering	Elandsfontein 412JR	Malmani Subgroup	600-800	2000-2250	Yes	1500-1700	Diabase and cavities	A-45 000; B-25 000
	Leeuwkraal 517IR	Vryheid Formation	600-800	2000-2250	Yes	1200-2000	Basalt/dolerite contact	A-6 800; B-2 400
<i>Clerodendrum glabrum</i> (tinderwood)	Brits Town	Rustenburg Layered Suite	600-800	2000-2250	No	800-1200	Weathered basins	A-18 000; B-7 520
	Enkeldoornog 219JR	Selonsrivier Formation	600-800	2000-2250	Yes	1200-1600	Diabase contact	A-7 500; B-1 770
	Mooikloof-Pretoria	Hekpoort Formation	600-800	2000-2250	Yes	1500-1700	Weathering and fault	A-20 000; B-6 750
	Skeerpoort 477JQ	Silverton Formation	600-800	2000-2250	Yes	1500-1700	Diabase contact	A-2 500; B-3 375
<i>Combretum</i> <i>erythrophyllum</i> (river bush-willow)	Badfontein 114JT	Silverton Formation	600-800	1750-2000	Yes	1200-1600	Weathering and diabase	A-7 200; B-4 800
	Elandsfontein 493JR	Wilgerivier Formation	600-800	1750-2250	Yes	1200-1600	Weathered basin	A-11 000; B-3 000
	Klipfontein 258JS	Nebo Granite	600-800	2000-2250	Yes	1200-1600	Diabase and weathering	A-55 000; B-3 750
	Klipspruit 86JT	Silverton Formation	600-800	1750-2000	Yes	1200-1600	Weathering and diabase	A-8 400; B-4 800
	Langkuil 13JR	Letaba Formation	400-600	2000-2250	Yes	800-1200	Weathered basin	A-8 000; B-5 500
	Rietfontein 88JT	Silverton Formation	600-800	1750-2000	Yes	1200-1600	Weathering and diabase	A-8 000; B-4 800
	Vlakfontein 453JR	Wilgerivier Formation	600-800	1750-2250	Yes	1200-1600	Lineament contact	A-18 000; B-3 000
	Zusterstroom 447JR	Nebo Granite	600-800	2000-2250	Yes	1200-1600	Diabase contact	A-18 000; B-3 750
<i>Combretum imberbe</i> (leadwood)	Newcastle 202LQ	Lisbon, Clarens Formations	400-600	2250-2500	No	800-1200	Fault zone	A-4 500; B-2 300
	Pennsylvania 336LR	Mogalakwena Formation	400-800	2250-2500	No	800-1600	Lineament contact	A-8 000; B-4 000
	Wolvedans 68MR	Beit Bridge Complex	400-600	2250-2500	No	800-1200	Basic rock contact	A-770; B-360

<i>Combretum imberbe</i> (Continued)	Zoetfontein 154MQ	Mount Dowe Group	400-600	2250-2500	No	800-1200	Diabase contact	A-650; B-360
<i>Euclea crispa</i> (blue guarri)	Bankfontein 264JS	Wilgerivier Formation	600-800	1750-2250	Yes	1200-1600	Diabase contact	A-3 800; B-3 000
	Bankplaas 239JS	Wilgerivier Formation	600-800	1750-2250	Yes	1200-1600	Diabase contact	A-3 250; B-3 000
	Buffelskloof 342JS	Wilgerivier Formation	600-800	1750-2250	Yes	1200-1600	Diabase contact	A-3 500; B-3 000
	Elandsfontein 412JR	Malmani Subgroup	600-800	2000-2250	Yes	1500-1700	Diabase and cavities	A-45 000; B-25 000
	Elandsfontein 493JR	Wilgerivier Formation	600-800	1750-2250	Yes	1200-1600	Weathered basin	A-11 000; B-3 000
	Goedehoop 244JS	Wilgerivier Formation	600-800	1750-2250	Yes	1200-1700	Diabase contact	A-2 700; B-3 000
	Klipleiland 524JR	Diabase	600-800	2000-2250	Yes	1200-1600	Weathered diabase	A-9 000; B-4 600
	Leeuwkraal 517IR	Vryheid Formation	600-800	2000-2250	Yes	1200-2000	Basalt/dolerite contact	A-6 800; B-2 400
	Mooikloof-Pretoria	Hekpoort Formation	600-800	2000-2250	Yes	1500-1700	Weathering and fault	A-20 000; B-6 750
	Onverwacht 532JR	Wilgerivier Formation	600-800	1750-2250	Yes	1200-1600	Diabase contact	A-3 000; B-3 000
	Rhenosterkop 452JR	Loskop Formation	600-800	2000-2250	Yes	1400-1700	Diabase and fractures	A-2 050; B-1 770
	Trigaardspoort 451JR	Wilgerivier Formation	600-800	1750-2250	Yes	1200-1600	Diabase contact	A-3 500; B-3 000
<i>Ficus ingens</i> (red-leafed fig) & <i>F. sur</i> (broom cluster fig)	Blokdrift 512KQ	Leeuwpoot Formation	500-800	2000-2250	No	800-1600	Diabase/fault structure	A-60 000; B-2 500
	Droogekloof 471KR	Nebo Granite	600-800	2000-2250	No	1200-1600	Diabase/fault structure	A-17 000; B-1 800
	Newcastle 202LQ	Lisbon, Clarens Formations	400-600	2250-2500	No	800-1200	Fault zone	A-4 500; B-2 300
	Rietfontein 88JT	Silverton Formation	600-800	1750-2000	Yes	1200-1600	Weathering and diabase	A-8 000; B-4 800
	Waterval 386KT	Magaliesberg Formation	600-800	1750-2000	Yes	1200-1600	Diabase contact	A-5 500; B-4 800
<i>Fingerhuthia sesleriiformis</i> (thimble grass)	Schoongezicht 225IR	Vryheid Formation	600-800	2000-2250	Yes	1200-2000	Diabase contact	A-9 000; B-2 400
<i>Rhus lancea</i> (karee)	Brits Town	Rustenburg Layered Suite	600-800	2000-2250	No	800-1200	Weathered basins	A-18 000; B-7 520
	Droogeloot 476KR	Clarens Formation	400-600	2250-2500	No	800-1200	Fractures	A-6 000; B-3 300
	Elandsfontein 412JR	Malmani Subgroup	600-800	2000-2250	Yes	1500-1700	Diabase and cavities	A-45 000; B-25 000
	Enkeldoornog 219JR	Selonsrivier Formation	600-800	2000-2250	Yes	1200-1600	Diabase contact	A-7 500; B-1 770
	Grootfontein 528KQ	Irrigasie Formation	400-600	2250-2500	No	800-1200	Fractures	A-5 000; B-3 300
	Hartbeesfontein 394KR	Schilpadkop Formation	400-800	2250-2500	Yes	800-1600	Lineament contact	A-15 000; B-2 600
	Kalkheuvel 73JR	Dolerite/Irrigasie Formation	400-600	2000-2250	Yes	800-1200	Dolerite contact	A-5 500; B-5 500
	Rietfontein 314JS	Loskop Formation	600-800	2000-2250	Yes	1200-1600	Diabase contact	A-7 500; B-5 000

<i>Rhus lancea</i> (Continued)	Skeerpoort 477JQ Vaalfontein 491KQ	Silverton Formation Leeuwpoot Formation	600-800 500-800	2000-2250 2000-2250	Yes No	1500-1700 800-1600	Diabase contact Diabase contact	A-2 500; B-3 375 A-1 500; B-500
<i>Strychnos pungens</i> (spine-leafed monkey orange)	Droogesloot 476KR Grootfontein 528KQ Hartbeesfontein 394KR Onverwacht 532JR	Clarens Formation Irrigasie Formation Schilpadkop Formation Wilgerivier Formation	400-600 400-600 400-800 600-800	2250-2500 2250-2500 2250-2500 1750-2250	No No Yes Yes	800-1200 800-1200 800-1600 1200-1600	Fractures Fractures Lineament contact Diabase contact	A-6 000; B-3 300 A-5 000; B-3 300 A-15 000; B-2 600 A-3 000; B-3 000
<i>Ximenia americana</i> & <i>X. caffra</i> (Blue sourplum & sourplum)	Hartbeesfontein 394KR Kameelfontein 297JR Kareefontein 432KR Rhenosterkop 452JR Vlakplaats 483KR Zandfontein 476KQ Zoetfontein 154MQ	Schilpadkop Formation Rayton Formation Nebo Granite Loskop Formation Letaba Formation Nebo Granite Mount Dowe Group	400-800 600-800 600-800 600-800 400-600 600-800 400-600	2250-2500 2000-2250 2000-2250 2000-2250 2000-2250 2000-2250 2250-2500	Yes Yes No Yes Yes No No	800-1600 1500-1700 1200-1600 1400-1700 800-1200 1200-1600 800-1200	Lineament contact Diabase contact Diabase contact Diabase and fractures Fractures Diabase contact Diabase contact	A-15 000; B-2 600 A-8 000; B-3 000 A-5 500; B-1 800 A-2 050; B-1 770 A-15 400; B-5 500 A-4 250; B-1 800 A-650; B-360
<i>Zanthoxylum capense</i> (small knobwood)	Blokdrift 512KQ Droogekloof 471KR Elandsfontein 493JR Kameeldrift 313JR Kareefontein 432KR Mooikloof-Pretoria Rietfontein 88JT Vlakplaats 483KR Zandfontein 476KQ	Leeuwpoot Formation Malmani Subgroup Wilgerivier Formation Silverton Formation Nebo Granite Hekpoort Formation Silverton Formation Letaba Formation Nebo Granite	500-800 500 -800 600-800 600-800 600-800 600-800 600-800 400-600 600-800	2000-2250 2000-2250 1750-2250 2000-2250 2000-2250 2000-2250 1750-2000 2000-2250 2000-2250	No No Yes Yes No Yes Yes Yes No	800-1600 800-1600 1200-1600 1500-1700 1200-1600 1500-1700 1200-1600 800-1200 1200-1600	Diabase/fault structure Diabase and cavities Weathered basin Diabase contact Diabase contact Weathering and fault Weathering and diabase Fractures Diabase contact	A-60 000; B-2 500 A-100 000; B-8 000 A-11 000; B-3 000 A-12 000; B-3 375 A-5 500; B-1 800 A-20 000; B-6 750 A-8 000; B-4 800 A-15 400; B-5 500 A-4 250; B-1 800
<i>Ziziphus mucronata</i> (buffalo-thorn)	Brits Town Kameelfontein 297JR Rhenosterkop 452JR	Rustenburg Layered Suite Rayton Formation Loskop Formation	600-800 600-800 600-800	2000-2250 2000-2250 2000-2250	No Yes Yes	800-1200 1500-1700 1400-1700	Weathered basins Diabase contact Diabase and fractures	A-18 000; B-7 520 A-8 000; B-3 000 A-2 050; B-1 770
Warrants more study:								
<i>Acacia erioloba</i>	Langkuil 13JR	Letaba Formation	400-600	2000-2250	Yes	800-1200	Weathered basin	A-8 000; B-5 500

(camel thorn)								
<i>Boscia foetida</i> subsp. <i>rehmanniana</i> (stink shepherd's tree)	Loskop Noord 12JS	Ecce Group	400-600	2000-2250	No	800-1200	Diabase contact	Unknown
<i>Commiphora mollis</i> (velvet corkwood)	Command 588MS Pennsylvania 336LR	Beit Bridge Complex Mogalakwena Formation	300-400 400-800	2250-2500 2250-2500	No No	400-800 800-1600	Diabase contact Lineament contact	A-500; B-360 A-8 000; B-4 000
<i>Gardenia volkensii</i> (savanna gardenia)	Pennsylvania 336LR	Mogalakwena Formation	400-800	2250-2500	No	800-1600	Lineament contact	A-8 000; B-4 000
<i>Lonchocarpus capassa</i> (apple-leaf)	Pennsylvania 336LR	Mogalakwena Formation	400-800	2250-2500	No	800-1600	Lineament contact	A-8 000; B-4 000
<i>Olea europaea</i> subsp. <i>africana</i> (wild olive)	Langkuil 13JR	Letaba Formation	400-600	2000-2250	Yes	800-1200	Weathered basin	A-8 000; B-5 500
<i>Pappea capensis</i> (jacket-plum)	Kameelfontein 297JR Wolvedans 68MR	Silverton Formation Beit Bridge Complex	600-800 400-600	2000-2250 2250-2500	Yes No	1500-1700 800-1200	Diabase contact Basic rock contact	A-8 000; B-3 000 A-770; B-360
<i>Spirostachys africana</i> (tamboti)	Blokdrift 512KQ Pennsylvania 336LR	Leeuwpoot Formation Mogalakwena Formation	500-800 400-800	2000-2250 2250-2500	No No	800-1600 800-1600	Diabase/fault structure Lineament contact	A-60 000; B-2 500 A-8 000; B-4 000
Note:								
<i>Aloe Ferox</i> , <i>A. greatheadii</i> var. <i>davyana</i> & <i>A. Marlothii</i> (bitter aloe, unnamed aloe & mountain aloe)	Farms with diabase and dolerite intrusions	Diabase/Dolerite Intrusions	400-1000	1750-2500	Yes & No	800-2000	Diabase/dolerite soil	Not applicable

The parameters of the geochemical soil analysis and their importance to vegetation nutrition, growth and development (Hawkin, 2005) are:

- pH: an indication of the alkalinity or acidity of the soil. The pH can affect the availability of nutrients in the soil. A decrease in the pH results in a release of positively charged ions (cations) from the cation exchange surfaces (organic matter and clay minerals). In the short term, acidification thus increases the concentration of K, Mg and Ca in soil solution, but no simple relationship exists between the soil solution concentrations of Ca, Mg and K and reasonable pH-values. The soil solution pH is dependent on mineral weathering which increases the pH by releasing Ca, Mg and K: a soil which is rich in easily weathered minerals tends to possess both a higher pH and higher soil solution concentrations of Ca, Mg and K (see the turf-derived soils of the case studies). Many nutrient cations such as zinc (Zn), aluminium (Al), iron (Fe) and manganese (Mn) are soluble and available for uptake by plants below pH 5.0, although their availability can be excessive and thus toxic in more acidic conditions. Phosphorous requires a pH between 6.0 and 7.0 and becomes chemically immobile outside this range, forming insoluble compounds with Fe and Al in acid soils and with Ca in calcareous soils. Soil acidification may also occur by the addition of hydrogen owing to the decomposition of organic matter and exchange of basic cations for H^+ by the roots. Soil acidity is reduced by the volatilisation and denitrification of nitrogen. A pH level of around 6.3-6.8 is the optimum range preferred by most soil bacteria and earthworms.
- Phosphorous (P): stimulates root growth and promotes fruit and seed maturation. Enriching soil with readily available phosphorous reserves stimulates vegetation growth and the circumferences of the trees to a greater extent than that found in similar soils without such reserves. Root growth is an important key in the process of soil diffusion (Johnston & Steén, 2005); as the root takes up nutrients from the soil solution, the concentration of nutrients decreases and, to redress the balance, nutrients move in the soil solution towards the root. Organic phosphorus in the soil can be associated with soil organic matter (humus) or recently added organic debris derived from plants or animals and is probably the most important source supplying phosphorous to plants. These organic molecules cannot be used directly by plants. They have to be broken down by soil microbes in order to release inorganic phosphate ions which can be

absorbed by plant roots, although at a slow rate because of the reactions with iron, aluminium, manganese (acid soils), calcium (neutral soils) or other elements that are not very soluble in water. Phosphorus remains in the soil solution, because it is quite immobile (pH dependent) and phosphate ions do not leach; and is either absorbed by plant roots or weakly held in a readily available pool (Johnston & Steén, 2005).

- Calcium (Ca): important for plant cell wall integrity, root development and leaf growth.
- Magnesium (Mg): essential for chlorophyll and green leaf development (photosynthesis).
- Potassium (K): promotes plant vitality and disease resistance.
- Sodium (Na): sodium (not a plant nutrient) is considered since it relates to the physical condition of the soil where high Na-levels (dispersive soil) restrict water entry to the soil and drainage, and these soils set hard when drying. These conditions may prevent the growth of plants.
- Trace minerals (Fe, Mn, Zn): essential to sustain basic plant development in low (trace) quantities, but under acidic pH conditions these elements may build up in large quantities that can be toxic to the plant.
- Aluminium (Al): like Na, it is not a plant nutrient and is therefore not wanted by the plant. At a pH of below 4.5, Al becomes available in toxic levels by displacing other cations from the clay or humus particles.
- Soil resistance (Ohm): an indication of the water-holding (humus) content of the sub-soil since the resistance drops with an increase of water content, and also the state of weathering because less weathered rock tends to possess higher resistivities.
- Organic carbon (C%): plants acquire carbon from the atmosphere through photosynthesis. Using carbon dioxide (CO₂) from the atmosphere and energy from sunlight, plants convert CO₂ to organic carbon as they produce stems, leaves and roots. The cycle of life and death of plants results in the accumulation of decomposing plant tissue and produces a significant amount of soil organic carbon and releases nitrogen. Organic carbon bonds soil sulphur. The dark black colour associated with rich, fertile soil is largely a measure of its organic carbon content. As the organic carbon content of the soil drops, the soil's colour lightens and reflects its mineral content. Red soils, for instance, indicate a higher iron

concentration and lower soil carbon levels (McVay & Rice, 2002): a key measure of soil quality.

- Total nitrogen (N%): contains proteins and is a food source for humus, and stimulates green growth in plants. Nitrogen in the air is the ultimate source of all soil nitrogen. Nitrogen may enter the soil by means of rainfall, plant residues, nitrogen fixation by soil organisms, animal manures and commercial fertilizers. Organic nitrogen is converted by micro organisms to a form of nitrogen that plants can use and this can increase the pH of the soil (Barbarick, 2004): a key measure of soil quality.
- Sulphur (S): stimulant for soil microbial life, protein and vitamin synthesis and also plant growth and abundance. If the sulphur content of the soil is low, the influence of soil N is diminished (Kline, 1991, Kertesz & Mirleau, 2004).
- Cation exchange capacity (CEC)/humus: the total number of cations a soil can hold, or its total negative charge, is the soil's cation exchange capacity. The higher the CEC, the higher the negative charge and the more cations that can be held. A soil's CEC increases the water-holding capacity, modifies the soil structure, is a source of soil sulphur (sulphate minerals decay), serves as a reserve for many essential nutrients (especially nitrogen), stimulates plant growth, permits root penetration and helps to correct soil imbalances. The CEC is a key measure of soil quality and soil fertility because it indicates the soil's ability to supply three important plant nutrients: Ca, Mg and K. The soil pH is important for CEC because as the pH increases (becoming less acid), the number of negative charges on the colloids (negatively charged particles of clay and humus) increase, thereby increasing CEC.

From the indicated geochemical soil parameters above it is obvious that the cation exchange capacity is the most important factor since it encompasses all the different attributes of plant growth and development and exhibits the ability to correct soil imbalances. It is important to note that great care was taken to stress that all the soil samples were to be taken in areas that are not fertilised by means of the application of inorganic or concentrated organic fertiliser. Furthermore, the geochemical analysis of a soil sample indicates the available ions of a specific element in the soil that can be viewed against particular CEC-values.

One can investigate further possible correlations or relationships between the different elements indicated in the present undertaking, but these relationships are not of crucial importance to the said study. However, in order to establish the overall enrichment of soil nutrients at geobotanical communities, the status of the soil nutrient at the geobotanical communities and the other sampled sites with no conspicuous vegetation growth should be compared. As indicated in Table 5.1, most of the geobotanical indicators are associated with intrusive rocks, such as basalt, diabase and dolerite. These rocks quite readily weather chemically quite easy in the wetter parts of South Africa ($N < 5$) and releasing an abundance of elements. These elements sustain a wider spectrum of vegetation than normally observed in the natural environment. Weathered intrusive rocks and their contact zones usually act as aquifers in the north-eastern parts of South Africa, so that water is available at weathered contact zones that can supply plants with water, even through capillary action. An overview of the nutrient status of the geobotanical communities and other sampled localities is presented in Table 5.2. No distinction is made between the different sampling horizons, namely 0.5 and 1.2 metres.

Table 5.2. Soil nutrient status of geobotanical and non-geobotanical communities for different geological lithologies/formations.

Lithology	Element: pH	Counts: Geobotanical community	Counts: Non-geobotanical community
Swazian metamorphic rocks (n = 8)	<5.01 5.01-6.00 6.01-7.00 >7.00	2 0 1 5	1 4 2 1
Vaalium dolomite (n = 6)	<5.01 5.01-6.00 6.01-7.00 >7.00	0 2 2 2	0 0 6 0
Vaalium andesite and gabbro (n = 6)	<5.01 5.01-6.00 6.01-7.00 >7.00	0 1 1 4	0 2 1 3
Vaalium shale and slate (n = 8)	<5.01 5.01-6.00 6.01-7.00 >7.00	0 1 6 1	0 0 8 0
Vaalium quartzite (n = 10)	<5.01 5.01-6.00 6.01-7.00 >7.00	4 2 3 1	5 3 1 1
Vaalium rhyolite (n = 6)	<5.01 5.01-6.00 6.01-7.00 >7.00	0 5 1 0	1 4 1 0
Vaalium diabase sills (n = 4)	<5.01 5.01-6.00 6.01-7.00 >7.00	1 2 1 0	0 1 1 2
Mogolian granite (n = 10)	<5.01 5.01-6.00 6.01-7.00 >7.00	0 6 4 0	2 5 3 0
Mogolian sandstone (n = 24)	<5.01 5.01-6.00 6.01-7.00 >7.00	0 10 14 0	11 12 1 0
Karoo sediments: Waterberg area (n = 6)	<5.01 5.01-6.00 6.01-7.00 >7.00	0 0 0 6	0 0 0 6
Karoo sediments: Highveld (n = 6)	<5.01 5.01-6.00 6.01-7.00 >7.00	0 2 4 0	2 3 1 0
Karoo: mafic intrusions (n = 6)	<5.01 5.01-6.00 6.01-7.00 >7.00	0 0 1 5	0 0 3 3

Lithology	Element: P	Counts: Geobotanical community	Counts: Non-geo-botanical community
Swazian metamorphic rocks (n = 8)	<1.01 1.01-10.00 10.01-20.00 >20.00	0 4 2 2	0 9 1 0
Vaalium dolomite (n = 6)	<1.01 1.01-10.00 10.01-20.00 >20.00	0 6 0 0	0 6 0 0
Vaalium andesite and gabbro (n = 6)	<1.01 1.01-10.00 10.01-20.00 >20.00	0 3 2 1	0 3 3 0
Vaalium shale and slate (n = 8)	<1.01 1.01-10.00 10.01-20.00 >20.00	0 8 0 0	0 8 0 0
Vaalium quartzite (n = 10)	<1.01 1.01-10.00 10.01-20.00 >20.00	0 8 1 1	0 6 4 0
Vaalium rhyolite (n = 6)	<1.01 1.01-10.00 10.01-20.00 >20.00	1 5 0 0	0 6 0 0
Vaalium diabase sills (n = 4)	<1.01 1.01-10.00 10.01-20.00 >20.00	0 4 0 0	0 4 0 0
Mogolian granite (n = 10)	<1.01 1.01-10.00 10.01-20.00 >20.00	1 3 6 0	3 2 4 1
Mogolian sandstone (n = 24)	<1.01 1.01-10.00 10.01-20.00 >20.00	3 20 0 1	2 21 0 1
Karoo sediments: Waterberg area (n = 6)	<1.01 1.01-10.00 10.01-20.00 >20.00	0 4 2 0	1 3 2 0
Karoo sediments: Highveld (n = 6)	<1.01 1.01-10.00 10.01-20.00 >20.00	2 4 0 0	0 6 0 0
Karoo: mafic intrusions (n = 6)	<1.01 1.01-10.00 10.01-20.00 >20.00	2 4 0 0	1 5 1 0

Lithology	Elements: Ca & Mg	Counts: Geobotanical community	Counts: Non-geo- botanical community
Swazian metamorphic rocks (n = 8)	<100 100-500 501-1000 >1000	Ca: 0 Mg: 0 Ca: 0 Mg: 2 Ca: 0 Mg: 5 Ca: 8 Mg: 1	Ca: 0 Mg: 2 Ca: 6 Mg: 6 Ca: 2 Mg: 0 Ca: 0 Mg: 0
Vaalium dolomite (n = 6)	<100 100-500 501-1000 >1000	Ca: 0 Mg: 0 Ca: 2 Mg: 6 Ca: 2 Mg: 0 Ca: 2 Mg: 0	Ca: 0 Mg: 0 Ca: 2 Mg: 6 Ca: 4 Mg: 0 Ca: 0 Mg: 0
Vaalium andesite and gabbro (n = 6)	<100 100-500 501-1000 >1000	Ca: 0 Mg: 0 Ca: 0 Mg: 1 Ca: 0 Mg: 4 Ca: 6 Mg: 1	Ca: 0 Mg: 0 Ca: 0 Mg: 4 Ca: 2 Mg: 0 Ca: 4 Mg: 2
Vaalium shale and slate (n = 8)	<100 100-500 501-1000 >1000	Ca: 0 Mg: 0 Ca: 1 Mg: 3 Ca: 0 Mg: 5 Ca: 7 Mg: 0	Ca: 0 Mg: 0 Ca: 1 Mg: 2 Ca: 5 Mg: 6 Ca: 2 Mg: 0
Vaalium quartzite (n = 10)	<100 100-500 501-1000 >1000	Ca: 0 Mg: 3 Ca: 8 Mg: 5 Ca: 2 Mg: 2 Ca: 0 Mg: 0	Ca: 1 Mg: 9 Ca: 9 Mg: 1 Ca: 0 Mg: 0 Ca: 0 Mg: 0
Vaalium rhyolite (n = 6)	<100 100-500 501-1000 >1000	Ca: 0 Mg: 2 Ca: 1 Mg: 3 Ca: 5 Mg: 1 Ca: 0 Mg: 0	Ca: 0 Mg: 4 Ca: 4 Mg: 2 Ca: 2 Mg: 0 Ca: 0 Mg: 0
Vaalium diabase sills (n = 4)	<100 100-500 501-1000 >1000	Ca: 0 Mg: 0 Ca: 2 Mg: 4 Ca: 1 Mg: 0 Ca: 1 Mg: 0	Ca: 0 Mg: 0 Ca: 2 Mg: 4 Ca: 0 Mg: 0 Ca: 2 Mg: 0
Mogolian granite (n = 10)	<100 100-500 501-1000 >1000	Ca: 0 Mg: 0 Ca: 4 Mg: 8 Ca: 3 Mg: 1 Ca: 3 Mg: 1	Ca: 0 Mg: 7 Ca: 10 Mg: 3 Ca: 0 Mg: 0 Ca: 0 Mg: 0
Mogolian sandstone (n = 24)	<100 100-500 501-1000 >1000	Ca: 0 Mg: 4 Ca: 7 Mg: 14 Ca: 7 Mg: 5 Ca: 10 Mg: 1	Ca: 2 Mg: 22 Ca: 22 Mg: 2 Ca: 0 Mg: 0 Ca: 0 Mg: 0
Karoo sediments: Waterberg area (n = 6)	<100 100-500 501-1000 >1000	Ca: 0 Mg: 0 Ca: 0 Mg: 4 Ca: 0 Mg: 2 Ca: 6 Mg: 0	Ca: 0 Mg: 0 Ca: 0 Mg: 2 Ca: 0 Mg: 4 Ca: 6 Mg: 0
Karoo sediments: Highveld (n = 6)	<100 100-500 501-1000 >1000	Ca: 0 Mg: 0 Ca: 0 Mg: 0 Ca: 0 Mg: 5 Ca: 6 Mg: 1	Ca: 0 Mg: 3 Ca: 4 Mg: 3 Ca: 2 Mg: 0 Ca: 0 Mg: 0
Karoo: mafic intrusions (n = 6)	<100 100-500 501-1000 >1000	Ca: 0 Mg: 0 Ca: 0 Mg: 2 Ca: 0 Mg: 2 Ca: 6 Mg: 2	Ca: 0 Mg: 0 Ca: 0 Mg: 4 Ca: 0 Mg: 0 Ca: 6 Mg: 2

Lithology	Elements:		Counts: Geobotanical community		Counts: Non-geo-botanical community	
	K	Na				
Swazian metamorphic rocks (n = 8)	<50 50-100 101-200 >200	<25 25-50 51-100 >100	K: 0 K: 0 K: 7 K: 1	Na: 0 Na: 1 Na: 4 Na: 3	K: 1 K: 3 K: 3 K: 1	Na: 7 Na: 1 Na: 0 Na: 0
Vaalium dolomite (n = 6)	<50 50-100 101-200 >200	<25 25-50 51-100 >100	K: 1 K: 1 K: 2 K: 2	Na: 2 Na: 4 Na: 0 Na: 0	K: 0 K: 1 K: 4 K: 1	Na: 4 Na: 1 Na: 0 Na: 1
Vaalium andesite and gabbro (n = 6)	<50 50-100 101-200 >200	<25 25-50 51-100 >100	K: 0 K: 0 K: 3 K: 3	Na: 1 Na: 4 Na: 1 Na: 0	K: 0 K: 1 K: 2 K: 3	Na: 2 Na: 2 Na: 0 Na: 2
Vaalium shale and slate (n = 8)	<50 50-100 101-200 >200	<25 25-50 51-100 >100	K: 2 K: 1 K: 5 K: 0	Na: 7 Na: 0 Na: 0 Na: 1	K: 2 K: 4 K: 3 K: 0	Na: 5 Na: 1 Na: 2 Na: 0
Vaalium quartzite (n = 10)	<50 50-100 101-200 >200	<25 25-50 51-100 >100	K: 5 K: 5 K: 0 K: 0	Na: 7 Na: 2 Na: 1 Na: 0	K: 10 K: 0 K: 0 K: 0	Na: 9 Na: 1 Na: 0 Na: 0
Vaalium rhyolite (n = 6)	<50 50-100 101-200 >200	<25 25-50 51-100 >100	K: 0 K: 1 K: 3 K: 2	Na: 2 Na: 4 Na: 0 Na: 0	K: 0 K: 0 K: 6 K: 0	Na: 5 Na: 1 Na: 0 Na: 0
Vaalium diabase sills (n = 4)	<50 50-100 101-200 >200	<25 25-50 51-100 >100	K: 0 K: 2 K: 2 K: 0	Na: 3 Na: 1 Na: 0 Na: 0	K: 0 K: 3 K: 1 K: 0	Na: 3 Na: 1 Na: 0 Na: 0
Mogolian granite (n = 10)	<50 50-100 101-200 >200	<25 25-50 51-100 >100	K: 4 K: 4 K: 2 K: 0	Na: 1 Na: 3 Na: 3 Na: 3	K: 7 K: 1 K: 2 K: 0	Na: 8 Na: 2 Na: 0 Na: 0
Mogolian sandstone (n = 24)	<50 50-100 101-200 >200	<25 25-50 51-100 >100	K: 7 K: 12 K: 2 K: 3	Na: 11 Na: 11 Na: 2 Na: 0	K: 17 K: 5 K: 2 K: 0	Na: 18 Na: 4 Na: 2 Na: 0
Karoo sediments: Waterberg area (n = 6)	<50 50-100 101-200 >200	<25 25-50 51-100 >100	K: 0 K: 0 K: 3 K: 3	Na: 1 Na: 4 Na: 1 Na: 0	K: 0 K: 1 K: 1 K: 4	Na: 2 Na: 2 Na: 1 Na: 1
Karoo sediments: Highveld (n = 6)	<50 50-100 101-200 >200	<25 25-50 51-100 >100	K: 0 K: 2 K: 4 K: 0	Na: 2 Na: 2 Na: 2 Na: 0	K: 1 K: 3 K: 2 K: 0	Na: 3 Na: 2 Na: 1 Na: 0
Karoo: mafic intrusions (n = 6)	<50 50-100 101-200 >200	<25 25-50 51-100 >100	K: 0 K: 0 K: 4 K: 2	Na: 0 Na: 4 Na: 1 Na: 1	K: 0 K: 0 K: 4 K: 2	Na: 3 Na: 2 Na: 1 Na: 0

Lithology	Element: Resistivity	Counts: Geobotanical community	Counts: Non-geo- botanical community
Swazian metamorphic rocks (n = 8)	<1000 1000-2000 2001-3000 >3000	1 7 0 0	0 1 3 4
Vaalium dolomite (n = 6)	<1000 1000-2000 2001-3000 >3000	0 1 1 4	0 1 1 4
Vaalium andesite and gabbro (n = 6)	<1000 1000-2000 2001-3000 >3000	3 2 1 0	2 3 1 0
Vaalium shale and slate (n = 8)	<1000 1000-2000 2001-3000 >3000	3 4 0 1	1 2 4 1
Vaalium quartzite (n = 10)	<1000 1000-2000 2001-3000 >3000	0 1 2 7	0 0 0 10
Vaalium rhyolite (n = 6)	<1000 1000-2000 2001-3000 >3000	1 1 3 1	0 2 2 2
Vaalium diabase sills (n = 4)	<1000 1000-2000 2001-3000 >3000	1 2 0 1	1 1 0 2
Mogolian granite (n = 10)	<1000 1000-2000 2001-3000 >3000	0 3 3 4	0 0 1 9
Mogolian sandstone (n = 24)	<1000 1000-2000 2001-3000 >3000	2 4 12 6	1 2 1 20
Karoo sediments: Waterberg area (n = 6)	<1000 1000-2000 2001-3000 >3000	1 3 2 0	1 3 2 0
Karoo sediments: Highveld (n = 6)	<1000 1000-2000 2001-3000 >3000	0 6 0 0	0 1 3 2
Karoo: mafic intrusions (n = 6)	<1000 1000-2000 2001-3000 >3000	0 3 3 0	1 3 2 0

Lithology	Elements: Fe & Mn	Counts: Geobotanical community	Counts: Non-geo- botanical community
Swazian metamorphic rocks (n = 8)	<50.00 50.00-100.00 100.01-200.00 >200.00	Fe: 2 Mn: 1 Fe: 1 Mn: 0 Fe: 3 Mn: 2 Fe: 2 Mn: 5	Fe: 2 Mn: 1 Fe: 5 Mn: 3 Fe: 0 Mn: 2 Fe: 1 Mn: 2
Vaalium dolomite (n = 6)	<50.00 50.00-100.00 100.01-200.00 >200.00	Fe: 0 Mn: 0 Fe: 2 Mn: 0 Fe: 3 Mn: 0 Fe: 1 Mn: 6	Fe: 0 Mn: 0 Fe: 0 Mn: 0 Fe: 4 Mn: 0 Fe: 2 Mn: 6
Vaalium andesite and gabbro (n = 6)	<50.00 50.00-100.00 100.01-200.00 >200.00	Fe: 2 Mn: 0 Fe: 1 Mn: 0 Fe: 3 Mn: 2 Fe: 0 Mn: 4	Fe: 2 Mn: 0 Fe: 2 Mn: 1 Fe: 2 Mn: 1 Fe: 0 Mn: 4
Vaalium shale and slate (n = 8)	<50.00 50.00-100.00 100.01-200.00 >200.00	Fe: 1 Mn: 0 Fe: 2 Mn: 1 Fe: 4 Mn: 1 Fe: 1 Mn: 6	Fe: 2 Mn: 0 Fe: 3 Mn: 0 Fe: 3 Mn: 1 Fe: 0 Mn: 7
Vaalium quartzite (n = 10)	<50.00 50.00-100.00 100.01-200.00 >200.00	Fe: 5 Mn: 2 Fe: 4 Mn: 1 Fe: 1 Mn: 4 Fe: 0 Mn: 3	Fe: 10 Mn: 6 Fe: 0 Mn: 2 Fe: 0 Mn: 2 Fe: 0 Mn: 0
Vaalium rhyolite (n = 6)	<50.00 50.00-100.00 100.01-200.00 >200.00	Fe: 2 Mn: 2 Fe: 2 Mn: 0 Fe: 1 Mn: 1 Fe: 1 Mn: 3	Fe: 1 Mn: 2 Fe: 4 Mn: 1 Fe: 0 Mn: 2 Fe: 1 Mn: 1
Vaalium diabase sills (n = 4)	<50.00 50.00-100.00 100.01-200.00 >200.00	Fe: 2 Mn: 0 Fe: 2 Mn: 0 Fe: 0 Mn: 1 Fe: 0 Mn: 3	Fe: 3 Mn: 0 Fe: 1 Mn: 1 Fe: 0 Mn: 1 Fe: 0 Mn: 2
Mogolian granite (n = 10)	<50.00 50.00-100.00 100.01-200.00 >200.00	Fe: 5 Mn: 4 Fe: 4 Mn: 3 Fe: 0 Mn: 2 Fe: 1 Mn: 1	Fe: 5 Mn: 4 Fe: 4 Mn: 4 Fe: 1 Mn: 2 Fe: 0 Mn: 0
Mogolian sandstone (n = 24)	<50.00 50.00-100.00 100.01-200.00 >200.00	Fe: 10 Mn: 2 Fe: 13 Mn: 5 Fe: 1 Mn: 11 Fe: 0 Mn: 6	Fe: 20 Mn: 15 Fe: 4 Mn: 4 Fe: 0 Mn: 4 Fe: 0 Mn: 1
Karoo sediments: Waterberg area (n = 6)	<50.00 50.00-100.00 100.01-200.00 >200.00	Fe: 5 Mn: 4 Fe: 1 Mn: 0 Fe: 0 Mn: 1 Fe: 0 Mn: 1	Fe: 5 Mn: 3 Fe: 1 Mn: 1 Fe: 0 Mn: 1 Fe: 0 Mn: 1
Karoo sediments: Highveld (n = 6)	<50.00 50.00-100.00 100.01-200.00 >200.00	Fe: 0 Mn: 0 Fe: 0 Mn: 0 Fe: 4 Mn: 0 Fe: 2 Mn: 6	Fe: 3 Mn: 3 Fe: 1 Mn: 0 Fe: 1 Mn: 2 Fe: 1 Mn: 1
Karoo: mafic intrusions (n = 6)	<50.00 50.00-100.00 100.01-200.00 >200.00	Fe: 2 Mn: 0 Fe: 4 Mn: 1 Fe: 0 Mn: 3 Fe: 0 Mn: 2	Fe: 2 Mn: 0 Fe: 2 Mn: 0 Fe: 2 Mn: 0 Fe: 0 Mn: 6

Lithology	Element: Zn	Counts: Geobotanical community	Counts: Non-geo- botanical community
Swazian metamorphic rocks (n = 8)	<0.500 0.500-1.000 1.001-5.000 >5.000	0 1 5 2	2 4 2 0
Vaalium dolomite (n = 6)	<0.500 0.500-1.000 1.001-5.000 >5.000	3 2 1 0	3 2 1 0
Vaalium andesite and gabbro (n = 6)	<0.500 0.500-1.000 1.001-5.000 >5.000	0 1 3 2	1 1 4 0
Vaalium shale and slate (n = 8)	<0.500 0.500-1.000 1.001-5.000 >5.000	3 3 2 0	1 4 3 0
Vaalium quartzite (n = 10)	<0.500 0.500-1.000 1.001-5.000 >5.000	6 2 2 0	5 5 0 0
Vaalium rhyolite (n = 6)	<0.500 0.500-1.000 1.001-5.000 >5.000	1 1 3 1	2 1 3 0
Vaalium diabase sills (n = 4)	<0.500 0.500-1.000 1.001-5.000 >5.000	2 1 0 1	2 2 0 0
Mogolian granite (n = 10)	<0.500 0.500-1.000 1.001-5.000 >5.000	6 0 4 0	8 1 1 0
Mogolian sandstone (n = 24)	<0.500 0.500-1.000 1.001-5.000 >5.000	19 4 1 0	19 4 0 1
Karoo sediments: Waterberg area (n = 6)	<0.500 0.500-1.000 1.001-5.000 >5.000	2 4 0 0	4 2 0 0
Karoo sediments: Highveld (n = 6)	<0.500 0.500-1.000 1.001-5.000 >5.000	1 0 5 0	2 2 2 0
Karoo: mafic intrusions (n = 6)	<0.500 0.500-1.000 1.001-5.000 >5.000	4 0 2 0	1 3 2 0

Lithology	Element: AI	Counts: Geobotanical community	Counts: Non-geo- botanical community
Swazian metamorphic rocks (n = 8)	<0.001 0.001-0.200 0.201-0.750 >0.750	1 5 1 1	0 5 3 0
Vaalium dolomite (n = 6)	<0.001 0.001-0.200 0.201-0.750 >0.750	4 0 2 0	6 0 0 0
Vaalium andesite and gabbro (n = 6)	<0.001 0.001-0.200 0.201-0.750 >0.750	4 2 0 0	2 3 1 0
Vaalium shale and slate (n = 8)	<0.001 0.001-0.200 0.201-0.750 >0.750	7 0 1 0	8 0 0 0
Vaalium quartzite (n = 10)	<0.001 0.001-0.200 0.201-0.750 >0.750	4 1 2 3	2 3 2 3
Vaalium rhyolite (n = 6)	<0.001 0.001-0.200 0.201-0.750 >0.750	4 2 0 0	1 1 4 0
Vaalium diabase sills (n = 4)	<0.001 0.001-0.200 0.201-0.750 >0.750	1 3 0 0	3 1 0 0
Mogolian granite (n = 10)	<0.001 0.001-0.200 0.201-0.750 >0.750	3 3 0 4	3 1 3 3
Mogolian sandstone (n = 24)	<0.001 0.001-0.200 0.201-0.750 >0.750	14 7 3 0	4 1 13 6
Karoo sediments: Waterberg area (n = 6)	<0.001 0.001-0.200 0.201-0.750 >0.750	6 0 0 0	6 0 0 0
Karoo sediments: Highveld (n = 6)	<0.001 0.001-0.200 0.201-0.750 >0.750	2 4 0 0	0 1 4 1
Karoo: mafic intrusions (n = 6)	<0.001 0.001-0.200 0.201-0.750 >0.750	6 0 0 0	6 0 0 0

Lithology	Element: Organic C	Counts: Geobotanical community	Counts: Non-geo- botanical community
Swazian metamorphic rocks (n = 8)	<0.50 0.50-1.00 1.01-2.00 >2.00	0 3 3 2	4 3 0 1
Vaalium dolomite (n = 6)	<0.50 0.50-1.00 1.01-2.00 >2.00	2 4 0 0	5 1 0 0
Vaalium andesite and gabbro (n = 6)	<0.50 0.50-1.00 1.01-2.00 >2.00	0 0 2 4	0 3 3 0
Vaalium shale and slate (n = 8)	<0.50 0.50-1.00 1.01-2.00 >2.00	0 2 5 1	2 3 2 1
Vaalium quartzite (n = 10)	<0.50 0.50-1.00 1.01-2.00 >2.00	8 0 1 1	8 1 1 0
Vaalium rhyolite (n = 6)	<0.50 0.50-1.00 1.01-2.00 >2.00	1 1 1 3	1 1 3 1
Vaalium diabase sills (n = 4)	<0.50 0.50-1.00 1.01-2.00 >2.00	2 1 1 0	1 3 0 0
Mogolian granite (n = 10)	<0.50 0.50-1.00 1.01-2.00 >2.00	9 1 0 0	7 3 0 0
Mogolian sandstone (n = 24)	<0.50 0.50-1.00 1.01-2.00 >2.00	5 5 13 1	12 11 1 0
Karoo sediments: Waterberg area (n = 6)	<0.50 0.50-1.00 1.01-2.00 >2.00	6 0 0 0	5 1 0 0
Karoo sediments: Highveld (n = 6)	<0.50 0.50-1.00 1.01-2.00 >2.00	2 0 4 0	2 2 0 2
Karoo: mafic intrusions (n = 6)	<0.50 0.50-1.00 1.01-2.00 >2.00	4 1 1 0	4 1 1 0

Lithology	Element: Total N	Counts: Geobotanical community	Counts: Non-geo- botanical community
Swazian metamorphic rocks (n = 8)	<0.020 0.020-0.070 0.071-0.100 >0.100	0 2 4 2	1 5 1 1
Vaalium dolomite (n = 6)	<0.020 0.020-0.070 0.071-0.100 >0.100	0 5 1 0	0 5 0 1
Vaalium andesite and gabbro (n = 6)	<0.020 0.020-0.070 0.071-0.100 >0.100	0 2 0 4	0 4 2 0
Vaalium shale and slate (n = 8)	<0.020 0.020-0.070 0.071-0.100 >0.100	0 3 4 1	0 4 2 2
Vaalium quartzite (n = 10)	<0.020 0.020-0.070 0.071-0.100 >0.100	2 6 1 1	6 3 0 1
Vaalium rhyolite (n = 6)	<0.020 0.020-0.070 0.071-0.100 >0.100	0 2 1 3	0 2 4 0
Vaalium diabase sills (n = 4)	<0.020 0.020-0.070 0.071-0.100 >0.100	0 4 0 0	1 3 0 0
Mogolian granite (n = 10)	<0.020 0.020-0.070 0.071-0.100 >0.100	4 6 0 0	1 8 1 0
Mogolian sandstone (n = 24)	<0.020 0.020-0.070 0.071-0.100 >0.100	2 7 10 5	3 19 2 0
Karoo sediments: Waterberg area (n = 6)	<0.020 0.020-0.070 0.071-0.100 >0.100	1 4 1 0	2 4 0 0
Karoo sediments: Highveld (n = 6)	<0.020 0.020-0.070 0.071-0.100 >0.100	0 4 2 0	1 3 0 2
Karoo: mafic intrusions (n = 6)	<0.020 0.020-0.070 0.071-0.100 >0.100	4 0 2 0	2 2 1 1

Lithology	Element: S	Counts: Geobotanical community	Counts: Non-geo- botanical community
Swazian metamorphic rocks (n = 8)	<50 50-250 251-500 >500	6 0 0 2	6 2 0 0
Vaalium dolomite (n = 6)	<50 50-250 251-500 >500	0 0 3 3	0 0 4 2
Vaalium andesite and gabbro (n = 6)	<50 50-250 251-500 >500	4 0 0 2	2 0 0 4
Vaalium shale and slate (n = 8)	<50 50-250 251-500 >500	6 1 1 0	6 2 0 0
Vaalium quartzite (n = 10)	<50 50-250 251-500 >500	2 0 4 4	2 0 1 7
Vaalium rhyolite (n = 6)	<50 50-250 251-500 >500	0 2 0 4	2 0 0 4
Vaalium diabase sills (n = 4)	<50 50-250 251-500 >500	2 2 0 0	4 0 0 0
Mogolian granite (n = 10)	<50 50-250 251-500 >500	0 4 3 3	0 3 2 5
Mogolian sandstone (n = 24)	<50 50-250 251-500 >500	4 9 5 6	2 13 3 6
Karoo sediments: Waterberg area (n = 6)	<50 50-250 251-500 >500	0 4 1 1	1 3 0 2
Karoo sediments: Highveld (n = 6)	<50 50-250 251-500 >500	2 4 0 0	2 2 2 0
Karoo: mafic intrusions (n = 6)	<50 50-250 251-500 >500	2 4 0 0	1 4 0 1

Lithology	Element: CEC	Counts: Geobotanical community	Counts: Non-geo- botanical community
Swazian metamorphic rocks (n = 8)	<5.00 5.00-10.00 10.01-15.00 >15.00	0 0 1 7	3 5 0 0
Vaalium dolomite (n = 6)	<5.00 5.00-10.00 10.01-15.00 >15.00	0 2 4 0	2 1 3 0
Vaalium andesite and gabbro (n = 6)	<5.00 5.00-10.00 10.01-15.00 >15.00	1 0 1 4	0 2 2 2
Vaalium shale and slate (n = 8)	<5.00 5.00-10.00 10.01-15.00 >15.00	0 1 1 6	1 2 2 3
Vaalium quartzite (n = 10)	<5.00 5.00-10.00 10.01-15.00 >15.00	5 2 1 2	8 2 0 0
Vaalium rhyolite (n = 6)	<5.00 5.00-10.00 10.01-15.00 >15.00	0 4 2 0	5 1 0 0
Vaalium diabase sills (n = 4)	<5.00 5.00-10.00 10.01-15.00 >15.00	0 1 1 2	0 3 0 1
Mogolian granite (n = 10)	<5.00 5.00-10.00 10.01-15.00 >15.00	0 5 3 2	6 2 0 2
Mogolian sandstone (n = 24)	<5.00 5.00-10.00 10.01-15.00 >15.00	4 7 9 4	20 4 0 0
Karoo sediments: Waterberg area (n = 6)	<5.00 5.00-10.00 10.01-15.00 >15.00	0 0 2 4	0 2 1 3
Karoo sediments: Highveld (n = 6)	<5.00 5.00-10.00 10.01-15.00 >15.00	0 0 1 5	0 4 1 1
Karoo: mafic intrusions (n = 6)	<5.00 5.00-10.00 10.01-15.00 >15.00	0 1 1 4	0 3 1 2

According to Table 5.2 it is clear that no distinct relationship exist between some available cations and other nutrients in the soil and the cation exchange capacity. Higher values of CEC indicates higher levels of available humus or clay in certain instances. The cation magnesium has the highest correlation with CEC values which indicates the trend of higher Mg-levels with increased CEC-values. Magnesium is essential to create humus, as Mg is the cation responsible for photosynthesis and the formation of energy. Dead leaves in turn form compost which promotes microbiological activity.

Certain distinct differences in the soil nutrient status exist between geobotanical and non-geobotanical communities, as laid out in Table 5.2. Some remarks on the differences in the status of soil nutrients include:

- pH: Soils with a pH above 7.0 (alkaline) is characteristic of only the geobotanical communities associated with the case studies representing the Swazian metamorphic rocks and Vaalium andesite and gabbro, whereas a pH > 7.0 is recorded for both communities representing the Karoo sediments in the Waterberg area and Karoo mafic intrusions. The natural environment hosts free lime resulting from weathered rock or drier conditions ($N > 5$) that can increase the pH of the soil. On the other hand, it is noteworthy that rocks associated with sandstone and quartzite tend to have acid soils ($pH < 5.0$), especially the non-geobotanical member.
- P: the availability of available phosphorous is quite similar for all the lithologies and varying levels of pH, except the Swazian metamorphic rocks that indicate P levels in excess of 20 mg/kg for various soil samples. It is known that P is readily available between a pH of 6-7, but the same trend is not observed regarding soil samples from other lithologies which have high pH values as well. Higher P values associated with Swazian metamorphic rocks can be obtained from Swazian-aged weathered rock not found elsewhere in the case study area.
- Ca & Mg: Similarly for the pH values, the same scenario is present regarding Ca and Mg values, especially since soils with a higher pH tend to possess higher values of available Ca, Mg and K. The geobotanical communities of the Swazian metamorphic rocks, Vaalium andesite and gabbro, Vaalium shale and slate lithologies, Mogolian granite and sandstone, and Karoo sediments on the Highveld all have higher Ca-values compared to the opposing non-geobotanical community. A more even distribution of Mg-values among the geobotanical and non-geobotanical communities is observed. Even the distribution of Ca-values is coupled with the Karoo sediments of the Waterberg area and Karoo mafic, intrusive rocks. The non-geobotanical communities of Vaalium quartzite, Mogolian granite

and sandstone differ sharply from their geobotanical counterparts in the same vicinity with regards to Ca and Mg availability. In a manner, this phenomenon explains why more luxurious vegetation growth is found in intrusion derived soil than that derived from weathered sedimentary or metamorphic rocks.

- K & Na: higher values of K and Na are measured at geobotanical communities associated with the case studies representing the Swazian metamorphic rocks and the Mogolian sandstone. Geobotanical and non-geobotanical community soils of the Karoo mafic intrusions are both rich in K and Na, whereas soils derived from Vaalium quartzite case studies are low in K and Na concentrations in the case of both the communities. In these instances, it does not appear that Na is a limiting factor with regards to the establishment of vegetation and growth.
- Resistivity: it is conspicuous to note that, overall, the geobotanical communities have lower resistivities compared to the non-geobotanical localities. This can be attributed to a higher percentage of clay or humus (CEC) available at the geobotanical site. Furthermore, the description of the soil texture, as depicted in the various tables of the case studies, indicates that soil texture of the geobotanical communities tend to be clayey.
- Fe & Mn: the contrast between the soils derived from weathered sedimentary, metamorphic or intrusive rocks is prominent in the soil nutrient status of these soils. Trace minerals, such as Fe and Mn, occur in abundance at the geobotanical community associated with weathered intrusive rocks in the sub-surface, notably, in Swazian metamorphic rocks, Vaalium quartzite, Mogolian sandstone and the Karoo sediments of the Highveld. In contrast to this, the non-geobotanical community associated with Karoo mafic intrusions (basalt and dolerite) indicates a higher manganese value which is also associated with dolomitic terrain (Vaalium dolomite). According to Tables 2.1-2.2, dolomite and basalt rocks contain high MnO-values compared to other rocks. The weathering of these rocks release abundant Mn in the soil environment. Since intrusive rocks, especially those that create an anomaly on a magnetometer are rich in iron ions: it is not unusual to expect high iron values in the geobotanical community. Lower Fe-values measured at the Vaalium andesite and gabbro localities might imply a lesser availability of free iron, most of which is bound to other constituents, such as oxygen.
- Zn: geobotanical communities found at the following sites contain higher zinc values compared to the non-geobotanical communities and may indicate that most of the Zn is derived from weathered intrusive rocks: Swazian metamorphic rocks, Vaalium andesite and gabbro, Mogolian granite and Karoo sediments of the Highveld.

- Al: high aluminium levels are toxic to plants that grow in an environment with high available Al-levels, mostly owing to acidic soil conditions ($\text{pH} < 5$). A reasonable relationship between sites with a low pH and high Al exists: high Al-values are recorded for Vaalium quartzite, Mogolian granite & sandstone and Karoo sediments on the Highveld, particularly at the non-geobotanical localities. Higher levels of Al contribute to sparse vegetation on the surface of the mentioned lithologies.
- Organic carbon: mostly found in greater abundance in localities with increased micro-biological activity, places with a neutral soil pH or abundant vegetation in order to supply organic matter for decomposition processes. The geobotanical communities of the Swazian metamorphic rocks, Vaalium andesite and gabbro, Vaalium shale and slate, and Mogolian sandstone have higher organic carbon levels than the non-geobotanical communities which is important to note, since increased levels of organic carbon in the soil increase the growth of vegetation, hence the establishment of geobotanical communities.
- Total nitrogen: sites with higher pH-values, especially those differences between the geobotanical and non-geobotanical communities can expect large differences in the amount of total nitrogen available for absorption. Geobotanical communities located in Swazian metamorphic rocks, Vaalium andesite and gabbro, Vaalium rhyolite and Mogolian sandstone contain higher total N-values. It seems that sites with a higher organic carbon content may also have higher total nitrogen values (this compares favourably with the remarks by McVay & Rice (2002) regarding the C-N relationship). The relationship between organic carbon and the total nitrogen of the soil samples included in this study, is displayed in Figure 5.1, where the linear trend line indicates an exceptional correlation, indicated by a regression coefficient of $R^2 = 0.9026$. (see Young, 1962 regarding statistical treatment of data). The indicated formula:

$$Y = 0.06X + 0.0106 \quad (5.1)$$

The formula (5.1) indicates the relationship between the total nitrogen (Y) and organic carbon (X), and the linear regression states that soil with higher organic carbon levels will also benefit from higher total nitrogen levels available to plants, and therefore encourages growth and the development of vegetation, an important factor for geobotanical communities.

- Soil sulphur: the amounts of S vary between geobotanical and non-geobotanical communities and occur, only at certain geobotanical localities associated with Swazian

metamorphic rocks where very high S-values are measured. In general, no clear distinction of sulphur content between the soils of geobotanical and non-geobotanical communities can be indicated, which is therefore not of great importance to the study of the interaction between the geobotanical indicators and the nutrients of the soil. The relationship between S and C+N in the soil samples gathered in the present study, is not clearly defined, since sites with high or low C+N-values do not necessarily have high or low S-values (see also Table 5.2).

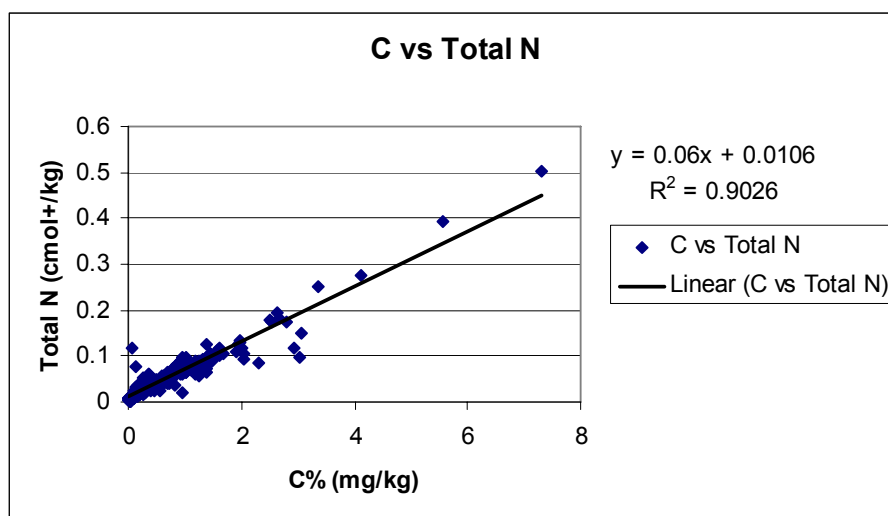


Figure 5.1. The relationship between organic carbon and total nitrogen for the case studies (n = 200).

- Cation exchange capacity (CEC): basically all the geobotanical communities have higher CEC-values compared to the non-geobotanical localities, except for those associated with clay soils throughout the soil profile, thus implying either geobotanical or non-geobotanical communities. Cation exchange capacity is one of the main elements that supply the roots of the plants with nutrients and stabilise the pH of the soil, thereby releasing more phosphorous and limiting the occurrence of aluminium toxicity. Therefore, CEC is a crucial parameter for the analysis in order to determine the existence of and importance to prove the hypothesis that geobotanical indicators exist in nature and that there is a certain reason behind their position in the natural environment. The pie charts (Figure 5.2) indicate the distribution of CEC-values (Table 5.2) among the geobotanical and non-geobotanical communities and from these diagrams it is clear that geobotanical communities benefit from larger CEC-values.

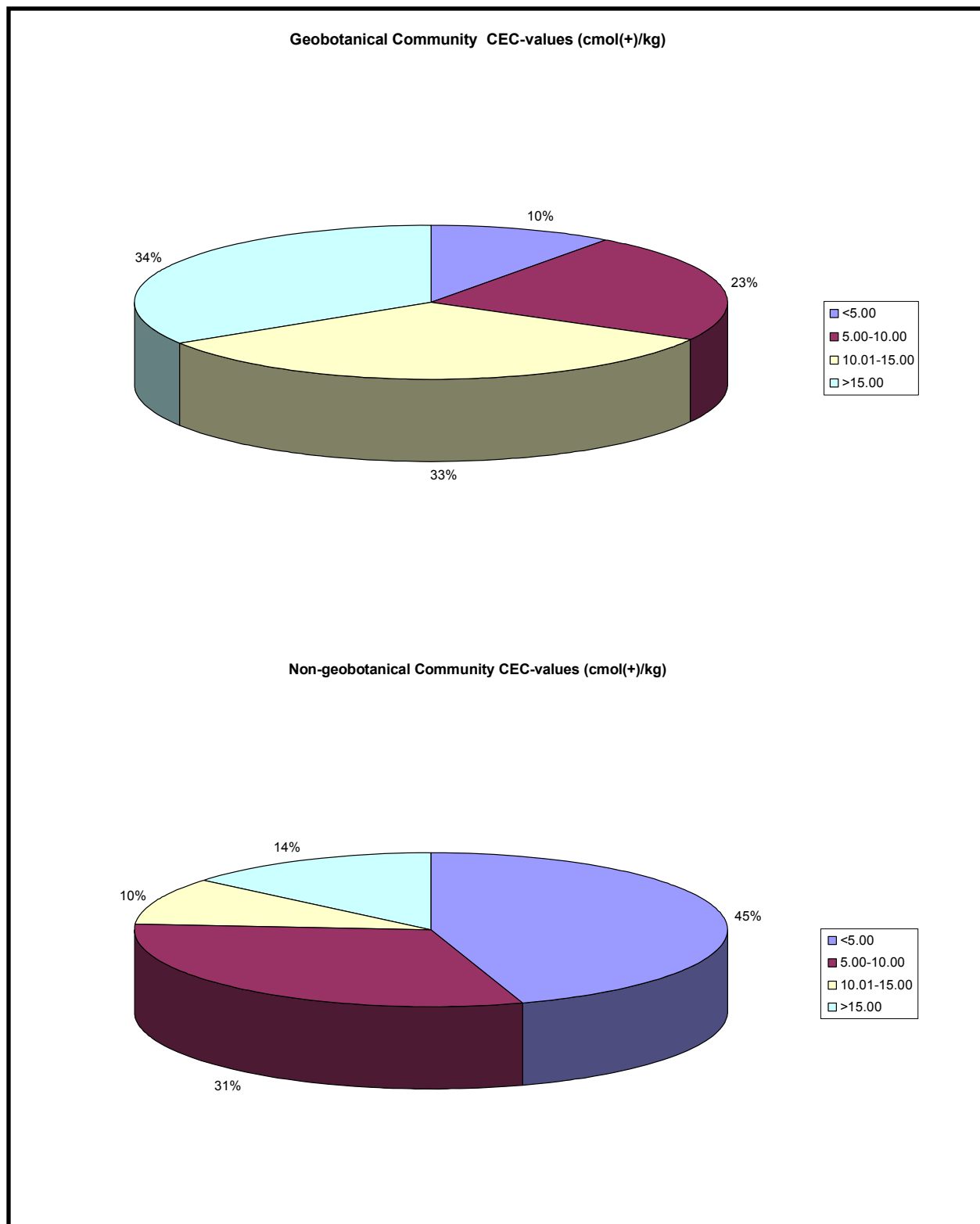


Figure 5.2. Distribution of CEC-values among geobotanical and non-geobotanical communities (n = 100 for each pie diagram).

5.3 STATISTICAL TREATMENT OF DATA

5.3.1 Distribution patterns

The distribution of the borehole yields at the geobotanical communities compared to the average yield of the geological formation is presented in Figure 5.3. This graph illustrates that in the north-eastern parts of South Africa, the boreholes in geobotanical communities tend to yield between 151-300% more than the average yield of the geological formation of the region.

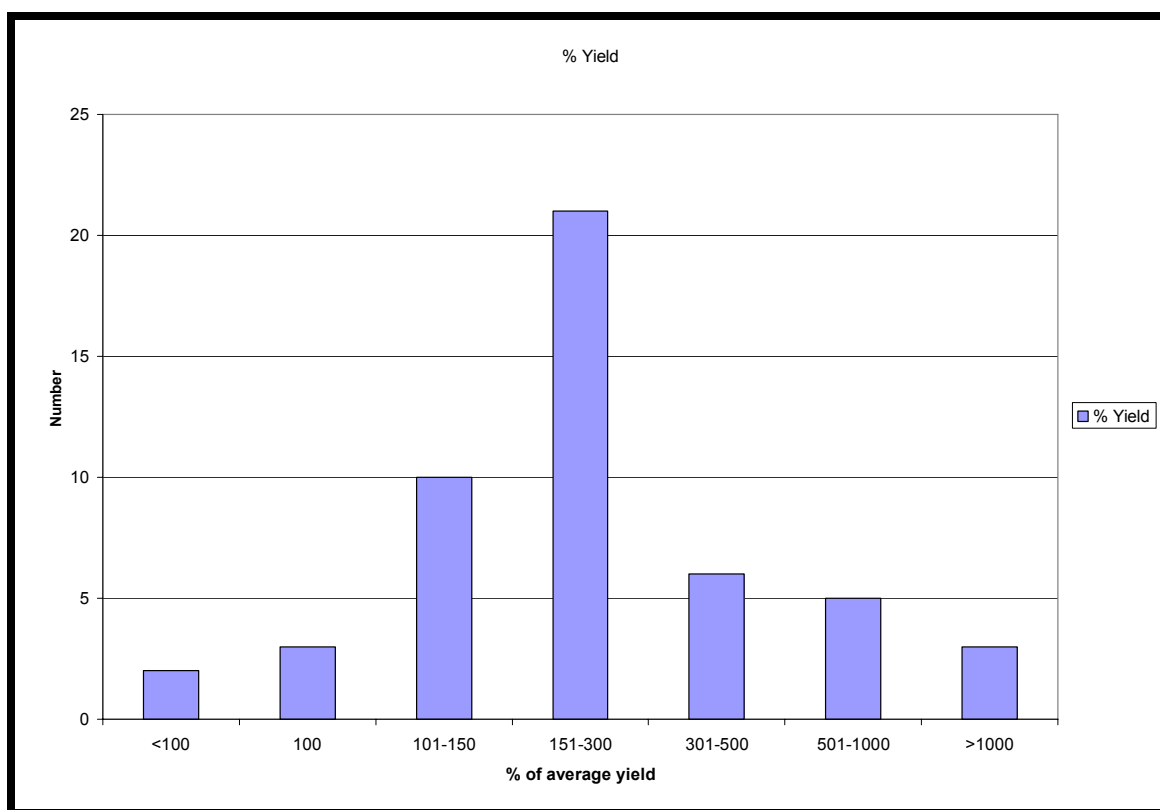


Figure 5.3. Distribution of borehole yield associated with geobotanical communities compared to the average yield of the geological formation for the north-eastern parts of South Africa (n = 50).

Since geobotanical communities generally have higher CEC values according to the analysis of the soils sampled at these communities, it is crucial to link this to borehole yield in order to obtain a geohydrological measure of its importance (Figure 5.4).

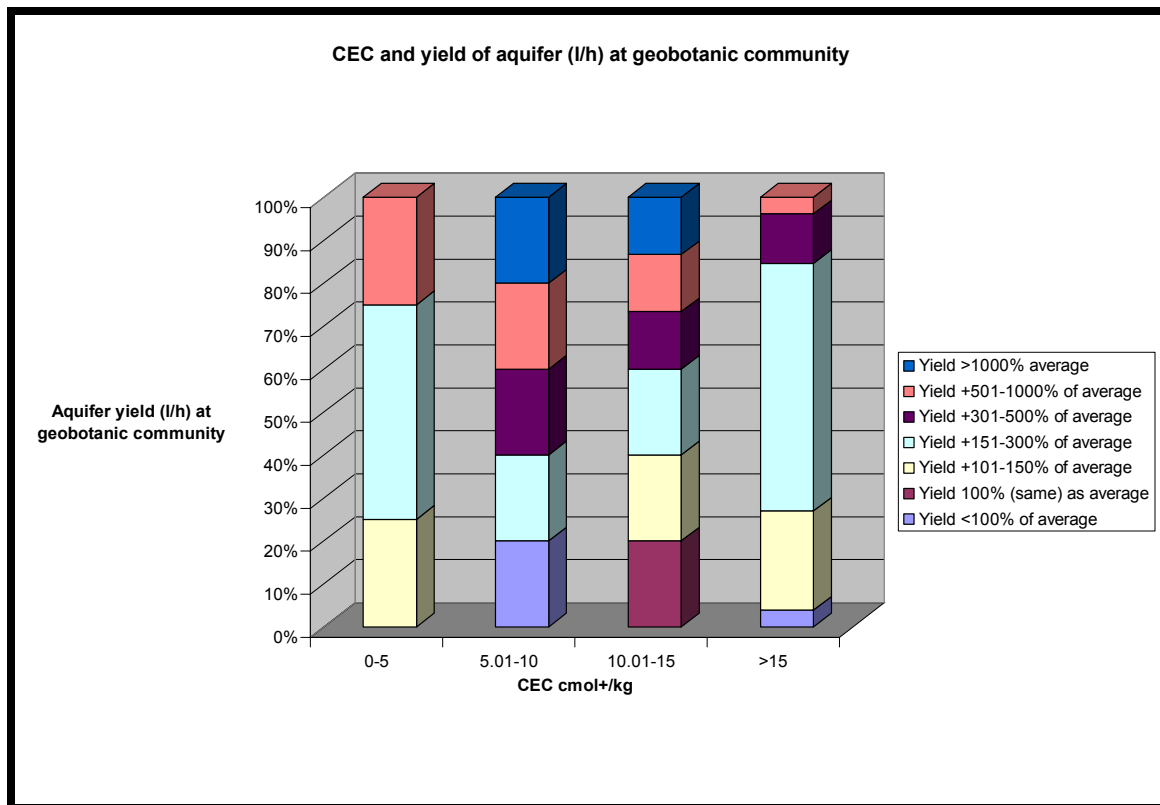


Figure 5.4. CEC and aquifer yield measured at geobotanical communities. The average aquifer yield implies average aquifer yields of geological formations in the north-eastern parts of South Africa (n = 50).

The following figure indicates the distribution of CEC values at non-geobotanical communities and the yield of boreholes drilled at these localities (Figure 5.5).

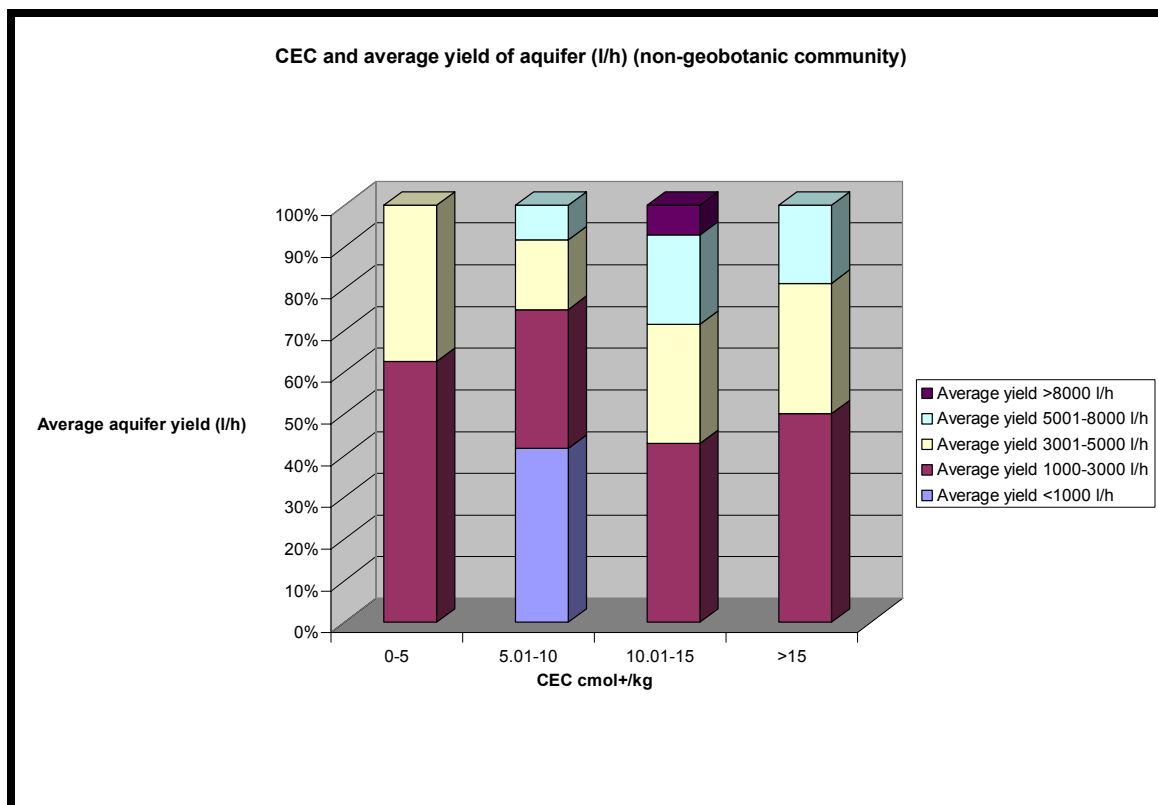


Figure 5.5. CEC and the average yield of an aquifer at non-geobotanical communities (n = 50).

The previous two figures (Figures 5.4 and 5.5) clearly illustrate that the group of CEC values in excess of 15 cmol+/kg are associated with 55% of the boreholes in the geobotanical communities that yield between 151-300% above the average borehole yields of aquifers of geological formations in the north-eastern parts of South Africa. Although CEC values in excess of 15 cmol+/kg are also associated with boreholes not associated with geobotanical communities, these boreholes usually yield between 1000-3000 l/h which is lower than the yields obtained at geobotanical communities. The importance of and the linkage between CEC and geobotany is analysed in terms of regression analysis.

Figure 5.6 demonstrates that boreholes in geobotanical communities generally have much higher yields than those of the average borehole in the geological formation when geobotanical influences or relationships between geobotany, geohydrology, geochemistry, geophysics and geology were not considered when siting a borehole. In addition, Figure 5.7 presents the significance of the number of geobotanical species encountered at a site when drilling a borehole with a reasonable yield. Note the huge difference in average yield between sites with

no geobotanical indicators and those with only one geobotanical indicator. The number of species encountered does not play a vital role in the increase of the borehole yield.

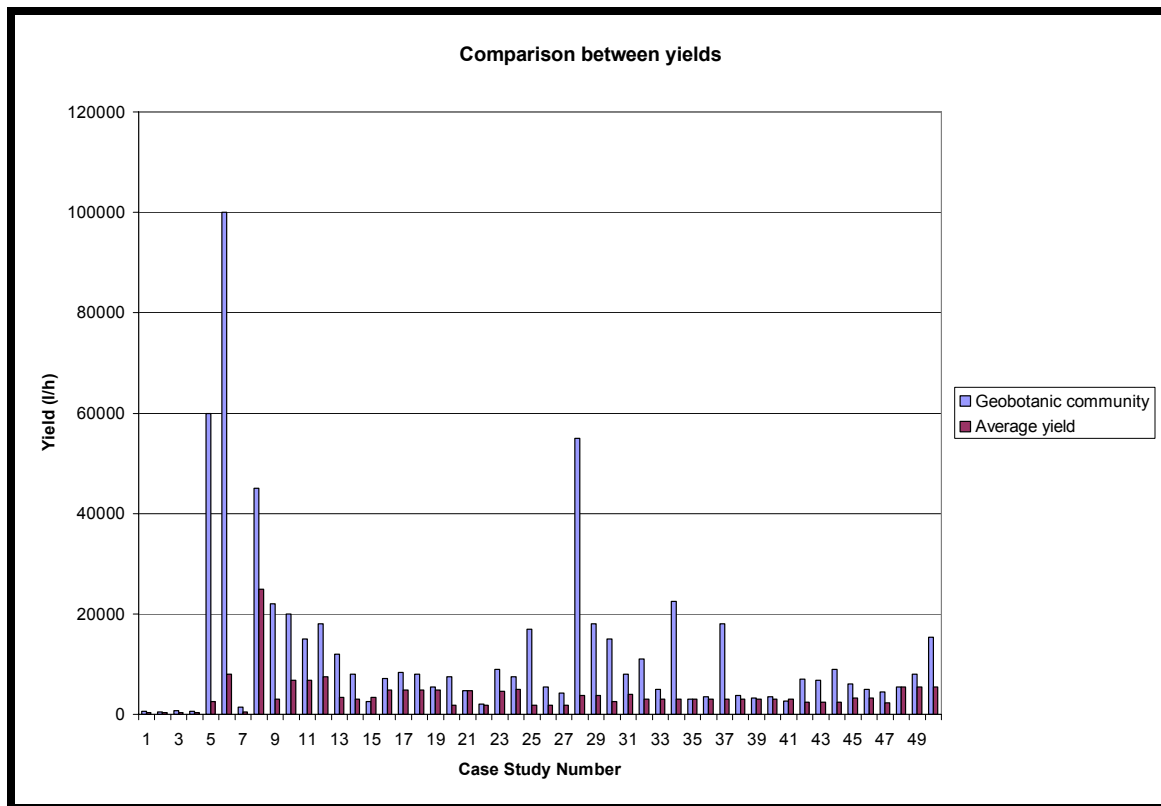


Figure 5.6. Comparison between the borehole yield at the geobotanical community and the average yield of the geological formation for every case study ($n = 50$).

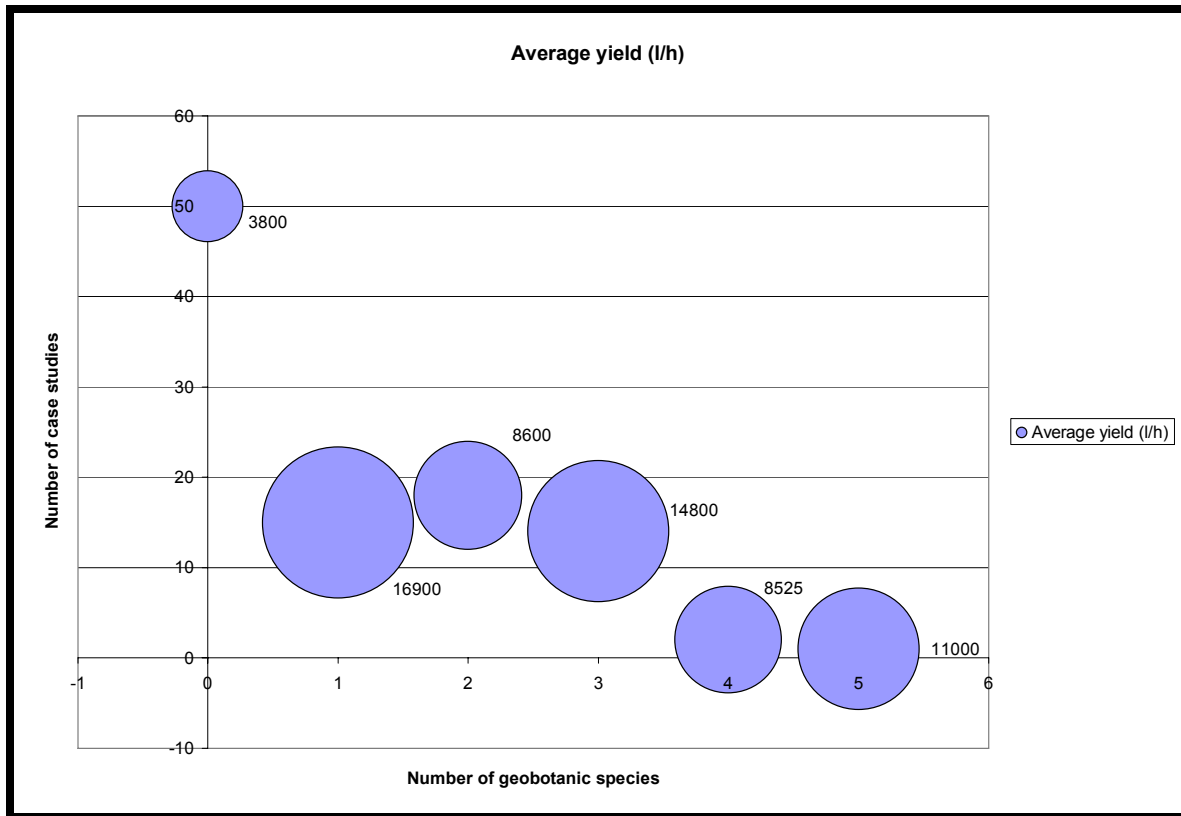


Figure 5.7. Importance of the geobotanical species encountered in order to site a borehole with a reasonable yield. The average yield is that for all boreholes included in the indicated group as classified under the number of geobotanical species noted. The size of the circle reflects the average yield for the group with the average yield indicated next to the circle ($n = 50$).

5.3.2 Regression analysis

Regression analysis is concerned with the study of the dependence of one variable, the dependent variable, on one or more other variables, the explanatory variables, with a view to estimating and/or predicting the population mean or average value of the former in terms of the known or fixed values of the latter (Gujarati, 2003).

The following theoretical background is provided by Koop (2000) and Gujarati (2003), unless otherwise indicated. Regression line equation:

$$Y = \alpha + \beta X_1$$

where α = intercept of the linear regression line and

β = slope of the regression line

Y = dependent variable

X = explanatory variable

The explanatory variable causes Y, and the coefficient β measures the influence of X on Y. In addition, if β is positive, then X and Y are positively correlated and *vice versa*.

In the current study one explanatory variable with real values has been employed:

- Groundwater yield (actual value of borehole yield).

The measure of fit regarding the regression line is referred to as R^2 , otherwise the proportion of the total variance of Y that can be explained by X is measured by R^2 . This relates closely to the correlation between Y and X. In fact, for the simple regression model, the correlation is squared. This provides the formal statistical link between regression and correlation. The proportion of the total variance of Y that can be explained by X is measured by R^2 . A good fit is indicated by a R^2 value close to 1 and a bad fit is indicated by a R^2 value close to 0. In addition, the fit has to be significant ($R^2 \neq 0$) in order to determine whether X has any explanatory power for Y. This test of the hypothesis $R^2 = 0$ can be interpreted as a test of whether the regression explains anything at all and is expressed by the F-statistic value. Large values of F indicate $R^2 \neq 0$ while small values (for this study an F value less than 3, see Gill (1978)) indicate $R^2 = 0$. The probability of the F-value is indicated by the P-value of the F-statistic value (probability F-statistic) and implies:

1. If significance F is less than 5% (0.05), then $R^2 \neq 0$.
2. If significance F is greater than 5% (0.05), then $R^2 = 0$.

Furthermore, it is important to calculate a confidence interval for β . This interval reflects the uncertainty surrounding the accuracy of the estimate of β . If the confidence interval is small (<0.05), it indicates accuracy. Conversely, a large confidence interval indicates great uncertainty regarding the true value of β . The mathematical formula for the confidence interval for β is:

$$[\beta - t_b s_b, \beta + t_b s_b]$$

The value s_b represents the standard deviation or error of β . Large values of s_b will imply large uncertainty. In this case, β may be a very inaccurate estimate of the real β . In contrast, small values of s_b will imply small uncertainty and β will be an accurate estimate of the real β .

The value t_b represents a value taken from statistical tables for the Student-*t* distribution and exhibits the following characteristics:

1. t_b decreases with N (the number of data points). This implies that the greater the number of data points, the smaller the confidence interval will be.
2. t_b increases with the level of confidence one chooses.

In order to determine whether X really explains the dependent variable, Y , then $\beta \neq 0$. To test this hypothesis, a test statistic has to be calculated, or t -statistic to calculate whether $\beta = 0$:

$t = \beta/s_b$. Large values of t indicate that $\beta \neq 0$, while small values indicate that $\beta = 0$. The measure of the magnitude of t is indicated by the P -value or probability/significance that $\beta = 0$. If the P -value is low, $\beta = 0$ is unlikely to be true. Accordingly,

1. If the P -value is less than 5% (usually written as 0.05 by the computer programme), then t is large and $\beta \neq 0$;
2. If the P -value is greater than 5% then t is low and $\beta = 0$; and
3. A large t -value implies that the absolute value of t is greater than 1.96 ($|t| > 1.96$).

In cases where more than one explanatory variable predicts the outcome of the dependent variable, multiple regression must be employed. Multiple regression extends simple regression (one explanatory variable) to the case of many explanatory variables ($X_1, X_2, X_3, \dots, X_i$). In the present some of the explanatory variables were replaced with dummy variables that take one of two values, either 0 or 1. A zero (0) implies “no” and a one (1) implies “yes”. Typical dummy variables used in the research include:

- Geology (is there an intrusion, palaeo-channel or weathered basin present; yes = 1 and no = 0);
- Geophysical anomaly (significant anomaly observed that indicates the presence of groundwater; yes = 1 and no = 0); and
- Geobotany (represents the groundwater occurrence linked to the geobotanical species mentioned in the research; yes = 1 and no = 0).

The data was treated in three ways:

1. Linear relationships between geobotany as the dependent variable and the explanatory variables defined by groundwater, geophysical anomaly and geology.
2. Linear relationships between CEC as the dependent variable and the explanatory variables defined by groundwater, geology, geobotany and geophysical anomaly.
3. A correlation between CEC and geobotany so as to investigate collinearity problems between these parameters.

The selection of explanatory variables is based on the fact that in the absence of geological features that can be detected by a geophysical apparatus, and where these geological features are responsible for geohydrological conditions favourable to host groundwater, no geobotanical indicators relating to groundwater occurrences or CEC differences can be observed. Hence, geobotany and CEC are dependent variables (they exist owing to the presence of a geological feature or groundwater). In certain cases geobotany was included as a dummy explanatory variable in order to determine its influence on CEC, but only in association with geology and groundwater in order to classify or group them as geobotanical and non-geobotanical communities. CEC real values were excluded from the explanatory variables, where it was based on the fact that CEC cannot be the source of groundwater and/or geological features detectable by means of geophysics. CEC values are rather a cause or a result that can serve as an indicator.

Table 5.3. Regression analysis of the case study data.

Sample points & Area	Dependent (Y)	Intercept A-value	Explanatory variable X ₁ 's β_1 -value	Explanatory variable X ₂ 's β_2 -value	R ²	F-statistic	Probability F-statistic	Standard Error: α β_1 β_2	t-statistic: α β_1 β_2	Probability/significance: α β_1 β_2	Verdict
100 All case studies	Geobotany	0.398	1.24E-05 Groundwater, Geology, Anomaly	-	0.109	12.0356	0.001	0.056 3.56E-06	7.115 3.469	0.000 (100%) 0.001 (100%)	In In
100 All case studies	CEC	10.477	-2.97E-05 Groundwater	7.631 Geology, Anomaly, Geobotany	0.090	5.890	0.004	1.560 8.55E-05 2.286	6.715 -0.348 3.337	0.000 (100%) 0.729 (27%) 0.001 (100%)	In Out In
8 Case studies 1-4 (Limpopo)	Geobotany	-0.943	0.003 Groundwater, Geology, Anomaly	-	0.813	26.112	0.002	0.296 0.001	-3.187 5.110	0.019 (98%) 0.002 (100%)	In In
8 Case studies 1-4 (Limpopo)	CEC	-10.631	0.048 Groundwater	0.070 Geology, Anomaly, Geobotany	0.889	29.110	0.002	5.487 0.015 4.614	-1.938 3.284 0.015	0.110 (89%) 0.022 (98%) 0.988 (1%)	In In Out
40 Case studies 5-24 (Vaalium)	Geobotany	0.386	9.72E-06 Groundwater, Geology, Anomaly	-	0.125	5.424	0.025	0.090 4.17E-06	4.267 2.324	0.000 (100%) 0.025 (97%)	In In
40 Case studies 5-24 (Vaalium)	CEC	12.093	-4.82E-05 Groundwater	7.244 Geology, Anomaly, Geobotany	0.013	1.251	0.298	3.126 0.000 4.613	3.869 -0.380 1.570	0.000 (100%) 0.706 (29%) 0.125 (87%)	Out Out Out

10 Case studies 5,7,13-15 (Quartzite)	Geobotany	0.382	1.22E-05 Groundwater, Geology, Anomaly	-	0.174	1.684	0.231	0.185 9.40E-06	2.068 1.298	0.072 (93%) 0.231 (77%)	Out Out
10 Case studies 5,7,13-15 (Quartzite)	CEC	5.654	-0.001 Groundwater	19.828 Geology, Anomaly, Geobotany	0.070	1.336	0.322	7.866 0.000 12.157	0.719 -0.579 1.631	0.496 (50%) 0.581 (42%) 0.147 (85%)	Out Out Out
6 Case studies 6,8,9 (Dolomite)	Geobotany	0.429	1.26E-05 Groundwater, Geology, Anomaly	-	0.408	8.348	0.032	0.053 3.67E-06	2.116 3.448	0.042 (96%) 0.018 (98%)	In In
6 Case studies 6,8,9 (Dolomite)	CEC	9.733	-2.60E-05 Groundwater	4.694 Geology, Anomaly, Geobotany	- 0.129	0.715	0.557	2.365 6.55E-05 4.258	4.115 -0.398 1.102	0.026 (97%) 0.718 (28%) 0.351 (65%)	Out Out Out
8 Case studies 16-19 (Lydenburg)	Geobotany	-1.238	0.001 Groundwater, Geology, Anomaly	-	0.712	14.858	0.008	0.464 7.47E-05	-2.668 3.855	0.037 (96%) 0.008 (99%)	In In
8 Case studies 16-19 (Lydenburg)	CEC	-17.522	0.007 Groundwater	-15.460 Geology, Anomaly, Geobotany	0.192	1.834	0.253	18.225 0.004 10.847	-0.961 1.889 -1.425	0.381 (62%) 0.118 (88%) 0.213 (79%)	Out Out Out
10 Case studies 10-12,23,24 (Mafic)	Geobotany	-0.201	7.00E-05 Groundwater, Geology, Anomaly	-	0.544	9.558	0.015	0.256 2.26E-05	-0.784 3.092	0.456 (54%) 0.015 (98%)	Out In
10 Case studies 10-12,23,24 (Mafic)	CEC	8.447	0.002 Groundwater	-11.930 Geology, Anomaly, Geobotany	- 0.038	0.837	0.472	12.459 0.002 16.569	0.678 1.257 -0.720	0.520 (48%) 0.249 (75%) 0.495 (50%)	Out Out Out

6 Case studies 20-22 (Rhyolite)	Geobotany	0.077	0.001 Groundwater, Geology, Anomaly	-	0.226	1.170	0.340	0.449 1.04E-04	0.170 1.081	0.873 (13%) 0.340 (66%)	Out Out
6 Case studies 20-22 (Rhyolite)	CEC	5.289	1.63E-05 Groundwater	4.252 Geology, Anomaly, Geobotany	0.654	5.735	0.094	1.296 3.42E-04 1.438	4.080 0.048 2.956	0.027 (97%) 0.965 (3%) 0.060 (94%)	In Out In
10 Case studies 25-29 (Granite)	Geobotany	0.301	1.77E-05 Groundwater, Geology, Anomaly	-	0.307	3.548	0.096	0.181 9.39E-06	1.660 1.884	0.136 (86%) 0.096 (90%)	Out Out
10 Case studies 25-29 (Granite)	CEC	10.383	5.40E-05 Groundwater	1.373 Geology, Anomaly, Geobotany	- 0.246	0.112	0.895	4.072 2.19E-04 6.852	2.550 0.247 0.200	0.038 (96%) 0.812 (19%) 0.847 (15%)	Out Out Out
6 Case studies 25-27 (Granite: Warmbad)	Geobotany	0.173	6.11E-05 Groundwater, Geology, Anomaly	-	0.435	3.076	0.154	0.265 3.48E-05	0.652 1.754	0.550 (45%) 0.154 (85%)	Out Out
6 Case studies 25-27 (Granite: Warmbad)	CEC	4.401	5.91E-05 Groundwater	5.057 Geology, Anomaly, Geobotany	0.882	19.750	0.019	0.648 1.08E-04 1.164	6.789 0.548 4.346	0.007 (99%) 0.622 (38%) 0.023 (98%)	In Out In
4 Case studies 28-29 (Granite: Verena)	Geobotany	0.125	1.86E-05 Groundwater, Geology, Anomaly	-	0.610	3.134	0.219	0.306 1.05E-05	0.408 1.770	0.723 (28%) 0.219 (78%)	Out Out

4 Case studies 28-29 (Granite: Verena)	CEC	20.555	-2.70E-04 Groundwater	6.400 Geology, Anomaly, Geobotany	- 1.314	0.148	0.878	9.904 5.25E-04 21.994	2.075 -0.515 0.291	0.286 (71%) 0.698 (30%) 0.820 (18%)	Out Out Out
24 Case studies 30-41 (Mogolian sandstone)	Geobotany	0.237	4.64E-05 Groundwater, Geology, Anomaly	-	0.242	7.037	0.015	0.136 1.75E-05	1.748 2.653	0.094 (91%) 0.015 (98%)	In In
24 Case studies 30-41 (Mogolian sandstone)	CEC	4.836	-1.27E-04 Groundwater	8.592 Geology, Anomaly, Geobotany	0.419	9.279	0.001	1.452 2.02E-04 2.137	3.331 -0.632 4.020	0.003 (100%) 0.534 (47%) 0.001 (100%)	In Out In
18 Case studies 42-50 (Karoo)	Geobotany	-0.062	1.01E-04 Groundwater, Geology, Anomaly	-	0.390	10.217	0.006	0.201 3.17E-05	-0.308 3.196	0.762 (24%) 0.006 (99%)	Out In
18 Case studies 42-50 (Karoo)	CEC	9.652	0.002 Groundwater	1.005 Geology, Anomaly, Geobotany	0.305	4.729	0.026	4.121 8.29E-04 5.107	2.342 2.275 0.197	0.033 (97%) 0.038 (96%) 0.847 (15%)	In In Out

The following table indicates that no collinearity problem exists between geobotany and CEC since 0.327 is far from 1.000. Collinearity refers to the existence of a perfect or exact linear relationship among some or all explanatory variables, and as a result, R^2 values will be close to 1 (Gujarati, 2003). As a result, CEC and geobotany, generally, do not influence one another in certain interactions. This was proven in the present study since some variations were sampled in CEC values at geobotanical communities that, at times, were lower than those analysed at non-geobotanical communities. This is an important finding, because geobotany can now be employed to explain the existence (dependency) of CEC.

Table 5.4. Correlation between geobotany and CEC.

	Geobotany	CEC
Geobotany	1.000	0.327
CEC	0.327	1.000

The following relationships between geological features (mafic intrusions, faults, weathered basins and palaeo-channels), geochemical values (CEC), geohydrological information (borehole yield), geophysical anomalies (indicating the abovementioned geological features and/or water-bearing strata) and geobotanical species (those listed in the current study and Table 5.2) are statistically proven with respect to the case study area:

(*Note that “significant” implies 95% probability/confidence unless otherwise stated and the correlation value (R^2) is mentioned every time.)

- Regarding all the case studies combined, a significant (>95%) correlation of 11% was calculated between geobotany (dependent variable) and groundwater, geology and a geophysical anomaly (explanatory variables). The low correlation value (11%) indicates that the explanatory variables of the regression contribute only 11% to the correlation. The remaining 89% could be influenced by values such as porosity, permeability, climate, geomorphological conditions, etcetera. This significant regression is of critical importance to the present research since it proves that a significant correlation or relationship exists between certain identified geobotanical species, geological features, borehole yield and geophysical anomalies. Table 5.4 indicates that some interaction exists between geobotany and CEC, in other words, geobotanical sites may exhibit higher CEC

values. The sample number of 100 data sets will be divided into geological groupings in order to identify significant correlations where the explanatory variables have a higher net contribution.

- For all the case studies combined, a significant (>95%) correlation of 9% was calculated between CEC (dependent variable) and geology, geophysical anomaly and geobotany (explanatory variables). No significant correlation between CEC and groundwater exists. If groundwater is not included in the multiple regressions as an explanatory variable, then the correlation increases to an 11% influence of the explanatory variables on the dependent variable (data analyses not referenced in Table 5.3).
- The case studies representing the Limpopo Granulite-Gneiss Belt indicate two important correlations:

- o A significant correlation of 81% exists between identified geobotanical species and groundwater, geology and the resulting geophysical anomaly. According to the regression line equation:

$$Y_{\text{geobotany}} = -0.943 + 0.003X_{(\text{groundwater, geology, anomaly})} \quad (5.2)$$

the higher the yield of the aquifer (borehole yield) in the presence of a geological feature, as previously mentioned (such as a mafic intrusion) and indicated by a geophysical anomaly, the greater the likelihood that these features will be indicated by at least one geobotanical indicator as listed for that area.

- o A significant correlation of 89% exists between the analysed CEC values and groundwater. The β -value indicates that the correlation between CEC and groundwater is positive, which implies that higher CEC values measured (normally at the geobotanical site), will be a function of higher yielding boreholes. In such a case, a direct link between CEC and groundwater exists. With the previous regression in mind, a distinct dependency is present in such a geological setting between groundwater, geology and the resulting geophysical anomaly on the one hand and geobotanical indicators and CEC on the other.
- The case studies representing the Vaalium Eonothem indicate that a significant correlation of 12% exists between the identified geobotanical species of this geological grouping and groundwater, geological features and identified geophysical anomalies. It can thus be stated that the occurrence of groundwater,

in association with geologic features presented in the study (mafic intrusions, palaeo-channels, weathered basins and possible faults) with an anomalous signature on a geophysical profile and/or sounding, indicates the presence of a geobotanical indicator(s) as listed in the current research. A higher significant correlation (>60%) can be obtained if other parameters are included, but these are unknown at present.

- Dolomite indicates a significant correlation of 41% when groundwater, geology and geophysics constitute are the explanatory variables, and the geobotanical species represent the dependent variable. Thus groundwater, geology and geophysics alone explain 41% of the occurrence of geobotanical species on dolomite. Furthermore, as the β -value is positive, it is indicative that higher yielding boreholes have a greater probability that they will be associated with at least a geobotanical indicator as long the groundwater is associated with intrusive bodies or weathered basins (as presented in the case studies) that are noticeable on geophysical data.
- In the Lydenburg district (shale and quartzite of the Pretoria Group), a significant correlation (71%) is calculated between the geobotanical species of this area (dependent variable) and groundwater, geology and geophysics (explanatory variables). Once again, the groundwater and geology (detected by geophysical exploration) allow the occurrence of geobotanical species in this area.
- Mafic intrusions among mafic rocks indicate that a significant correlation (54%) exists between geobotany and groundwater, geology (mafic intrusions) and geophysical anomalies. However, the intercept value of the calculated regression line is not significant (54% significant) and cannot be used to fit a linear regression line with the data set. Since the β -value bears significance, the slope of the regression line is known and it can be stated that the mafic intrusions among mafic rocks that yield above average groundwater and are detected by geophysical methods are more likely to be indicated by at least one geobotanical indicator.
- Regarding rhyolite of the Vaalium Eonothem, a significant ($\geq 94\%$) correlation of 65% exists between the dependent variable CEC and the explanatory variables of geology, geophysical anomaly and geobotany. The regression is positive. This means that geobotanical communities and geological features that are detectable by means of geophysical exploration methods contribute to higher CEC values at

the localities where geobotanical species and geological features occur. This is certainly a function of geochemical weathering where the weathered mafic and rhyolite rocks define different CEC values at each site. No significant correlation between groundwater (explanatory variable) and CEC exists which indicates that groundwater occurrence does not play a vital role in the rhyolite environment to boost CEC values. It is true that the occurrence of groundwater is dependent on geological conditions.

- Granite in the Warmbad area has a significant correlation (88%), which indicates that CEC in this granite environment is positively influenced by geology, geophysical anomaly and geobotany. This demonstrates the role that geochemical weathering of the rock plays (and maybe nutrient cycling through trees) in establishing different CEC values among different rocks, based on their chemical composition.
- The Waterberg Group has two significant correlations:
 - o Geobotany (dependent variable) is significantly 24%, which can be explained by the occurrence of groundwater, geology and the geophysical identification of the two previously mentioned variables in this geological environment.
 - o CEC (dependent variable) is significantly 42%, which can be explained by the occurrence of geology, a geophysical anomaly that explains the geology and geobotanical indicator(s). Thus, it is evident that geobotany and CEC feature strongly in the Waterberg Group owing to the variations in geology and groundwater occurrence.
- Similar to the Waterberg Group, the Karoo Supergroup researched also has two significant correlations of the same dependent variables, but different explanatory variables of a different magnitude:
 - o Between geobotany and geology, groundwater and geophysical anomaly, is 39%.
 - o Between CEC and groundwater, is 30%. This indicates that the composition of the groundwater will rather influence CEC values than the geology (the norm in most other cases). Furthermore, this can be a function of rooting depth and water tables (especially the presence of shallow perched aquifers).

No significant correlations were obtained for:

- o Between CEC (dependent variable) and groundwater, geology, geophysical anomaly and geobotany in the Vaalium Eonothem.
- o For all the quartzite related case studies. This implies that the search for geobotanical indicators among quartzite outcrops is not statistically significant and more data points might alter the situation. Nevertheless, certain case studies of the current undertaking indicate a lower than average yield for the formation obtained at the geobotanical community, yet a successful borehole in an aquifer poor area was sited. Therefore, groundwater exploration on a property continues to rely on geology, geophysics and geobotany to ensure success compared to other sites with the same conditions. Data sets restricted to a certain outcrop might yield significant correlations.
- o Between CEC (dependent variable) and groundwater, geology, geophysical anomaly and geobotany in the dolomite of the Vaalium Eonothem.
- o Between CEC (dependent variable) and groundwater, geology, geophysical anomaly and geobotany in the Lydenburg district, although almost a significant contribution of groundwater to CEC is made. More case studies can strengthen this contribution.
- o Between CEC (dependent variable) and groundwater, geology, geophysical anomaly and geobotany in mafic intrusions among mafic rocks.
- o Between geobotany and groundwater in a rhyolite environment.
- o All the granite related case studies. When broken up in outcrop related case studies, some significant correlations in the Warmbad area became evident. The case studies of the Verena area (only 4 references) did not indicate any significant correlations and may be the result of differences in groundwater yield owing to the presence of palaeo-channels close to the Wilge River and mafic intrusions that are not in contact with these water-bearing features and therefore yield less groundwater. A larger data set could alter the outcome of the correlation.

5.3.3 Statistical data interpretation

The statistical treatment of the data indicates the following conclusions and remarks regarding the relationships between geological, geochemical, geohydrological, geophysical and geobotanical features:

- Table 5.1 listed geobotanical species identified in certain geological formations. Most of the listed geobotanical sites had borehole yields in excess of the average yield for that formation, which is an indication that geobotanical indicators are generally associated with aquifers that yield substantially more groundwater than the average known yield of the geological formation. Since there are a few exceptions, these exceptions will reduce the fit value of the regression line ($R^2 < 1$).
- The importance of CEC at geobotanical communities is indicated in Table 5.2. Only CEC values can offer a clear indication of the geobotanical communities or their association with aquifers. CEC values are important if no geobotanical communities are observed, like in a cleared field. However, variations in CEC occur and some higher CEC values are not linked to geobotanical communities. This phenomenon will reduce the fit of the regression line ($R^2 < 1$).
- The pie diagrams (Figure 5.2) indicate the distribution of CEC-values (see Table 5.2) among the geobotanical and non-geobotanical communities. These diagrams clearly indicate that geobotanical communities benefit from larger CEC-values.
- The distribution of the borehole yields at the geobotanical communities, compared to the average yield of the particular geological formation, is presented in Figure 5.3. This graph illustrates that boreholes in geobotanical communities tend to yield between 151-300% more than the average yield of the geological formation in the north-eastern parts of South Africa.
- The two figures, 5.4 and 5.5, clearly indicate that the group of CEC values in excess of 15 cmol+/kg are associated with 55% of the boreholes in geobotanical communities that yield between 151-300% above the average borehole yields of aquifers of geological formations in the north-eastern parts of South Africa. Although CEC values in excess of 15

cmol+/kg are also associated with boreholes not associated with geobotanical communities, they usually yield between 1000-3000 l/h and less than the yields obtained at the geobotanical communities. This is an indication that CEC is an important indicator for aquifers with an above average yield. Note that CEC is an indicator and cannot be used on its own. The guidance of geology, geobotany and geophysics is advised.

- Figure 5.6 demonstrates that boreholes in geobotanical communities generally have somewhat higher yields than the average borehole yield of the particular geological formation where the geobotanical influences or relationships between geobotany, geohydrology, geochemistry, geophysics and geology were not considered when siting the boreholes.
- In addition, Figure 5.7 presents the significance of the amount of geobotanical species encountered at a site when drilling a borehole with a reasonable yield. A huge difference in average yield exists between the sites where no geobotanical indicators occur and those with only one geobotanical indicator. The number of species encountered does not play a vital role in increasing the borehole yield.
- The regression analysis demonstrated the existence of a significant dependency of geobotanical indicators and/or CEC on groundwater, geology and geophysical anomalies. In certain geological formations the dependency is exceptional by achieving R^2 values above 65% (Limpopo Granulite-Gneiss Belt, Lydenburg district (shale and quartzite of the Pretoria Group), rhyolite of the Vaalium Eonothem and granite in the Warmbad area). Variations in the R^2 values is primary a function of the variations measured amongst the borehole yield values between the geobotanical and non-geobotanical communities since these variables carried real values and the others were dummy variables. Larger data sets focussing on small areas might yield significant regressions with $R^2 \approx 1$.
- It is evident that the objective of the present study has been achieved since geophysical (geohydrological)-geobotanical relationships occur in the north-eastern parts of South Africa. This is proven by the regression analysis. Geobotany and CEC is dependent on geology, groundwater and geophysical responses, where the geophysics is a reflection of the

geology and groundwater. In certain cases a strong linkage exists between the geobotanical indicators and CEC values, as in the Limpopo Granulite-Gneiss Belt, Waterberg Group and Karoo Supergroup.

5.4 GEOPHYSICS

The study of the existence of geobotanical indicators based on geological and geohydrological criteria cannot be complete without the inclusion of certain geophysical profiling and sounding methods in order to obtain an image of the sub-surface. Geobotanical indicators are linked to weathered geological entities in the sub-surface that create aquifer conditions. Geophysical methods can identify such geological entities. The drilling of boreholes proves the existence of aquifers and if substantial yields are obtained compared to the average yield of such an aquifer, then botanical species indicate the occurrence of favourable groundwater localities based on certain geological (hence geobotanical) conditions. Geophysical methods incorporated in this study include electromagnetic profiling (Genie-SE88, EM-34-3), magnetic profiling (Geotron G4 proton magnetometer) and Schlumberger soundings (Geotron G41 resistivity meter). Profiling is conducted perpendicular to the strike of the anticipated structural bodies to be measured and soundings are laid out parallel to the strike of the geological formation. The equipment is easy to operate and readily available. Exploration costs are relatively inexpensive compared to other methods and is supported by geobotanical indicators that can increase the success rate when drilling a borehole that yields a substantial quantity of water: thus the economical cost of geophysical groundwater exploration decreases. Furthermore, particular laymen in the field also refer to geobotanical indicators, however, they do not understand the clear interaction between botany-geology-geohydrology and the divining device. The purpose of science is to understand and explore and liquidate grey, misty or hocus-pocus notions. The existence of geobotanical indicators and their value in the field regarding groundwater exploration is indicated and proven by means of the identification of botanic species, soil sampling and geochemical analysis, geohydrological properties and geophysical exploration. The attainment and fulfilment of this objective, significantly contributes to the scientific understanding of certain aspects of water-divining in terms of traditional knowledge.

5.5 GUIDELINES

5.5.1 Soil quality

The use of soil samples in predicting groundwater resources must be applied with extreme care because soil samples must be representative of the geological environment under investigation. This implies that soil samples of one geological environment can not be easily compared with those from another geological environment. This was one of the reasons why a higher R^2 -value for particular geological formations was obtained in comparison to the R^2 -value for all the geological formations combined. Climatic conditions and geomorphological changes must also be taken into account. Therefore, the quality of the results of the soil samples are site specific. Differences in soil quality from a specific site can be attributed mostly to changes in the underlying geology that constitutes varying quantities of cations and anions released through weathering of the original rock throughout the soil profile. The chemical composition of the mafic rock also varies from area to area and defines different nutrient levels in the weathered rock and soil. In certain cases, groundwater also influences the CEC (soil quality) since the groundwater carries cations that are absorbed by plant roots and become part of the nutrient recycling process in the soil profile. According to Table 5.2 it can generally be stated that pH-values above 6 are representative of geobotanical communities. However, in soils that tend to be acidic (soils derived from quartzite for example), pH-values lower than 6 can be associated with geobotanical communities, but the pH-value of the geobotanical community tends to be higher than the soil samples taken at non-geobotanical sites. Higher pH-values are derived from the weathering of the mafic rock intrusions since more minerals are exposed to the weathering process, whereof Ca is the most crucial one.

The results presented in Table 5.2 further indicate that geobotanical communities possess elevated concentrations of the following elements compared to the surrounding commonly vegetated areas: Ca, Mg, K, Na, Fe, Mn, Zn, increased concentrations of organic carbon, total N, CEC and lower resistivity and Al-values.

Phosphorous and sulphur present pitfalls when establishing groundwater occurrences solely based on quality analysis of soil samples. Phosphorous levels of the soil are dependent on the pH of the soil and the content of the organic matter.

The relationship between the existence of geobotanical communities and CEC-values is the most profound and recommended for use in the field as an indicator for geobotanical communities and hence groundwater occurrences (see Figure 5.2). Since this study embraces various scientific disciplines, it is strongly advised that the determination of groundwater occurrences cannot solemnly be based on soil quality analysis and must include geophysical measurements and geobotanical observations. The quality of the soil is an indication of the underlying rock that cannot always be visually established while the soil is a thin representation of the upper part of the interior of the earth. Soils with the highest CEC-values can be considered as preferred target areas for groundwater exploration because the soil is rich in cations and anions resulting from the weathering of the underlying mafic rock and conducive to root and plant growth. Normally one would observe denser vegetation in such a spot, or vegetation of a different kind and a lower frequency of occurrence compared to the surrounding veld. CEC is a useful tool in situations where the natural vegetation has been cleared. Sampling soil with the purpose of analysing CEC values can be undertaken at areas identified on aerial photographs and on the surface by observing geological features and/or geophysical anomalies.

5.5.2 Geophysical methods, anomalies and geobotanical indicators

The study used the following geophysical methods: electromagnetic profiling (Genie-SE88, EM-34-3), magnetic profiling (Geotron G4 proton magnetometer) and Schlumberger soundings (Geotron G41 resistivity meter). The selection of these apparatus was based on (1) groundwater exploration effectiveness, (2) availability and (3) cost. The case studies only presented profiles and soundings applicable to the geobotanical communities since this was the main objective of the research. All the geophysical field data was not presented since this will encompass too much data of little importance to the objective of the present research. However, in performing geophysical exploration, more than one traverse has to be laid out in order to understand the strike of the geological phenomena, the dip and weathering profile. The

following are guidelines regarding when this equipment is utilised for groundwater exploration in the area of research:

1. Electromagnetic profiling (Genie-SE88):

- Used in the Limpopo Granulite-Gneiss Belt in previous studies and proven to be of valuable assistance.
- Will detect anomalies with greater ease if the resistivity of the weathered layer or rock surrounding the aquifer is less than 100 $\Omega\cdot\text{m}$ (Vegter, 2001b).
- Absence of an inter-connecting cable, levelling of coils and freedom from noise owing to errors in coil position or orientation makes it a suitable electromagnetic exploration method in bush and rocky areas.
- As a profiling technique.
- Able to detect sheet-like aquifers and other conductive zones that act as electrical conductors and are detectable by the machine.
- The presence of magnetite quartzite makes the application of the some other methods useless.
- Exploration targets are defined by a drop in ratio and/or a lower amplitude frequency ratio with regards to the rest of the data points on the profile.
- Since readings are plotted as they come up on the instrument, decisions can be made quickly regarding the placement of markers and/or drilling targets. Erroneous readings can be easily recognised and rectified (re-sampled) which increases the accuracy of the profile.
- Unfortunately, this instrument is heavy (difficult to move around) and not readily available.

2. Electromagnetic profiling (EM-34-3):

- Preference was given to a contrasting HD-VD reading, with HD $\gg$ VD in either a conductive or resistive environment. The horizontal dipole is a representation of weathering basins or contacts, whereas the vertical dipole indicates less weathered, vertical structures.
- The receiver indicates the accuracy of the coil orientations and separation distance and reduces reading errors. The machine is more sensitive to the misalignment of the coils in a resistive (low mS/m values) than a conductive terrain. However, in a terrain with a conductive overburden, the EM-34-3 might shadow (not detect) underlying aquifers.

- Profiling technique.
 - Able to detect sheet-like aquifers and other conductive zones that act as electrical conductors and are detectable by the machine: notably mafic intrusions and weathering zones.
 - Difficult to operate in bush and rocky terrain owing to the coil separation and interconnecting cable.
 - Since readings are plotted as they appear on the instrument, decisions can be made quickly regarding the placement of the markers and/or drilling targets. Erroneous readings can be easily recognised and rectified (re-sampled) which increases the accuracy of the profile.
 - Readily available and not as heavy as the Genie-SE88.
3. Magnetic profiling (Geotron G4 proton magnetometer):
- Light, easily obtainable and can be operated by only one person.
 - Quick profiling technique able to distinguish between rocks that differ in magnetite content (chemical composition). Mafic intrusions are normally high in magnetite compared to the surrounding rock and are easy detectable.
 - Mafic intrusions decompose at the contact zone with the surrounding rock in clay, boulders and fragmented pieces that serve as an aquifer. These water-bearing contact zones can be inferred from the magnetic profile but more easily identified on the electromagnetic profile which deals with conductivity.
 - An increase in the magnetic intensity of the rock is indicated by an increase in the measured nano-tesla value. Contact zones are demarcated by a decrease in nano-tesla values immediately before the values begin to incline.
 - Since readings are plotted as they appear on the instrument, decisions can be made quickly regarding the placement of the markers and/or drilling targets. Erroneous readings can easily be recognised and be rectified (re-sampled) which increases the accuracy of the profile.
 - Cannot be used where the rock is inherently magnetic.
4. Schlumberger soundings (Geotron G41 resistivity meter):
- Straightforward methods employed to investigate sub-surface conditions at a particular point. Interpretation can be carried out *in situ*.
 - Since readings are plotted as they appear on the instrument, decisions can be made quickly regarding the placement of the markers and/or drilling

targets. Erroneous readings can be easily recognised and rectified (re-sampled) which increases the accuracy of the profile.

- As a sounding technique, the electrode layout must be parallel to the strike of the formation.
- Requires at least three people to operate.
- Difficult to employ in bush and rocky terrain since visibility and electrode soil penetration is limited and increases electrode effects that reflect as faulty readings and presents interpretation difficulties (fit of a sounding model curve). The cable can also be damaged by vegetation and/or rock which increases noise.
- The resistivity technique is used to map boundaries between layers with different conductivities as an electrical current at low frequencies flows through the earth materials and the response thereof is measured.
- Lower resistivities (possible aquifers) are indicated through conductive layers in bowl shaped and descending curves (respectively K- and Q-type).
- A sounding's current can penetrate deeper if it moves downward from a conductive to a resistive layer (obtain a deeper resistivity model). Hence, conductive layers between resistive layers are detectable, if these layers have sufficient thickness and contrasting resistivity values (principles of equivalence and suppression).

Other geophysical methods, such as the gravimetric and seismic techniques are not discussed because these were not utilised owing to their difficulty to operate in bush and rocky terrain, their availability is restricted and the high cost (especially in data treatment and interpretation). If a specific method is firstly cumbersome in obtaining readings/data and secondly one cannot make a reasonable interpretation in the field with ease, its use becomes questionable because often, decisions have to be made on site. Costly methods will not easily find acceptance amongst the clients of groundwater exploration practitioners.

Geophysical exploration is enhanced by the utilisation of aerial photographs of the exploration area in order to search for significant geological features that could serve as aquifers (see the annexure). These features include lineaments, palaeo-channels, faults, fracture zones and others. An understanding of the local geology is always necessary in

order to limit electrode effects and to plan the direction of profiles in order to cross certain geological features.

With the abovementioned in mind, it is important to list the identified geobotanical indicators for each geological formation (Table 5.5). All these methods will aid in the location of a drilling site.

Table 5.5. Geobotanical indicators associated with geological formations. The geobotanical indicators that warrant further study regarding their geobotanical-geohydrological importance are indicated in brackets.

Lithology	Geobotanical indicators
Limpopo Granulite-Gneiss Belt	<i>Adansonia digitata</i> <i>Combretum imberbe</i> <i>Ximenia americana</i> & <i>X. caffra</i> (<i>Commiphora mollis</i>) (<i>Pappea capensis</i>)
Vaalium Eonothem: Malmani Subgroup dolomite	<i>Acacia karroo</i> <i>Celtis Africana</i> <i>Euclea crispa</i> <i>Rhus lancea</i> <i>Zanthoxylum capense</i>
Vaalium Eonothem: Quartzite of the Leeuwpoot Formation	<i>Acacia karroo</i> <i>Ficus ingens</i> <i>Rhus lancea</i> <i>Zanthoxylum capense</i> (<i>Spirostachys africana</i>)
Vaalium Eonothem: Shale and quartzite of the Pretoria Group-Pretoria area	<i>Acacia karroo</i> <i>Clerodendrum glabrum</i> <i>Rhus lancea</i> <i>Ximenia americana</i> & <i>X. caffra</i> <i>Zanthoxylum capense</i> <i>Ziziphus mucronata</i> (<i>Pappea capensis</i>)
Vaalium Eonothem: Shale and quartzite of the Pretoria Group-Lydenburg area	<i>Combretum erythrophyllum</i> <i>Ficus ingens</i> <i>Zanthoxylum capense</i>
Vaalium Eonothem: Rhyolite of the Rooiberg Group and Loskop Formation	<i>Acacia karroo</i> <i>Clerodendrum glabrum</i> <i>Euclea crispa</i> <i>Rhus lancea</i> <i>Ximenia americana</i> & <i>X. caffra</i> <i>Ziziphus mucronata</i>

	<i>(Spirostachys africana)</i>
Vaalium Eonothem: Andesite and gabbro (mafic intrusions)	<i>Acacia karroo</i> <i>Clerodendrum glabrum</i>
Vaalium Eonothem: Andesite and gabbro (mafic intrusions) (Continued)	<i>Euclea crispa</i> <i>Rhus lancea</i> <i>Zanthoxylum capense</i> <i>Ziziphus mucronata</i>
Mogolian Eonothem: Granite (Nebo Granite) in the Rooiberg area	<i>Acacia karroo</i> <i>Ficus ingens</i> <i>Ximenia americana</i> & <i>X. caffra</i> <i>Zanthoxylum capense</i>
Mogolian Eonothem: Granite (Nebo Granite) in the Verena area	<i>Acacia karroo</i> <i>Combretum erythrophyllum</i>
Mogolian Eonothem: Waterberg Group in the Waterberg area	<i>Acacia karroo</i> <i>Combretum imberbe</i> <i>Rhus lancea</i> <i>Strychnos pungens</i> <i>Ximenia americana</i> & <i>X. caffra</i> <i>(Commiphora mollis)</i> <i>(Gardenia volkensii)</i> <i>(Lonchocarpus capassa)</i> <i>(Spirostachys africana)</i>
Mogolian Eonothem: Waterberg Group in the Middelburg area	<i>Acacia karroo</i> <i>Burkea Africana</i> associated with <i>Dichapetalum cymosum</i> <i>Combretum erythrophyllum</i> <i>Euclea crispa</i> <i>Strychnos pungens</i> <i>Zanthoxylum capense</i>
Karoo Supergroup: Sandstone and shale in the Highveld area	<i>Acacia karroo</i> <i>Celtis Africana</i> <i>Euclea crispa</i> <i>Fingerhuthia sesleriiformis</i>
Karoo Supergroup: Sandstone and shale in the Mabula-Waterberg area	<i>Combretum imberbe</i> <i>Ficus ingens</i> <i>Rhus lancea</i> <i>Strychnos pungens</i>
Karoo Supergroup: Basalt/dolerite in the Springbok Flats area	<i>Acacia karroo</i> <i>Combretum erythrophyllum</i> <i>Rhus lancea</i> <i>Ximenia americana</i> & <i>X. caffra</i> <i>Zanthoxylum capense</i> <i>(Acacia erioloba)</i> <i>(Olea europaea subsp. africana)</i>

One further remark can be made regarding the Tamboti (*Spirostachys africana*). Although data regarding the association of Tamboti as a geobotanical indicator with groundwater is limited and this species warrants further study regarding its geobotanical-geohydrological importance, various geophysical profiles indicate the presence of the Tamboti species on the edges of a mafic intrusion. The geophysical profile in Figure 5.8 is one of the geophysical profiles indicating the association of Tamboti trees with mafic intrusions. The profile was measured at Loskop Dam (rhyolite rock of the Rooiberg Group is intruded by east-west striking diabase intrusions). The only ingredient missing is a borehole.

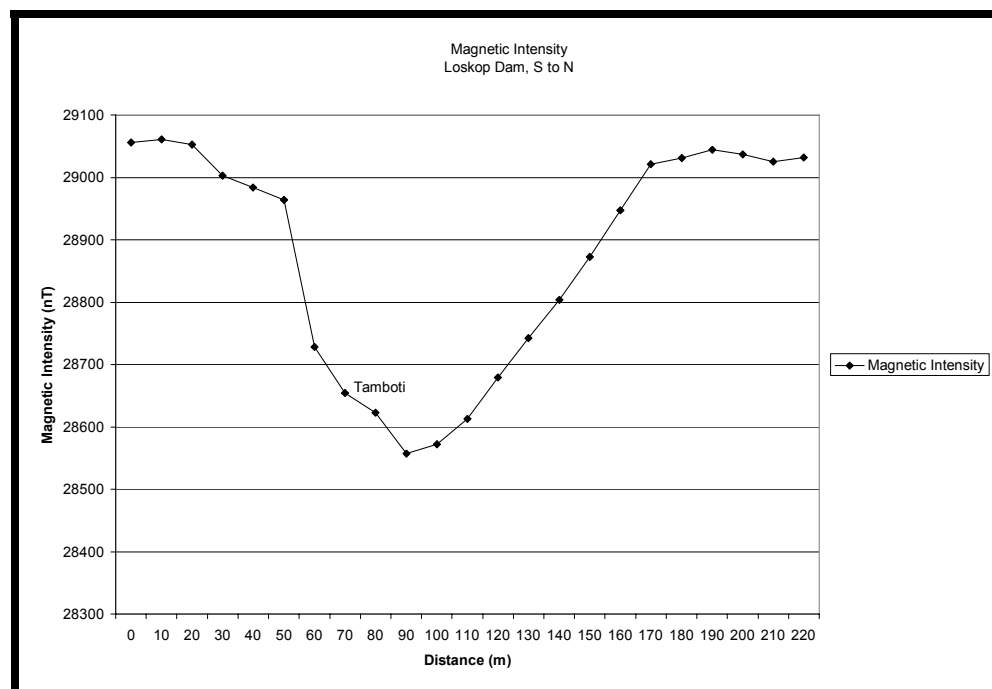


Figure 5.8. Magnetic profile indicating the relevance of Tamboti trees to indicate mafic intrusions as measured at Loskop Dam.

Since soil sampling is often expensive and time consuming (especially the analysis of the results), successful borehole siting can be achieved by:

- Applying the correct/applicable geophysical methods.
- Understanding the local geology.
- Knowing the geobotanical indicators that can be expected and looking for these.
- Recognising the development of local geohydrological conditions by the geological features.

- Identifying the geological features by means of aerial photographs, geophysical methods and geobotanical indicators.
- Soil sampling as a last resort in difficult circumstances. Soil sampling should be guided by the points mentioned above. CEC is a critical parameter that should be analysed.

CHAPTER 6 CONCLUSION

The present study succeeded in its object to establish and prove that certain geophysical-geobotanical relationships occur in the north-eastern parts of South Africa. In order to demonstrate this relationship, a comprehensive literature study was undertaken to build a scientific multi-disciplinary foundation, where the bricks consisted of geology, geophysics, geochemistry, remote sensing, geohydrology, soil science and botany. Rocks differ in their chemical composition and chemically weather differently, and as a result, various minerals are deposited in the soil that can be utilised by plants. Variations in weathering and geochemical composition of the soil define a variety of soil series that form part of a land type map. Differences in weathering can be observed on aerial photographs and confirmed on the ground by a variety of geophysical methods. In addition, weathered horizons act as aquifers. The roots of certain trees prefer to grow in such weathered areas, where they are able to extract nutrients and water using their deep rooting systems. The Pretoria case study presented the above in some detail. The case studies analysed all the sites on the basis of geology, geophysics, geochemistry, remote sensing, geohydrology, soil series and geobotany. Borehole logs were included in order to verify the geology with the interpretation of the geophysical profiles and/or soundings. Based on the unique climatic conditions of the lithologies and associated veld types, botanic species that act as indicators for groundwater were identified. The identification of species was based on the frequency of occurrence in the same locality and elsewhere, proximity to geophysical anomalies as plotted on a geophysical profile and association with drilled boreholes exhibiting a yield well-above the local or regional average yield for that particular aquifer. In instances where the yield was comparable to the average yield for a particular aquifer, the occurrence of groundwater in that particular case in a certain locality was poor, implying no major intrusions, structural bodies or fracturing in the country rock. It is important to note that the average yield of boreholes sited in a geobotanical community varies between 151-300% above the average borehole yields of aquifers of geological formations in the north-eastern parts of South Africa that are not associated with geobotanical indicators. Of importance to the study was the analysis of soil samples gathered at different depths at geobotanical and non-geobotanical communities. Geobotanical communities record notably higher CEC-values that are beneficial to plant growth and development. Higher CEC-values may be the result of more water being available to the soil, resulting from capillary movement from

the aquifer and related water table. Higher water content poses the opportunity to the geobotanical community of relief during periods of drought. In addition, high CEC-values host a variety of various soil nutrients crucial to sustain and promote life. It seems that higher CEC-values can supply a wider variety of trace minerals to vegetation and therefore that certain botanical species are associated with these high CEC-values or geobotanical communities. These botanical species do not occur outside of the geobotanical communities. A community cannot be regarded as a geobotanical community if the composition of its botanical members closely reflects that of the natural environment or veld type.

In addition, statistical treatment of the data was performed and it was found that certain statistical significant correlations exist between geobotanical indicators and/or CEC, being the dependent variables, and geology, geophysics and groundwater the explanatory variables. Geology, groundwater and indirectly, geophysics are the primary circumstances for geobotany and CEC which is why geology, geophysics and groundwater cannot be the dependent variables. The most significant regressions are (with $R^2 \geq 0.65$):

- Between the identified geobotanic species and groundwater, geology and the resulting geophysical anomaly in the Limpopo Granulite-Gneiss Belt.
- Between the analysed CEC-values and groundwater in the Limpopo Granulite-Gneiss Belt.
- In the Lydenburg district (shale and quartzite of the Pretoria Group), a significant correlation is calculated between geobotanical species of this area (dependent variable) and groundwater, geology and geophysics (explanatory variables).
- Regarding rhyolite of the Vaalium Eonothem, a significant correlation exists between the dependent variable CEC and the explanatory variables geology, geophysical anomaly and geobotany.
- Granite in the Warmbad area has a significant correlation that indicates that CEC in this granite environment is positively influenced by geology, geophysical anomaly and geobotany.

Of utmost importance is that a significant (>95%) correlation of 11% was calculated between geobotany (dependent variable) and groundwater, geology and a geophysical anomaly (explanatory variables) for all the case studies. For all the case studies combined, a significant (>95%) correlation of 9% was calculated between CEC

(dependent variable) and geology, geophysical anomaly and geobotany (explanatory variables). This implies that the explanatory variables, only about 10%, explain the change in the dependent variable (of the above), but it is significant, especially if the F- and t-statistic values are studied. Other explanatory factors explain the remaining 90%. This 90% decreases rapidly where $R^2 \approx 0.90$ to a mere 10%. One of the explanatory factors that can be adjusted for is the classification of case studies in lithologies that increase the significance and explanatory value of the regression. All the dependent slope values (β -values) are positive and imply that in all cases the likelihood of observing that a geobotanical indicator and/or the soil record higher CEC-values increases when the aquifer/borehole yield increases in the presence of a geological feature indicated by a geophysical anomaly.

Geobotanical-geophysical groundwater exploration is dependent on the following. Any investigation regarding groundwater has to be guided by the geology of the area and expected geohydrological conditions, expected aquifers and depth of water strike. This will define the geophysical method to be utilised. The same approach is followed in the regression analysis. These three aforementioned factors, in the present context, assist with discovering explanations in answer to the questions relating to why, how, what and where to look. The discussion of geophysical methods and anomalies in Chapter 5 as well as the published geophysical profiles and soundings in the annexure will be of some assistance. In undeveloped areas, aerial photographs, if available, are an excellent tool to define geological features such as lineaments, vegetated linear structures, faults, fracture zones, etcetera. Land type maps and the represented soil series are of some assistance where much heterogeneity among the soil series exists and soils richer in nutrients, such as Hutton compared to Clovelly, can host geobotanical indicators. Thereafter, thorough field observations are important in order to verify the fact that what is seen on the maps is actually visible in the field. With the guidance of the listed indigenous geobotanical species in their lithologic and biome environment, one has to search for these which are normally found in close association with the geological features identified on the aerial photographs. Soil sampling can be carried out since in most cases higher CEC-values are representative of geobotanical indicators; however, this is costly. Analysing soil samples in order to measure CEC-values can be of great assistance in cases where the vegetation has been cleared, and where these cases are

associated with geological features and geophysical anomalies. Higher CEC-values can be regarded as places of former geobotanical indicators.

As indicated by the statistical analysis, a pitfall occurs in certain cases when CEC (dependent variable) is directly linked or placed in a position to explain groundwater occurrences without consulting geologic, geophysical or geohydrological information that are the actual explanatory variables. Another pitfall is caused when listed geobotanical indicators for a certain lithology are so numerous in one place that one assumes that any place can be drilled. If trees of the same species are numerous, then outstanding or exceptional trees of that species must be identified on the basis of their size, height, circumference, frequency of occurrence and appearance. Furthermore, it is not advisable to consider exotic trees as geobotanical indicators since they have fewer natural enemies than indigenous trees and are normally taller, robust, appealing and greener throughout the year.

The value of geobotanical-geophysical groundwater exploration lies in socio-economic development since the client as well as communities benefit from successful groundwater exploration so as to obtain reliable results at a cheaper cost, owing to less geophysical exploration time being taken. Therefore, it is crucial and important to conserve natural vegetation in its habitat, otherwise geobotanical indicators will vanish and geophysical groundwater exploration (and probably layman divining) will become less accurate and more expensive.

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SYNOPSIS

The determination whether certain botanic species can be associated and linked to the existence of groundwater resources by considering the relationship of these species with certain lithologies has been studied in the present research with the aid of geophysics, geology, soil quality analysis (geochemistry), aerial photographs and proven borehole records. Ordinary scientific groundwater exploration makes use of methods such as aerial photographic interpretation, geological modelling of the area under investigation by making use of published geological maps and field reconnaissance work, geohydrological concerns and geophysical data interpretation. The scientific approach can further be enhanced by incorporating other scientific fields such as botany and soil science. Any botanical species is a living organism that requires nutrients to function and live. Nutrients are derived from the soil wherein it grows, while soil is a weathering component of the original underlying rock. Differences in soil can be attributed to changes in the composition or type of the natural rock. By including soil and botany in groundwater exploration, the chances of success are increased. Numerous case studies are presented to illustrate that certain botanical species prefer to grow in nutritious places derived from weathered rock, where this rock acts as a groundwater resource. Soil samples taken from these places indicate different soil quality compositions when compared to the surrounding common veld. This phenomenon is representative throughout the entire study, representing various geological formations. The presence of alien rock formations in a fairly homogenous geological environment is indicated by means of geophysical profiles and soundings. Existing boreholes, whether at or removed from geobotanical communities, indicate the importance of such communities since they hint to the keen observer the likely presence of groundwater at such a community. The current study presents aquifer yields obtained at geobotanical communities and the average yield of aquifers in the same geological environment, where most boreholes are drilled without the incorporation of geobotanical indicators. Lastly, the value of soil quality samples is discussed with a preference for CEC-values to indicate geobotanical communities and/or the presence of groundwater. The statistical treatment of the data indicates distinctively that statistically significant regressions exist between geology, geophysics and groundwater as the explanatory variables and CEC and geobotany as the dependent variables.

Key words: geobotany, geophysics, geohydrology, cation exchange capacity (CEC), aerial photographs, soil series, case studies, regression analysis, statistically significant.

SAMEVATTING

Met behulp van geofisika, geologie, grondkwaliteit-analise (geochemie), lugfoto's en bewese boorgatresultate is bepaal dat sekere botaniese spesies geassosieer en verbind kan word aan die bestaan van grondwaterhulpbronne deur die spesie se verhouding met sekere sedimentêre en andere gesteentes. Gewone wetenskaplike grondwater-eksplorاسie maak gebruik van metodes soos lugfoto-interpretasie, geologiese modellering van die ondersoekgebied deur gebruik te maak van gepubliseerde geologiese kaarte en verkenningswerk in die veld, geohidrologiese oorwegings en geofisiese data interpretasie. Die wetenskaplike benadering kan verder bevorder word deur ander wetenskaplike velde te inkorporeer soos plantkunde en grondkunde. Enige plantkundige spesie is 'n lewende organisme wat voedingstowwe benodig om te funksioneer en te lewe. Voedingstowwe word verkry vanaf die grond waarin dit groei. Grond is 'n verweringskomponent van die oorspronklike onderliggende gesteentes. Verskille in grond kan toegeskryf word aan veranderinge in die samestelling of soort van die oorspronklike gesteente. Deur grond en plantkunde in te sluit in grondwater-eksplorاسie, word die kanse om sukses te behaal verhoog. 'n Aantal gevallestudies word aangebied om aan te dui dat sekere botaniese spesies 'n geneigdheid het om in voedsame plekke te groei, waar die voedingstowwe vanaf verweerde gesteentes kom. Die verweerde gesteente dien as 'n grondwaterhulpbron. Grondmonsters wat geneem is van hierdie lokaliteite dui op verskille in grondkwaliteit samestelling indien dit vergelyk word met die omliggende, gewone veld en hierdie verskynsel word waargeneem dwarsdeur die studie wat verskillende geologiese formasies verteenwoordig. Die teenwoordigheid van vreemde gesteentes in 'n betreklik homogene geologiese omgewing word aangedui deur middel van geofisiese profiele en sonderings. Bestaande boorgate in die teenwoordigheid van geobotaniese gemeenskappe, maar ook verwyder daarvan, dui op die belangrikheid van sulke gemeenskappe as hierdie gemeenskappe aan die skerp waarnemer die voorkoms van grondwater aldaar aandui. Hierdie navorsing sluit akwifeerlewering verkry by geobotaniese gemeenskappe in en die gemiddelde lewering van akwifere in dieselfde geologiese omgewing, waar die meeste boorgate geboor is sonder die insluiting van geobotaniese aanwysers. Laastens, die waarde van grondkwaliteitsmonsters word bespreek met 'n voorkeur vir KUK-waardes om geobotaniese gemeenskappe mee aan te dui en/of die teenwoordigheid van grondwater. Die statistiese behandeling van die data dui duidelik daarop aan dat daar 'n statisties

betekenisvolle regressie bestaan tussen geologie, geofisika en grondwater as die verklarende veranderlikes en KUK en geobotanie as die afhanklike veranderlikes.

Sleutelwoorde: geobotanie, geofisika, geohidrologie, kationuitruilkapasiteit (KUK), lugfoto's, grondseries, gevallestudies, regressie analise, statisties beduidend.

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A1. CASE STUDY INFORMATION

Additional information regarding the case studies as presented in Chapter 4 is listed in this annexure. Geological maps, land type maps and the aerial photograph of every case study are presented. On the aerial photograph the location of the borehole(s) is denoted, layout of the geophysical travers(es) and geological features like lineaments. Some additional information or background to the site might be discussed.

Of importance is the inclusion of the soil sampling tables (see Table 3.1) representing the geobotanic and non-geobotanic communities. Furthermore, some additional information about the case study area, climate and veld types, geology and hydrogeology, geophysics and geobotany is offered. The presentation of the case studies corresponds to Chapter 4.

Table A1.1. The Pretoria geobotany example.

Parameter	Swazian Granite	Malmani Dolomite	Timeball Hill Quartzite	Hekpoort Andesite	Daspoort Quartzite	Silverton Shale	Magaliesberg Quartzite	Bushveld Complex Norite	Bushveld Complex Granite	Karoo Sandstone & Shale
Geological Formation	Swazian Granite	Malmani Subgroup	Timeball Hill Formation	Hekpoort Formation	Daspoort Formation	Silverton Formation	Magaliesberg Formation	Main Zone: Rustenburg Layered Suite	Nebo Granite	Ecca Group
Depth Sampled	0.5m	0.5m	0.5m	0.5m	0.5m	0.5m	0.5m	0.5m	0.5m	0.5m
Sample Co-ordinates:										
S.L.	25°54.189'	25°51.622'	25°46.892'	25°45.135'	25°44.324'	25°44.865'	25°41.486'	25°38.784'	25°29.730'	25°19.595'
E.L.	28°06.119'	28°06.269'	28°12.537'	28°13.731'	28°15.522'	28°25.522'	28°11.194'	28°16.418'	28°16.567'	28°19.851'
Soil colour	Pale yellowish orange	Dusky yellowish brown	Blackish red	Dark red	Yellowish brown	Strong brown	Light brown	Dark grey	Dark yellowish orange	Moderate yellowish brown
pH	6.29	6.68	5.50	5.79	5.07	4.57	5.08	7.54	5.83	5.54
P (mg/kg)	2.5	2.6	10.1	3.1	3.0	2.6	2.6	2.7	2.6	2.7
Ca (mg/kg)	486	1090	1474	2166	127	215	150	8627	324	128
Mg (mg/kg)	145	237	468	473	44	86	71	1824	109	60
K (mg/kg)	74	151	242	270	33	80	60	204	62	24
Na (mg/kg)	16	20	29	29	20	20	17	44	18	16
Fe (mg/kg)	11.85	21.02	3.94	2.12	29.93	7.78	6.64	0.0	5.81	9.46
Mn (mg/kg)	29.61	152.08	179.77	128.35	10.12	57.71	5.65	8.63	18.13	8.47
Zn (mg/kg)	1.24	0.3	17.69	4.31	2.2	2.44	0.2	0.2	1.44	1.02

Al (cmol _c /kg)	0.00	0.00	0.209	0.00	0.99	0.829	0.584	0.00	0.00	0.246
Resistance (Ohm)	3000	2400	1600	1800	6200	6600	7600	400	4800	8000
C%	0.50	0.75	5.09	3.71	2.87	1.78	0.85	1.10	0.32	0.40
Total N%	0.024	0.031	0.398	0.259	0.149	0.105	0.040	0.043	0.016	0.020
Parameter	Swazian Granite	Malmani Dolomite	Timeball Hill Quartzite	Hekpoort Andesite	Daspoort Quartzite	Silverton Shale	Magalies- berg Quartzite	Bushveld Complex Norite	Bushveld Complex Granite	Karoo Sandstone & Shale
S (mg/kg)	15.86	25.06	89.91	46.09	84.2	82.01	43.74	21.72	8.97	21.55
CEC (cmol _c /kg)	4.17	8.42	17.87	18.18	8.4	5.74	3.37	55.84	3.13	2.64
Clay %	22.0	26.0	22.0	42.0	10.0	30.0	22.0	52.0	12.0	12.0
Silt %	16.3	30.7	41.1	30.2	25.9	28.8	11.0	28.6	3.8	12.7
Sand %	61.7	43.3	36.9	27.8	64.1	41.2	67.0	19.4	84.2	75.3
Distinct Tree Species	Grassland	4. Acacia karroo 5. Dombeya rotundifolia 6. Rhus lancea	5. Ochna pulchra 6. Brachylaena rotundata 7. Euclea crispa 8. Vangueria infausta	4. Acacia caffra 5. Gymnosporia buxifolia 6. Rhus lancea	3. Protea caffra 4. Mundulea sericea	Grassland	3. Englerophytum magalisanthum 4. Vangueria infausta	3. Euphorbia ingens 4. Acacia karroo	4. Cussonia paniculata 5. Terminalia sericea 6. Grewia flavescens	4. Faurea saligna 5. Sclerocarya birrea 6. Rhus lancea

Average rooting depth of the indicated species (m)	1 - 2	13 - 50	2 - 7	13 - 50	3 - 7	1 - 2	4 - 8	4 - 50	2 - 8	2 - 13
Average depth of weathering (m)	1.2	2.7	0.5	3.1	0.4	0.8	0.2	3.4	1.1	1.3
Average Aquifer Yield (l/h)	2 800	7 000	3 000	6 750	3 000	3 400	3 000	6 000	2 600	3 000
Average Borehole Depth (m)	45	35	45	60	50	35	45	35	55	60
Average Depth of Water Strike (m)	31	21	32	31	37	24	37	22	43	29
Average Static Water Level (m)	16	12	19	17	16	10	16	10	21	16
Information gathered from Land Type Series Maps, Veld Type Maps and Hydrogeological Maps										
Land Type Series	Bb1a Glenrosa	Ab2a Hutton	Ib7a Rock	Ba9a Hutton	Ib3c Rock	Ba8b Mispah	Ib3a Rock	Ea3a Arcadia	Fa4b Glenrosa	Ae20b Hutton
Profile No	No data	P93	No data	P56	No data	P94	No data	P71	P73	P83

				(diabase)				(Belfast)	(Moloto)	
Depth Sampled	-	0.64m	-	0.51m	-	0.71m	-	0.38m	0.52m	0.6m
Gravel %	-	2	-	4	-	0	-	8	4	0
Sand %	-	44	-	40	-	39	-	22	75	63
Silt %	-	14	-	14	-	6	-	13	4	5
Parameter	Swazian Granite	Malmani Dolomite	Timeball Hill Quartzite	Hekpoort Andesite	Daspoort Quartzite	Silverton Shale	Magaliesberg Quartzite	Bushveld Complex Norite	Bushveld Complex Granite	Karoo Sandstone & Shale
Clay %	-	40	-	42	-	55	-	57	17	32
pH	-	5.9	-	6.4	-	5.4	-	7.0	4.6	5.6
P (mg/kg)	-	0.8	-	1.1	-	0.5	-	-	1.1	0.6
Ca (mg/kg)	-	580	-	2060	-	580	-	561	80	820
Mg (mg/kg)	-	144	-	1728	-	396	-	1620	36	192
K (mg/kg)	-	156	-	78	-	39	-	117	156	273
Na (mg/kg)	-	<23	-	69	-	23	-	161	<23	23
Fe (mg/kg)	-	-	-	-	-	-	-	-	-	-
Mn (mg/kg)	-	557.3	-	90.4	-	105.1	-	1126.3	16.7	109.6
Zn (mg/kg)	-	0.33	-	0.65	-	0.21	-	0.32	0.39	0.45
Resistance (Ohm)	-	2000	-	430	-	1200	-	320	2800	900
C%	-	0.7	-	1.1	-	1.0	-	1.3	0.6	0.3
CEC (cmol _e /kg)	-	75	-	288	-	103	-	460	32	102
Veld Type	61	61	19	20	19	19	19	13	19	16

	Bankenveld	Bankenveld	Sourish Mixed Bushveld	Sour Bushveld	Sourish Mixed Bushveld	Sourish Mixed Bushveld	Sourish Mixed Bushveld	Other Turf Thornveld	Sourish Mixed Bushveld	Kalahari Thornveld
Hydrogeo- logical Unit	D3	B3	D2	D3	B2	D3	B3	D3	D3	D2

The average aquifer yield, average borehole depth, average water strike and average static water level were obtained from Frommurze (1937) and Meulenbeld (1998). It must be noted that the presented value is only an average for the geological formation. Information obtained from the land type maps and accompanying memoir is from Land Type Survey Staff (1987), veld type information from Acocks (1988) and hydrogeological information from DWAF: Johannesburg (1999). Soil colour was identified and classified in the veld according to the Corstor Colour Gauge that lists 168 different soil colours. Average weathering depth is extracted from the indicated Land Type Survey Staff and average rooting depth of the geobotanical indicators is referenced from Canadell *et al.* (1996).

A1.1 SWAZIAN EONOTHEM: LIMPOPO GRANULITE-GNEISS BELT

The Limpopo Granulite-Gneiss Belt is an unique geological setting in the northern parts of South Africa due to the presence of metamorphosed rocks, hotter and dryer climate with distinct vegetation species and poor aquifer conditions. Nevertheless, four sites were visited and the results are presented in Table A1.3 (a&b).

A1.1.1 CASE STUDY AREA

The Limpopo Granulite-Gneiss Belt is a lenticularly shaped, north-easterly trending belt, situated in the Limpopo Province, about 375 km long, measures about 60 km at its widest and is about 13 910 km² in extent. It occurs basically north of the Soutpansberg to the Limpopo River. The case study area can be sub-divided into two different areas, based on the veld types of those areas. The northern part, towards Messina, and a western part in the region of Swartwater, close to the Botswana border.

A1.1.2 CLIMATE AND VELD TYPES

Climatic data is presented in Table A1.2. The area is characterised by hot and humid summers and cool, dry winters. The wet season lasts approximately from October to April with rainfall occurring mostly as heavy thunderstorms (Sami *et al.*, 2002b). The veld types that occur (see also Table A1.3a) are Mopani veld north of the Soutpansberg in the Messina area and Arid Sweet Bushveld to Mixed Bushveld around Swartwater. Farms close to the Limpopo can be classified as part of the Arid Sweet Bushveld and those further into the interior of the country as Mixed Bushveld (Acocks, 1988). Game farming and extensive stock farming is most commonly practiced in the presented case study areas. The following tree species are eminent of these veld types (after Bonsma, 1976, Acocks, 1988 and Van Wyk & Van Wyk, 1997):

- Arid Sweet Bushveld: *Adansonia digitata* (baobab), *Grewia flava* (velvet raisin) and *Acacia mellifera* (black thorn).

- Mixed Bushveld: *Combretum apiculatum* (red bushwillow), *Adansonia digitata* (baobab) and *Combretum imberbe* (leadwood).
- Mopani Veld: *Colophospermum mopane* (mopane), *Combretum apiculatum* (red bushwillow), *Cassia abbreviata* (sjambok pod) and *Adansonia digitata* (baobab).

Geobotanical investigations on the presented case studies will indicate other occurring tree species as well and the marker tree species that can be utilised for groundwater exploration.

Table A1.2. Climatic Data of the Messina & Swartwater Areas (Bonsma, 1976, Schulze, 1997 & Messina, 2002).

	Quantity	
	<i>Messina area</i>	<i>Swartwater area</i>
Average Yearly Temperature (°C)	>20	>20
Mean Minimum Temperature (°C) in July	>8	4-6
Mean Maximum Temperature (°C) in January	>32.5	>32.5
Average Yearly Rainfall (mm)	300-400	400-600
Elevation (m)	400-800	800-1200
Evaporation (mm/year)	2250-2500	2250-2500
Frost area?	No	Almost none

A1.1.3 GEOLOGY AND HYDROGEOLOGICAL CLASSIFICATION

Polymetamorphosed and highly deformed supracrustal and intrusive rocks of Swazian age and belonging to the Central Zone of the Limpopo Mobile Belt (Beit Bridge Complex) occupy the case study areas. The supracrustal rocks consist of metaquartzite, magnetite quartzite, metapelite, granulite, leucogneiss, calc-silicate rock and marble. Intrusive rocks comprise biotite gneiss, meta-anorthosite, metagabbro, serpentinite,

metapyroxenite and hornblendite. The Limpopo Mobile Belt has been intruded by east-west striking granite dykes, pegmatites and by diabase and dolerite dykes, generally striking east-northeast and west-northwest (Vegter, 2001b). Although some major fault structures occur in the study area, no fault structure intersected any of the sites visited. The geology of the area is discussed at some length in Sami *et al.* (2002b).

Vegter (2001b) and Sami *et al.* (2002b) states that drilling results in these hard-rock formations are poor and those drilled by government drilling machines yield about 40% more than 360 l/h. Borehole yields fall mainly in the category between 36 l/h and 3600 l/h. These boreholes were sited by laymen and professional earth/physical scientists and no distinct difference could be observed on borehole siting by either. Statistical analysis of drilling results in this region by Vegter (2001b) indicates that the maximum optimal strike depth ranges between 50 and 85 m below the surface and between 15 and 25 m below the water level. Higher yields do not go hand-in-hand with greater strike depth below water level.

Brittle tectonic deformation, weathering and unloading are the agents responsible for the development of openings in rocks of the Limpopo Mobile Belt. Unless faults, dykes, dyke and formational contacts are weathered and/or fractured to below water level, they do not act *ipso facto* as aquifers. Although composition and texture determine the extent to which different rock types are affected by these processes, local variability and conditions do not allow a clear-cut lithological classification in terms of water-bearing properties. The supracrustal rocks of which metaquartzite perhaps should be singled out, seem more favourable targets, than the granite gneiss (Vegter, 2001b). The rocks of the Limpopo Granulite-Gneiss Belt is a poor aquifer due to marginal to poor water quality related to nitrate levels, low recharge and extractable quantities and the extreme heterogeneity in targets (Sami *et al.*, 2002b).

A1.1.4 GEOPHYSICAL AND GEOBOTANICAL INFORMATION

According to Vegter (2001b), hydrogeological and geophysical siting of boreholes in the Swartwater area has shown that the probability of striking water is greatest:

- Where weathering extends to below the piezometric level (water level).

- Where the depth of weathering and of the piezometric surface does not exceed 40 m, and
- In the first 10 m below the piezometric level.

Bush (1989) advocates the application of magnetics as a primary investigation tool. This technique determines the possible presence of basic/mafic intrusions and to establish the magnetic properties of the country rocks. However, the presence of magnetite quartzite rocks prevents the application of the magnetic technique in such an area. Electromagnetic instrumentation like the Genie SE-88 was used in those cases. The Genie SE-88 must not be used in frequencies below 400 Hz as they fail to produce a significant anomaly even when large coil separations (150 m) are used (Botha *et al.*, 1992). This means rather use the 3037.5/112.5 Hz frequency pair than the 337.5/112.5 Hz frequency pair. Poor conductors will yield large negative peak amplitudes at the former mentioned frequency pair. Furthermore, the Genie was found to be more cost effective (Botha *et al.*, 1992), of the various electromagnetic systems evaluated, in locating good conductive fracture zones and interpreting its dip direction. This is due to data quality, absence of inter-connecting cable (benefit in bushveld), large available coil separations and survey speed. The Geonics EM-34 instrument was not used in this geological environment due to encountered instrument malfunctioning. However, this instrument is capable of operating in both low (less than 100 ohm.m) and high resistivity environments, its use as an alternative reconnaissance tool is recommended. Schlumberger soundings are less affected by lateral resistivity changes than those using the Wenner configuration, they are preferred for determining depth of weathering and fracturing across EM anomalies. Application of geophysical techniques utilised is a function of instrumentation and time available as all the case studies were derived from professional groundwater consultation work. The obtained results, together with the application of geobotany, will indicate the value of it.

A1.1.5 SOIL SAMPLING AND RESULTS PRESENTATION

Four farms were visited and the results and information gathered is presented in Table A1.3 (a&b). Where possible, two soil samples were taken at the indicated drilling spot and geobotanical indicator at depths of 0.5 m and 1.2 m. Another two soil samples were

taken about 25 m away from the observed geological anomaly as indicated on the geophysical traverse. If no sample could be obtained at a depth of 1.2 m, due to the presence of unweathered rock or other obstructions, then another sample was taken in another spot at a depth of 0.5 m. The previous chapter deals with the taking of the samples, basically at the borehole or indicated drilling spot and the other one away from it and the particular soil analyses requested. It was ensured that soil sampling at the borehole was done as close as possible to any observed geobotanical indicators.

Table A1.3a. Limpopo Granulite-Gneiss Belt: along intrusive contact.

Parameter	Beck 568MS		Command 588MS		Wolvedans 68MR		Zoetfontein 154MR	
Geological Formation	Diabase in granite-gneiss (Beit Bridge Complex)	Diabase in granite-gneiss (Beit Bridge Complex)	Diabase in granite-gneiss (Beit Bridge Complex)	Diabase in granite-gneiss (Beit Bridge Complex)	Basic and ultrabasic rocks in granite-gneiss (Beit Bridge Complex)	Basic and ultrabasic rocks in granite-gneiss (Beit Bridge Complex)	Magnetite quartzite and diabase in granite-gneiss (Mount Dowe Group)	Magnetite quartzite and diabase in granite-gneiss (Mount Dowe Group)
Depth Sampled	0.5m	1.2m	0.5m	1.2m	0.5m	1.2m	0.5m	1.2m
Borehole Co-ordinates:								
S.L.	22°38.649'	22°38.649'	22°43.108'	22°43.108'	22°50.008'	22°50.008'	22°56.486'	22°56.486'
E.L.	29°58.235'	29°58.235'	29°49.706'	29°49.706'	28°20.441'	28°20.441'	28°20.558'	28°20.558'
Soil colour	Black	Dark grey	Dark grey	Greyish black	Dark grey	Greyish black	Dusky yellowish brown	Dark brown
Soil texture description	clay	clay	clay	Clay	clay	clay	gravel and sandy silt	gravel and sandy silt
pH	6.64	8.27	7.44	8.16	8.96	7.31	4.67	4.92
P (mg/kg)	12.15	3.89	12.63	8.67	6.88	7.25	104.56	99.73
Ca (mg/kg)	1460	3038	1539	3397	5589	1734	1327	1180
Mg (mg/kg)	505	964	665	655	2273	758	272	239
K (mg/kg)	143	188	179	110	225	191	165	143
Na (mg/kg)	43	145	102	73	644	96	90	59
Fe (mg/kg)	122.39	94.52	142.03	38.02	24.21	143.00	270.59	472.15
Mn (mg/kg)	375.28	302.96	464.71	147.69	37.45	497.20	102.08	234.93

Zn (mg/kg)	1.03	1.27	1.55	1.23	0.51	1.84	11.83	11.84
Al (cmol _c /kg)	0.048	0.018	0.021	0	0.033	0.028	0.971	0.570
Resistance (Ohm)	1900	560	1800	1600	1400	1800	1600	1800
C%	1.16	0.99	1.16	0.58	0.58	1.31	7.31	5.55
Total N%	0.082	0.070	0.079	0.045	0.037	0.094	0.501	0.392
S (mg/kg)	11.78	17.27	15.30	14.01	20.31	14.27	102.44	73.70
CEC (cmol _c /kg)	15.058	17.536	16.105	11.556	29.786	20.450	18.657	15.877
Distinct Tree Species	1. Adansonia digitata	1. Adansonia digitata	1. Adansonia digitata	1. Adansonia digitata	1. Adansonia digitata 2. Combretum imberbe 3. Pappea capensis	1. Adansonia digitata 2. Combretum imberbe 3. Pappea capensis	1. Adansonia digitata 2. Combretum imberbe 3. Ximenia americana 4. Pappea capensis	1. Adansonia digitata 2. Combretum imberbe 3. Ximenia americana 4. Pappea capensis
Average rooting depth of the indicated species (m)	30 (estimated)	30 (estimated)	30 (estimated)	30 (estimated)	2 - 35	2 - 35	2 - 35	2 - 35
Average depth of weathering (m)	1.8	1.8	1.8	1.8	0.6	0.6	1.8	1.8

Geomorphology	Plain	Plain	Plain with ridges	Plain with ridges	Undulating plain	Undulating plain	Plain with ridges	Plain with ridges
Geophysical instrumentation used	Magnetics	Magnetics	Magnetics	Magnetics	a. Genie SE-88 b. Schlumberger soundings	a. Genie SE-88 b. Schlumberger soundings	Genie SE-88	Genie SE-88
Water features present?	No	No	No	No	No	No	Small Pan, <0.01ha	Small Pan, <0.01 ha
Aquifer Yield (l/h)	650	650	500	500	770	770	650	650
Borehole Depth (m)	78	78	80	80	85	85	85	85
Depth of Water Strike (m)	58	58	46	46	52	52	37	37
Static Water Level (m)	46	46	38	38	40	40	24	24
Average Aquifer Yield (l/h)	360	360	360	360	360	360	360	360
Average Borehole Depth (m)	75	75	75	75	95	95	95	95

Average Depth of Water Strike (m)	25	25	25	25	20	20	20	20
Average Static Water Level (m)	15	15	15	15	10	10	10	10
Land Type Series	Ah89b Hutton	Ah89b Hutton	Ah89b Hutton	Ah89b Hutton	Fc620a Glenrosa, Mispah	Fc620a Glenrosa, Mispah	Ae285b Hutton	Ae285b Hutton
Profile No	P8474	P8474	P8474	P8474	P10126	P10126	P10125	P10125
Depth Sampled	350 – 1200 mm	350 – 1200 mm	350 – 1200 mm	350 – 1200 mm	100 – 560 mm	100 – 560 mm	200 – 1050 mm	200 – 1050 mm
Gravel %	0.0	0.0	0.0	0.0	1.6	1.6	2.2	2.2
Sand %	33.5	33.5	33.5	33.5	57.3	57.3	73.0	73.0
Silt %	44.1	44.1	44.1	44.1	17.7	17.7	7.6	7.6
Clay %	22.4	22.4	22.4	22.4	23.4	23.4	17.2	17.2
pH (H ₂ O)	7.26	7.26	7.26	7.26	8.16	8.16	6.99	6.99
P (mg/kg)	2.80	2.80	2.80	2.80	2.90	2.90	1.70	1.70
Ca (mg/kg)	487	487	487	487	677	677	54	54
Mg (mg/kg)	2	2	2	2	20	20	9	9
K (mg/kg)	39	39	39	39	20	20	16	16
Na (mg/kg)	83	83	83	83	3	3	1	1
Fe (mg/kg)	-	-	-	-	-	-	-	-
Mn (mg/kg)	18.29	18.29	18.29	18.29	51.72	51.72	70.65	70.65
Zn (mg/kg)	1.03	1.03	1.03	1.03	0.21	0.21	0.12	0.12

Resistance (Ohm)	26	26	26	26	1400	1400	3000	3000
C%	0.32	0.32	0.32	0.32	2.26	2.26	0.40	0.40
CEC (cmol _c /kg)	19.44	19.44	19.44	19.44	19.78	19.78	4.09	4.09
Veld Type	15 Mopani Veld	15 Mopani Veld	15 Mopani Veld	15 Mopani Veld	14/18 Arid Sweet Bushveld/Mixed Bushveld	14/18 Arid Sweet Bushveld/Mixed Bushveld	18 Mixed Bushveld	18 Mixed Bushveld
Hydrogeo-logical Unit	D2	D2	D2	D2	D2/D3	D2/D3	D2/D3	D2/D3

The average aquifer yield, average borehole depth, average water strike and average static water level were obtained from Vegter (2001b). It must be noted that the presented value is only an average for the geological formation. Information obtained from the veld type maps from Acocks (1988) and hydrogeological information from DWAF: Messina (2002). Soil colour was identified and classified in the veld according to the Corstor Colour Gauge that lists 168 different soil colours. Information obtained from the land type maps and accompanying memoir is from Land Type Survey Staff (2003). Average weathering depth is extracted from the indicated Land Type Survey Staff and average rooting depth of the geobotanical indicators is referenced from Canadell *et al.* (1996).

Table A1.3b. Limpopo Granulite-Gneiss Belt: no intrusive contact.

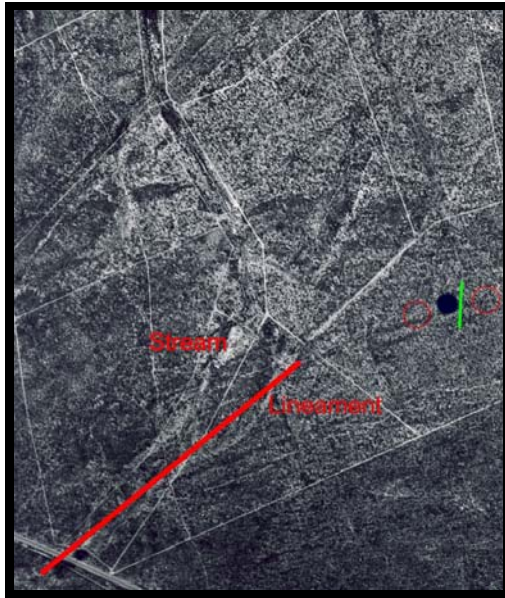
	Beck 568MS		Command 588MS		Wolvedans 68MR		Zoetfontein 154MR	
Geological Formation	Granite-gneiss (Beit Bridge Complex)	Granite-gneiss (Beit Bridge Complex)	Granite-gneiss (Beit Bridge Complex)	Granite-gneiss (Beit Bridge Complex)	Granite-gneiss (Beit Bridge Complex)	Granite-gneiss (Beit Bridge Complex)	Granite- gneiss (Beit Bridge Complex)	Granite- gneiss (Beit Bridge Complex)
Depth Sampled	0.5m	1.2m	0.5m	1.2m	0.5m	0.5m	0.5m	1.2m
Borehole Co- ordinates:								
S.L.	22°38.649'	22°38.649'	22°43.108'	22°43.108'	22°50.008'	22°50.008'	22°56.486'	22°56.486'
E.L.	29°58.235'	29°58.235'	29°49.706'	29°49.706'	28°20.441'	28°20.441'	28°20.558'	28°20.558'
Soil colour	Pale yellowish orange	Dusky yellowish brown	Blackish red	Dark red	Yellowish brown		Strong brown	Light brown
pH	7.24	5.70	5.64	4.96	6.08	5.78	5.04	6.16
Soil texture description	Clay	Sandy silt	Clay	Sandy silt	Clay	Clay	Clay	Sandy silt
P (mg/kg)	3.09	2.37	3.94	2.46	5.80	12.75	5.65	2.43
Ca (mg/kg)	187	313	483	396	292	607	306	653
Mg (mg/kg)	78	146	115	138	110	174	62	290
K (mg/kg)	38	57	156	110	69	258	60	113
Na (mg/kg)	14	13	17	15	12	19	10	32
Fe (mg/kg)	48.29	67.30	56.35	83.21	59.02	215.53	46.74	90.95
Mn (mg/kg)	40.84	96.40	54.37	196.02	59.16	306.01	212.35	109.93
Zn (mg/kg)	0.65	0.38	0.69	0.77	0.78	4.10	1.38	0.46
Al (cmol _c /kg)	0.095	0.224	0.098	0.304	0.045	0.096	0.379	0.118

Resistance (Ohm)	6400	3400	2200	3200	3000	2000	3800	2600
C%	0.25	0.30	0.92	0.49	0.77	2.65	0.65	0.08
Total N%	0.020	0.033	0.074	0.047	0.050	0.196	0.050	0.012
S (mg/kg)	8.19	58.16	19.81	79.78	10.47	13.98	13.85	20.62
CEC (cmol _c /kg)	2.608	5.734	5.370	5.611	2.853	6.686	3.221	9.107
Distinct Tree Species	Colophospermum mopane	Colophospermum mopane	Colophospermum mopane	Colophospermum mopane	Combretum apiculatum	Combretum apiculatum	Combretum apiculatum	Combretum apiculatum
Average rooting depth of the indicated species (m)	5	5	5	5	4	4	4	4
Average depth of weathering (m)	1.8	1.8	1.8	1.8	0.6	0.6	1.8	1.8
Geomorphology	Plain	Plain	Plain with ridges	Plain with ridges	Undulating plain	Undulating plain	Plain with ridges	Plain with ridges
Geophysical instrumentation used	Magnetics	Magnetics	Magnetics	Magnetics	c. Genie SE-88 d. Schlumberger soundings	c. Genie SE-88 d. Schlumberger soundings	Genie SE-88	Genie SE-88
Water features present?	No	No	No	No	No	No	Small Pan, <0.01ha	Small Pan, <0.01 ha
Aquifer Yield (l/h)	650	650	500	500	770	770	650	650
Borehole Depth (m)	78	78	80	80	85	85	85	85

Depth of Water Strike (m)	58	58	46	46	52	52	37	37
Static Water Level (m)	46	46	38	38	40	40	24	24
Average Aquifer Yield (l/h)	360	360	360	360	360	360	360	360
Average Borehole Depth (m)	75	75	75	75	95	95	95	95
Average Depth of Water Strike (m)	25	25	25	25	20	20	20	20
Average Static Water Level (m)	15	15	15	15	10	10	10	10
Land Type Series	Ah89b Hutton	Ah89b Hutton	Ah89b Hutton	Ah89b Hutton	Fc620a Glenrosa, Mispah	Fc620a Glenrosa, Mispah	Ae285b Hutton	Ae285b Hutton
Profile No	P8474	P8474	P8474	P8474	P10126	P10126	P10125	P10125
Depth Sampled	350 – 1200 mm	350 – 1200 mm	350 – 1200 mm	350 – 1200 mm	100 – 560 mm	100 – 560 mm	200 – 1050 mm	200 – 1050 mm
Gravel %	0.0	0.0	0.0	0.0	1.6	1.6	2.2	2.2
Sand %	33.5	33.5	33.5	33.5	57.3	57.3	73.0	73.0
Silt %	44.1	44.1	44.1	44.1	17.7	17.7	7.6	7.6
Clay %	22.4	22.4	22.4	22.4	23.4	23.4	17.2	17.2
pH (H ₂ O)	7.26	7.26	7.26	7.26	8.16	8.16	6.99	6.99
P (mg/kg)	2.80	2.80	2.80	2.80	2.90	2.90	1.70	1.70

Ca (mg/kg)	487	487	487	487	677	677	54	54
Mg (mg/kg)	2	2	2	2	20	20	9	9
K (mg/kg)	39	39	39	39	20	20	16	16
Na (mg/kg)	83	83	83	83	3	3	1	1
Fe (mg/kg)	-	-	-	-	-	-	-	-
Mn (mg/kg)	18.29	18.29	18.29	18.29	51.72	51.72	70.65	70.65
Zn (mg/kg)	1.03	1.03	1.03	1.03	0.21	0.21	0.12	0.12
Resistance (Ohm)	26	26	26	26	1400	1400	3000	3000
C%	0.32	0.32	0.32	0.32	2.26	2.26	0.40	0.40
CEC (cmol _c /kg)	19.44	19.44	19.44	19.44	19.78	19.78	4.09	4.09
Veld Type	15 Mopani Veld	15 Mopani Veld	15 Mopani Veld	15 Mopani Veld	14/18 Arid Sweet Bushveld/Mixed Bushveld	14/18 Arid Sweet Bushveld/Mixed Bushveld	18 Mixed Bushveld	18 Mixed Bushveld
Hydrogeological Unit	D2	D2	D2	D2	D2/D3	D2/D3	D2/D3	D2/D3

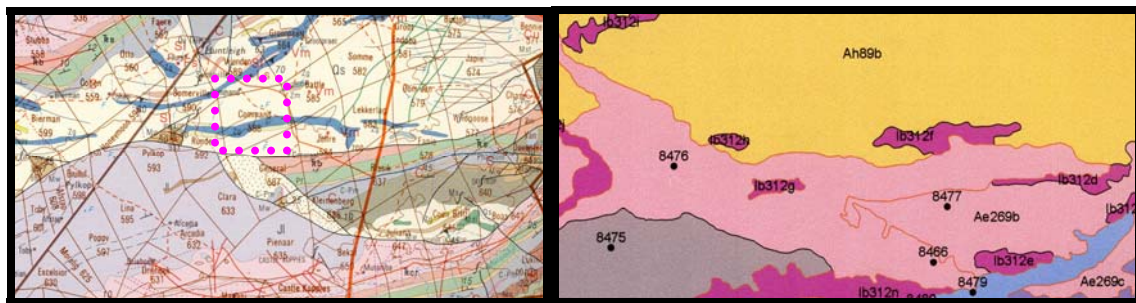
The average aquifer yield, average borehole depth, average water strike and average static water level were obtained from Vegter (2001b). It must be noted that the presented value is only an average for the geological formation. Information obtained from the veld type maps from Acocks (1988) and hydrogeological information from DWAF: Messina (2002). Soil colour was identified and classified in the veld according to the Corstor Colour Gauge that lists 168 different soil colours. Information obtained from the land type maps and accompanying memoir is from Land Type Survey Staff (2003). Average weathering depth is extracted from the indicated Land Type Survey Staff and average rooting depth of the geobotanical indicators is referenced from Canadell *et al.* (1996).



Abbreviation	Geology
Zg	Marble, calc-silicate rocks
Zm	Leucocratic quartzo-feldspathic gneiss
Qs	Sandy soil
	Diabase dyke
Abbreviation	Soil series
Ah89b	Hutton
Fa646f	Glenrosa

Figure A1.1. The geology (top left), land type (top right) and aerial photograph (bottom) of Beck 568MS. The blue circle denotes the position of the borehole and the green line the direction of the magnetic profile. The positions of the stream and the lineament, as seen on the geological map, are indicated. The red circles indicate minor lineaments (east-west strike). The area covered by the aerial photograph is indicated by the purple shape in the geological map.

2. Command 588MS



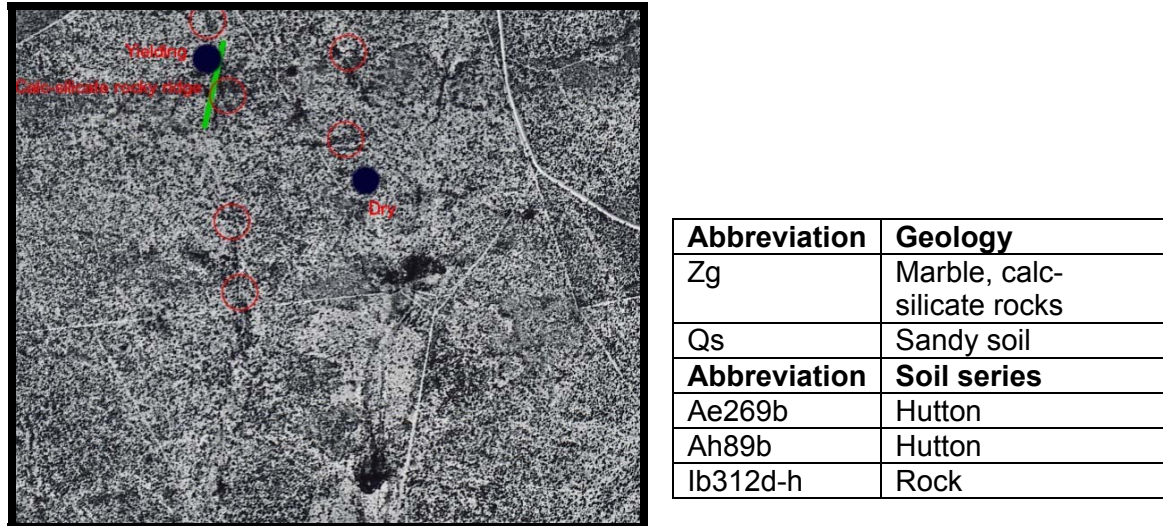
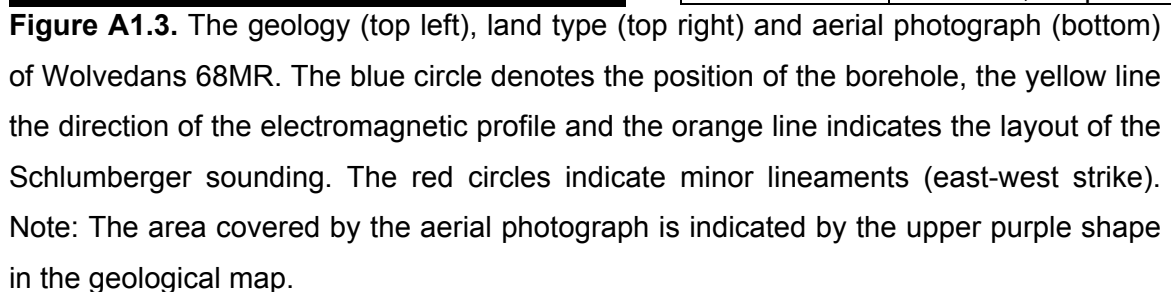


Figure A1.2. The geology (top left), land type (top right) and aerial photograph (bottom) of Command 588MS. The blue circles denote the positions of the boreholes (dry and yielding) and the green line the direction of the magnetic profile. The position of the calc-silicate rocky ridge is indicated. The red circles indicate minor lineaments (mainly north-west strike). The area covered by the aerial photograph is indicated by the purple shape in the geological map.

The farm Command is situated between the railway line and main road to Messina, from the Soutpansberg. It is southeast of the station Huntleigh.

3. Wolvedans 68MR



Wolwedans is about 20 km to the northeast of Swartwater.

4. Zoetfontein 154MR

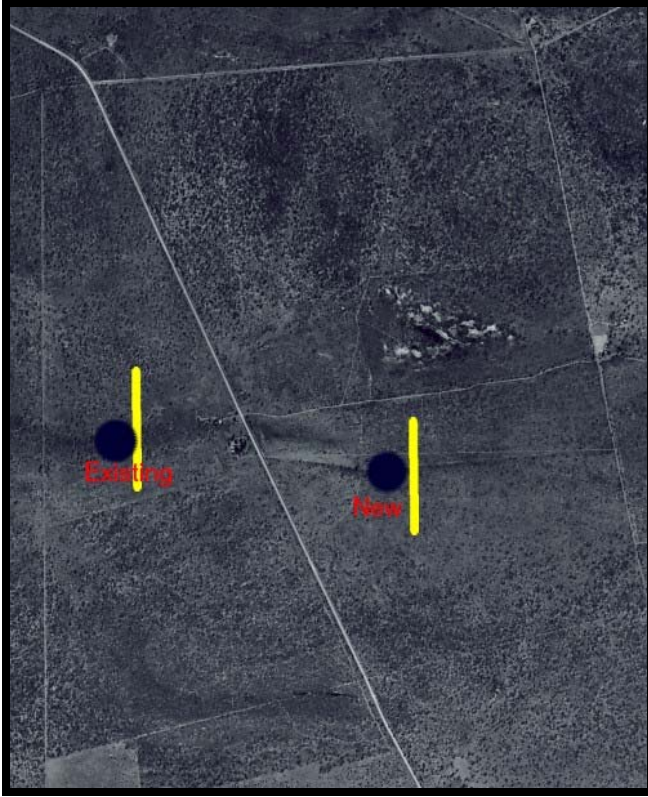


Figure A1.4. The geology (top left, Figure A1.3), land type (top right, Figure A1.3) and aerial photograph (bottom) of Zoetfontein 154MR. The blue circles denote the position of the boreholes (existing and new) and the yellow lines the direction of the electromagnetic profiles. The area covered by the aerial photograph is indicated by the lower purple shape in the geological map.

Zoetfontein is neighbouring the De Beers “The Oaks” diamond mine, approximately 20 km east of Swartwater.

A1.2 VAALIUM EONOTHEM: ROOIBERG-WARMBATHS AREA: QUARTZITE OF THE LEEUWPOORT FORMATION AND DOLOMITE OF THE MALMANI SUBGROUP

The occurrence of quartzite and dolomite in the Rooiberg-Warmbaths area is confined to small areas as the majority of the region is underlain by igneous rocks. The case studies presented are valuable as geobotanic indicators in this terrain were identified, see Table A1.5(a&b).

A1.2.1 CASE STUDY AREA

The Pretoria Group is predominantly part of the Vaalium Eonothem and outcrops are widely dispersed in the old Transvaal. Leeuwpoot Formation quartzite and shale outcrop in the Rooiberg area, with predominant faulting (north-eastern strike) and intrusive diabase dykes in a northwestern strike. Two case studies represent this geologic setting. A small band of dolomite (Malmani Subgroup) occurs in a graben between the Droogekloof and Boschpoort faults, northwest of Warmbaths. The farm Droogekloof 471KR is situated in this graben.

A1.2.2 CLIMATE AND VELD TYPES

Climatic data is presented in Table A1.4. The area is characterised by hot and humid summers and cool, dry winters. The wet season lasts approximately from October to April with rainfall occurring mostly as heavy thunderstorms. The veld types that occur (see also Table A1.5a) are Sourish Mixed Bushveld in the lower regions and Sour Bushveld in the ridges and elevated areas (Acocks, 1988). Game farming and extensive stock farming is most commonly practiced in the presented case study areas. Irrigation practices occur in areas of high groundwater availability (more than 36 000 l/h). The following tree species are eminent of these veld types (after Bonsma, 1976, Acocks, 1988 and Van Wyk & Van Wyk, 1997), all veld types are part of the savanna biome:

- Sourish Mixed Bushveld: *Acacia caffra* (common hook-thorn), *A. karroo* (sweet thorn), *A. robusta subsp. robustu* (brack thorn) & *A. tortillis subsp. heteracantha* (umbrella thorn), *Rhus gueinzii* (thorny karree), *Peltophorum africanum* (weeping wattle), *Pappea capensis* (jacket-plum) and *Ziziphus mucronata* (buffalo-thorn).

- Sour Bushveld: *Acacia caffra* (common hook-thorn), *Combretum molle* (velvet bushwillow) & *C. apiculatum* (red bushwillow) & *C. zeyheri* (large-fruited bushwillow), *Euclea crispa* (blue guarri), *Faurea saligna* (Transvaal beech), *Burkea africana* (wild seringa), *Ochna pulchra* (peeling plane), *Olea europaea subsp. africana* (wild olive), *Ficus ingens* (red-leaved fig) and *Strychnos pungens* (spine-leaved monkey orange).

Geobotanical investigations on the included case studies will indicate other occurring tree species as well and the marker tree species (geobotanic indicators) that can be utilised for groundwater exploration.

Table A1.4. Climatic Data of the Rooiberg-Warmbaths Areas (Bonsma, 1976, Schulze, 1997 & Polokwane, 2003).

	Quantity
Average Yearly Temperature (°C)	18-20
Mean Minimum Temperature (°C) in July	2-4
Mean Maximum Temperature (°C) in January	27.5-30.0
Average Yearly Rainfall (mm)	500-800
Elevation (m)	800-1600
Evaporation (mm/year)	2000-2250
Frost area?	Almost none

A1.2.3 GEOLOGY AND HYDROGEOLOGICAL CLASSIFICATION

The Transvaal craton was stabilised 2 500 My ago, but during the Proterozoic portions of the crust became less stable resulting in subsidence and the formation of partly overlapping basins. These were developed along deep fractures, which have been repeatedly reactivated and along which lavas extruded until early Waterberg times (Mogolian eonothem) (Schutte, 1974). Deformation increased in intensity in the Rooiberg area immediately prior to or during emplacement of the Bushveld Complex granite. A north-eastern trend was superimposed, as illustrated by the Rooiberg syncline. Finally,

thrustfaults developed on the limbs of the major synclines and were subsequently mineralised (Schutte, 1974).

Quartzite and shale of the Leeuwpoot Formation underlie the Rooiberg area. Rhyolite belonging to the Rooiberg Group occurs in the north of the old mining village of Rooiberg. Faulting (north-eastern strike) and diabase intrusions (northwestern strike) occur frequently in the area east of Rooiberg. The Leeuwpoot Formation is surrounded by igneous rocks, i.e. granite, granophyre and rhyolite. In the Warmbaths-Droogekloof area, a small linear dolomite outcrop of the Malmani Subgroup can be seen. Subsequent folding, flexing and faulting during Waterberg and post-Waterberg times (Mogolian eonothem) transformed the embryonic structures into their present shape and locally their limbs were tilted to the vertical or over-turned. The Droogekloof overthrust developed along the Zwartkloof anticline (Walraven, 1978).

Aquifers associated with the mentioned granite are:

- Basins in the granite caused by deep weathering.
- Weathered fractured zones associated with faults, dykes, shear zones or changes in lithology.
- Weathered contact zones along intrusive dykes.

Groundwater levels vary between 5 m and 30 m depending on topography and recharge.

Quartzite, dolomite and rhyolite in the area can be generalised in terms of aquifer conditions for these kinds of rock types. Dolomite aquifers consist of karst (sub-surface cavities and other solution features). Quartzite aquifers tend to be weathered contact zones with intrusive rocks and joints (Hattingh, 1996 & Meulenbeld, 1998). Rhyolite aquifers can be associated with the granite aquifers, mentioned above. Meulenbeld (1998) indicated that granite aquifers tend to yield more quantities of groundwater than rhyolite aquifers. Rhyolite, as a fine grained acid igneous rock, erodes with more difficulty than granite (medium to coarse-grained acid igneous rock). Rhyolite constitutes often hills and mountains, where granite occurs in plains.

According to the Polokwane (2003) hydrogeological map, the Leeuwpoot Formation quartzite can be classified as a meta-arenaceous fractured aquifer with a possible yield

of 1800-7200 l/h. The dolomite encountered in the Droogekloof graben can be grouped as a karst aquifer with a possible yield of 1800-7200 l/h. However, acid igneous rocks in the area (rhyolite and granite) constitute an intergranular-fractured aquifer with a possible yield of 360-1800 l/h. Detailed geohydrological information on the study area is lacking in literature. Bonsma (1976) tabled depth to the water table in this area.

A1.2.4 GEOPHYSICAL AND GEOBOTANICAL INFORMATION

Although no detailed geophysical studies in the area of concern are published, geophysical studies conducted on the same rock formations elsewhere can be used for reference and background information. Parts of the study area that is underlain by the Lebowa Granite Suite of the Bushveld Igneous Complex, can be referenced to the geophysical-geohydrological work of Meulenbeld (1998) & Botha *et al.* (2001).

Geophysical methods utilised depend on the expected properties of the aquifer. The presence of weathered and intrusive structures in the igneous rocks makes the utilisation of various geophysical methods preferable, like Schlumberger soundings, electromagnetic and magnetic profiles. Information on geobotany related to aquifers in the area is unknown.

A1.2.5 SOIL SAMPLING AND RESULTS PRESENTATION

Three farms were visited and the results and information gathered is outlined in Tables A1.5 (a&b). Where possible, two soil samples were taken at the indicated drilling spot and geobotanical indicator at depths of 0.5 m and 1.2 m. Another two soil samples were taken about 25 m away from the observed geological anomaly as indicated on the geophysical traverse. If no sample could be obtained at a depth of 1.2 m, due to the presence of unweathered rock or other obstructions, then another sample was taken in another spot at a depth of 0.5 m. The previous chapter deals with the taking of the samples, basically at the borehole or indicated drilling spot and the other one away from it. It was ensured that soil sampling at the borehole was done as close as possible to any observed geobotanical indicators.

Table A1.5a. Vaalium Eonothem: Rooiberg-Warmbaths Area: along intrusive contact.

Parameter	Blokdriфт 512KQ		Droogekloof 471KR		Vaalfontein 491KQ	
Geological Formation	Diabase/fault structure in quartzite (Leeuwpoot Formation)	Diabase/fault structure in quartzite (Leeuwpoot Formation)	Diabase and cavities in dolomite (Malmani Subgroup)	Diabase and cavities in dolomite (Malmani Subgroup)	Diabase in quartzite (Leeuwpoot Formation)	Diabase in quartzite (Leeuwpoot Formation)
Depth Sampled	0.5m	1.2m	0.5m	1.2m	0.5m	1.2m
Borehole Co-ordinates:						
S.L.	24°45.243'	24°45.408'	24°42.039'	24°42.039'	24°51.354'	24°51.354'
E.L.	27°45.362'	27°45.604'	27°33.481'	27°33.481'	28°07.736'	28°07.736'
Soil colour	Very dark red	Strong brown	Brownish black	Dusky brown	Dusky red	Moderate reddish brown
Soil texture description	Silt	Silty clay	Sandy loam	Gravel and sand	Clayey silt	Clayey silt
pH	4.50	4.86	7.60	7.34	4.70	4.96
P (mg/kg)	9.66	7.39	2.10	2.05	21.83	15.47
Ca (mg/kg)	138	250	683	2891	115	158
Mg (mg/kg)	49	112	299	294	54	112
K (mg/kg)	41	71	159	153	23	18
Na (mg/kg)	5	61	34	15	7	19
Fe (mg/kg)	57.11	26.97	213.32	86.24	24.37	44.40
Mn (mg/kg)	17.79	172.99	1318.28	484.39	16.52	118.58
Zn (mg/kg)	0.39	0.27	0.38	0.45	0.55	0.10
Al (cmol _c /kg)	2.156	0.974	0.000	0.000	0.999	0.647

Resistance (Ohm)	3400	2400	4800	2000	4400	4200
C%	3.37	0.24	0.71	0.58	0.37	0.35
Total N%	0.252	0.023	0.065	0.057	0.062	0.032
S (mg/kg)	166.44	56.99	22.09	32.76	32.47	34.76
CEC (cmol _c /kg)	9.993	7.023	9.205	10.500	2.842	4.126
Distinct Tree Species	1. Zanthoxylum capense 2. Ficus sur 3. Acacia karroo	1. Zanthoxylum capense 2. Ficus sur 3. Acacia karroo	1. Zanthoxylum capense	1. Zanthoxylum capense	4. Rhus lancea 5. Acacia karroo	1. Rhus lancea 2. Acacia karroo
Average rooting depth of the indicated species (m)	5 - 50	5 - 50	5	5	13 - 50	13 - 50
Average depth of weathering (m)	1.8	1.8	2.3	2.3	2.1	2.1
Geomorphology	Plain	Plain	Mountain slope	Mountain slope	Mountain slope with periodic stream	Mountain slope with periodic stream
Geophysical instrumentation used	Magnetics	Magnetics	Magnetics	Magnetics	Magnetics	Magnetics
Water features present?	No	No	No	No	River bed to the west (~100m)	River bed to the west (~100m)
Aquifer Yield (l/h)	60 000	60 000	100 000	100 000	1 500	1 500
Borehole Depth (m)	75	75	60	60	85	85
Depth of Water Strike (m)	70	70	50	50	45	45

Static Water Level (m)	12	12	9	9	14	14
Average Aquifer Yield (l/h)	1 900	1 900	1 400	1 400	1 900	1 900
Average Borehole Depth (m)	60	60	75	75	60	60
Average Depth of Water Strike (m)	30	30	38	38	30	30
Average Static Water Level (m)	27	27	27	27	27	27
Land Type Series	Fa4k Clovelly	Fa4k Clovelly	Ah76a Hutton	Ah76a Hutton	Bc41a Hutton	Bc41a Hutton
Profile No	P755	P755	P1377	P1377	P1405	P1405
Depth Sampled	100 – 520 mm	100 – 520 mm	280 – 1200 mm	280 – 1200 mm	200 – 1200 mm	200 – 1200 mm
Gravel %	3	3	1	1	0	0
Sand %	87	87	68	68	84	84
Silt %	4	4	12	12	3	3
Clay %	6	6	19	19	13	13
pH (H ₂ O)	6.0	6.0	6.4	6.4	5.2	5.2
P (mg/kg)	1.3	1.3	0.9	0.9	3.4	3.4
Ca (mg/kg)	160	160	300	300	141	141
Mg (mg/kg)	84	84	144	144	60	60
K (mg/kg)	156	156	41	41	154	154
Na (mg/kg)	23	23	11	11	25	25
Fe (mg/kg)	-	-	-	-	-	-
Mn (mg/kg)	15.4	15.4	1473.5	1473.5	36.7	36.7
Zn (mg/kg)	0.35	0.35	0.11	0.11	0.17	0.17

Resistance (Ohm)	4300	4300	2900	2900	2100	2100
C%	0.4	0.4	0.2	0.2	0.1	0.1
CEC (cmol _c /kg)	30	30	35	35	2.9	2.9
Veld Type	19/20 Sourish Mixed Bushveld/Sour Bushveld	19/20 Sourish Mixed Bushveld/Sour Bushveld	20 Sour Bushveld	20 Sour Bushveld	19/20 Sourish Mixed Bushveld/Sour Bushveld	19/20 Sourish Mixed Bushveld/Sour Bushveld
Hydrogeo-logical Unit	D3	D3	C3	C3	D2/D3	D2/D3

Information obtained from the veld type maps from Acocks (1988) and hydrogeological information from DWAF: Polokwane (2003). Soil colour was identified and classified in the veld according to the Corstor Colour Gauge that lists 168 different soil colours. Average static level depth was obtained from Bonsma (1976). The average aquifer yield, average borehole depth and average water strike level were obtained from Hattingh (1996). It must be noted that the presented value is only an average for the geological formation. Information obtained from the land type maps and accompanying memoir is from Land Type Survey Staff (1988). Average weathering depth is extracted from the indicated Land Type Survey Staff and average rooting depth of the geobotanical indicators is referenced from Canadell *et al.* (1996).

Table A1.5b. Vaalium Eonothem: Rooiberg-Warmbaths Area: no intrusive contact.

	Blokdriest 512KQ		Droogekloof 471KR		Vaalfontein 491KQ	
Geological Formation	Quartzite & shale (Leeuwpoot Formation) and Rhyolite (Rooiberg Group)	Quartzite & shale (Leeuwpoot Formation) and Rhyolite (Rooiberg Group)	Dolomite (Malmani Subgroup)	Dolomite (Malmani Subgroup)	Quartzite & shale (Leeuwpoot Formation)	Quartzite & shale (Leeuwpoot Formation)
Depth Sampled	0.5m	1.2m	0.5m	1.2m	0.5m	0.5m
Borehole Co-ordinates:						
S.L.	24°45.243'	24°45.408'	24°42.039'	24°42.039'	24°51.354'	24°51.354'
E.L.	27°45.362'	27°45.604'	27°33.481'	27°33.481'	28°07.736'	28°07.736'
Soil colour	Grayish red	Light brown	Brownish black	Brownish black	Moderate brown	Moderate brown
Soil texture description	Sand	Sand	Sandy loam	Sandy loam	Sand	Sand
pH	4.74	4.96	6.52	6.53	5.53	5.53
P (mg/kg)	14.53	10.97	2.64	1.54	4.45	3.92
Ca (mg/kg)	112	100	886	838	198	115
Mg (mg/kg)	36	37	363	338	80	58
K (mg/kg)	34	49	206	186	28	16
Na (mg/kg)	1	5	17	12	46	22
Fe (mg/kg)	45.42	44.24	181.98	180.50	23.78	16.77
Mn (mg/kg)	29.65	27.65	1395.76	1402.09	115.51	64.57
Zn (mg/kg)	0.50	0.59	0.43	0.46	0.52	0.82
Al (cmol _c /kg)	1.202	0.912	0.000	0.000	0.083	0.142

Resistance (Ohm)	4600	5600	4200	4200	20000	24000
C%	1.69	0.46	0.16	0.39	0.10	0.12
Total N%	0.106	0.028	0.034	0.048	0.010	0.014
S (mg/kg)	29.19	37.89	21.97	21.06	27.26	23.98
CEC (cmol _c /kg)	3.933	5.341	9.894	10.716	3.824	5.207
Distinct Tree Species	1. Zanthoxylum capense 2. Ficus sur 3. Acacia karroo	1. Zanthoxylum capense 2. Ficus sur 3. Acacia karroo	1. Zanthoxylum capense	1. Zanthoxylum capense	1. Rhus lancea 2. Acacia karroo	1. Rhus lancea 2. Acacia karroo
Average rooting depth of the indicated species (m)	5 - 50	5 - 50	5	5	13 - 50	13 - 50
Average depth of weathering (m)	1.8	1.8	2.3	2.3	2.1	2.1
Geomorphology	Plain	Plain	Mountain slope	Mountain slope	Mountain slope with periodic stream	Mountain slope with periodic stream
Geophysical instrumentation used	Magnetics	Magnetics	Magnetics	Magnetics	Magnetics	Magnetics
Water features present?	No	No	No	No	River bed to the west (~100m)	River bed to the west (~100m)
Aquifer Yield (l/h)	60 000	60 000	100 000	100 000	1 500	1 500
Borehole Depth (m)	75	75	60	60	85	85

Depth of Water Strike (m)	70	70	50	50	45	45
Static Water Level (m)	12	12	9	9	14	14
Average Aquifer Yield (l/h)	1 900	1 900	1 400	1 400	1 900	1 900
Average Borehole Depth (m)	60	60	75	75	60	60
Average Depth of Water Strike (m)	30	30	38	38	30	30
Average Static Water Level (m)	27	27	27	27	27	27
Land Type Series	Fa4k Clovelly	Fa4k Clovelly	Ah76a Hutton	Ah76a Hutton	Bc41a Hutton	Bc41a Hutton
Profile No	P755	P755	P1377	P1377	P1405	P1405
Depth Sampled	100 – 520 mm	100 – 520 mm	280 – 1200 mm	280 – 1200 mm	200 – 1200 mm	200 – 1200 mm
Gravel %	3	3	1	1	0	0
Sand %	87	87	68	68	84	84
Silt %	4	4	12	12	3	3
Clay %	6	6	19	19	13	13
pH (H ₂ O)	6.0	6.0	6.4	6.4	5.2	5.2
P (mg/kg)	1.3	1.3	0.9	0.9	3.4	3.4
Ca (mg/kg)	160	160	300	300	141	141
Mg (mg/kg)	84	84	144	144	60	60
K (mg/kg)	156	156	41	41	154	154

Na (mg/kg)	23	23	11	11	25	25
Fe (mg/kg)	-	-	-	-	-	-
Mn (mg/kg)	15.4	15.4	1473.5	1473.5	36.7	36.7
Zn (mg/kg)	0.35	0.35	0.11	0.11	0.17	0.17
Resistance (Ohm)	4300	4300	2900	2900	2100	2100
C%	0.4	0.4	0.2	0.2	0.1	0.1
CEC (cmol _e /kg)	30	30	35	35	2.9	2.9
Veld Type	19/20 Sourish Mixed Bushveld/Sour Bushveld	19/20 Sourish Mixed Bushveld/Sour Bushveld	20 Sour Bushveld	20 Sour Bushveld	19/20 Sourish Mixed Bushveld/Sour Bushveld	19/20 Sourish Mixed Bushveld/Sour Bushveld
Hydrogeological Unit	D3	D3	C3	C3	D2/D3	D2/D3

Information obtained from the veld type maps from Acocks (1988) and hydrogeological information from DWAF: Polokwane (2003).

Soil colour was identified and classified in the veld according to the Corstor Colour Gauge that lists 168 different soil colours.

Average static level depth was obtained from Bonsma (1976). The average aquifer yield, average borehole depth and average water strike level were obtained from Hattingh (1996). It must be noted that the presented value is only an average for the geological formation. Information obtained from the land type maps and accompanying memoir is from Land Type Survey Staff (1988). Average weathering depth is extracted from the indicated Land Type Survey Staff and average rooting depth of the geobotanical indicators is referenced from Canadell *et al.* (1996).

5. Blokdriфт 512KQ

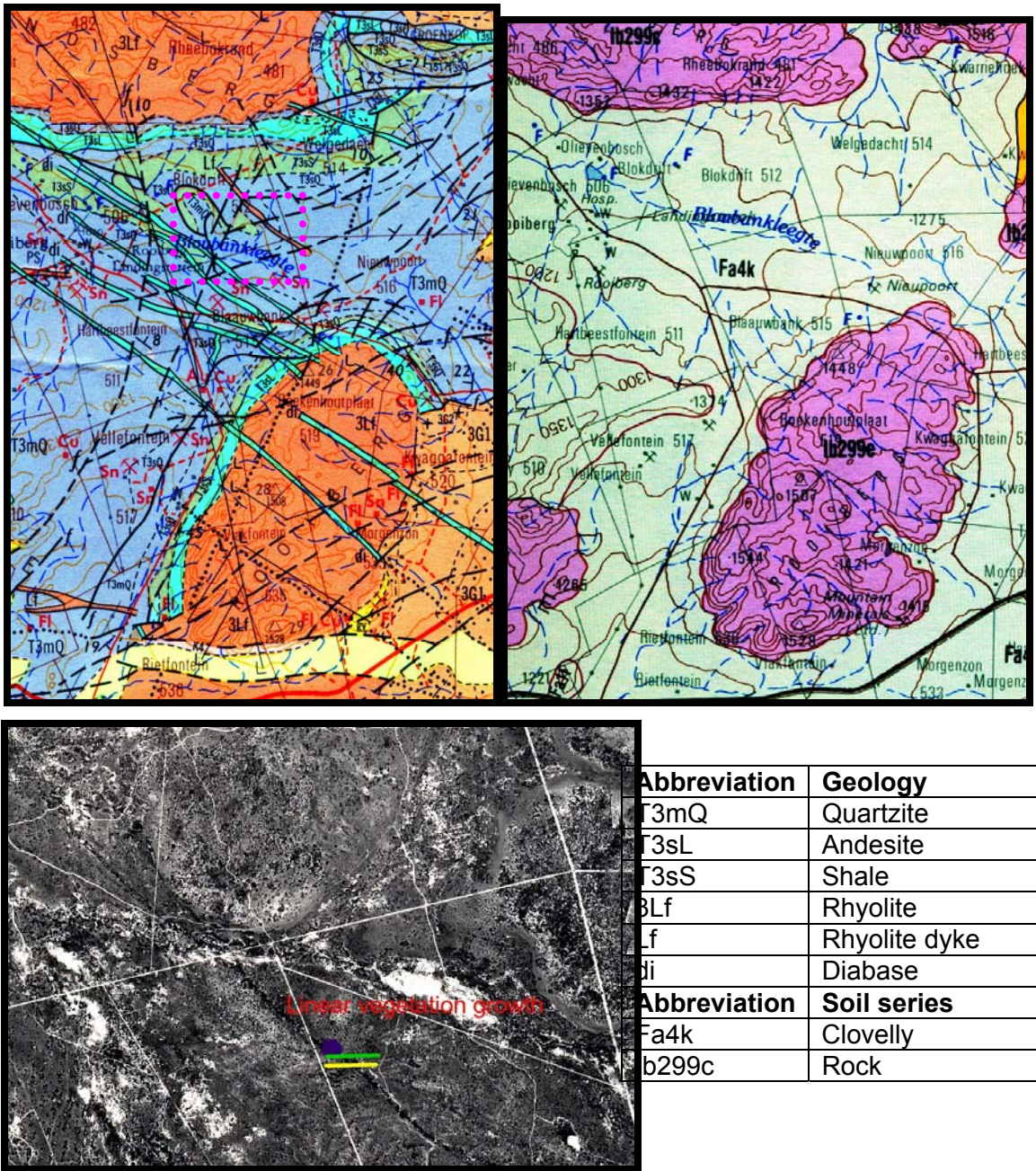


Figure A1.5. The geology (top left), land type (top right) and aerial photograph (bottom) of Blokdriфт 512KQ. The blue circle denotes the position of the borehole, the green line the direction of the magnetic profile and the yellow line indicates the electromagnetic traverse direction. The area covered by the aerial photograph is indicated by the purple shape in the geological map.

6. Droogekloof 471KR

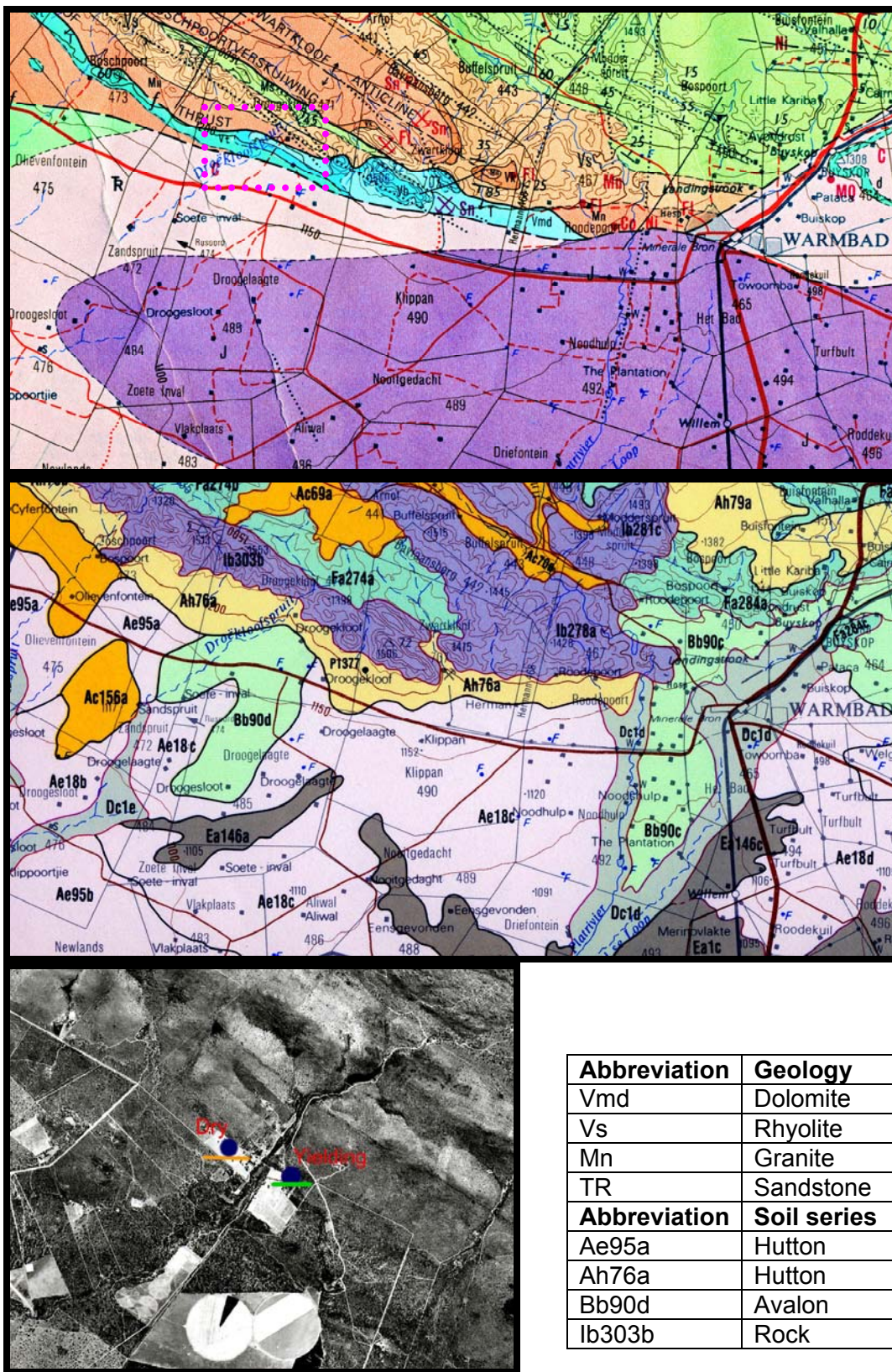


Figure A1.6. The geology (top), land type (middle) and aerial photograph (bottom) of Droogekloof 471KR. The blue circles denote the position of the boreholes (dry and yielding), the green line the direction of the magnetic profile and the orange line indicates the sounding direction at the dry borehole. The area covered by the aerial photograph is indicated by the purple shape in the geological map.

7. Vaalfontein 491KQ

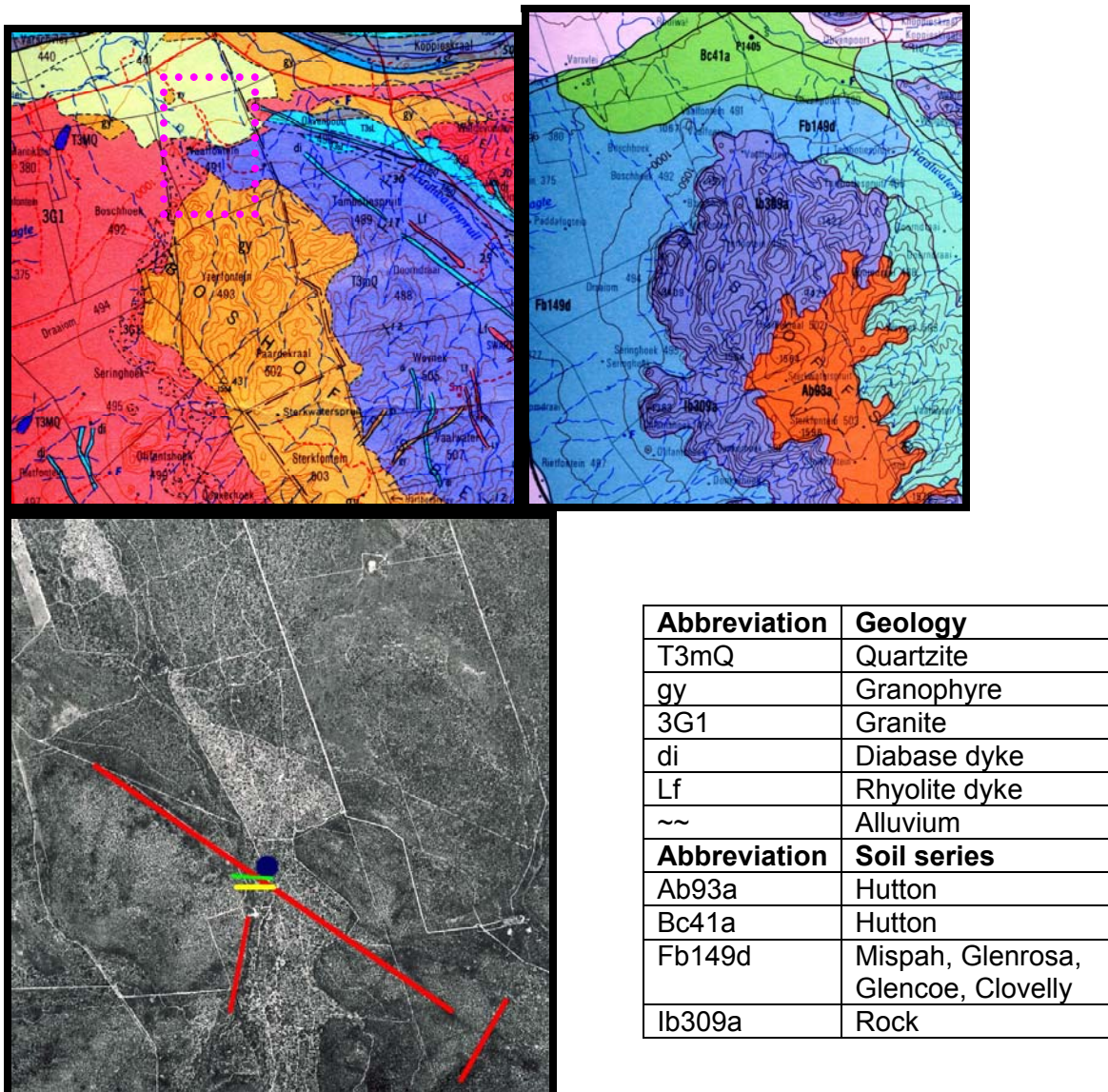


Figure A1.7. The geology (top), land type (middle) and aerial photograph (bottom) of Vaalfontein 491KQ. The blue circle denotes the position of the borehole, the green line the direction of the magnetic profile and the yellow line indicates the electromagnetic profile direction. The red lines are interpreted lineaments. The area covered by the aerial photograph is indicated by the purple shape in the geological map.

A1.3 VAALIUM EONOTHEM: DOLOMITE OF THE MALMANI SUBGROUP IN THE PRETORIA AREA

A band of dolomite surrounds the Pretoria Group sediments on its outer margin. In the Pretoria area, the dolomite is highly regarded for its high groundwater yield capacity. A few case studies are discussed.

A1.3.1 CASE STUDY AREA

Between the archaic granite of Halfway House and the quartzite ridges of Pretoria, a band of dolomite outcrops. This band of dolomite extends south of Pretoria and stretches towards Delmas and Bapsfontein in the southeast. This area is characterised by intensive farming practices that demand large quantities of water. Today, this huge subtraction is responsible for sinkhole forming at Bapsfontein. The dolomite defines plains with a deep soil profile, where chert stands out as hills and ridges, if quite thick, as it more resistant to the elements of weathering and erosion. Some of the dolomite and chert is intersected by intrusions of syenite, carbonatite and diabase. In general these intrusions strike from north and northwest to south and southeast. Two case studies are presented from the Bapsfontein – Kempton Park area.

A1.3.2 CLIMATE AND VELD TYPES

Climatic data is presented in Table A1.6. The area is characterised by cool and wet summers and cold, dry winters. The wet season lasts approximately from October to April with rainfall occurring mostly as heavy thunderstorms. The veld type that occur (see also Table A1.7a) is Bankenveld (Acocks, 1988). Intensive (crop irrigation) and extensive (cattle, maize) agricultural practices occur in this area, depending on the availability of groundwater and dolomite outcrops as the dolomite is surrounded by shale and quartzite of the Pretoria Group with extremely lower aquifer yields. The following tree species are eminent of this veld type (after Acocks, 1988 and Van Wyk & Van Wyk, 1997):

- Bankenveld: *Acacia caffra* (common hook-thorn), *Celtis africana* (white stinkwood) and *Protea caffra* (common sugarbush).

Due to the winters being severely frosty, high rainfall, altitude and regular burning of the grassland, the veld is particularly sour with acid soils and is not hosting a wide variety of trees or shrubs. The Bankenveld represents the grassland biome in this region.

Geobotanical investigations on the presented case studies will indicate other occurring tree species as well and the marker tree species that can be utilised for groundwater exploration.

Table A1.6. Climatic Data of the Bapsfontein Area (Schulze, 1997 & Johannesburg, 1999).

	Quantity
Average Yearly Temperature (°C)	14-16
Mean Minimum Temperature (°C) in July	0-2
Mean Maximum Temperature (°C) in January	25.0-27.5
Average Yearly Rainfall (mm)	600-800
Elevation (m)	1500-1700
Evaporation (mm/year)	2000-2250
Frost area?	150-175 days a year

A1.3.3 GEOLOGY AND HYDROGEOLOGICAL CLASSIFICATION

The Chuniespoort Group and Malmani Subgroup south and southwest of Pretoria are composed of dolomite with interbedded quartzite and chert. Manganese oxides occur in small deposits in the Malmani Subgroup (Walraven, 1978b). Overburden of soil and shale belonging to the Dwyka Formation of the Karoo Supergroup occurs frequently in the study area and are a concern during geophysical groundwater exploration as depressions are often filled up with these and yield lower resistivities with depth, although it only represents clay and no aquifer or water filled cavity. Some dykes cross the dolomite and as for the study area these dykes consist of diabase. On the one Elandsfontein 412JR case study, quartzite of the Boshhoek Formation is present and forms small ridges and scattered quartzite pebbles can be found on the lands.

Furthermore, a lineament, most probably diabase, stretches from north to south on this farm. Along this lineament is a perennial spring situated with an estimated yield of 10 800 ℓ/h. This water is gathered in a dam and utilised for irrigation purposes.

In this environment, the dolomite aquifer is classified as karst with a possible yield above 18 000 ℓ/h (Johannesburg, 1999). Aquifer targets are solution cavities (gravimetric and direct current sounding methods) and contact zones with diabase (magnetic and electromagnetic methods).

A1.3.4 GEOPHYSICAL AND GEOBOTANICAL INFORMATION

Most geophysical studies relating to dolomite is on the topic of sinkhole definition by means of the gravimetric method. This method is highly specialised and too expensive to use in the field for ordinary groundwater exploration methods. Therefore, it is easy to obtain geophysical reports dealing with dolomitic sinkholes and gravimetric results. Information on geophysical groundwater exploration by means of magnetic, electric and electromagnetic methods is less abundant and difficult to obtain, as these are mostly confident consultants reports. The exploration target is intrusive bodies within the dolomite or possible sinkholes.

Groundwater levels vary around 12-20 m and the level where groundwater can be struck is about around 21-34 m according to Frommurze (1937), but it was found that currently this level increased to around 40-50 m, most probably to over utilising of this pristine resource.

Diabase intrusions can be localised with the magnetic method. If the electromagnetic method is incorporated, then one is able to distinguish between different rock types on ground of their electrical conductivity. Basins of weathering along intrusions can also with ease be established. Electrical sounding's purpose is to determine resistivity changes with depth and to locate possible aquifers or weathering basins. The local hydrocensus will indicate depths of weathering, or alterations in resistivity, co-incite with the required depth to strike groundwater as indicated in Table A1.7. The occurrence of

sinkholes in the area will also indicate the likelihood of the existence of other cavities that can act as aquifers.

Geobotanic indicators are not known relating to dolomite (Scott & Le Maitre, 1998) and are even worse to study on the Highveld due to the localised and rare occurrence of shrubs and trees. However, this study identified some and as a fact are not so rare where intrusions occur in the dolomite or zones of deeper weathering in the dolomite that are often covered with white stinkwood (*Celtis africana*) trees.

A1.3.5 SOIL SAMPLING AND RESULTS PRESENTATION

The same soil sampling procedure was followed as in the previous cases. Take two samples at the geobotanic/borehole site at depths of respectively 0.5 m and 1.2 m and another one some distance removed from this spot where there are neither obvious signs of conspicuous vegetation growth nor any anomalous signatures on the geophysical data. The same sampling depths applies here, see Tables A1.7a&b. Two farms were studied in close vicinity of each other. The farm Elandsfontein 412JR is situated on the road between Bapsfontein and Kempton Park, a well known dolomite and sinkhole area with numerous agricultural irrigation installations.

Table A1.7a. Vaalium Eonothem: Dolomite in the Pretoria Area: along intrusive contact.

Parameter	Elandsfontein 412JR (1)		Elandsfontein 412JR (2)	
	Small diabase intrusion in dolomite/cavity	Small diabase intrusion in dolomite/cavity	Diabase intrusion in dolomite	Diabase intrusion in dolomite
Depth Sampled	0.5m	1.2m	0.5m	1.2m
Borehole Co-ordinates:				
S.L.				
E.L.	25°59.317' 28°22.433'	25°59.317' 28°22.433'	26°00.815' 28°20.151'	26°00.815' 28°20.151'
Soil colour	Brownish black	Brownish black	Moderate brown	Moderate brown
Soil texture description	Sandy loam	Sandy loam	Clayey silt	Clay
pH	6.73	6.53	5.54	5.16
P (mg/kg)	1.23	1.07	3.40	2.99
Ca (mg/kg)	1859	861	323	221
Mg (mg/kg)	252	329	397	496
K (mg/kg)	210	211	56	49
Na (mg/kg)	40	9	25	34
Fe (mg/kg)	136.10	188.80	59.30	183.14
Mn (mg/kg)	893.72	1381.32	434.00	1035.38
Zn (mg/kg)	0.24	0.50	0.88	2.77
Al (cmol _c /kg)	0	0	0.519	0.589
Resistance (Ohm)	2400	3600	4800	5200
C%	0.79	0.34	0.37	0.81
Total N%	0.071	0.046	0.060	0.035
S (mg/kg)	37.17	12.46	88.25	10.84

CEC (cmol _c /kg)	8.470	13.774	10.926	14.658
Distinct Tree Species	1. Acacia karroo 2. Rhus lancea	1. Acacia karroo 2. Rhus lancea	1. Acacia karroo 2. Euclea crispa 3. Rhus lancea 4. Celtis africana	1. Acacia karroo 2. Euclea crispa 3. Rhus lancea 4. Celtis africana
Average rooting depth of the indicated species (m)	13 - 50	13 - 50	6 - 50	6 - 50
Average depth of weathering (m)	3.1	3.1	3.1	3.1
Geomorphology	Plain	Plain	Undulating terrain	Undulating terrain
Geophysical instrumentation used	Magnetometer & Schlumberger soundings	Magnetometer & Schlumberger soundings	Magnetometer & Electromagnetics	Magnetometer & Electromagnetics
Water features present?	No	No	To the north a spring (800m)	To the north a spring (800m)
Aquifer Yield (l/h)	22 000	22 000	45 000	45 000
Borehole Depth (m)	50	50	65	65
Depth of Water Strike (m)	46	46	43	43
Static Water Level (m)	17	17	15	15
Average Aquifer Yield (l/h)	25 000	25 000	25 000	25 000
Average Borehole Depth (m)	60	60	60	60
Average Depth of Water Strike (m)	44	44	44	44
Average Static Water Level (m)	19	19	19	19

Land Type Series	Ab6a Hutton	Ab6a Hutton	Ab6a Hutton	Ab6a Hutton
Profile No	P55	P55	P55	P55
Depth Sampled	830-1200mm	830-1200mm	830-1200mm	830-1200mm
Gravel %	2	2	2	2
Sand %	66	66	66	66
Silt %	8	8	8	8
Clay %	24	24	24	24
pH	5.6	5.6	5.6	5.6
P (mg/kg)	2.0	2.0	2.0	2.0
Ca (mg/kg)	92	92	92	92
Mg (mg/kg)	44	44	44	44
K (mg/kg)	414	414	414	414
Na (mg/kg)	229	229	229	229
Fe (mg/kg)	-	-	-	-
Mn (mg/kg)	2.8	2.8	2.8	2.8
Zn (mg/kg)	0.46	0.46	0.46	0.46
Resistance (Ohm)	7000	7000	7000	7000
C%	0.4	0.4	0.4	0.4
CEC (cmol _c /kg)	4.0	4.0	4.0	4.0
Veld Type	61 Bankenveld	61 Bankenveld	61 Bankenveld	61 Bankenveld
Hydrogeological Unit	C5	C5	C5	C5

The average aquifer yield, average borehole depth, average water strike and average static water level were obtained from Frommurze (1937) and a local hydrocensus. It must be noted that the presented value is only an average for the geological

formation. Information obtained from the land type maps and accompanying memoir is from Land Type Survey Staff (1987), veld type information from Acocks (1988) and hydrogeological information from DWAF: Johannesburg (1999). Soil colour was identified and classified in the veld according to the Corstor Colour Gauge that lists 168 different soil colours. Average weathering depth is extracted from the indicated Land Type Survey Staff and average rooting depth of the geobotanical indicators is referenced from Canadell *et al.* (1996).

Table A1.7b. Vaalium Eonothem: Dolomite in the Pretoria Area: no intrusive contact.

	Elandsfontein 412JR (1)		Elandsfontein 412JR (2)	
Geological Formation	Dolomite (Malmani Subgroup)	Dolomite (Malmani Subgroup)	Dolomite (Malmani Subgroup), quartzite (Boshoeck Formation) and Karoo overburden	Dolomite (Malmani Subgroup), quartzite (Boshoeck Formation) and Karoo overburden
Depth Sampled	0.5m	1.2m	0.5m	1.2m
Borehole Co-ordinates: S.L. E.L.	25°59.317' 28°22.433'	25°59.317' 28°22.433'	26°00.815' 28°20.151'	26°00.815' 28°20.151'
Soil colour	Moderate brown	Pale reddish brown	Brownish grey	Greyish brown
Soil texture description	Sandy gravel	Sandy loam & gravel	Clay	Silty clay
pH	6.52	6.50	6.44	6.04
P (mg/kg)	2.77	1.02	2.23	1.90
Ca (mg/kg)	877	564	372	243
Mg (mg/kg)	365	416	285	193
K (mg/kg)	178	146	92	126

Na (mg/kg)	33	8	12	138
Fe (mg/kg)	191.77	226.96	175.95	340.05
Mn (mg/kg)	1426.25	1356.11	1203.42	1615.81
Zn (mg/kg)	0.64	1.95	0.23	0.56
Al (cmol _c /kg)	0	0	0	0
Resistance (Ohm)	3800	5200	2600	1600
C%	0.19	0.24	0.06	0.95
Total N%	0.037	0.033	0.117	0.022
S (mg/kg)	21.13	20.97	134.38	90.05
CEC (cmol _c /kg)	12.958	11.464	4.588	4.497
Distinct Tree Species	1. Acacia karroo 2. Rhus lancea	1. Acacia karroo 2. Rhus lancea	1. Acacia karroo 2. Euclea crispa 3. Rhus lancea 4. Celtis africana	1. Acacia karroo 2. Euclea crispa 3. Rhus lancea 4. Celtis africana
Average rooting depth of the indicated species (m)	13 - 50	13 - 50	6 - 50	6 - 50
Average depth of weathering (m)	3.1	3.1	3.1	3.1
Geomorphology	Plain	Plain	Undulating terrain	Undulating terrain
Geophysical instrumentation used	Magnetometer & Schlumberger soundings	Magnetometer & Schlumberger soundings	Magnetometer & Electromagnetics	Magnetometer & Electromagnetics
Water features present?	No	No	To the north a spring (800m)	To the north a spring (800m)
Aquifer Yield (l/h)	22 000	22 000	45 000	45 000
Borehole Depth (m)	50	50	65	65
Depth of Water Strike (m)	46	46	43	43
Static Water Level (m)	17	17	15	15

Average Aquifer Yield (l/h)	25 000	25 000	25 000	25 000
Average Borehole Depth (m)	60	60	60	60
Average Depth of Water Strike (m)	44	44	44	44
Average Static Water Level (m)	19	19	19	19
Land Type Series	Ab6a Hutton	Ab6a Hutton	Ab6a Hutton	Ab6a Hutton
Profile No	P55	P55	P55	P55
Depth Sampled	830-1200mm	830-1200mm	830-1200mm	830-1200mm
Gravel %	2	2	2	2
Sand %	66	66	66	66
Silt %	8	8	8	8
Clay %	24	24	24	24
pH	5.6	5.6	5.6	5.6
P (mg/kg)	2.0	2.0	2.0	2.0
Ca (mg/kg)	92	92	92	92
Mg (mg/kg)	44	44	44	44
K (mg/kg)	414	414	414	414
Na (mg/kg)	229	229	229	229
Fe (mg/kg)	-	-	-	-
Mn (mg/kg)	2.8	2.8	2.8	2.8
Zn (mg/kg)	0.46	0.46	0.46	0.46
Resistance (Ohm)	7000	7000	7000	7000
C%	0.4	0.4	0.4	0.4
CEC (cmol _c /kg)	4.0	4.0	4.0	4.0

Veld Type	61 Bankenveld	61 Bankenveld	61 Bankenveld	61 Bankenveld
Hydrogeological Unit	C5	C5	C5	C5

The average aquifer yield, average borehole depth, average water strike and average static water level were obtained from Frommurze (1937) and a local hydrocensus. It must be noted that the presented value is only an average for the geological formation. Information obtained from the land type maps and accompanying memoir is from Land Type Survey Staff (1987), veld type information from Acocks (1988) and hydrogeological information from DWAF: Johannesburg (1999). Soil colour was identified and classified in the veld according to the Corstor Colour Gauge that lists 168 different soil colours. Average weathering depth is extracted from the indicated Land Type Survey Staff and average rooting depth of the geobotanical indicators is referenced from Canadell *et al.* (1996).

8. Elandsfontein 412JR (1)

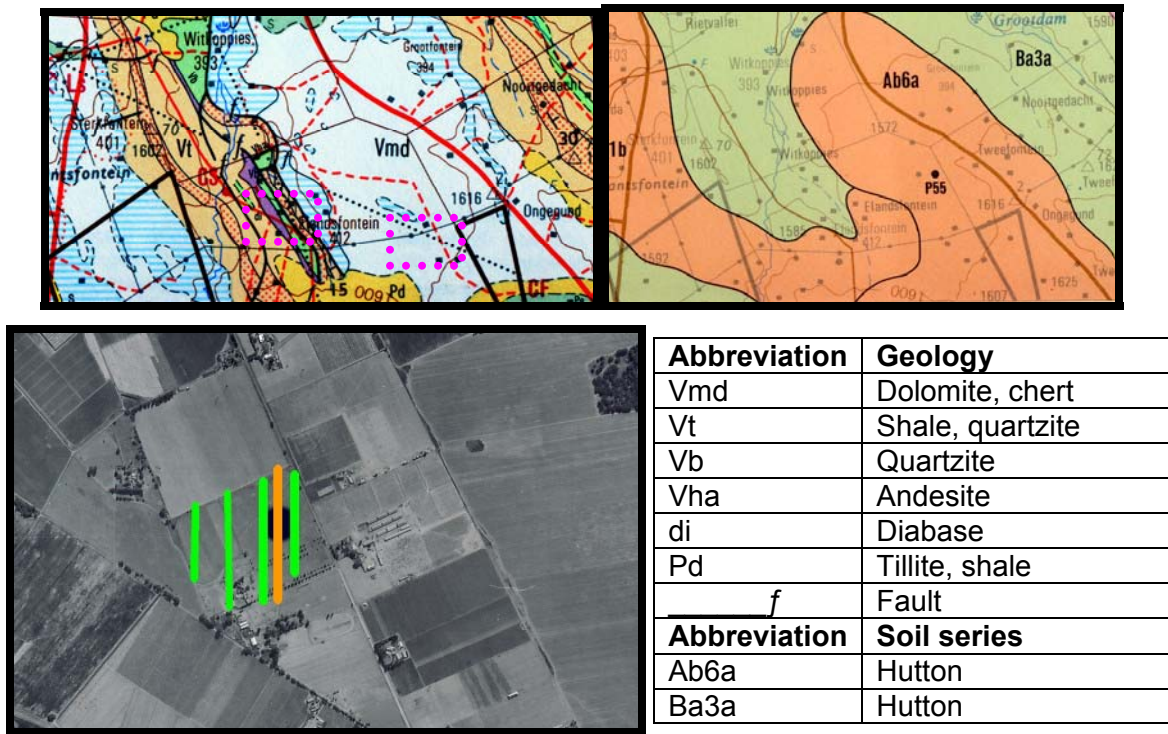


Figure A1.8. The geology (top left), land type (top right) and aerial photograph (bottom) of Elandsfontein 412JR (1). The blue circle denotes the position of the borehole, the green lines the direction of the magnetic profiles in order to obtain the contour map and the orange line indicates the sounding direction. The area covered by the aerial photograph is indicated by the right purple shape in the geological map.

The first case study on the farm Elandsfontein 412JR is about 7 km to the west of Bapsfontein, between Pretoria and Delmas.

9. Elandsfontein 412JR (2)



Figure A1.9. The geology and land type can be seen in Figure A1.8. Aerial photograph of Elandsfontein 412JR (2). The blue circle denotes the position of the borehole, the green line the direction of the magnetic profile, and the yellow line indicates the electromagnetic traverse direction. The area covered by the aerial photograph is indicated by the left purple shape in the geological map.

The second case study on the farm Elandsfontein 412JR is situated about 12 km to the west of the town Bapsfontein.

A1.4 VAALIUM EONOTHEM: ANDESITE AND GABBRO IN THE PRETORIA-BRITS AREA

All the results are presented in Table A1.9 (a&b). The name gabbro will be used in the text as no mineralogical analyses were done on rock samples of the Brits area to

distinguish between gabbro and norite. Preference is given to the name gabbro as gabbro is darker in appearance than norite, as observed from the local outcrops.

A1.4.1 CASE STUDY AREA

New residential development east of Pretoria, named Mooikloof Estates, urged the need for groundwater supply to every new household. Each residential development is on 1 ha and establishes the arena for in depth geophysical profiling on these properties with the aid of contouring the data in order to select the best drilling spot. The two smallholdings investigated were both situated on andesite (Hekpoort Formation of the Pretoria Group) and localised tree clusters and stand alone trees occur on these smallholdings prior to the commence of building activities. The terrain is extremely undulating and scattered andesite boulders are common. It is a pity that when a successful borehole is sited, often all the vegetation around it is cleared and diminishes the existence of geobotanical indicators if the site is visited afterwards. The one remaining case study is situated in Brits Industrial Area. The entire area consists of gabbro and norite of the Rustenburg Layered Suite - Bushveld Igneous Complex. The borehole was drilled for groundwater pollution monitoring and selected on the basis of geophysical data and observed geobotanical growth. This terrain is basically plain with some small ridges that may be reminiscent of exfoliation weathering.

A1.4.2 CLIMATE AND VELD TYPES

Climatic data is presented in Table A1.8. The Pretoria area is characterised by cool and wet summers and cold, dry winters, but the Brits area experiences hotter, wet summers (and abundant hail) and the winters are mild and dry. The wet season lasts approximately from October to April with rainfall occurring mostly as heavy thunderstorms. The veld type that occurs (see also Table A1.9a) is Bankenveld for Pretoria and Norite Black Turf Thornveld in the Brits area (Acocks, 1988). Intensive (crop irrigation) and extensive (cattle, maize) agricultural practices occur in this area, depending on the availability of groundwater and weathering profiles in the norite, especially close to water courses. The following tree species are eminent of the veld types (after Acocks, 1988 and Van Wyk & Van Wyk, 1997):

- Bankenveld: *Acacia caffra* (common hook-thorn), *Celtis africana* (white stinkwood) and *Protea caffra* (common sugarbush)-Grassland biome.
- Norite Black Turf Thornveld: *Acacia karroo* (sweet thorn), *Rhus lancea* (karree), *Ziziphus mucronata* (buffalo-thorn)-Savanna biome.

The andesite on the Bankenveld supports various tree species, normally in tree clusters that are very conspicuous around ridges, valleys and sometimes in the open veld, unless the fact that frost occurs. Normally more frost resistant tree species protect less frost resistant tree species in such a cluster as it serves as a shield. The Brits area is less impacted by frost and hence more abundant vegetation growth occurs on the black turf, although in patches, where more species variation occurs along small ridges (about 500mm in height) that are more probably residues of exfoliation of the gabbro rock.

Geobotanical investigations on the presented case studies will indicate other occurring tree species as well and the marker tree species that can be utilised for groundwater exploration.

Table A1.8. Climatic Data of the Pretoria and Brits Areas (Schulze, 1997 & Johannesburg, 1999).

	Pretoria Area Quantity	Brits Area Quantity
Average Yearly Temperature (°C)	14-16	16-18
Mean Minimum Temperature (°C) in July	0-2	2-4
Mean Maximum Temperature (°C) in January	25.0-27.5	27.5-30.0
Average Yearly Rainfall (mm)	600-800	600-800
Elevation (m)	1500-1700	800-1200
Evaporation (mm/year)	2000-2250	2000-2250
Frost area?	150-175 days a year	Almost none

A1.4.3 GEOLOGY AND HYDROGEOLOGICAL CLASSIFICATION

Volcanic rocks (andesite) of the Hekpoort Formation, Pretoria Group, Transvaal Sequence, occur in a east-west band through Pretoria. It stipulates a plain with a red-

brown clay soil between the quartzite ridges of the Timeball Formation and Daspoort Formation. The volcanic beds of the Hekpoort Formation do not have any dip. About 10 km north of the Hekpoort Formation gabbro of the Bushveld Igneous Complex (Rustenburg Layered Suite) outcrops in a vast plain, just north of the quartzite mountains of the Magaliesberg Formation (Pretoria Group). The gabbro in the Brits area weathers to a black turf and small variations in the local topography can be ascribed to exfoliation of weathered gabbro. Exfoliation planes act as aquifers (Hattingh, 1996).

Aquifers associated with andesite and gabbro are classified as intergranular and fractured according to the Johannesburg (1999) hydrogeological map. Yields vary from 360-5400 l/h in the andesite to 1800-7200 l/h obtained from boreholes drilled in gabbro. Water strike is about 31 m in andesite and 20 m in gabbro (Frommurze, 1937).

A1.4.4 GEOPHYSICAL AND GEOBOTANICAL INFORMATION

Published geophysical case studies of the Pretoria-Brits area are scarce. Abundant confidential geophysical reports exist of the area regarding groundwater supply and groundwater pollution studies. A couple a case studies relating to the Pretoria Group and similar lithologies are presented and discussed by Meulenbeld (1998). The nature of the Pretoria Group in this area is that numerous intrusive basic or ultra-basic bodies at various depths often intersect sedimentary rocks. Empirical implication is that groundwater can therefore be intersected at basic any point. However, geophysical siting of these boreholes is extremely important as it improves the yield of such a borehole significantly. Other case studies in the Pretoria Group, Pretoria area, will also illustrate this. The range of metamorphic, volcanic and sedimentary rocks in the Pretoria Group creates a distinctive signature of every rock type regarding conductivity/ resistivity values and eases interpretation of the geophysical data.

Information on geobotany of the Pretoria area is not elsewhere documented. The discussion in Chapter 3 can be incorporated in these case studies.

A1.4.5 SOIL SAMPLING AND RESULTS PRESENTATION

Two 1 ha small holdings in the Mooikloof Estate, east of Pretoria are presented together with a geophysical pollution borehole siting study in the Brits Industrial area. Depth of

soil sampling varies between 0.5 m and 1.2 m at the geobotanic indicator and at the same corresponding depth at some distance removed from it. The soil sample results and other useful information is presented in Tables A1.9 (a&b).

Table A1.9a. Vaalium Eonothem: Andesite and Gabbro in the Pretoria-Brits Areas: along intrusive/weathering contact.

	Mooikloof Estate (1) Pretoria East		Mooikloof Estate (2) Pretoria East		Brits Industrial Area	
Geological Formation	Andesite (Hekpoort Formation) and fault zone	Andesite (Hekpoort Formation) and fault zone	Fractured andesite (Hekpoort Formation)	Fractured andesite (Hekpoort Formation)	Weathered basins in gabbro (Rustenburg Layered Suite)	Weathered basins in gabbro (Rustenburg Layered Suite)
Depth Sampled	0.5m	1.2m	0.5m	1.2m	0.5m	0.5m
Borehole Co-ordinates:						
S.L.	25°49.467'	25°49.467'	25°49.217'	25°49.217'	25°38.257'	25°38.257'
E.L.	28°20.283'	28°20.283'	28°19.701'	28°19.701'	27°47.433'	27°47.433'
Soil colour	Greyish brown	Dusky yellowish brown	Dark reddish brown	Weak red	Brownish black	Black
Soil texture description	Clay	Clay	Sandy loam	Loam	Silty clay	Clay
pH	7.84	7.64	5.54	6.02	7.71	7.89
P (mg/kg)	11.26	6.50	4.62	3.19	22.85	19.46
Ca (mg/kg)	2380	3291	2330	1771	10849	10497
Mg (mg/kg)	698	617	533	460	888	1431
K (mg/kg)	108	132	244	196	540	562
Na (mg/kg)	61	25	19	36	41	37
Fe (mg/kg)	121.25	139.21	102.11	70.55	22.43	14.02
Mn (mg/kg)	289.18	355.16	425.05	372.62	141.98	107.08
Zn (mg/kg)	1.29	0.84	4.37	1.29	8.87	11.68
Al (cmol _c /kg)	0.060	0.037	0.00	0.00	0	0
Resistance (Ohm)	1600	1600	580	2200	310	360

C%	1.01	1.02	4.11	2.81	2.03	3.07
Total N%	0.064	0.064	0.275	0.173	0.104	0.151
S (mg/kg)	14.20	14.46	36.25	30.34	34.40	25.63
CEC (cmol _e /kg)	17.662	19.816	14.968	15.556	1.00	55.32
Distinct Tree Species	1. Euclea crispa	1. Euclea crispa	1. Clerodendrum glabrum 2. Zanthoxylum capense 3. Euclea crispa	1. Clerodendrum glabrum 2. Zanthoxylum capense 3. Euclea crispa	1. Clerodendrum glabrum 2. Ziziphus mucronata 3. Rhus lancea	1. Clerodendrum glabrum 2. Ziziphus mucronata 3. Rhus lancea
Average rooting depth of the indicated species (m)	4	4	4 - 7	4 - 7	4 - 13	4 - 13
Average depth of weathering (m)	0.9	0.9	0.9	0.9	2.3	2.3
Geomorphology	Steep ridges and valleys	Steep ridges and valleys	Steep ridges and valleys	Steep ridges and valleys	Plain	Plain
Geophysical instrumentation used	Magnetics	Magnetics	Magnetics	Magnetics	Magnetics Electro-magnetics	Magnetics Electro-magnetics
Water features present?	No	No	No	No	No	No
Aquifer Yield (l/h)	15000	15000	20000	20000	18000	18000
Borehole Depth (m)	60	60	65	65	45	45
Depth of Water Strike (m)	23	23	21	21	17	17

Static Water Level (m)	9	9	7	7	11	11
Average Aquifer Yield (l/h)	6750	6750	6750	6750	7520	7520
Average Borehole Depth (m)	56	56	56	56	44	44
Average Depth of Water Strike (m)	31	31	31	31	20	20
Average Static Water Level (m)	17	17	17	17	12	12
Land Type Series	lb7b Mispah, Clovelly	lb7b Mispah, Clovelly	lb7b Mispah, Clovelly	lb7b Mispah, Clovelly	Ae21 Hutton	Ae21 Hutton
Profile No	No Data	No Data	No Data	No Data	No Data	No Data
Veld Type	61 Bankenveld	61 Bankenveld	61 Bankenveld	61 Bankenveld	13 Norite Black Turfveld	13 Norite Black Turfveld
Hydrogeological Unit	D2	D2	D2	D2	D3	D3

The average aquifer yield, average borehole depth, average water strike and average static water level was obtained from Frommurze (1937). It must be noted that the presented value is only an average for the geological formation. Information obtained from the land type maps and accompanying memoir is from Land Type Survey Staff (1987), veld type information from Acocks (1988) and hydrogeological information from DWAF: Johannesburg (1999). Soil colour was identified and classified in the veld according to the Corstor Colour Gauge that lists 168 different soil colours. Average weathering depth is extracted from the indicated Land Type Survey Staff and average rooting depth of the geobotanical indicators is referenced from Canadell *et al.* (1996).

Table A1.9b. Vaalium Eonothem: Andesite and Gabbro in the Pretoria-Brits Areas: absent intrusive/weathering contact.

	Mooikloof Estate (1) Pretoria East		Mooikloof Estate (2) Pretoria East		Brits Industrial Area	
Geological Formation	Andesite (Hekpoort Formation)	Andesite (Hekpoort Formation)	Andesite (Hekpoort Formation)	Andesite (Hekpoort Formation)	Gabbro (Rustenburg Layered Suite)	Gabbro (Rustenburg Layered Suite)
Depth Sampled	0.5m	1.2m	0.5m	1.2m	0.5m	0.5m
Borehole Co-ordinates:						
S.L.	25°49.467'	25°49.467'	25°49.217'	25°49.217'	25°38.257'	25°38.257'
E.L.	28°20.283'	28°20.283'	28°19.701'	28°19.701'	27°47.433'	27°47.433'
Soil colour	Greyish brown	Dark reddish brown	Dark reddish brown	Weak red	Dark grey	Dark grey
Soil texture description	Clay	Clay	Sandy loam	Loam	Silty	Silty
pH	7.40	6.91	5.06	5.61	7.79	8.18
P (mg/kg)	15.91	7.19	3.48	3.28	19.43	17.98
Ca (mg/kg)	1696	1551	721	741	10829	7111
Mg (mg/kg)	469	388	273	324	3053	2720
K (mg/kg)	95	110	199	211	260	272
Na (mg/kg)	33	22	29	23	133	186
Fe (mg/kg)	134.02	199.07	55.34	65.80	20.29	39.11
Mn (mg/kg)	310.42	276.15	318.10	393.77	56.61	138.64
Zn (mg/kg)	1.04	1.28	0.91	2.29	0.41	2.11
Al (cmol _c /kg)	0.091	0.051	0.317	0.044	0	0
Resistance (Ohm)	1800	2000	2000	2200	400	440
C%	0.94	1.00	1.45	1.60	0.73	1.02

Total N%	0.062	0.066	0.095	0.100	0.042	0.065
S (mg/kg)	13.32	10.55	60.83	39.20	25.79	23.11
CEC (cmol _c /kg)	13.351	11.460	8.725	9.623	52.555	43.651
Distinct Tree Species	1. Euclea crispa	1. Euclea crispa	1. Clerodendrum glabrum 2. Zanthoxylum capense 3. Euclea crispa	1. Clerodendrum glabrum 2. Zanthoxylum capense 3. Euclea crispa	1. Clerodendrum glabrum 2. Rhus lancea 3. Ziziphus mucronata	1. Clerodendrum glabrum 2. Rhus lancea 3. Ziziphus mucronata
Average rooting depth of the indicated species (m)	4	4	4 - 7	4 - 7	4 - 13	4 - 13
Average depth of weathering (m)	0.9	0.9	0.9	0.9	2.3	2.3
Geomorphology	Steep ridges and valleys	Steep ridges and valleys	Steep ridges and valleys	Steep ridges and valleys	Plain	Plain
Geophysical instrumentation used	Magnetics	Magnetics	Magnetics	Magnetics	Magnetics Electro-magnetics	Magnetics Electro-magnetics
Water features present?	No	No	No	No	No	No
Aquifer Yield (l/h)	15000	15000	20000	20000	18000	18000
Borehole Depth (m)	60	60	65	65	45	45
Depth of Water Strike (m)	23	23	21	21	17	17

Static Water Level (m)	9	9	7	7	11	11
Average Aquifer Yield (l/h)	6750	6750	6750	6750	7520	7520
Average Borehole Depth (m)	56	56	56	56	44	44
Average Depth of Water Strike (m)	31	31	31	31	20	20
Average Static Water Level (m)	17	17	17	17	12	12
Land Type Series	lb7b Mispah, Clovelly	lb7b Mispah, Clovelly	lb7b Mispah, Clovelly	lb7b Mispah, Clovelly	Ea3b Arcadia	Ea3b Arcadia
Profile No	No Data	No Data	No Data	No Data	No Data	No Data
Veld Type	61 Bankenveld	61 Bankenveld	61 Bankenveld	61 Bankenveld	13 Norite Black Turfveld	13 Norite Black Turfveld
Hydrogeological Unit	D2	D2	D2	D2	D3	D3

The average aquifer yield, average borehole depth, average water strike and average static water level was obtained from Frommurze (1937). It must be noted that the presented value is only an average for the geological formation. Information obtained from the land type maps and accompanying memoir is from Land Type Survey Staff (1987), veld type information from Acocks (1988) and hydrogeological information from DWAF: Johannesburg (1999). Soil colour was identified and classified in the veld according to the Corstor Colour Gauge that lists 168 different soil colours. Average weathering depth is extracted from the indicated Land Type Survey Staff and average rooting depth of the geobotanical indicators is referenced from Canadell *et al.* (1996).

10. Mooikloof Estate (1)

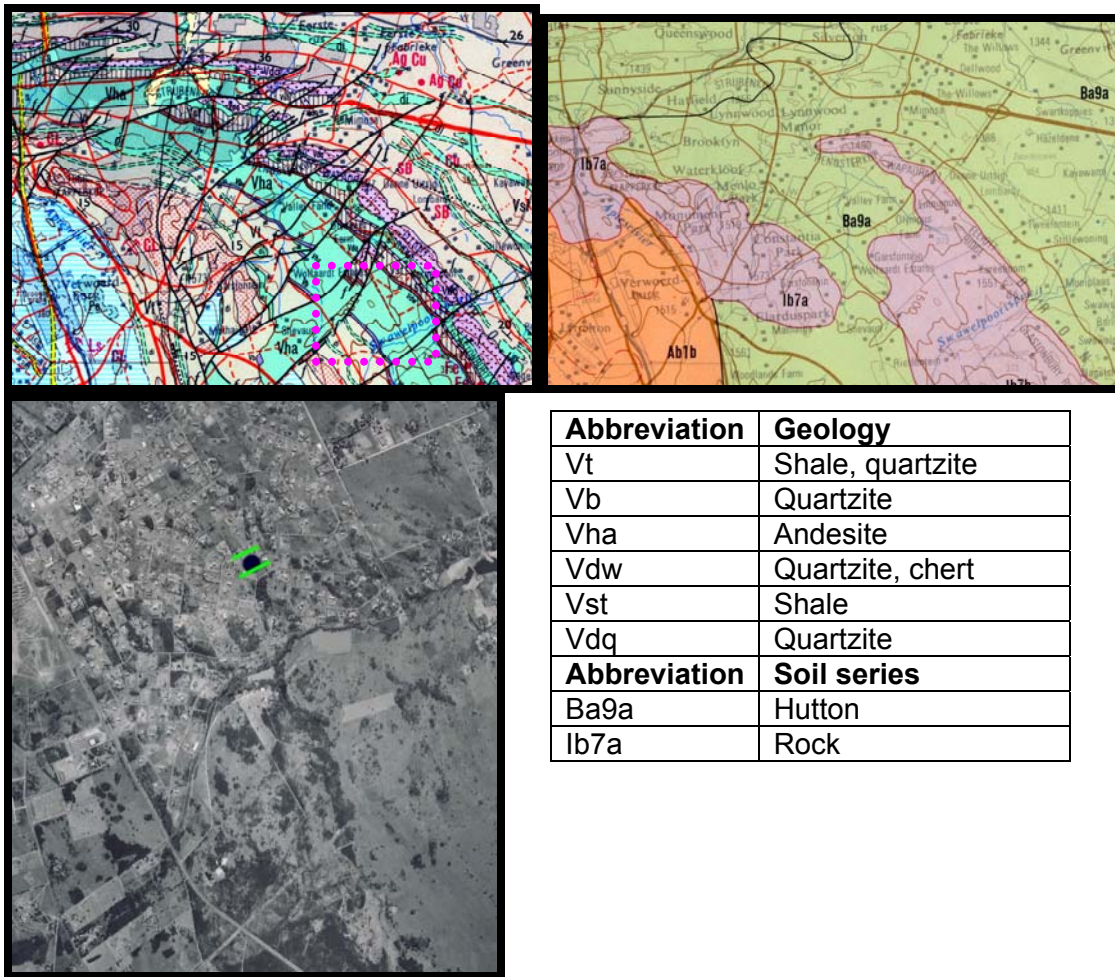


Figure A1.10. The geology (top left), land type (top right) and aerial photograph (bottom) of Mooikloof Estate (1). The blue circle denotes the position of the borehole and the green lines the direction of the magnetic profiles in order to obtain the contour map. The area covered by the aerial photograph is indicated by the purple shape in the geological map.

Mooikloof Estate is a new small holding development east of Pretoria and is part of the suburb Garsfontein.

11. Mooikloof Estate (2)

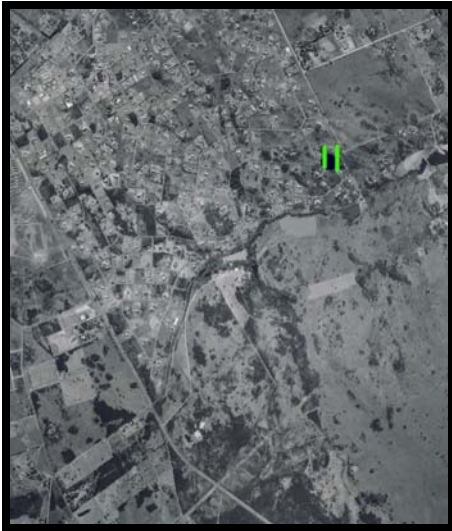


Figure A1.11. The geology and land type are pictured in Figure A1.10. The aerial photograph of Mooikloof Estate (1). The blue circle denotes the position of the borehole and the green lines the direction of the magnetic profiles in order to obtain the contour map. The area covered by the aerial photograph is indicated by the purple shape in the geological map (shares the same area as the previous Mooikloof case study).

12. Brits Industrial Area

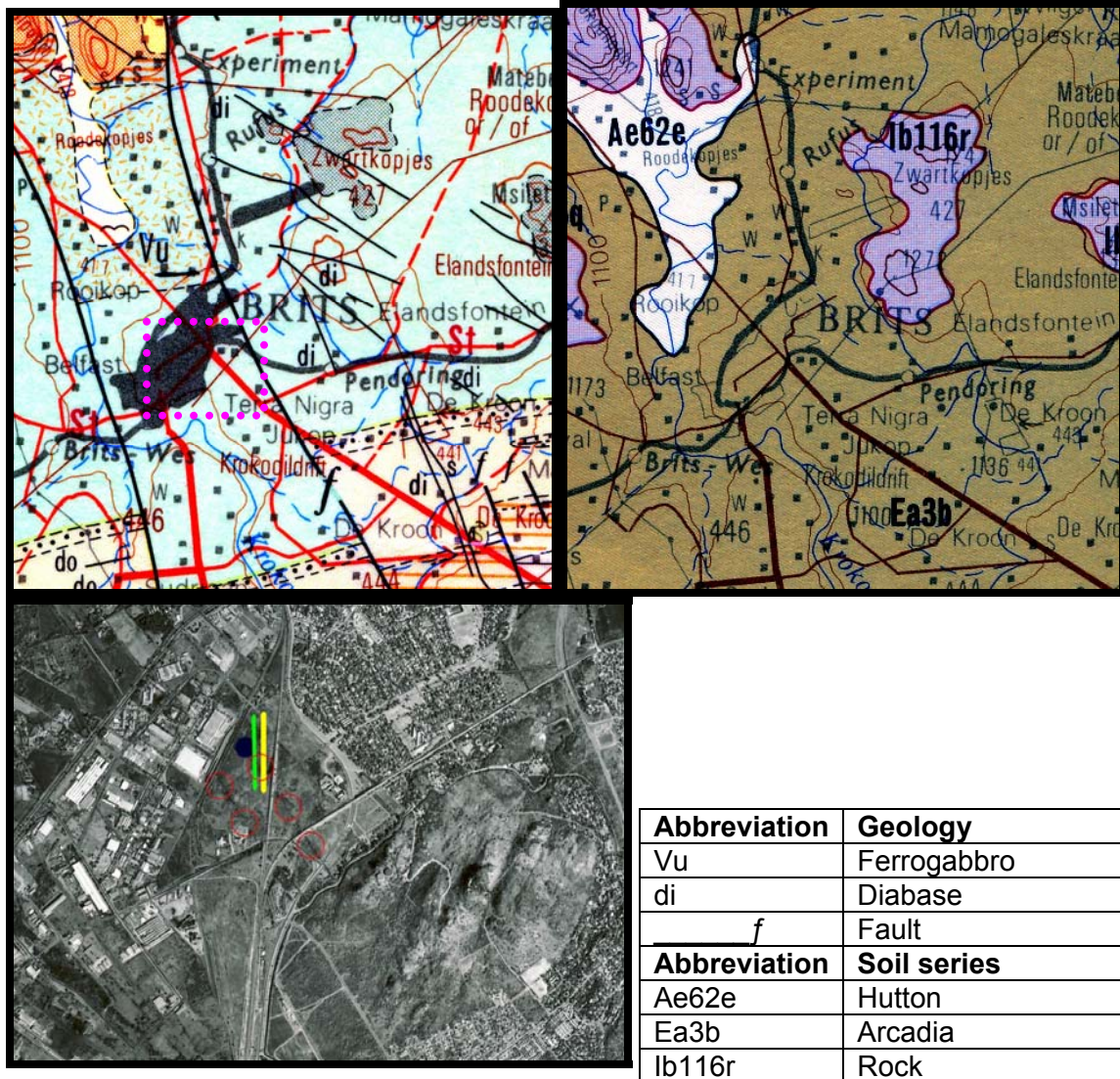


Figure A1.12. The geology (top left), land type (top right) and aerial photograph (bottom) of Brits Industrial Area. The blue circle denotes the position of the borehole, the green line the direction of the magnetic profile and the yellow line the orientation of the electromagnetic traverse. The red circles indicate exfoliation ridges that are covered with vegetation (dark lines). The area covered by the aerial photograph is indicated by the purple shape in the geological map.

A1.5 VAALIUM EONOTHEM: SHALE AND QUARTZITE OF THE PRETORIA GROUP IN THE PRETORIA AREA

The Pretoria Group of the Transvaal Sequence is widely distributed in the old Transvaal as outcrops occur in Thabazimbi in the west, Pretoria and Marble Hall in the centre towards Lydenburg in the eastern escarpment. The case studies relating to the Pretoria Group in the Lydenburg area will be discussed separately in this chapter as the climate and geological conditions differ from these around Pretoria. A milder climate gives rise to more abundant vegetation cover and the Pretoria Group sediments are intruded by numerous diabase intrusions in the Lydenburg area that metamorphosed shale into slate and hornfels at certain sites. This section will deal with shale and quartzite outcrops of the Pretoria Group in the region around Pretoria. All the results are presented in Table A1.11 (a&b).

A1.5.1 CASE STUDY AREA

The extent of the Pretoria Group around the city of Pretoria results in a huge population residing on the sediments and metamorphosed rocks of this group. In the outskirts of the city numerous smallholdings can be counted. Most of these smallholdings do not have access to municipal drinking water, or if they have, groundwater abstraction is required for intensive agricultural farming enterprises. As indicated in Chapter 3, Pretoria is an interesting case study on its own regarding geobotany. The shale, for instance, of the Silverton and Rayton Formations stipulate vast plains with sparse vegetation cover. These plains are structurally confined by quartzite ridges or mountains of the Magaliesberg and Daspoort Formations in the northern parts of Pretoria. Loose standing quartzite-sandstone ridges among the shale plains belong to the Rayton Formation. This kind of geological environment can be observed around the Cullinan diamond mine. Abundant diabase intrusions in the form of sills and dykes can readily be identified in the sediments of the Pretoria Group and especially among the Rayton Formation on the basis of botanic abundance. The three case studies presented stretch from the Hartebeespoortdam area west of Pretoria towards Cullinan, east of Pretoria.

A1.5.2 CLIMATE AND VELD TYPES

Due to the Bankenveld geomorphology of the Pretoria area, a vast amount of microclimates can be measured in the region. The influence of the microclimate can be observed in the diversity of botanic species in the region and on various rocks and soils. The temperature rises from north to south with a definite hotter climate just north of the Magaliesberg mountain range. The climatic conditions of Pretoria are cool, wet summers and cold, dry winters (Table A1.10). The climatic conditions confine the two biomes important to this study. The grassland biome south of the Magaliesberg and north of it transgressing into the savanna biome.

All the case studies have some kind of vegetation growth, some more luxurious than the other depending on the development of the smallholding. Therefore, it is not difficult to understand that all three case studies belong to some kind of Bushveld veld type as classified by Acocks (1988). The following tree species are eminent of the veld types (after Acocks, 1988 and Van Wyk & Van Wyk, 1997), all part of the savanna biome:

- Mixed Bushveld: *Acacia caffra* (common hook-thorn), *Burkea africana* (wild seringa), *Combretum apiculatum* (red bushwillow), *Grewia flava* (velvet raisin) and *Mundulea sericea* (cork bush).
- Sourish Mixed Bushveld: *Acacia caffra* (common hook-thorn), *A. karroo* (sweet thorn), *A. robusta subsp. robustu* (brack thorn) & *A. tortillis subsp. heteracantha* (umbrella thorn), *Rhus gueinzii* (thorny karree), *Peltophorum africanum* (weeping wattle), *Pappea capensis* (jacket-plum) and *Ziziphus mucronata* (buffalo-thorn).

In general the entire surface is encroached by shrubs and trees. The gaps in between are grassed. This makes it difficult to identify any geobotanic indicators or bush-clusters due to an uniform and general homogenic species occurrence. A survey of the trees in such an area will reveal if any conspicuous botanic species occur.

Table A1.10. Climatic Data of the Pretoria and Brits Areas (Schulze, 1997 & Johannesburg, 1999).

	Pretoria Area Quantity
Average Yearly Temperature (°C)	14-16
Mean Minimum Temperature (°C) in July	0-2
Mean Maximum Temperature (°C) in January	25.0-27.5
Average Yearly Rainfall (mm)	600-800
Elevation (m)	1500-1700
Evaporation (mm/year)	2000-2250
Frost area?	150-175 days a year

A1.5.3 GEOLOGY AND HYDROGEOLOGICAL CLASSIFICATION

The Pretoria Group of sediments stretches east-west through the city of Pretoria with a north-east extension towards the town of Cullinan. In the Cullinan area sediments and meta-sediments of the Rayton Formation (Pretoria Group) cover mafic rocks of the Bushveld Igneous Complex. The Silverton Formation is confined by quartzite of the Daspoort and Magaliesberg Formations. The Rayton Formation occurs north of the Magaliesberg and is surrounded by the Bushveld Igneous Complex, sandstone and conglomerate of the Waterberg Group and sandstone and shale of the Karoo Supergroup. Abundant dykes and sills of diabase are to be found among the sediments of the Rayton Formation. Dykes and sills intrude shale of the Silverton Formation as well but on a lesser spatial extent. West of Pretoria the shale beds of the Silverton Formation dip about 25° north. Localised dips of the Rayton Formation can be observed, but are not mapped due to the irregular outcrops of this formation intersected with diabase intrusions.

Hydrogeological classification of the aquifers associated with the discussed lithologies, after Johannesburg (1999), are undifferentiated rock and various mixed lithologies attached to the Rayton Formation and predominantly meta-argillaceous rocks (slate and hornfels) regarding the Silverton Formation. Both formations' aquifers can yield 1800-7200 l/h according to the hydrogeological mapping. Aquifers are typically associated with contact zones of intrusions (Hattingh, 1996).

A1.5.4 GEOPHYSICAL AND GEOBOTANICAL INFORMATION

Some geophysical case studies of the Pretoria Group of sediments are published in the guide by Hattingh (1996) and dissertation by Meulenbeld (1998). These works can be referenced to understand the depth profile of the Pretoria Group, namely its association with diabase intrusions in the sub-surface. The numerous diabase intrusions make every case study quite unique in the sense that different weathering, metamorphoses, dips and soil covers with associated vegetation originate at every site. In this kind of environment geophysical instruments like the magnetometer and electromagnetic EM34-3 apparatus will yield favourable results as the variations in magnetic intensity and conductivity of the various rocks and its weathered products will have its own distinct signature. Information on geobotanical indicators in this area is not known. However, some farmers believe that *Zizuphus mucronata* in this area can be used as a geobotanic indicator. This must be used with caution, however, as it is one of the distinct and frequent occurring tree species in the Sourish Mixed Bushveld veld type (Acocks, 1988).

A1.5.5 SOIL SAMPLING AND RESULTS PRESENTATION

In order to establish if geobotanic communities have remarkable differences in their soil make-up, soil sampling at depths of 0.5 and 1.2 m was undertaken. Another site with no distinct geobotanic cover was also sampled at the same depth intervals. These results are listed in Tables A1.11(a&b). From these results and the other case studies presented elsewhere, certain remarks can be made regarding available soil nutrients and the presence of geobotanic communities.

Table A1.11a. Vaalium Eonothem: Shale and Quartzite in the Pretoria Area: along intrusive/weathering contact.

	Kameeldrift 313JR		Kameelfontein 297JR		Skeerpoort 477JQ	
Geological Formation	Shale (Silverton Formation) with diabase intrusions	Shale (Silverton Formation) with diabase intrusions	Quartzite (Rayton Formation) with diabase intrusions	Quartzite (Rayton Formation) with diabase intrusions	Shale (Silverton Formation) with diabase intrusions	Shale (Silverton Formation) with diabase intrusions
Depth Sampled	0.5m	1.2m	0.5m	1.2m	0.5m	0.5m
Borehole Co-ordinates:						
S.L.	25°41.757'	25°41.757'	25°38.483'	25°38.483'	25°46.364'	25°46.364'
E.L.	28°00.512'	28°00.512'	28°24.857'	28°24.857'	27°46.751'	27°46.751'
Soil colour	Dark reddish brown	Moderate brown	Dark reddish brown	Dark red	Moderate brown	Greyish brown
Soil texture Description	Clay	Clay	Silt	Clayey silt	Clayey silt	Clay
pH	5.31	6.13	7.23	6.49	8.03	5.86
P (mg/kg)	2.40	2.23	3.79	3.37	1.64	1.26
Ca (mg/kg)	881	688	265	195	1256	385
Mg (mg/kg)	575	685	137	100	555	227
K (mg/kg)	52	46	55	54	89	137
Na (mg/kg)	14	39	0	19	471	13
Fe (mg/kg)	133.13	84.18	60.38	38.44	286.46	48.56
Mn (mg/kg)	586.34	305.83	314.62	138.66	128.90	67.11
Zn (mg/kg)	0.18	1.36	2.63	0.81	0.42	0.96
Al (cmol _c /kg)	0.243	0	0	0	0	0.255
Resistance (Ohm)	1800	2800	3120	4970	540	4400
C%	1.41	0.47	0.46	0.39	0.92	0.82

Total N%	0.087	0.038	0.024	0.023	0.062	0.067
S (mg/kg)	39.88	23.46	13.27	11.82	20.90	20.85
CEC (cmol _e /kg)	16.797	10.349	63.26	3.64	15.93	8.72
Distinct Tree Species	1. Acacia karroo 2. Zanthoxylum capense	1. Acacia karroo 2. Zanthoxylum capense	1. Ximenia caffra 2. Ziziphus mucronata	1. Ximenia caffra 2. Ziziphus mucronata	1. Rhus lancea 2. Acacia karroo 3. Clerodendrum glabrum	1. Rhus lancea 2. Acacia karroo 3. Clerodendrum glabrum
Average rooting depth of the indicated species (m)	5 - 50	5 - 50	4 - 13	4 - 13	4 - 50	4 - 50
Average depth of weathering (m)	1.7	1.7	2.5	2.5	1.7	1.7
Geomorphology	Even terrain	Even terrain	Even terrain with small koppies	Even terrain with small koppies	Northern slope	Northern slope
Geophysical instrumentation used	Magnetics and Electromagnetics	Magnetics and Electromagnetics	Magnetics and Electromagnetics	Magnetics and Electromagnetics	Magnetics and Electromagnetics	Magnetics and Electromagnetics
Water features present?	No	No	No	No	Skeerpoort River 500m to the north in valley	Skeerpoort River 500m to the north in valley
Aquifer Yield (l/h)	12000	12000	8000	8000	2500	2500
Borehole Depth (m)	55	55	70	70	80	80
Depth of Water Strike (m)	24	24	38	38	33	33
Static Water Level (m)	8	8	13	13	16	16

Average Aquifer Yield (l/h)	3375	3375	3000	3000	3375	3375
Average Borehole Depth (m)	35	35	45	45	35	35
Average Depth of Water Strike (m)	24	24	27	27	24	24
Average Static Water Level (m)	17	17	13	13	17	17
Land Type Series	Ba8a Mispah, Clovelly, Hutton, Glenrosa	Ba8a Mispah, Clovelly, Hutton, Glenrosa	Ae22a Hutton	Ae22a Hutton	Ba8a Mispah, Clovelly, Hutton	Ba8a Mispah, Clovelly, Hutton
Profile No	No Data	No Data	No Data	No Data	No Data	No Data
Veld Type	19 Sourish Mixed Bushveld	19 Sourish Mixed Bushveld	19 Sourish Mixed Bushveld	19 Sourish Mixed Bushveld	18 Mixed Bushveld	18 Mixed Bushveld
Hydrogeological Unit	D3	D3	D3	D3	D3	D3

The average aquifer yield, average borehole depth, average water strike and average static water level was obtained from Frommurze (1937). It must be noted that the presented value is only an average for the geological formation. Information obtained from the land type maps and accompanying memoir is from Land Type Survey Staff (1987), veld type information from Acocks (1988) and hydrogeological information from DWAF: Johannesburg (1999). Soil colour was identified and classified in the veld according to the Corstor Colour Gauge that lists 168 different soil colours. Average weathering depth is extracted from the indicated Land Type Survey Staff and average rooting depth of the geobotanical indicators is referenced from Canadell *et al.* (1996).

Table A1.11b. Vaalium Eonothem: Shale and Quartzite in the Pretoria Area: intrusive/weathering contact absent.

	Kameeldrift 313JR		Kameelfontein 297JR		Skeerpoort 477JQ	
Geological Formation	Shale (Silverton Formation)	Shale (Silverton Formation)	Quartzite (Rayton Formation)	Quartzite (Rayton Formation)	Shale (Silverton Formation)	Shale (Silverton Formation)
Depth Sampled	0.5m	1.2m	0.5m	1.2m	0.5m	0.5m
Borehole Co-ordinates:						
S.L.	25°41.757'	25°41.757'	25°38.483'	25°38.483'	25°46.364'	25°46.364'
E.L.	28°00.512'	28°00.512'	28°24.857'	28°24.857'	27°46.751'	27°46.751'
Soil colour	Moderate brown	Dark brown	Moderate brown	Strong brown	Clay	Clay
Soil texture description	Loam	Loam	Silty sand	Silty sand	Dark reddish brown	Dark reddish brown
pH	4.62	5.36	7.02	6.38	6.67	6.81
P (mg/kg)	4.95	2.81	4.17	4.04	1.60	1.26
Ca (mg/kg)	128	253	237	191	928	548
Mg (mg/kg)	54	72	90	104	174	104
K (mg/kg)	20	22	31	22	117	91
Na (mg/kg)	2	1	19	10	7	7
Fe (mg/kg)	23.81	41.88	13.21	9.28	47.68	30.33
Mn (mg/kg)	16.27	57.64	43.52	8.71	280.63	163.21
Zn (mg/kg)	0.54	0.17	0	0.34	0.50	0.48
Al (cmol _c /kg)	0.614	0.115	0	0	0	0
Resistance (Ohm)	3200	4200	5900	3300	3000	4600
C%	0.36	0.63	0.12	0.06	0.60	0.48
Total N%	0.035	0.049	0.012	0.009	0.047	0.048

S (mg/kg)	20.08	17.93	4.01	14.59	2.98	1.75
CEC (cmol _c /kg)	2.421	3.126	4.66	3.13	6.79	7.31
Distinct Tree Species	1. Acacia karroo 2. Zanthoxylum capense	1. Acacia karroo 2. Zanthoxylum capense	1. Ximenia caffra 2. Ziziphus mucronata	1. Ximenia caffra 2. Ziziphus mucronata	1. Rhus lancea 2. Acacia karroo 3. Clerodendrum glabrum	1. Rhus lancea 2. Acacia karroo 3. Clerodendrum glabrum
Average rooting depth of the indicated species (m)	5 - 50	5 - 50	4 - 13	4 - 13	4 - 50	4 - 50
Average depth of weathering (m)	1.7	1.7	2.5	2.5	1.7	1.7
Geomorphology	Even terrain	Even terrain	Even terrain with small koppies	Even terrain with small koppies	Northern slope	Northern slope
Geophysical instrumentation used	Magnetics and Electromagnetics	Magnetics and Electromagnetics	Magnetics and Electromagnetics	Magnetics and Electromagnetics	Magnetics and Electromagnetics	Magnetics and Electromagnetics
Water features present?	No	No	No	No	Skeerpoort River 500m to the north in valley	Skeerpoort River 500m to the north in valley
Aquifer Yield (l/h)	12000	12000	8000	8000	2500	2500
Borehole Depth (m)	55	55	70	70	80	80
Depth of Water Strike (m)	24	24	38	38	33	33
Static Water Level (m)	8	8	13	13	16	16

Average Aquifer Yield (l/h)	3375	3375	3000	3000	3375	3375
Average Borehole Depth (m)	35	35	45	45	35	35
Average Depth of Water Strike (m)	24	24	27	27	24	24
Average Static Water Level (m)	17	17	13	13	17	17
Land Type Series	Ba8a Mispah, Clovelly, Hutton, Glenrosa	Ba8a Mispah, Clovelly, Hutton, Glenrosa	Ae22a Hutton	Ae22a Hutton	Ea72a Shortlands	Ea72a Shortlands
Profile No	No Data	No Data	No Data	No Data	No Data	No Data
Veld Type	19 Sourish Mixed Bushveld	19 Sourish Mixed Bushveld	19 Sourish Mixed Bushveld	19 Sourish Mixed Bushveld	18 Mixed Bushveld	18 Mixed Bushveld
Hydrogeological Unit	D3	D3	D3	D3	D3	D3

The average aquifer yield, average borehole depth, average water strike and average static water level was obtained from Frommurze (1937). It must be noted that the presented value is only an average for the geological formation. Information obtained from the land type maps and accompanying memoir is from Land Type Survey Staff (1987), veld type information from Acocks (1988) and hydrogeological information from DWAF: Johannesburg (1999). Soil colour was identified and classified in the veld according to the Corstor Colour Gauge that lists 168 different soil colours. Average weathering depth is extracted from the indicated Land Type Survey Staff and average rooting depth of the geobotanical indicators is referenced from Canadell *et al.* (1996).

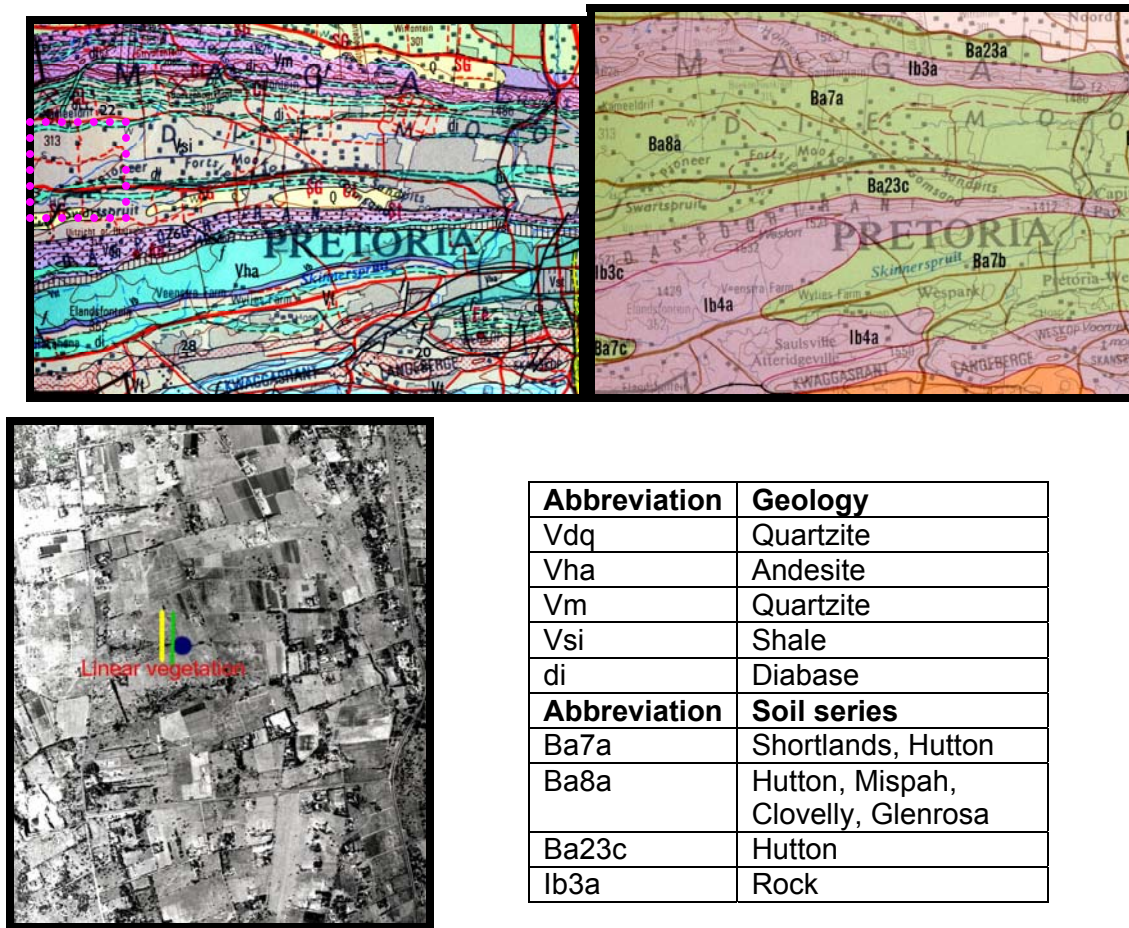
13. Kameeldrift 313JR

Figure A1.13. The geology (top left), land type (top right) and aerial photograph (bottom) of Kameeldrift 313JR. The blue circle denotes the position of the borehole, the green line the direction of the magnetic profile and the yellow line indicates the electromagnetic traverse direction. The area covered by the aerial photograph is indicated by the purple shape in the geological map. Note the linear vegetation growth on the diabase intrusions around the borehole.

17. Kameelfontein 297JR

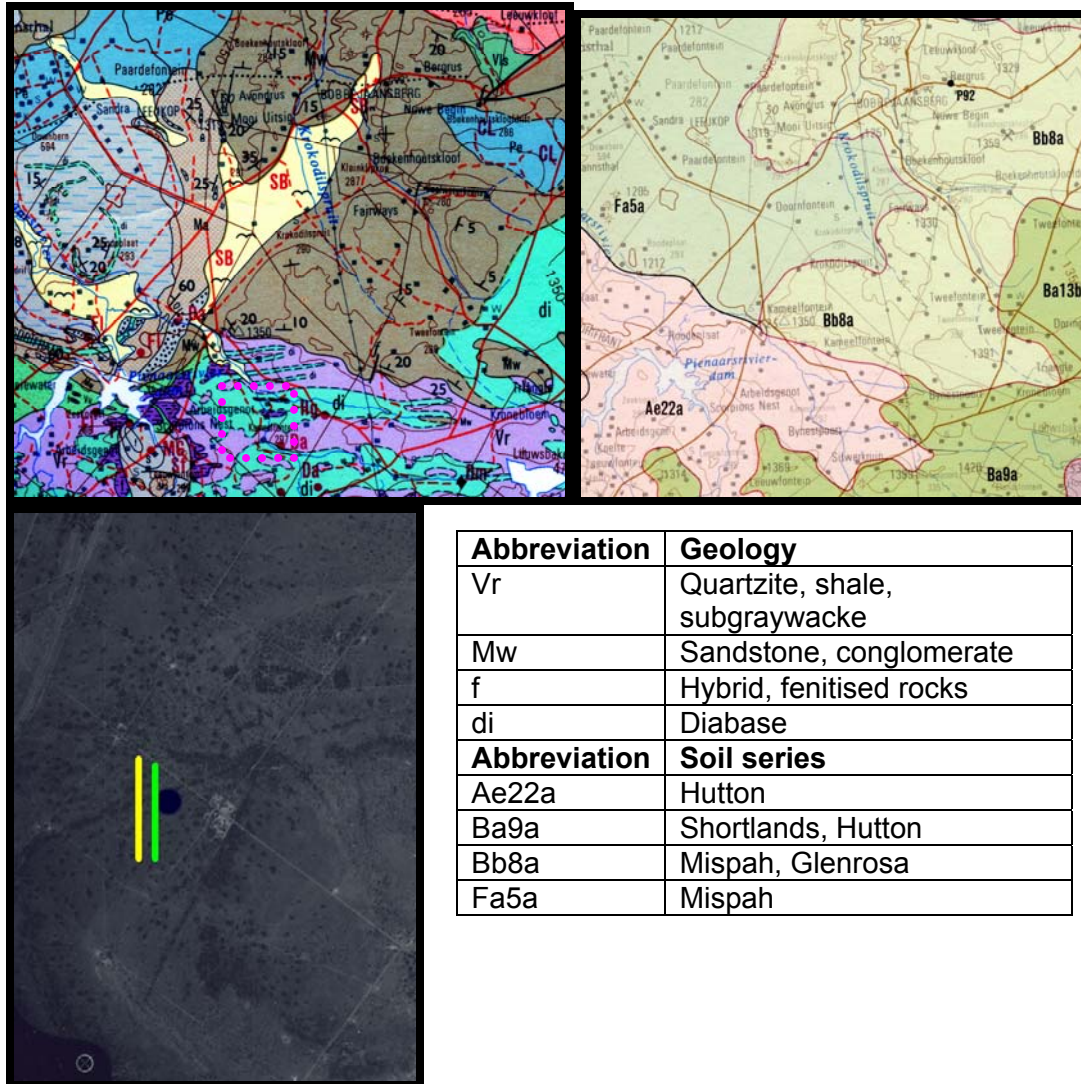


Figure A1.14. The geology (top left), land type (top right) and aerial photograph (bottom) of Kameelfontein 297JR. The blue circle denotes the position of the borehole, the green line the direction of the magnetic profile and the yellow line indicates the electromagnetic traverse direction. The area covered by the aerial photograph is indicated by the purple shape in the geological map. Note the linear vegetation growth on the lineaments.

The area northeast of Pretoria is divided in smallholdings of about 20-30 ha in size due to its popularity as a residential dwelling just outside the city. Kameelfontein 297JR is also subdivided in a couple of smallholdings. This portion of Kameelfontein was developed for agricultural purposes, namely an peach orchard was established on the farm and the existing borehole was yielding only 3 500 l/h, too little groundwater supply for the existing and planned extension of the orchard, especially during times of drought stress.

18. Skeerpoort 477JQ

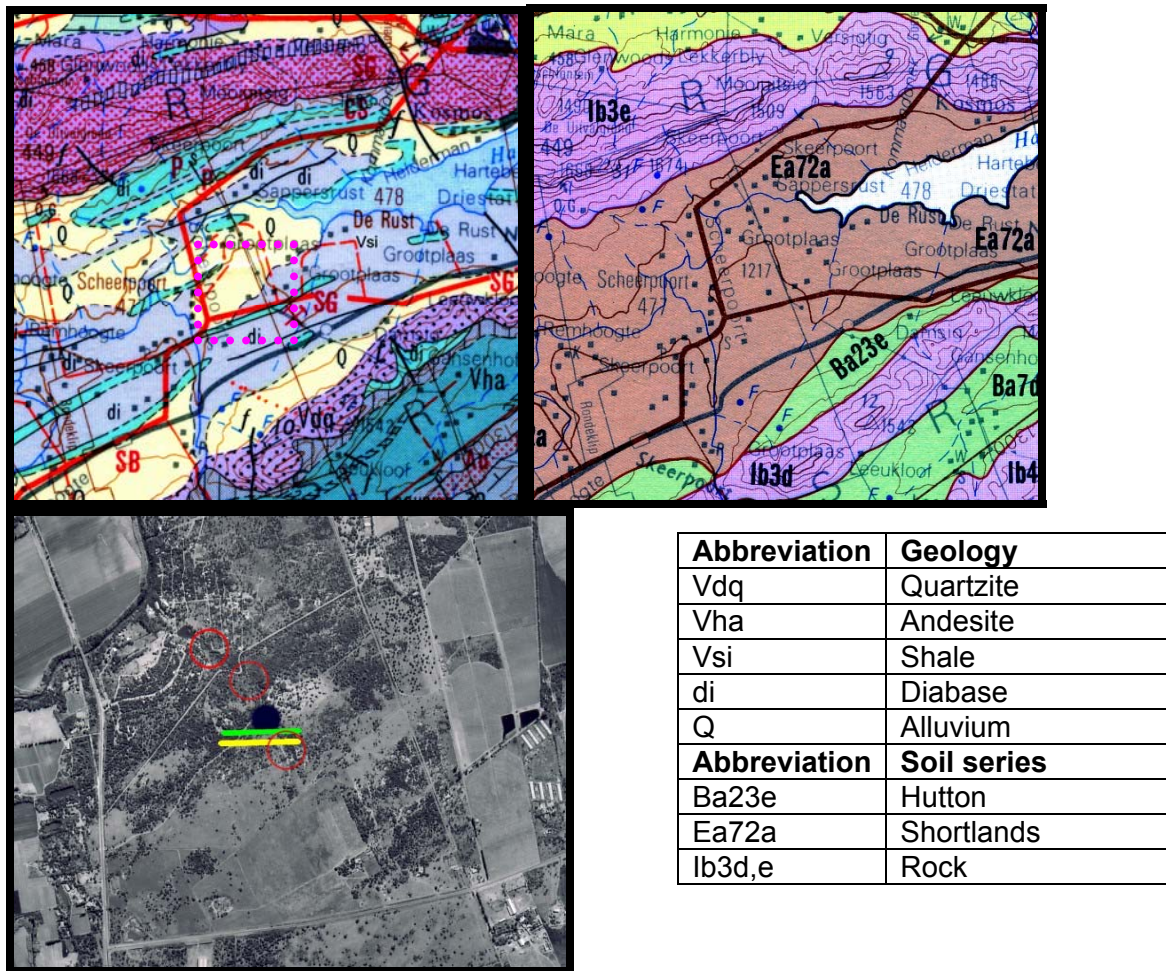


Figure A1.15. The geology (top left), land type (top right) and aerial photograph (bottom) of Skeerpoort 477JQ. The blue circle denotes the position of the borehole, the green line the direction of the magnetic profile and the yellow line indicates the electromagnetic traverse direction. The area covered by the aerial photograph is indicated by the purple shape in the geological map. The lineament (exploration target) is indicated by red circles.

A1.6 VAALIUM EONOTHEM: SHALE AND QUARTZITE OF THE PRETORIA GROUP IN THE LYDENBURG AREA

The eastern escarpment of the South African Highveld constitutes outcrops of the Pretoria Group of the Transvaal Sequence. The same sequence of rocks, as described in the Pretoria case in Chapter 3, can be found from the archaic granite and gneiss in

the Lowveld towards the norite and gabbro of the Bushveld Igneous Complex further inland. It appears that the Lydenburg area was subjected to intense volcanic activities that altered the composition of the lithology in this area, as slate and hornfels with numerous diabase, andesite intrusions, volcanic tuff and some extinct volcanoes are silent remains of the abrupt energy of the past millennia. One such extinct volcano is the Motlolo volcano, west of Lydenburg. The pipe of the volcano is rich in lime (Walraven, 1989).

A1.6.1 CASE STUDY AREA

The Badfontein area between Machadodorp and Lydenburg, in the Kwena basin, was investigated and represented by three case studies. The area was previously known for its thermal springs, but unfortunately the building of the Kwena dam flooded these springs. One other case study is situated between Lydenburg and Burgersfort on the Watervalsrivier Pass. All areas' primary economic activity is in the agricultural sector, namely livestock, cultivation of land and orchards towards Burgersfort.

A1.6.2 CLIMATE AND VELD TYPES

Lydenburg is situated in the transgression zone from Highveld to Lowveld and is hence called Middelveld. The botany that occurs in this area reflects a climatic zone between the Highveld and Lowveld; abundant in *Acacia* and some other species, with some Lowveld species occurring, like *Syzygium cordatum* (water berry). It still reflects the savanna biome. The climatic conditions are represented in Table A1.12, cool and dry winters and hot, wet summers associated with violent thunderstorms. The undulating nature of the topography gives rise to numerous microclimates and veld types. The botany is indicative of warmer conditions towards the poort of the Crocodile River. The following tree species are eminent of the veld types (after Acocks, 1988 and Van Wyk & Van Wyk, 1997):

- Lowveld Sour Bushveld: *Acacia caffra* (common hook-thorn), *A. sieberiana* var *woodii* (paperbark thorn), *Englerophytum magalismontanum* (Transvaal milkplum), *Dombeya rotundifolia* (common wild pear), *Ficus ingens* (red-leaved fig) and *Gymnosporia senegalensis* (red spike-thorn).

- Lowveld: *Acacia nilotica* subsp. *kraussiana* (scented thorn), *A. nigrescens* (knob thorn), *A. tortilis* subsp. *heteracantha* (umbrella thorn), *Bauhinia galpinii* (pride-of-De-Kaap), *Cussonia natalensis* (rock cabbage tree), *Euclea crispa* (blue guarri), *Olea europaea* subsp. *africana* (wild olive), *Grewia hexamita* (giant raisin), *Strychnos madagascariensis* (black monkey orange) and *Ziziphus mucronata* (buffalo-thorn).
- Mixed Bushveld: *Acacia caffra* (common hook-thorn), *Burkea africana* (wild seringa), *Combretum apiculatum* (red bushwillow), *Grewia flava* (velvet raisin) and *Mundulea sericea* (cork bush).
- Sourish Mixed Bushveld: *Acacia caffra* (common hook-thorn), *A. karroo* (sweet thorn), *A. robusta* subsp. *robusta* (brack thorn) & *A. tortilis* subsp. *heteracantha* (umbrella thorn), *Rhus gueinzii* (thorny karree), *Peltophorum africanum* (weeping wattle), *Pappea capensis* (jacket-plum) and *Ziziphus mucronata* (buffalo-thorn).

In general the entire surface is encroached by shrubs and trees. The gaps in between are grassed. A distinct frontier between grass and trees can be observed on certain hills and towards the high quartzite cliffs of the Pretoria Group. The bushed areas generally consists of *Acacia caffra*, *Rhus chirindensis* (red currant) and *Ziziphus mucronata*. Geobotanic indicators can be identified by the appearance (height, leave colour, bark) of certain tree species in this environment compared to the remaining resident botany.

Table A1.12. Climatic Data of the Lydenburg Area (Schulze, 1997, Nelspruit, 1999 & Phalaborwa, 1998).

	Badfontein Area	Watervalsrivier Pass Area
Average Yearly Temperature (°C)	14-16	12-14
Mean Minimum Temperature (°C) in July	2-4	0-2

Mean Maximum Temperature (°C) in January	25.0-27.5	22.5-25.0
Average Yearly Rainfall (mm)	600-800	600-800
Elevation (m)	1200-1600	1200-2000
Evaporation (mm/year)	1750-2000	1750-2000
Frost area?	<150 days a year	<150 days a year

A1.6.3 GEOLOGY AND HYDROGEOLOGICAL CLASSIFICATION

The geological map of the Badfontein area (Barberton, 1986) indicates surficial deposits, alluvium and scree with numerous outcrops and intrusions of diabase; medium-grained, current-bedded, flaggy quartzite with gritty and conglomeratic layers and occasional shale layers (Daspoort Formation); greenish, fine-grained shale and mudstone with tuff and subordinate carbonate layers, hornfels in places (Silverton Formation, Boven Member); and very fine-grained tuff, coarser grained agglomerate and basic lava (Silverton Formation, Machadodorp Member).

The farm Waterval 386KT crosses the Watervals River on a plain of surficial deposits, including alluvium and scree and greenish, fine-grained, laminated shale and subordinate mudstone with occasional limestone layers (Silverton Formation, Lydenburg Member). The entire farm is surrounded by cliffs of pure white, coarse-grained quartzite with non-continuous shaly layers belonging to the Magaliesberg Formation of the Pretoria Group, Transvaal Sequence. This area is stratigraphically younger in the sequence than the rocks in the Badfontein area.

Hydrogeological classification of the aquifers associated with the discussed lithologies, after Nelspruit (1999) and Phalaborwa (1998), are alluvium and undifferentiated rock and various mixed lithologies attached to the sedimentary rocks of the Pretoria Group in the Badfontein and Watervalsrivier Pass areas. The intergranular and fractured aquifers in the alluvium (surficial deposits) yield on average 1800-7200 ℓ/h according to the hydrogeological mapping. Aquifers associated with the Silverton Formation and diabase intrusions contact zones can yield up to 18 000 ℓ/h.

A1.6.4 GEOPHYSICAL AND GEOBOTANICAL INFORMATION

This area is not referenced in any published geophysical literature. As the basic geology is the Pretoria Group, obtained geophysical results can be compared to geophysical results obtained in Pretoria Group sediments in other regions. Due to the presence of numerous diabase intrusions and alluvium beds, the application of the magnetic, electro-magnetic and direct current sounding methods are suitable.

The area increased its interest and importance by its presence of various geobotanic indicators associated with the common vegetation. The case studies will reflect on the geobotanic indicators in detail, but for reference purposes they will be mentioned hereunder:

- *Combretum erythrophyllum* (river bushwillow)
- *Ficus ingens* (red-leaved fig)
- *Zanthoxylum capense* (small knobwood)

A1.6.5 SOIL SAMPLING AND RESULTS PRESENTATION

In order to establish if geobotanic communities have remarkable differences in their soil make-up, soil sampling at depths of 0.5 and 1.2 m was undertaken. Another site with no distinct geobotanic cover was also sampled at the same depth intervals. These results are listed in Tables A1.13(a&b). From these results and the other case studies presented elsewhere, certain remarks can be made regarding available soil nutrients and the presence or localisation of geobotanic communities.

Table A1.13a. Vaalium Eonothem: Shale, Hornfels and Quartzite in the Lydenburg Area: along intrusive/weathering contact.

	Badfontein 114JT		Klipspruit 86JT		Rietfontein 88JT		Waterval 386KT	
Geological Formation	Alluvium, Shale, Hornfels (Boven Member) with diabase intrusions	Alluvium, Shale, Hornfels (Boven Member) with diabase intrusions	Alluvium, Shale, Hornfels (Boven Member) with diabase intrusions	Alluvium, Shale, Hornfels (Boven Member) with diabase intrusions	Alluvium, Shale, Hornfels (Boven Member) with diabase intrusions	Alluvium, Shale, Hornfels (Boven Member) with diabase intrusions	Shale, Hornfels (Lydenburg Member), quartzite (Magaliesberg Formation) with diabase intrusions	Shale, Hornfels (Lydenburg Member), quartzite (Magaliesberg Formation) with diabase intrusions
Depth Sampled	0.5m	1.2m	0.5m	1.2m	0.5m	1.2m	0.5m	0.5m
Borehole Co-ordinates:								
S.L.	25°20.017'	25°20.017'	25°17.434'	25°17.434'	25°14.051'	25°14.051'	24°57.036'	24°57.036'
E.L.	30°23.933'	30°23.933'	30°24.405'	30°24.405'	30°26.512'	30°26.512'	30°18.339'	30°18.339'
Soil colour	Weak red	Dusky red	Dark brown	Dusky yellowish brown	Dusky red	Dusky red	Strong brown	Strong brown
Soil texture Description	Sandy silt	Clayey silt	Clayey silt	Clay	Clay	Clay	Clay	Clay
pH	6.67	6.56	6.40	6.69	6.49	6.56	5.97	6.21
P (mg/kg)	1.54	1.37	1.54	1.49	3.54	3.08	4.70	4.45
Ca (mg/kg)	1275	1490	1795	1968	1533	1035	216	228
Mg (mg/kg)	987	949	736	921	434	412	97	117
K (mg/kg)	101	123	119	126	31	26	43	71
Na (mg/kg)	12	13	19	11	16	21	6	28

Fe (mg/kg)	95.82	131.07	155.05	154.69	123.26	81.49	40.57	57.80
Mn (mg/kg)	500.53	754.72	880.51	776.37	515.46	295.39	72.06	172.93
Zn (mg/kg)	1.65	1.99	0.98	0.81	0	0	0.45	0.18
Al (cmol _c /kg)	0	0	0	0	0	0	0.095	0
Resistance (Ohm)	1160	860	790	1090	1010	1290	5600	6000
C%	1.10	1.45	1.18	1.09	2.32	1.26	0.08	0.01
Total N%	0.081	0.107	0.081	0.077	0.087	0.055	0.009	0.007
S (mg/kg)	16.32	21.25	23.26	8.95	39.13	23.87	16.28	28.21
CEC (cmol _c /kg)	16.82	19.18	22.79	23.38	10.87	24.36	3.831	4.482
Distinct Tree Species	Combretum erythro-phyllum	Combretum erythro-phyllum	Combretum erythro-phyllum	Combretum erythro-phyllum	Zanthoxy-lum capense Combretum erythro-phyllum Ficus ingens	Zanthoxylum capense Combretum erythro-phyllum Ficus ingens	Ficus ingens	Ficus ingens
Average rooting depth of the indicated species (m)	12	12	12	12	5 - 12	5 - 12	12	12

Average depth of weathering (m)	1.6	1.6	1.6	1.6	1.6	1.6	0.4	0.4
Geomorphology	Western slope to depression	Western slope to depression	Western slope to depression, with small hills	Western slope to depression, with small hills	Ridge close to stream	Ridge close to stream	Eastern ridge	Eastern ridge
Geophysical instrumentation used	Magnetics and Direct current soundings	Magnetics and Direct current soundings	Magnetics and Electromagnetics	Magnetics and Electromagnetics	Magnetics and Electromagnetics	Magnetics and Electromagnetics	Magnetics	Magnetics
Water features present?	No	No	No	No	Yes, 50m east (stream)	Yes, 50m east (stream)	Yes, 350m down (river)	Yes, 350m down (river)
Aquifer Yield (l/h)	7200	7200	8400	8400	8000	8000	5500	5500
Borehole Depth (m)	30	30	55	55	25	25	75	75
Depth of Water Strike (m)	14	14	18	18	8	8	34	34
Static Water Level (m)	9	9	12	12	5	5	31	31

Average Aquifer Yield (l/h)	4800	4800	4800	4800	4800	4800	4800	4800
Average Borehole Depth (m)	37	37	37	37	37	37	37	37
Average Depth of Water Strike (m)	17	17	17	17	17	17	17	17
Average Static Water Level (m)	5.5	5.5	5.5	5.5	5.5	5.5	5.5	5.5
Land Type Series	Ba64a Glenrosa, Hutton	Ba64a Glenrosa, Hutton	Ba64a Glenrosa, Hutton	Ba64a Glenrosa, Hutton	Ba64a Glenrosa, Hutton	Ba64a Glenrosa, Hutton	Ae107b, Fb170c Hutton, Rock	Ae107b, Fb170c Hutton, Rock
Profile No	P845	P845	P845	P845	P844	P844	P961	P961
Depth Sampled	250 – 500 mm	250 – 500 mm	250 – 500 mm	250 – 500 mm	250 – 620 mm	250 – 620 mm	860 – 1200 mm	860 – 1200 mm
Gravel %	4	4	4	4	0	0	1	1
Sand %	13	13	13	13	25	25	61	61
Silt %	14	14	14	14	27	27	21	21
Clay %	69	69	69	69	48	48	17	17
pH (H ₂ O)	7.0	7.0	7.0	7.0	6.2	6.2	9.0	9.0
P (mg/kg)	0.0	0.0	0.0	0.0	0.3	0.3	0.0	0.0
Ca (mg/kg)	320	320	320	320	100	100	28	28

Mg (mg/kg)	224	224	224	224	52	52	283	283
K (mg/kg)	7	7	7	7	8	8	35	35
Na (mg/kg)	7	7	7	7	2	2	44	44
Fe (mg/kg)	-	-	-	-	-	-	-	-
Mn (mg/kg)	952.5	952.5	952.5	952.5	405.6	405.6	15.3	15.3
Zn (mg/kg)	0.17	0.17	0.17	0.17	0.21	0.21	0.21	0.21
Resistance (Ohm)	320	320	320	320	900	900	200	200
C%	0.7	0.7	0.7	0.7	0.6	0.6	0.2	0.2
CEC (cmol _c /kg)	42.0	42.0	42.0	42.0	14.2	14.2	23.8	23.8
Veld Type	9 & 10 Lowveld Sour Bushveld & Lowveld	9 & 10 Lowveld Sour Bushveld & Lowveld	9 Lowveld Sour Bushveld	9 Lowveld Sour Bushveld	9 Lowveld Sour Bushveld	9 Lowveld Sour Bushveld	18 & 19 Mixed Bushveld & Sourish Mixed Bushveld	18 & 19 Mixed Bushveld & Sourish Mixed Bushveld
Hydrogeological Unit	A3	A3	A3/D4	A3/D4	A3/D4	A3/D4	D3	D3

The average aquifer yield, average borehole depth, average water strike and average static water level was obtained from Frommurge (1937). It must be noted that the presented value is only an average for the geological formation. Information obtained from the veld type maps originating from Acocks (1988) and hydrogeological information from DWAF: Nelspruit (1999) and Phalaborwa (1998). Soil colour was identified and classified in the veld according to the Corstor Colour Gauge that lists 168 different soil colours. Information obtained from the land type maps and accompanying memoir is from Land Type Survey Staff (1989a,b). Average weathering depth is extracted from the indicated Land Type Survey Staff and average rooting depth of the geobotanical indicators is referenced from Canadell *et al.* (1996).

Table A1.13b. Vaalium Eonothem: Shale, Hornfels and Quartzite in the Lydenburg Area: intrusive/weathering contact absent.

	Badfontein 114JT		Klipspruit 86JT		Rietfontein 88JT		Waterval 386KT	
Geological Formation	Alluvium, Shale, Hornfels (Boven Member)	Alluvium, Shale, Hornfels (Boven Member)	Alluvium, Shale, Hornfels (Boven Member)	Alluvium, Shale, Hornfels (Boven Member)	Alluvium, Shale, Hornfels (Boven Member)	Alluvium, Shale, Hornfels (Boven Member)	Shale, Hornfels (Lydenburg Member), quartzite (Magaliesberg Formation)	Shale, Hornfels (Lydenburg Member), quartzite (Magaliesberg Formation)
Depth Sampled	0.5m	1.2m	0.5m	1.2m	0.5m	1.2m	0.5m	0.5m
Borehole Co-ordinates:								
S.L.	25°20.017'	25°20.017'	25°17.434'	25°17.434'	25°14.051'	25°14.051'	24°57.036'	24°57.036'
E.L.	30°23.933'	30°23.933'	30°24.405'	30°24.405'	30°26.512'	30°26.512'	30°18.339'	30°18.339'
Soil colour	Greyish brown	Moderate yellowish brown	Moderate brown	Strong brown	Dark reddish brown	Light brown	Dark yellowish orange	Light brown
Soil texture Description	Silt	Silt	Sandy silt	Silty clay	Silt	Silty clay	Sand	Sand
pH	6.84	6.86	6.47	6.98	6.49	6.84	4.95	4.88
P (mg/kg)	1.40	1.38	2.12	1.88	5.30	4.77	19.60	18.11
Ca (mg/kg)	712	471	629	593	1734	1138	107	97
Mg (mg/kg)	779	544	565	683	600	888	42	43
K (mg/kg)	46	47	100	51	200	79	12	6
Na (mg/kg)	34	51	22	79	18	11	27	41
Fe (mg/kg)	143.97	81.23	105.79	89.24	98.23	105.68	30.71	15.64
Mn (mg/kg)	657.20	393.14	616.64	457.32	455.41	674.63	132.86	25.02
Zn (mg/kg)	1.08	0.72	2.69	0.93	0.87	1.75	0.12	0.49

Al (cmol _c /kg)	0	0	0	0	0	0	0.601	1.021
Resistance (Ohm)	2850	2550	2040	1800	780	1260	5200	5000
C%	0.46	1.13	1.44	0.71	2.49	0.79	0.10	0.03
Total N%	0.050	0.072	0.107	0.066	0.177	0.074	0.009	0.004
S (mg/kg)	9.20	11.16	16.43	10.52	32.14	23.17	71.90	51.53
CEC (cmol _c /kg)	12.39	12.01	28.83	15.38	3.42	18.74	4.108	3.636
Distinct Tree Species	Combretum erythro-phyllum	Combretum erythro-phyllum	Combretum erythro-phyllum	Combretum erythro-phyllum	Zanthoxylum capense Combretum erythrophyllum Ficus ingens	Zanthoxylum capense Combretum erythrophyllum Ficus ingens	Ficus ingens	Ficus ingens
Average rooting depth of the indicated species (m)	12	12	12	12	5 - 12	5 - 12	12	12
Average depth of weathering (m)	1.6	1.6	1.6	1.6	1.6	1.6	0.4	0.4

Geomorphology	Western slope to depression	Western slope to depression	Western slope to depression, with small hills	Western slope to depression, with small hills	Ridge close to stream	Ridge close to stream	Eastern ridge	Eastern ridge
Geophysical instrumentation used	Magnetics and Direct current soundings	Magnetics and Direct current soundings	Magnetics and Electro-magnetics	Magnetics and Electro-magnetics	Magnetics and Electromagnetics	Magnetics and Electro-magnetics	Magnetics	Magnetics
Water features present?	No	No	No	No	Yes, 50m east (stream)	Yes, 50m east (stream)	Yes, 350m down (river)	Yes, 350m down (river)
Aquifer Yield (l/h)	7200	7200	8400	8400	8000	8000	5500	5500
Borehole Depth (m)	30	30	55	55	25	25	75	75
Depth of Water Strike (m)	14	14	18	18	8	8	34	34
Static Water Level (m)	9	9	12	12	5	5	31	31
Average Aquifer Yield (l/h)	4800	4800	4800	4800	4800	4800	4800	4800
Average Borehole Depth (m)	37	37	37	37	37	37	37	37

Average Depth of Water Strike (m)	17	17	17	17	17	17	17	17
Average Static Water Level (m)	5.5	5.5	5.5	5.5	5.5	5.5	5.5	5.5
Land Type Series	Ba64a Glenrosa, Hutton	Ba64a Glenrosa, Hutton	Ba64a Glenrosa, Hutton	Ba64a Glenrosa, Hutton	Ba64a Glenrosa, Hutton	Ba64a Glenrosa, Hutton	Ae107b, Fb170c Hutton, Rock	Ae107b, Fb170c Hutton, Rock
Profile No	P845	P845	P845	P845	P844	P844	P961	P961
Depth Sampled	250 – 500 mm	250 – 500 mm	250 – 500 mm	250 – 500 mm	250 – 620 mm	250 – 620 mm	860 – 1200 mm	860 – 1200 mm
Gravel %	4	4	4	4	0	0	1	1
Sand %	13	13	13	13	25	25	61	61
Silt %	14	14	14	14	27	27	21	21
Clay %	69	69	69	69	48	48	17	17
pH (H ₂ O)	7.0	7.0	7.0	7.0	6.2	6.2	9.0	9.0
P (mg/kg)	0.0	0.0	0.0	0.0	0.3	0.3	0.0	0.0
Ca (mg/kg)	320	320	320	320	100	100	28	28
Mg (mg/kg)	224	224	224	224	52	52	283	283
K (mg/kg)	7	7	7	7	8	8	35	35
Na (mg/kg)	7	7	7	7	2	2	44	44
Fe (mg/kg)	-	-	-	-	-	-	-	-
Mn (mg/kg)	952.5	952.5	952.5	952.5	405.6	405.6	15.3	15.3
Zn (mg/kg)	0.17	0.17	0.17	0.17	0.21	0.21	0.21	0.21

Resistance (Ohm)	320	320	320	320	900	900	200	200
C%	0.7	0.7	0.7	0.7	0.6	0.6	0.2	0.2
CEC (cmol _c /kg)	42.0	42.0	42.0	42.0	14.2	14.2	23.8	23.8
Veld Type	9 & 10 Lowveld Sour Bushveld & Lowveld	9 & 10 Lowveld Sour Bushveld & Lowveld	9 Lowveld Sour Bushveld	9 Lowveld Sour Bushveld	9 Lowveld Sour Bushveld	9 Lowveld Sour Bushveld	18 & 19 Mixed Bushveld & Sourish Mixed Bushveld	18 & 19 Mixed Bushveld & Sourish Mixed Bushveld
Hydrogeological Unit	A3	A3	A3/D4	A3/D4	A3/D4	A3/D4	D3	D3

The average aquifer yield, average borehole depth, average water strike and average static water level was obtained from Frommurze (1937). It must be noted that the presented value is only an average for the geological formation. Information obtained from the veld type maps originating from Acocks (1988) and hydrogeological information from DWAF: Nelspruit (1999) and Phalaborwa (1998). Soil colour was identified and classified in the veld according to the Corstor Colour Gauge that lists 168 different soil colours. Information obtained from the land type maps and accompanying memoir is from Land Type Survey Staff (1989a,b). Average weathering depth is extracted from the indicated Land Type Survey Staff and average rooting depth of the geobotanical indicators is referenced from Canadell *et al.* (1996).

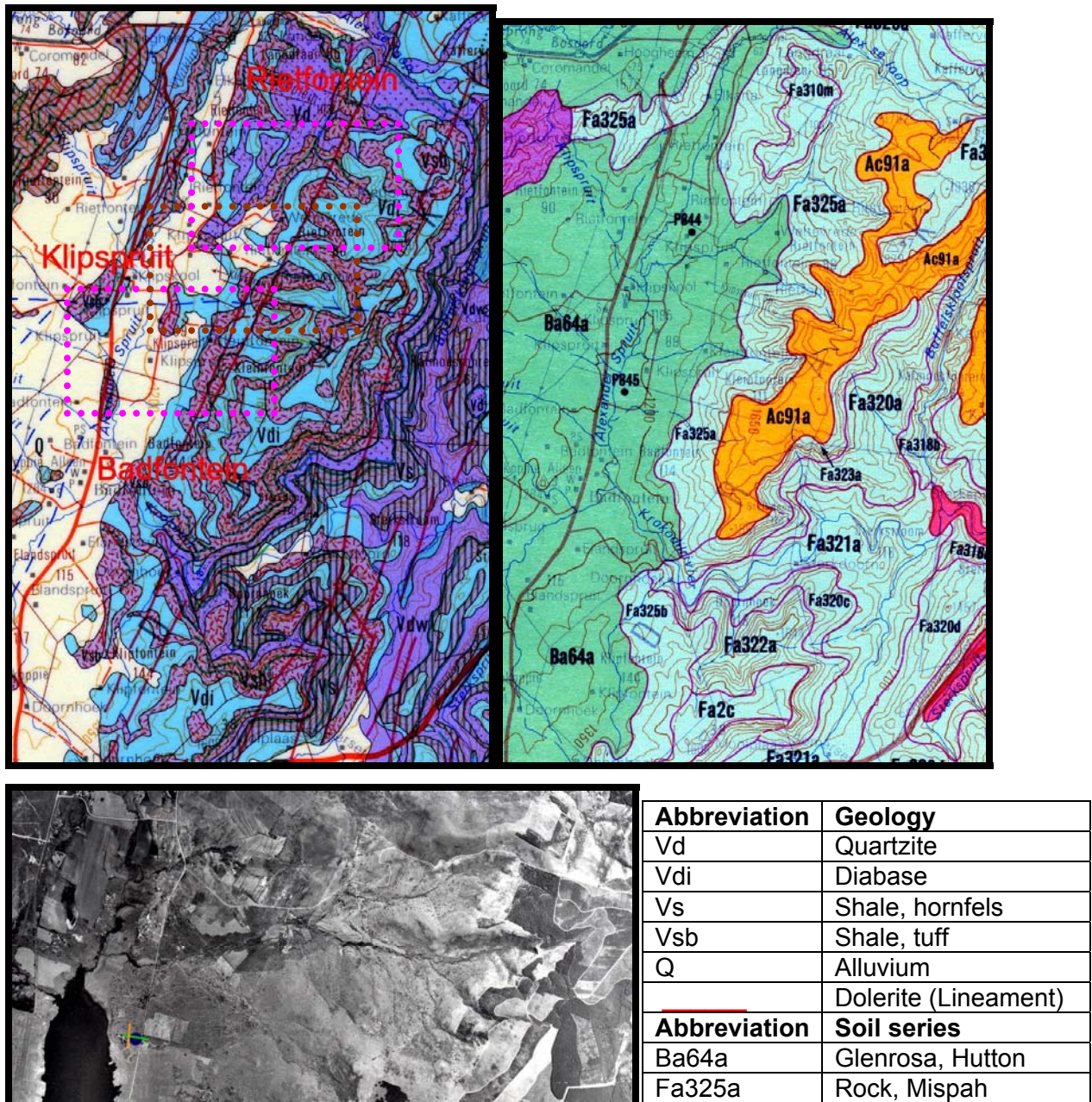
16. Badfontein 114JT

Figure A1.16. The geology (top left), land type (top right) and aerial photograph (bottom) of Badfontein 114JT. The blue circle denotes the position of the borehole, the green line the direction of the magnetic profile and the orange line indicates the sounding direction. The area covered by the aerial photograph is indicated by the purple shape in the geological map (lower rectangle).

Between the highlands of Machadodorp and Lydenburg a geological basin is situated. Locally it is known as the Kwena Basin and encloses the floodplain of the Crocodile River and Kwena dam. The Kwena dam flooded the hot, sulphur springs of the area, hence the name Badfontein referring to these hot springs that were used for recreational and therapeutic purposes in the past. These hot, sulphur springs reflect also on the abrupt, violent geological past. Remnants of this past are reflected in eroded volcanoes, tuff deposits and agglomerates, especially in the Silverton Formation, Machadodorp Member. With this kind of environment numerous diabase sills and dykes intruded the sediments of the Pretoria Group and altered/metamorphosed these rocks in rock types like hornfels and some slate (Walraven, 1989). The diabase is at times enriched in lime due to the fact that in weathered horizons of the diabase small, white lime nodules are found.

The farm is situated on the western slope of the foothills of the escarpment between Lydenburg, Sabie and Sudwala on the banks of the Kwena dam. It is notably covered with *Acacia caffra*, *A. karroo*, *Combretum erythrophyllum* and *Ziziphus mucronata*, forming part of the Lowveld Sour Bushveld & Lowveld veld types.

17. Klipspruit 89JT



Figure A1.17. Aerial photograph of Klipspruit 89JT. The blue circle denotes the position of the borehole, the green line the direction of the magnetic profile and the yellow line indicates the electromagnetic travers direction. The area covered by the aerial photograph is indicated by the brown shape in the geological map (middle rectangle). The geology and land type are depicted in Figure A1.16. Red lines indicate lineaments (suspicious linear vegetation growth, compare with Figure A1.16).

The farm Klipspruit 89JT is situated a couple of kilometers north of the farm Badfontein 114JT. The boreholes that were investigated and sited on this farm and the adjacent Kleinfontein 111JT are on a higher elevation situated than the borehole at Badfontein. The Kwena dam is also a couple of kilometers southwest of these localities.

18. Rietfontein 88JT



Figure A1.18. Aerial photograph of Rietfontein 88JT. The blue circle denotes the position of the borehole, the green line the direction of the magnetic profile and the yellow line indicates the electromagnetic travers direction. The area covered by the aerial photograph is indicated by the purple shape in the geological map (upper rectangle). The geology and land type are depicted in Figure A1.16. Red lines indicate lineaments (suspicious linear vegetation growth).

Some three kilometers to the north of the case study mentioned under Klipspruit 89JT, the case study on the farm Rietfontein 88JT is found. These cliffs are covered by luxurious vegetation growth not seen in other areas in this region. Tree species that occur are *Acacia caffra* (common hook-thorn), *Brachylaena rotundata* (mountain silver oak), *Celtis africana* (white stinkwood), *Clausena anisata* (horsewood), *Combretum erythrophyllum* (river bushwillow), *Ficus ingens* (red-leaved fig), some *Rhus* species, *Zanthoxylum capense* (small knobwood) and *Ziziphus mucronata* (buffalo thorn).

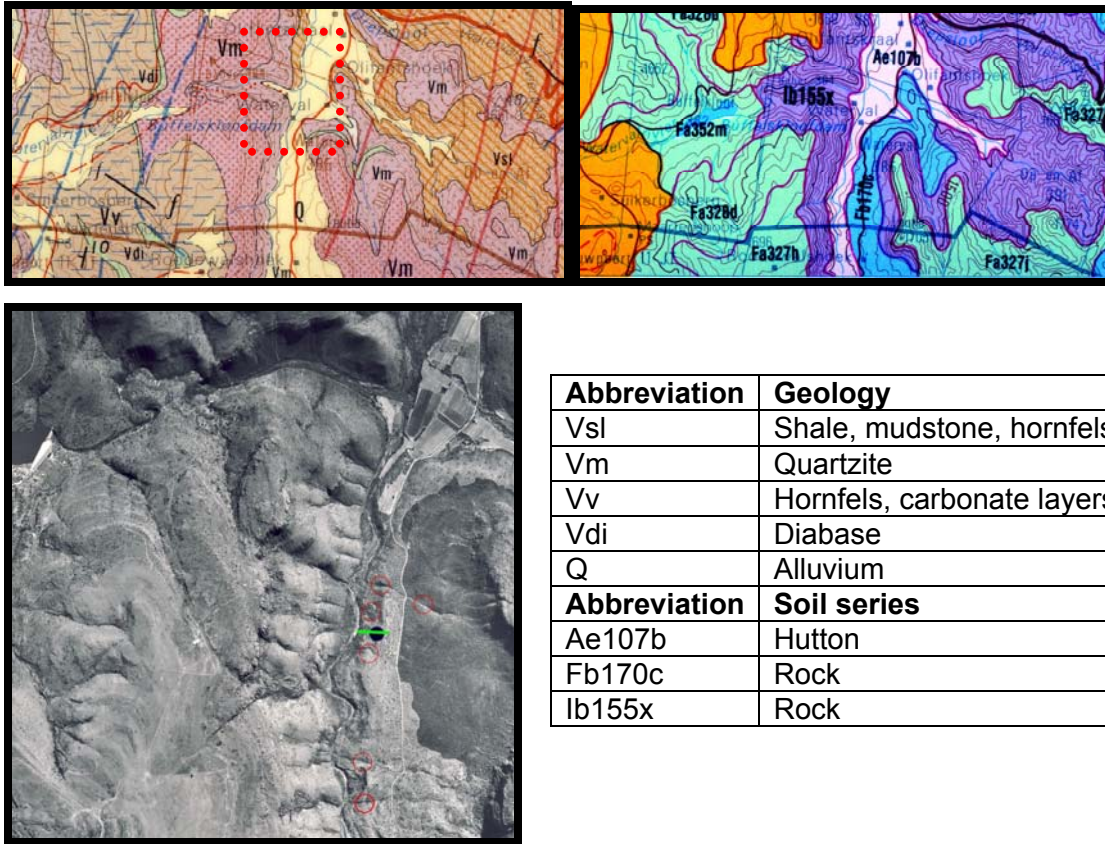
19. Waterval 386KT

Figure A1.19. The geology (top left), land type (top right) and aerial photograph (bottom) of Waterval 386KT. The blue circle denotes the position of the borehole and the green line the direction of the magnetic profile. The red circles points out small lineaments (general east-west strike). The borehole is sited at a lineament with a northwest-southeast strike. The area covered by the aerial photograph is indicated by the red shape in the geological map (lower rectangle).

A1.7 VAALIUM EONOTHEM: RHYOLITE OF THE ROOIBERG GROUP AND LOSKOP FORMATION IN THE VERENA-MIDDELBURG AREA

After the deposition and formation of the Pretoria Group sediments and igneous intrusions during the Vaalium Eonothem, the development of the Rooiberg Group had its origin and thereafter the Loskop Formation. The Rooiberg Group consists of the Damwal and Selonsrivier Formations, both formations lithology is predominantly volcanic rocks, namely rhyolite. The Selonsrivier Formation is relatively homogeneous and consists of red porphyritic lava and case studies of this formation will be discussed. The Loskop Formation follows more or less concordantly on the Rooiberg Group without any trace of a major regional unconformity. The formation is separated from the overlying Waterberg sediments by a prominent regional unconformity and consists of a thick succession of finely layered siltstone, mudstone, feldspathic sandstone and shale. Volcanic rocks of early Loskop age occur in a number of places, e.g. Rhenosterkop 452JR and Honingkranz 536JR. At Rhenosterkop the rocks are pyroclastic with fragments of lava (Pretoria, 1978). Sediments of the Loskop Formation associated with diabase intrusions will be addressed in the next section.

A1.7.1 CASE STUDY AREA

Three case studies situated on rhyolite is presented. The first case, Enkeldoornoog 219JR is situated east of Kwamhlanga, between Pretoria and Marble Hall. Rhyolite of the Rooiberg Group outcrops in this area. The second case, Rhenosterkop 452JR, is a remnant of an old volcano of the Loskop Formation, and is east of the road between Bronkhorstspuit and Groblersdal, close to Verena. The last case study of the Rooiberg Group is on the farm Kwaggasfontein 460JS, south of the road from Middelburg to Belfast, in the vicinity of Arnot Power Station. Agricultural practices range from subsistence farming at Enkeldoornoog to extensive livestock farming on Rhenosterkop and land cultivation at Kwaggasfontein.

A1.7.2 CLIMATE AND VELD TYPES

The study area is situated on the South African Highveld and the transgression zone towards the Bushveld including the savanna and grassland biomes. Climatic data is

indicated in Table A1.14, pointing to mild to cold, dry winters and mild to hot, wet summers. The south-eastern case study, Kwaggasfontein, is the coldest and hence sparse indigenous shrub and tree cover is observed. The farm Rhenosterkop is situated on Rhenosterkop, a prominent hill in the Bronkhorstspuit area. Due to its prominence, the wind chill factor is a restrictive factor that limits abundant and luxurious tree and shrub growth, but the narrow valleys are more luxurious inhabited by trees and shrubs as it is protected from wind. Enkeldoornoog is the warmest area of all three and a Bushveld character is eminent of the place. As mentioned earlier, the Highveld and the transgression to the Bushveld defines two veld types in this area, the Bankenveld at Kwaggasfontein (grassland biome), and Sourish Mixed Bushveld for the other two case studies (savanna biome). The following tree species are eminent of the veld types (after Acocks, 1988 and Van Wyk & Van Wyk, 1997):

- Bankenveld: *Acacia caffra* (common hook-thorn), *Celtis africana* (white stinkwood) and *Protea caffra* (common sugarbush).
- Sourish Mixed Bushveld: *Acacia caffra* (common hook-thorn), *A. karroo* (sweet thorn), *A. robusta subsp. robusta* (brack thorn) & *A. tortillis subsp. heteracantha* (umbrella thorn), *Rhus gueinzii* (thorny karree), *Peltophorum africanum* (weeping wattle), *Pappea capensis* (jacket-plum) and *Ziziphus mucronata* (buffalo-thorn).

Due to the winters being severely frosty in the Bankenveld combined with high rainfall, altitude and regular burning of the grassland, the veld is particularly sour with acid soils and is not hosting a wide variety of trees or shrubs.

Table A1.14. Climatic Data of the Verena-Middelburg Area (Land Type Survey Staff, 1987, Schulze, 1997 & Johannesburg, 1999).

	Enkeldoornoog	Rhenosterkop	Kwaggasfontein
Average Yearly Temperature (°C)	14-16	12-14	12-14
Mean Minimum Temperature (°C) in July	2-4	0-2	0-2
Mean Maximum Temperature (°C) in January	27.5-30.0	22.5-25.0	22.5-25.0
Average Yearly Rainfall (mm)	600-800	600-800	600-800
Elevation (m)	1200-1600	1400-1700	1600-2000
Evaporation (mm/year)	2000-2250	2000-2250	1750-2000
Frost area?	<150 days a year	<150 days a year	150-175 days a year

A1.7.3 GEOLOGY AND HYDROGEOLOGICAL CLASSIFICATION

The case studies presented in this section are all on rhyolite. The formations involved are the Selonsrivier (Rooiberg Group) and Loskop Formations. In the introduction to this section an overview over the geology has been explained. Of interest is the inclusion of a pyroclastic deposit, Rhenosterkop. Intrusions of diabase create potential aquifer positions and generally increase the possibility to drill a successful borehole with a yield larger than would be obtained if drilled in an aquifer not associated with diabase, see Frommurze (1937) and Meulenbeld (1998).

Rhyolite on the Johannesburg (1999) map is indicated as acid/intermediate and extrusive rocks with associated intergranular and fractured aquifers compatible with yields ranging from 360-7200 l/h.

A1.7.4 GEOPHYSICAL AND GEOBOTANICAL INFORMATION

The linear and limited extent together with its geographical location of the Selonsrivier and Loskop Formations makes it a non-important target for geophysical and geohydrological studies. The formations occur not in remote areas that are dependent on groundwater supply for survival. Large portions of the formation are in agricultural

areas, but primarily in areas of extensive livestock farming due to the fact that rhyolite is resistant to chemical weathering and thus these areas are mountainous. Where the formations occur close to towns like Witbank, Middelburg and Kwamhlanga, all these towns are served by municipal drinking water where dependency on aquifers diminishes. In the study by Meulenbeld (1998), Rhenosterkop was included and a farm close to Kwaggasfontein, namely Luipaardsfontein. The published results will be referenced in this study as well. Another geophysical study by Botha *et al.* (2001) in this area focuses only on Nebo Granite of the Mogolian Eonothem in the Limpopo Province. As the majority of aquifers are fractured and/or associated with diabase intrusions, the magnetic and electromagnetic methods are preferred.

The study of geobotanical indicators was initiated during a visit to the old volcano at Rhenosterkop by Meulenbeld (1998) where conspicuous vegetation clusters grow on diabase intrusions. Furthermore, termitary associated with these tree clusters were found to be red in colour, whereas termitary in the grassed field were grey in colour. Geophysical profiles along the vegetation clusters and termitary indicated the presence of small diabase intrusions. Mentioned geobotanic indicators were found to be applicable in other areas, like in the Swartwater region (section 4.1).

A1.7.5 SOIL SAMPLING AND RESULTS PRESENTATION

Soil sampling was undertaken as referenced in the previous sections at the same depths. The results are listed in Tables A1.15(a&b). From these results and the other case studies presented elsewhere, certain remarks can be made regarding available soil nutrients and the presence of geobotanic communities.

Table A1.15a. Vaalium Eonothem: Rhyolite in the Verena-Middelburg Areas: along intrusive/weathering contact.

	Enkeldoornoog 219JR		Rhenosterkop 452JR		Kwaggasfontein 460JS	
Geological Formation	Rhyolite (Selonsrivier Formation) and a diabase intrusion	Rhyolite (Selonsrivier Formation) and a diabase intrusion	Fractured rhyolite and diabase intrusions (Loskop Formation)	Fractured rhyolite and diabase intrusions (Loskop Formation)	Rhyolite (Selonsrivier Formation) and a diabase intrusion	Rhyolite (Selonsrivier Formation) and a diabase intrusion
Depth Sampled	0.5m	1.2m	0.5m	1.2m	0.5m	0.5m
Borehole Co-ordinates:						
S.L.	25°24.331'	25°24.331'	25°36.307'	25°49.217'	25°53.783'	25°53.783'
E.L.	28°47.409'	28°47.409'	28°55.659'	28°19.701'	29°38.339'	29°38.339'
Soil colour	Dark reddish brown	Moderate brown	Greyish orange	Pale reddish brown	Dark red	Moderate brown
Soil texture description	Loam	Clayey silt	Clay	Clay	Silty clay	Silty clay
pH	5.86	5.60	5.72	6.10	6.08	5.84
P (mg/kg)	7.98	1.94	8.52	6.79	1.02	0.73
Ca (mg/kg)	587	618	924	779	466	514
Mg (mg/kg)	230	300	80	96	405	508
K (mg/kg)	0	25	138	132	26	2
Na (mg/kg)	209	286	41	40	90	194
Fe (mg/kg)	30.88	64.27	202.22	130.67	41.36	64.04
Mn (mg/kg)	169.90	379.66	31.20	15.58	233.90	321.53
Zn (mg/kg)	47.20	1.03	1.82	3.64	0.53	0.26
Al (cmol _c /kg)	0	0.155	0.061	0	0	0
Resistance (Ohm)	2600	3200	670	1070	2600	2600

C%	3.02	1.60	1.91	2.94	0.46	0.83
Total N%	0.099	0.177	0.109	0.118	0.037	0.061
S (mg/kg)	39.39	27.26	106.43	54.91	102.86	46.68
CEC (cmol _e /kg)	6.605	8.392	10.26	8.34	7.911	10.204
Distinct Tree Species	1. Clerodendrum glabrum 2. Rhus lancea	1. Clerodendrum glabrum 2. Rhus lancea	1. Ximenia caffra 2. Acacia karroo 3. Euclea crispa 4. Ziziphus mucronata	1. Ximenia caffra 2. Acacia karroo 3. Euclea crispa 4. Ziziphus mucronata	1. Acacia karroo	2. Acacia karroo
Average rooting depth of the indicated species (m)	4 - 13	4 - 13	4 - 50	4 - 50	50	50
Average depth of weathering (m)	1.2	1.2	0.5	0.5	2.7	2.7
Geomorphology	Plain	Plain	Kop	Kop	Plain	Plain
Geophysical instrumentation used	Magnetics Electro-magnetics	Magnetics Electro-magnetics	Magnetics Electro-magnetics Direct current sounding	Magnetics Electro-magnetics Direct current sounding	Magnetics Electro-magnetics	Magnetics Electro-magnetics
Water features present?	No	No	Perennial stream, 100 m northwest	Perennial stream, 100 m northwest	Perennial stream, 400m south	Perennial stream, 400m south
Aquifer Yield (l/h)	7500	7500	2050	2050	4700	4700
Borehole Depth (m)	55	55	2	2	48	48
Depth of Water Strike (m)	17	17	2	2	21	21

Static Water Level (m)	11	11	2	2	14	14
Average Aquifer Yield (l/h)	1770	1770	1770	1770	4700	4700
Average Borehole Depth (m)	64	64	64	64	35	35
Average Depth of Water Strike (m)	44	44	44	44	24	24
Average Static Water Level (m)	16	16	16	16	8	8
Land Type Series	Fa7e Rock, Clovelly, Hutton, Glencoe, Mispah	Fa7e Rock, Clovelly, Hutton, Glencoe, Mispah	lb37a Rock, Mispah, Clovelly	lb37a Rock, Mispah, Clovelly	Bb14b/Ba19a Hutton, Avalon	Bb14b/Ba19a Hutton, Avalon
Profile No	No Data	No Data	No Data	No Data	P62	P62
Depth Sampled	No Data	No Data	No Data	No Data	250-500mm	250-500mm
Gravel %	No Data	No Data	No Data	No Data	6	6
Sand %	No Data	No Data	No Data	No Data	64	64
Silt %	No Data	No Data	No Data	No Data	6	6
Clay %	No Data	No Data	No Data	No Data	24	24
pH	No Data	No Data	No Data	No Data	4.7	4.7
P (mg/kg)	No Data	No Data	No Data	No Data	0.8	0.8
Ca (mg/kg)	No Data	No Data	No Data	No Data	800	800
Mg (mg/kg)	No Data	No Data	No Data	No Data	243	243

K (mg/kg)	No Data	No Data	No Data	No Data	2346	2346
Na (mg/kg)	No Data	No Data	No Data	No Data	70	70
Fe (mg/kg)	No Data	No Data	No Data	No Data	-	-
Mn (mg/kg)	No Data	No Data	No Data	No Data	132.60	132.60
Zn (mg/kg)	No Data	No Data	No Data	No Data	0.26	0.26
Resistance (Ohm)	No Data	No Data	No Data	No Data	5200	5200
C%	No Data	No Data	No Data	No Data	0.7	0.7
CEC (cmol _c /kg)	No Data	No Data	No Data	No Data	38	38
Veld Type	19 Sourish Mixed Bushveld	19 Sourish Mixed Bushveld	19 Sourish Mixed Bushveld	19 Sourish Mixed Bushveld	61 Bankenveld	61 Bankenveld
Hydrogeological Unit	D3	D3	D3	D3	D2	D2

The average aquifer yield, average borehole depth, average water strike and average static water level was obtained from Frommurze (1937). It must be noted that the presented value is only an average for the geological formation. Information obtained from the land type maps and accompanying memoir is from Land Type Survey Staff (1987), veld type information from Acocks (1988) and hydrogeological information from DWAF: Johannesburg (1999). Soil colour was identified and classified in the veld according to the Corstor Colour Gauge that lists 168 different soil colours. Average weathering depth is extracted from the indicated Land Type Survey Staff and average rooting depth of the geobotanical indicators is referenced from Canadell *et al.* (1996).

Table A1.15b. Vaalium Eonothem: Rhyolite in the Verena-Middelburg Areas: absent intrusive/weathering contact.

	Enkeldoornoog 219JR		Rhenosterkop 452JR		Kwaggasfontein 460JS	
Geological Formation	Rhyolite (Selonsrivier Formation)	Rhyolite (Selonsrivier Formation)	Rhyolite (Loskop Formation)	Rhyolite (Loskop Formation)	Rhyolite (Selonsrivier Formation) and sandstone (Vryheid Formation)	Rhyolite (Selonsrivier Formation) and sandstone (Vryheid Formation)
Depth Sampled	0.5m	1.2m	0.5m	1.2m	0.5m	0.5m
Borehole Co-ordinates:						
S.L.	25°24.331'	25°24.331'	25°36.307'	25°49.217'	25°53.783'	25°53.783'
E.L.	28°47.409'	28°47.409'	28°55.659'	28°19.701'	29°38.339'	29°38.339'
Soil colour	Light brown	Dark yellowish orange	Weak red	Weak red	Dark brown	Dark reddish brown
Soil texture description	Sandy silt	Silt	Silt	Silt	Silt	Loam
pH	5.37	4.86	5.12	6.23	5.34	5.79
P (mg/kg)	3.82	2.77	8.75	5.63	2.35	2.02
Ca (mg/kg)	322	268	562	653	313	332
Mg (mg/kg)	95	94	77	109	96	138
K (mg/kg)	11	23	108	111	0	10
Na (mg/kg)	141	153	38	19	120	123
Fe (mg/kg)	64.21	40.38	234.13	59.95	88.89	62.02
Mn (mg/kg)	211.64	181.08	26.13	47.36	67.30	190.22
Zn (mg/kg)	1.42	0.56	1.65	1.84	0.16	0.30
Al (cmol _c /kg)	0.251	0.293	0.412	0	0.203	0.156
Resistance (Ohm)	2900	2300	1470	1530	4000	4300

C%	1.39	0.54	2.03	1.32	1.02	0.43
Total N%	0.098	0.042	0.092	0.071	0.075	0.041
S (mg/kg)	18.33	27.83	34.06	23.01	21.07	21.73
CEC (cmol _e /kg)	4.384	3.750	1.20	7.15	3.779	4.468
Distinct Tree Species	1. Clerodendrum glabrum 2. Rhus lancea	1. Clerodendrum glabrum 2. Rhus lancea	1. Ximenia caffra 2. Acacia karroo 3. Euclea crispa 4. Ziziphus mucronata	1. Ximenia caffra 2. Acacia karroo 3. Euclea crispa 4. Ziziphus mucronata	1. Acacia karroo	1. Acacia karroo
Average rooting depth of the indicated species (m)	4 - 13	4 - 13	4 - 50	4 - 50	50	50
Average depth of weathering (m)	1.2	1.2	0.5	0.5	2.7	2.7
Geomorphology	Plain	Plain	Kop	Kop	Plain	Plain
Geophysical instrumentation used	Magnetics Electro-magnetics	Magnetics Electro-magnetics	Magnetics Electro-magnetics Direct current sounding	Magnetics Electro-magnetics Direct current sounding	Magnetics Electro-magnetics	Magnetics Electro-magnetics
Water features present?	No	No	Perennial stream, 100 m northwest	Perennial stream, 100 m northwest	Perennial stream, 400m south	Perennial stream, 400m south
Aquifer Yield (l/h)	7500	7500	2050	2050	4700	4700
Borehole Depth (m)	55	55	2	2	48	48
Depth of Water Strike (m)	17	17	2	2	21	21
Static Water Level (m)	11	11	2	2	14	14

Average Aquifer Yield (l/h)	1770	1770	1770	1770	4700	4700
Average Borehole Depth (m)	64	64	64	64	35	35
Average Depth of Water Strike (m)	44	44	44	44	24	24
Average Static Water Level (m)	16	16	16	16	8	8
Land Type Series	Ba11b/Fa7e Hutton/Rock, Clovelly, Hutton, Glencoe, Mispah	Fa7e Rock, Clovelly, Hutton, Glencoe, Mispah	Ib37a Rock, Mispah, Clovelly	Ib37a Rock, Mispah, Clovelly	Bb14b/Ba19a Hutton, Avalon	Bb14b/Ba19a Hutton, Avalon
Profile No	No Data	No Data	No Data	No Data	P62	P62
Depth Sampled	No Data	No Data	No Data	No Data	250-500 mm	250-500 mm
Gravel %	No Data	No Data	No Data	No Data	6	6
Sand %	No Data	No Data	No Data	No Data	64	64
Silt %	No Data	No Data	No Data	No Data	6	6
Clay %	No Data	No Data	No Data	No Data	24	24
pH (CaCl ₂)	No Data	No Data	No Data	No Data	4.7	4.7
P (mg/kg)	No Data	No Data	No Data	No Data	0.8	0.8
Ca (mg/kg)	No Data	No Data	No Data	No Data	800	800
Mg (mg/kg)	No Data	No Data	No Data	No Data	243	243
K (mg/kg)	No Data	No Data	No Data	No Data	2346	2346
Na (mg/kg)	No Data	No Data	No Data	No Data	70	70

Fe (mg/kg)	No Data	No Data	No Data	No Data	-	-
Mn (mg/kg)	No Data	No Data	No Data	No Data	132.60	132.60
Zn (mg/kg)	No Data	No Data	No Data	No Data	0.26	0.26
Resistance (Ohm)	No Data	No Data	No Data	No Data	5200	5200
C%	No Data	No Data	No Data	No Data	0.7	0.7
CEC (cmol _c /kg)	No Data	No Data	No Data	No Data	38	38
Veld Type	19 Sourish Mixed Bushveld	19 Sourish Mixed Bushveld	19 Sourish Mixed Bushveld	19 Sourish Mixed Bushveld	61 Bankenveld	61 Bankenveld
Hydrogeological Unit	D3	D3	D3	D3	D2	D2

The average aquifer yield, average borehole depth, average water strike and average static water level was obtained from Frommurze (1937). It must be noted that the presented value is only an average for the geological formation. Information obtained from the land type maps and accompanying memoir is from Land Type Survey Staff (1987), veld type information from Acocks (1988) and hydrogeological information from DWAF: Johannesburg (1999). Soil colour was identified and classified in the veld according to the Corstor Colour Gauge that lists 168 different soil colours. Average weathering depth is extracted from the indicated Land Type Survey Staff and average rooting depth of the geobotanical indicators is referenced from Canadell *et al.* (1996).

20. Enkeldoornoog 219JR

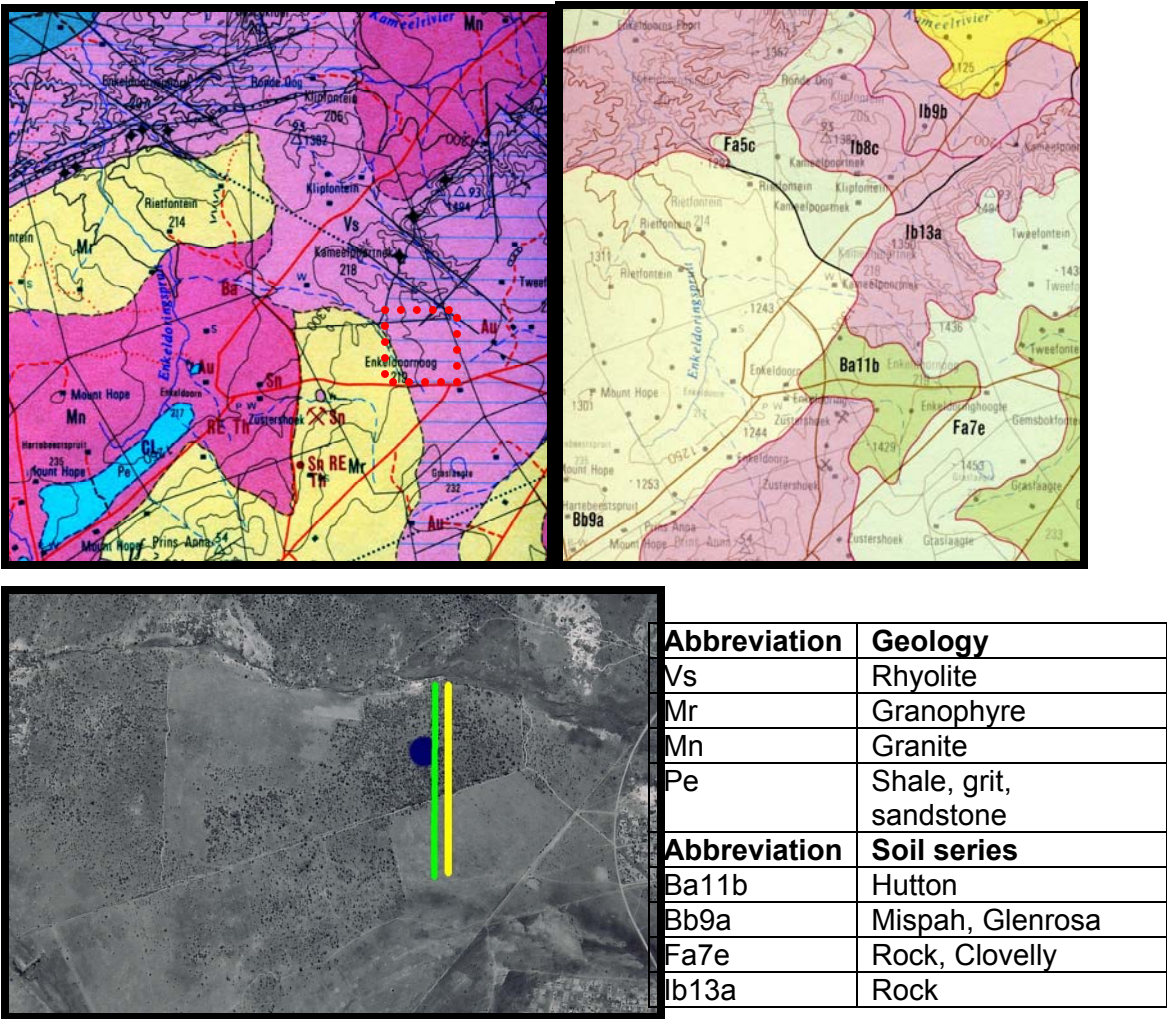


Figure A1.20. The geology (top left), land type (top right) and aerial photograph (bottom) of Enkeldoornoog 219JR. The blue circle denotes the position of the borehole and the green and yellow lines the direction of the (electro)-magnetic profiles. The area covered by the aerial photograph is indicated by the red shape in the geological map.

Enkeldoornoog 219JR is situated east of Kwamhlanga, the former capital of the homeland KwaNdebele.

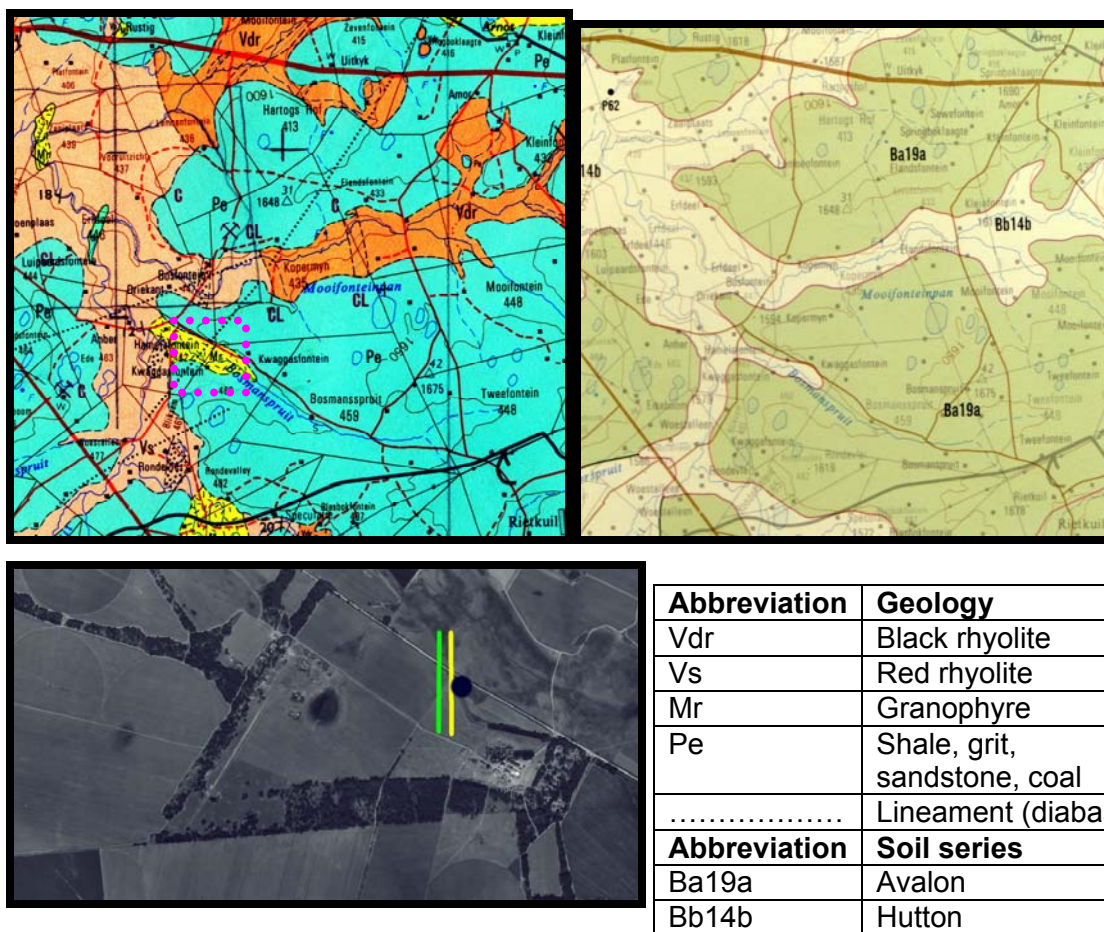
21. Kwaggasfontein 460JS

Figure A1.21. The geology (top left), land type (top right) and aerial photograph (bottom) of Kwaggasfontein 460JS. The blue circle denotes the position of the borehole and the green and yellow lines the direction of the (electro)-magnetic profiles. The area covered by the aerial photograph is indicated by the purple shape in the geological map (lower rectangle). Note the considerable coverage of exotic species establishment on this farm.

The farm is situated south of the main road between Middelburg and Belfast.

22. Rhenosterkop 452JR

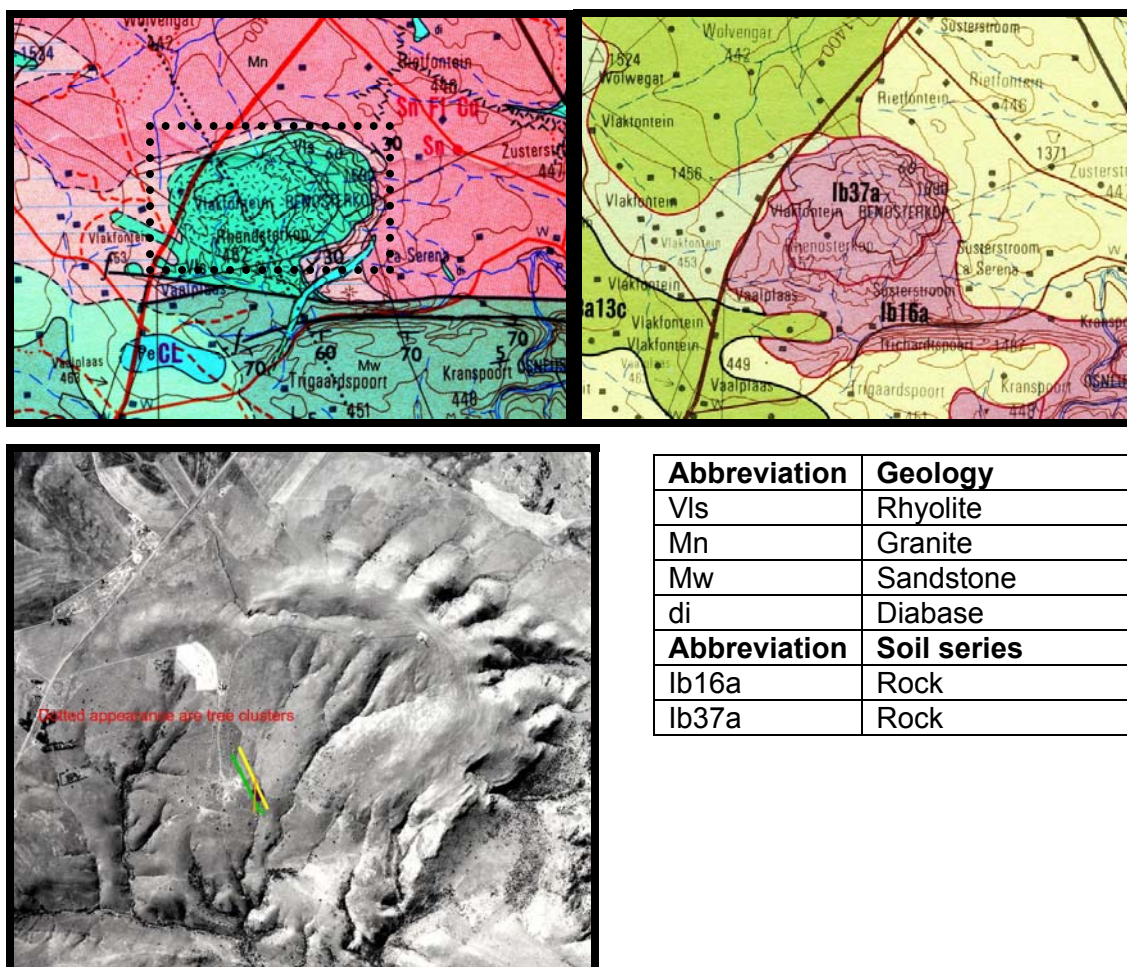


Figure A1.22. The geology (top left), land type (top right) and aerial photograph (bottom) of Rhenosterkop 452JR. The blue circle denotes the position of the borehole, the green and yellow lines the direction of the (electro)-magnetic profiles and the orange line indicates the sounding direction. The area covered by the aerial photograph is indicated by the black shape in the geological map (lower rectangle).

Rhenosterkop presents an unique example of geobotanic interaction with weathered rock, soil and termitary. Termitary reflects the parent rock in depth by the colour appearance of the termitary in association with tree clusters that are distinct features on the grassy hill sides of the kop. Another extinct volcano to the southeast of Rhenosterkop is the kop Honingkranz on the farm Honingkranz 536JR, close to Balmoral. The geobotanic communities as presented on Rhenosterkop are also present but not so distinct and well defined.

A1.8 VAALIUM EONOTHEM: SEDIMENTS OF THE LOSKOP FORMATION AND A DIABASE SILL IN THE BRONKHORSTSPRUIT-MIDDELBURG AREA

This chapter included various lithologies from the Pretoria Group and rhyolite of the Rooiberg Group and Loskop Formation. These lithologies are representative of the Vaalium Eonothem. However, sediments of the Loskop Formation and geophysical groundwater exploration in a diabase environment have not been addressed thus far. This section represents the sediments of the Loskop Formation, associated with diabase intrusions, and a diabase environment. Due to the limited extent of the Loskop Formation and confined occurrence of outcropping diabase sills amongst rocks of the Pretoria Group, only one case of each is included. The geobotanic occurrences is relevant and of importance in the context of this study. Both case studies are located in the grassland biome.

A1.8.1 CASE STUDY AREA

A diabase outcrop south of Bronkhorstspuit is investigated together with a case study southwest of Middelburg. Both case studies are associated with farming activities.

A1.8.2 CLIMATE AND VELD TYPES

Being on the Highveld implies cold, dry winters and hot, wet summers. Thunderstorms are the deliverers of rain. Climatic data of the area is indicated in Table A1.16. The climate restricts bush establishment due to frost, fire, wind and acid soil conditions in places (sourveld), due to higher rainfall compared to localities in the Bushveld. Notwithstanding this, the Bankenveld veld type of this area hosts some shrub and tree species in surroundings protected against the mentioned elements. The following tree species are eminent of the veld type (after Acocks, 1988 and Van Wyk & Van Wyk, 1997):

- Bankenveld: *Acacia caffra* (common hook-thorn), *Celtis africana* (white stinkwood) and *Protea caffra* (common sugarbush).

Table A1.16. Climatic Data of the Bronkhorstspuit-Middelburg Area (Land Type Survey Staff, 1987, Schulze, 1997 & Johannesburg, 1999).

	Study Area
Average Yearly Temperature (°C)	12-14
Mean Minimum Temperature (°C) in July	0-2
Mean Maximum Temperature (°C) in January	22.5-25.0
Average Yearly Rainfall (mm)	600-800
Elevation (m)	1200-1600
Evaporation (mm/year)	2000-2250
Frost area?	150-175 days a year

A1.8.3 GEOLOGY AND HYDROGEOLOGICAL CLASSIFICATION

The Loskop Formation follows more or less concordantly on the Rooiberg Group without any trace of a major regional unconformity. The Formation is separated from the overlying Waterberg sediments by a prominent regional unconformity and consists of a thick succession of finely layered siltstone, mudstone, feldspathic sandstone and shale. The deposition of the Loskop Formation is regarded as being the final sedimentary phase of the development of the Transvaal Basin, following directly on the volcanic phase of the Rooiberg Group (Pretoria, 1978). Basic rocks around Bronkhorstspuit form predominantly transgressive sills in the Pretoria Group and are locally also intrusive into Waterberg strata (section 4.10). They include diabase, granophyric quartz-norite, intermediate rocks and pseudorhyolite (Pretoria, 1978).

Sediments of the Loskop Formation are regarded as predominantly arenaceous rocks, like sandstone, on the Johannesburg (1999) map and classified as an intergranular and fractured aquifer with a yield ranging from 360-1800 l/h. If associated with intrusions, the arenaceous rocks will probably be brecciated and jointed (Hattingh, 1996). Aquifers associated with diabase, or described as undifferentiated rocks and mixed lithologies on the Johannesburg (1999) map, are also categorised in the intergranular and fractured aquifer group, but with yields ranging from 1800-7200 l/h.

A1.8.4 GEOPHYSICAL AND GEOBOTANICAL INFORMATION

The Loskop Formation and diabase environments around Bronkhorstspuit were included in the study by Meulenbeld (1998). The geophysical signatures listed under the case studies will be referenced to the mentioned work. The use of magnetics, electromagnetics and Schlumberger soundings on diabase derived soil is advocated due to differences in magnetic intensity and conductivity between sediments and intrusive rocks. Soundings indicate zones of deeper weathering, pointed out by differences in electrical conductivity of the measured dipoles (EM34-3).

Information on geobotanical indicators associated with the sediments of the Loskop Formation and diabase intrusions in the Bronkhorstspuit-Middelburg area is not available. However, geobotanical indicators as found in the same area but linked to other lithologies can be utilised for reference, especially if the basic soil chemical properties are corresponding.

A1.8.5 SOIL SAMPLING AND RESULTS PRESENTATION

Soil sampling was undertaken as referenced in the previous sections at the same depths. The results are listed in Tables A1.17(a&b). From these results and the other case studies presented elsewhere, certain remarks can be made regarding available soil nutrients and the presence of geobotanic communities.

Table A1.17a. Vaalium Eonothem: Other geological conditions in the Bronkhorstspruit-Middelburg area: along weathered basin or intrusive contact.

Parameter	Klapeiland 524JR		Rietfontein 314JS	
Geological Formation	Weathered basin in diabase	Weathered basin in diabase	Diabase intrusion in shale, sandstone and conglomerate (Loskop Formation)	Diabase intrusion in shale, sandstone and conglomerate (Loskop Formation)
Depth Sampled	0.5m	1.2m	0.5m	1.2m
Borehole Co-ordinates:				
S.L.				
E.L.	25°49.094' 28°44.433'	25°49.094' 28°44.433'	25°50.412' 29°21.517'	25°50.412' 29°21.517'
Soil colour	Dark yellowish orange	Strong brown	Moderate brown	Moderate brown
Soil texture description	Silty clay	Clay	Clay	Clay
pH	4.97	5.60	5.68	6.06
P (mg/kg)	1.54	1.30	2.37	2.34
Ca (mg/kg)	340	347	1001	724
Mg (mg/kg)	164	164	355	328
K (mg/kg)	87	83	160	109
Na (mg/kg)	29	20	13	0
Fe (mg/kg)	78.93	45.98	79.49	49.05
Mn (mg/kg)	343.15	216.87	297.75	178.90
Zn (mg/kg)	25.31	0.87	0.24	0.48
Al (cmol _e /kg)	0.040	0.041	0.037	0
Resistance (Ohm)	1910	3040	900	1660
C%	0.70	0.49	1.18	0.46
Total N%	0.048	0.036	0.059	0.027

S (mg/kg)	57.93	15.61	60.81	19.39
CEC (cmol _c /kg)	11.45	6.77	17.41	17.75
Distinct Tree Species	3. Acacia karroo 4. Euclea crispa	1. Acacia karroo 23. Euclea crispa	5. Acacia karroo 6. Rhus lancea	5. Acacia karroo 6. Rhus lancea
Average rooting depth of the indicated species (m)	4 - 50	4 - 50	4 - 50	4 - 50
Average depth of weathering (m)	3.2	3.2	2.6	2.6
Geomorphology	Plain	Plain	Undulating terrain	Undulating terrain
Geophysical instrumentation used	Magnetometer & Schlumberger soundings	Magnetometer & Schlumberger soundings	Magnetometer & Electromagnetics	Magnetometer & Electromagnetics
Water features present?	No	No	No	No
Aquifer Yield (l/h)	9 000	9 000	7 500	7 500
Borehole Depth (m)	42	42	60	60
Depth of Water Strike (m)	18	18	23	23
Static Water Level (m)	11	11	10	10
Average Aquifer Yield (l/h)	4 600	4 600	5 000	5 000
Average Borehole Depth (m)	39	39	57	57
Average Depth of Water Strike (m)	27	27	24	24
Average Static Water Level (m)	13	13	8	8
Land Type Series	Ab5a Hutton	Ab5a Hutton	Ba37a Hutton	Ba37a Hutton

Profile No	P56	P56	P60	P60
Depth Sampled	1010-1200+mm	1010-1200+mm	200-450mm	200-450mm
Gravel %	1	1	1	1
Sand %	70	70	62	62
Silt %	7	7	33	33
Clay %	22	22	4	4
pH (H ₂ O)	6.5	6.5	4.9	4.9
P (mg/kg)	2.8	2.8	-	-
Ca (mg/kg)	13026	13026	100	100
Mg (mg/kg)	10085	10085	365	365
K (mg/kg)	391	391	1173	1173
Na (mg/kg)	690	690	115	115
Fe (mg/kg)	-	-	-	-
Mn (mg/kg)	68.0	68.0	125.0	125.0
Zn (mg/kg)	0.63	0.63	0.16	0.16
Resistance (Ohm)	590	590	9999	9999
C%	0.3	0.3	0.4	0.4
CEC (cmol _c /kg)	163	163	31	31
Veld Type	61 Bankenveld	61 Bankenveld	61 Bankenveld	61 Bankenveld
Hydrogeological Unit	D3	D3	D2	D2

The average aquifer yield, average borehole depth, average water strike and average static water level were obtained from Frommurze (1937) and Meulenbeld (1998). It must be noted that the presented value is only an average for the geological formation. Information obtained from the land type maps and accompanying memoir is from Land Type Survey Staff (1987), veld type information from Acocks (1988) and hydrogeological information from DWAF: Johannesburg (1999). Soil colour was identified and

classified in the veld according to the Corstor Colour Gauge that lists 168 different soil colours. Average weathering depth is extracted from the indicated Land Type Survey Staff and average rooting depth of the geobotanical indicators is referenced from Canadell *et al.* (1996).

Table A1.17b. Vaalium Eonothem: Other geological conditions in the Bronkhorstspuit-Middelburg area: no weathered basin or intrusive contact.

	Klipeiland 524JR		Rietfontein 314JS	
Geological Formation	Shallow weathered diabase	Shallow weathered diabase	Shale, sandstone and conglomerate (Loskop Formation)	Shale, sandstone and conglomerate (Loskop Formation)
Depth Sampled	0.5m	1.2m	0.5m	1.2m
Borehole Co-ordinates:				
S.L.				
E.L.	25°49.094'	25°49.094'	25°50.412'	25°50.412'
	28°44.433'	28°44.433'	29°21.517'	29°21.517'
Soil colour	Yellowish brown	Dark yellowish orange	Very dusky red	Greyish brown
Soil texture description	Clayey silt	Silt	Clayey silt	Silt
pH	6.04	5.67	7.16	7.35
P (mg/kg)	1.65	1.53	2.10	1.81
Ca (mg/kg)	289	282	2381	1375
Mg (mg/kg)	161	112	198	176
K (mg/kg)	54	87	110	83
Na (mg/kg)	5	18	35	6
Fe (mg/kg)	29.19	40.79	57.83	47.52
Mn (mg/kg)	74.72	104.89	443.12	262.06
Zn (mg/kg)	0.12	0.24	0.89	0.83
Al (cmol _c /kg)	0	0.062	0	0
Resistance (Ohm)	4650	3720	940	1650
C%	0.54	0.53	0.80	0.14

Total N%	0.035	0.031	0.058	0.013
S (mg/kg)	14.07	15.71	7.62	4.81
CEC (cmol _e /kg)	5.68	5.26	8.62	21.54
Distinct Tree Species	1. Acacia karroo 2. Euclea crispa	1. Acacia karroo 2. Euclea crispa	1. Acacia karroo 2. Rhus lancea	1. Acacia karroo 2. Rhus lancea
Average rooting depth of the indicated species (m)	4 - 50	4 - 50	4 - 50	4 - 50
Average depth of weathering (m)	3.2	3.2	2.6	2.6
Geomorphology	Plain	Plain	Undulating terrain	Undulating terrain
Geophysical instrumentation used	Magnetometer & Schlumberger soundings	Magnetometer & Schlumberger soundings	Magnetometer & Electromagnetics	Magnetometer & Electromagnetics
Water features present?	No	No	No	No
Aquifer Yield (l/h)	9 000	9 000	7 500	7 500
Borehole Depth (m)	42	42	60	60
Depth of Water Strike (m)	18	18	23	23
Static Water Level (m)	11	11	10	10
Average Aquifer Yield (l/h)	4 600	4 600	5 000	5 000
Average Borehole Depth (m)	39	39	57	57
Average Depth of Water Strike (m)	27	27	24	24
Average Static Water Level (m)	13	13	8	8
Land Type Series	Ab5a Hutton	Ab5a Hutton	Ba37a Hutton	Ba37a Hutton

Profile No	P56	P56	P60	P60
Depth Sampled	1010-1200+mm	1010-1200+mm	200-450mm	200-450mm
Gravel %	1	1	1	1
Sand %	70	70	62	62
Silt %	7	7	33	33
Clay %	22	22	4	4
pH (H ₂ O)	6.5	6.5	4.9	4.9
P (mg/kg)	2.8	2.8	-	-
Ca (mg/kg)	13026	13026	100	100
Mg (mg/kg)	10085	10085	365	365
K (mg/kg)	391	391	1173	1173
Na (mg/kg)	690	690	115	115
Fe (mg/kg)	-	-	-	-
Mn (mg/kg)	68.0	68.0	125.0	125.0
Zn (mg/kg)	0.63	0.63	0.16	0.16
Resistance (Ohm)	590	590	9999	9999
C%	0.3	0.3	0.4	0.4
CEC (cmol _e /kg)	163	163	31	31
Veld Type	61 Bankenveld	61 Bankenveld	61 Bankenveld	61 Bankenveld
Hydrogeological Unit	D3	D3	D2	D2

The average aquifer yield, average borehole depth, average water strike and average static water level were obtained from Frommurze (1937) and Meulenbeld (1998). It must be noted that the presented value is only an average for the geological formation. Information obtained from the land type maps and accompanying memoir is from Land Type Survey Staff (1987), veld type information from Acocks (1988) and hydrogeological information from DWAF: Johannesburg (1999). Soil colour was identified and classified in the veld according to the Corstor Colour Gauge that lists 168 different soil colours. Average weathering depth is

extracted from the indicated Land Type Survey Staff and average rooting depth of the geobotanical indicators is referenced from Canadell *et al.* (1996).

23. Klipeland 524JR

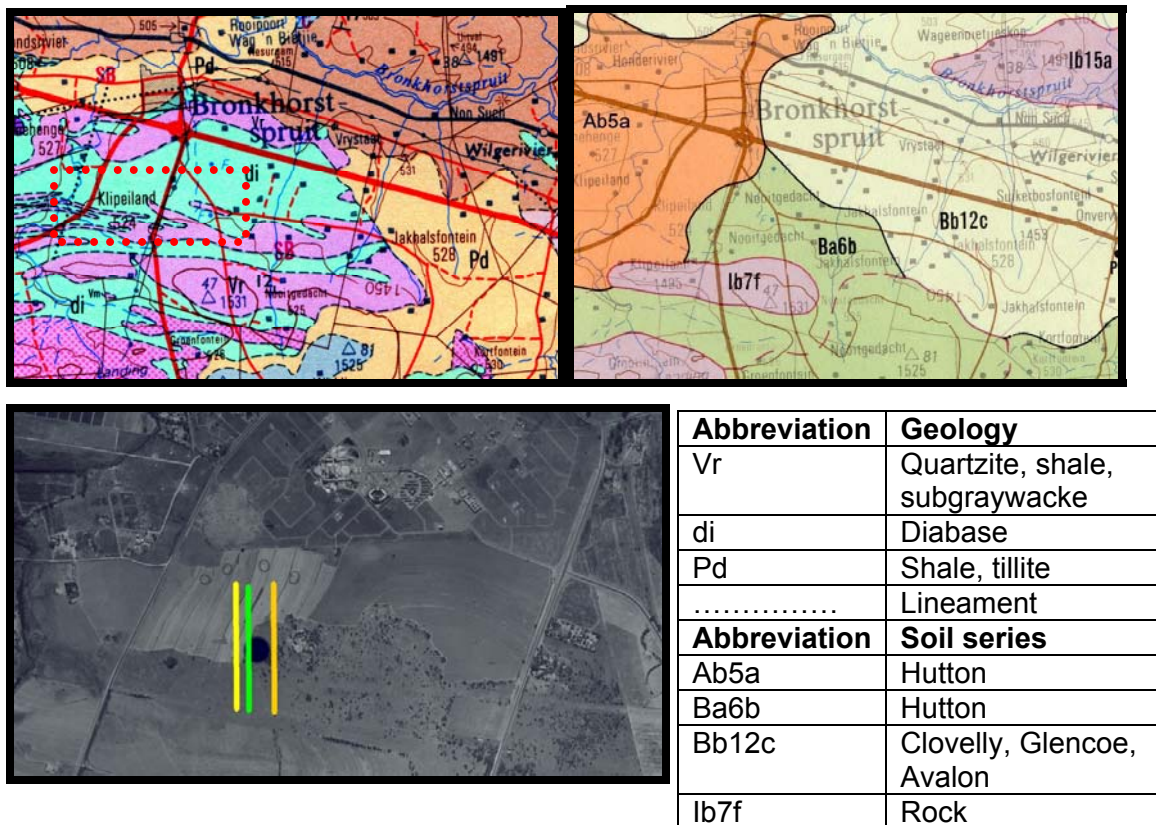


Figure A1.23. The geology (top), land type (middle) and aerial photograph (bottom) of Klipeland 524JR. The blue circle denotes the position of the borehole, the green line is the direction of the magnetic profile, the yellow line indicates the electromagnetic profile and the orange line is the sounding layout. The area covered by the aerial photograph is indicated by the red shape in the geological map.

Klipeland 524JR is adjoining the Taiwanese development of Bronkhorstspuit. The farm is utilised for the cultivation of crops to sustain the Taiwanese community. Need for irrigation was expressed to reduce drought risk.

24. Rietfontein 314JS

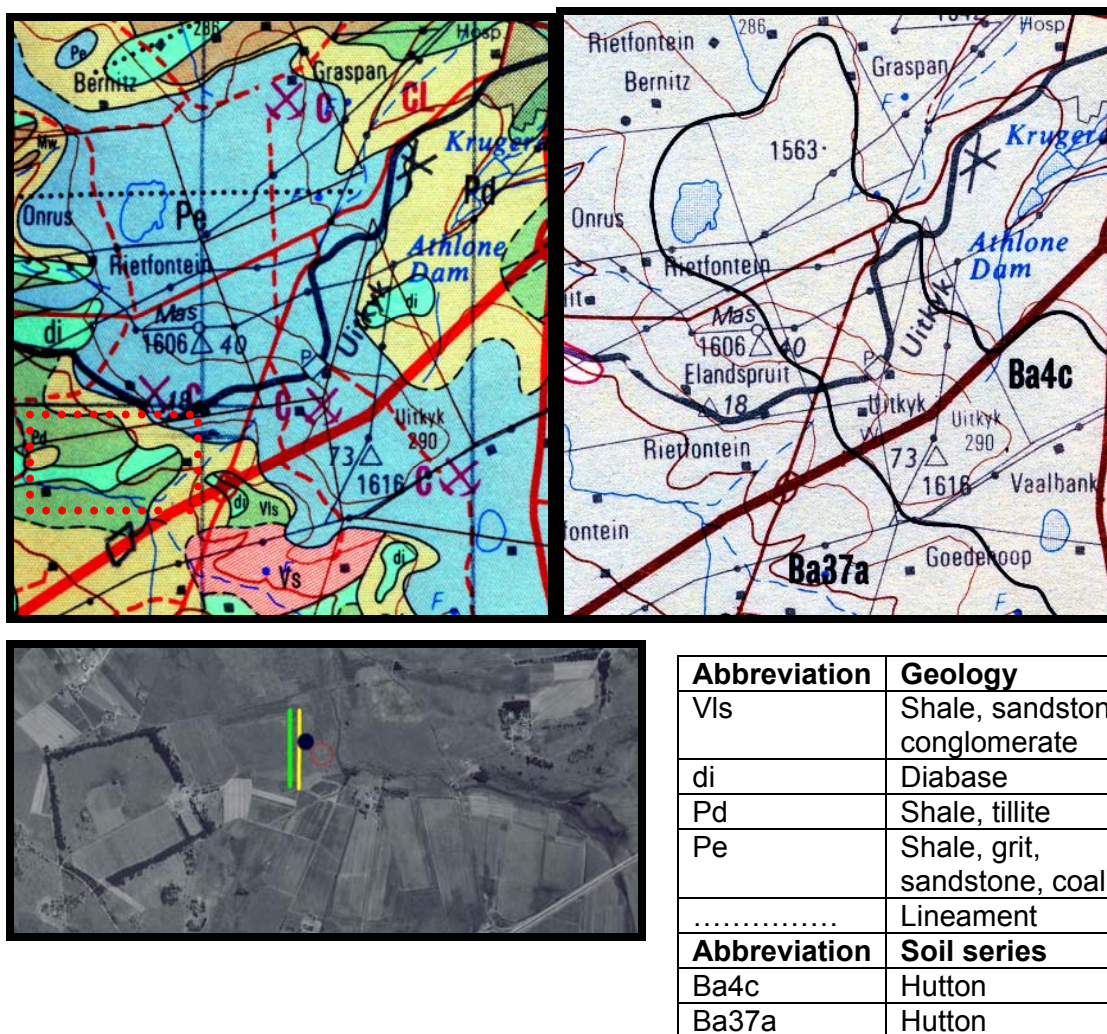


Figure A1.24. The geology (top), land type (middle) and aerial photograph (bottom) of Rietfontein 314JS. The blue circle denotes the position of the borehole, the green line is the direction of the magnetic profile and the yellow line indicates the electromagnetic profile. The area covered by the aerial photograph is indicated by the red shape in the geological map. The red circle in the aerial photograph indicates indigenous trees (serve as geobotanic indicators).

Southwest of Middelburg, north of the N4-freeway, the farm Rietfontein 314JS is located.

A1.9 MOGOLIAN EONOTHEM: GRANITE OF THE NEBO GRANITE IN THE ROOIBERG-WARMBATHS AND VERENA AREAS

Outcrops of rocks belonging to the Bushveld Igneous Complex are numerous in the central parts of the old Transvaal; now covering parts of the Limpopo, Mpumalanga, Gauteng and North-West Provinces. Some of these rocks were formed during the Vaalium Eonothem, and are discussed in Chapter 4. The Nebo Granite, Mogolian age, as presented in this section belongs to the Lebowa Granite Suite, part of the Bushveld Igneous Complex. The formation of the granite denotes the final stages of the Bushveld Igneous Complex. The granite in the Warmbaths area is separated from the granite in the Verena area by the Springbok Flats, mostly consisting of younger sediments and basalt, overlying the granite, belonging to the Karoo Supergroup (see Chapter 4). Due to the limited number of case studies for both areas, all the case studies will be presented together in this section with the relevant distinctions included regarding climatic and other conditions.

A1.9.1 CASE STUDY AREA

Case studies presented are situated to the northwest of Warmbaths towards the Swaershoek Mountains. This area is dominated by game ranches and extensive cattle farming. Case studies in the Verena area are situated in the Zusterstroom region, between Bronkhorstspuit and Verena. The natural vegetation of this region is altered by large scale intensive irrigation agricultural practices, where water supply is drawn from boreholes and the Wilge River.

A1.9.2 CLIMATE AND VELD TYPES

Both areas' (Warmbaths and Verena) altitude is ranging from 1200 – 1600 m, according to the Johannesburg (1999) and Polokwane (2003) maps. This altitude comparison gives rise to similar climatic conditions, see Table A1.18, with hot and humid summers and cool, dry winters. The wet season lasts approximately from October to April with rainfall occurring mostly as heavy thunderstorms. The veld types that occur (see also Table A1.19a) is Mixed Bushveld in the Verena area and Sourish Mixed Bushveld in the

lower regions and Sour Bushveld in the ridges and elevated areas in the Warmbaths area (Acocks, 1988). The following tree species are eminent of these veld types (after Bonsma, 1976, Acocks, 1988 and Van Wyk & Van Wyk, 1997), all veld types are part of the savanna biome:

- Mixed Bushveld: *Acacia caffra* (common hook-thorn), *Burkea africana* (wild seringa), *Combretum apiculatum* (red bushwillow), *Grewia flava* (velvet raisin) and *Mundulea sericea* (cork bush).
- Sourish Mixed Bushveld: *Acacia caffra* (common hook-thorn), *A. karroo* (sweet thorn), *A. robusta subsp. robustu* (brack thorn) & *A. tortillis subsp. heteracantha* (umbrella thorn), *Rhus gueinzii* (thorny karree), *Peltophorum africanum* (weeping wattle), *Pappea capensis* (jacket-plum) and *Ziziphus mucronata* (buffalo-thorn).
- Sour Bushveld: *Acacia caffra* (common hook-thorn), *Combretum molle* (velvet bushwillow) & *C. apiculatum* (red bushwillow) & *C. zeyheri* (large-fruited bushwillow), *Euclea crispa* (blue guarri), *Faurea saligna* (Transvaal beech), *Burkea africana* (wild seringa), *Ochna pulchra* (peeling plane), *Olea europaea subsp. africana* (wild olive), *Ficus ingens* (red-leaved fig) and *Strychnos pungens* (spine-leaved monkey orange).

Geobotanical investigations on the included case studies will indicate other occurring tree species as well and the marker tree species (geobotanic indicators) that can be utilised for groundwater exploration.

Table A1.18. Climatic Data of the Verena and Warmbaths Areas (Bonsma, 1976, Schulze, 1997, Johannesburg, 1999 & Polokwane, 2003).

	Quantity: Verena Area	Quantity: Warmbaths Area
Average Yearly Temperature (°C)	16-18	18-20
Mean Minimum Temperature (°C) in July	2-4	2-4
Mean Maximum Temperature (°C) in January	27.5-30.0	27.5-30.0
Average Yearly Rainfall (mm)	600-800	600-800
Elevation (m)	1200-1600	1200-1600
Evaporation (mm/year)	2000-2250	2000-2250
Frost area?	<150 days per year	Almost none

A1.9.3 GEOLOGY AND HYDROGEOLOGICAL CLASSIFICATION

(a) Warmbaths Area

The Nebo Granite (acid igneous rock) overlies basic rocks of the Bushveld Igneous Complex more or less conformably in the form of a huge sheet-like intrusion. The granite is homogeneous, but varies in grain size and ferromagnesian content, the coarser-grained varieties containing aplitic and pegmatitic sheets and lenses. The Nebo Granite consists of perthite, quartz, plagioclase, hornblende and/or biotite and accessory minerals. Hornblende is the most important mafic mineral in the lower and central parts of the granite sheet; close to the top biotite becomes progressively more important. The anorthite content of the plagioclase near the base of the sheetlike intrusion increases up to about 20%; near the top, in a leucocratic variety, the content of mafic minerals decreases from 11% to 4%. Some lineaments cross the granite in a northwestern-southeastern strike (Nylstroom, 1978).

Prominent structural structures are displayed in the Alma trough, namely the Swaershoekberge anticlinorium and the Nylstroom syncline, with accompanying anticlinal structures (Loubad and Zwartkloof anticlines). Their origin and original non-linear pattern are attributed to late-magmatic Bushveld activity during their embryonic stage. Subsequent folding, flexing and faulting during Waterberg and post-Waterberg times transformed the embryonic structures into their present shape and locally their limbs were tilted to the vertical or over-turned. The Droogekloof overthrust developed along the Zwartkloof anticline. Fault and fracture structures are frequently intruded by diabase (Nylstroom, 1978).

(b) Verena Area

The Nebo Granite ($1\,920 \pm 30$ Ma) forms a huge sheet with a leucocratic facies near the top (Pretoria, 1978). Porphyritic varieties frequently occur in marginal zones and near Verena they occupy large areas. Another variety in dome-shaped bodies contains fluorite, abundant pegmatite and also porphyritic types. The Dennilton anticline plunges to the south and the Nebo Granite cuts across the limbs and core. Both structures are probably uplifted portions of the floor of the Bushveld Complex. The core of a dome-like structure in the Pretoria Group near Balmoral has been intruded by the Nebo Granite. Broad shallow synclinal brachystructures are developed mainly in Rooiberg lava near

Verena (Pretoria, 1978). Some diabase intrusions occur in stress related fractures in the granite.

As both areas discussed belong to the Nebo Granite, their hydrogeological classification according to the Johannesburg (1999) and Polokwane (2003) maps are coinciding, namely acid intrusive rocks (various granitoids) that define an intergranular and fractured aquifer. Aquifer conditions vary from weathering basins on the contact of fractures and joints and also deep aquifers associated with faults and fractures, especially in the Warmbaths area (Hattingh, 1996). Meulenbeld (1998) and Botha *et al.* (2001) identified fractured aquifers associated with dykes also. Yield from these aquifers range from 360 – 1800 ℓ/h and a depth to the water table of about 38 m in the Warmbaths area, to 1800 – 7200 ℓ/h and a water table depth of 26.5 m in the Verena area (Bonsma, 1976, Johannesburg, 1999 & Polokwane, 2003). However, higher yields are possible as will be indicated (and lower also based on the borehole siting method).

A1.9.4 GEOPHYSICAL AND GEOBOTANICAL INFORMATION

Published geophysical studies in this study area are restricted to a study by Meulenbeld (1998), but only cover the Verena area. A study by Botha *et al.* (2001) focuses on the Nebo Granite, but in the former homeland of Lebowa, to the northeast of the presented case studies. The latter concluded that airborne geophysical data assisted in the identifying and mapping structures of regional extent. The electromagnetic method proved to work exceptionally well in areas of weathering, faults and fractures. However, the use of airborne geophysical data is not always available and if available, or desired, only at great expense to the individual landowner. Geophysics still has to compete with laymen methods and therefore the need for geobotanic indicators. The listed case studies in this thesis will present and discuss geophysical profiles (electromagnetic and magnetic) and direct current soundings.

Geobotanical information is limited to the work of Meulenbeld (1998) that listed *Combretum erythrophyllum* (river bushwillow) on granite derived soil in the Verena (Zusterstroom) area.

A1.9.5 SOIL SAMPLING AND RESULTS PRESENTATION

As in the previous case studies, soil samples were taken at depths of 0.5 and 1.2 m respectively at the site of the borehole and geobotanical indicator and the remaining sample some distance removed from it, not near such a geobotanical indicator. A total of five farms were visited, three in the Warmbaths area and two in the Verena area. The analysis of soil samples taken at these five farms are listed in Tables A1.19(a&b) i & ii.

Table A1.19a (i). Mogolian Eonothem: Nebo Granite - Warmbaths Area: along intrusive contact.

Parameter	Droogekloof 471KR		Kareefontein 432KR		Zandfontein 476KQ	
Geological Formation	Diabase/fault structure	Diabase/fault structure	Weathered diabase contact	Weathered diabase contact	Small weathered diabase dyke	Small weathered diabase dyke
Depth Sampled	0.5m	1.2m	0.5m	1.2m	0.5m	1.2m
Borehole Co-ordinates:						
S.L.	24°50.239'	24°50.239'	24°42.052'	24°42.052'	24°40.466'	24°40.466'
E.L.	28°08.787'	28°08.787'	28°01.359'	28°01.359'	27°50.332'	27°50.332'
Soil colour	Moderate reddish brown	Dark red	Strong brown	Yellowish brown	Brown	Moderate brown
Soil texture description	Sandy silt	Silty sand	Clay	Clay	Clayey silt	Clayey silt
pH	5.59	5.49	5.93	5.77	6.37	5.90
P (mg/kg)	1.52	1.14	1.48	0.88	15.81	13.72
Ca (mg/kg)	282	298	532	395	1091	453
Mg (mg/kg)	361	300	220	177	221	113
K (mg/kg)	70	69	29	27	101	68
Na (mg/kg)	38	30	18	120	230	28
Fe (mg/kg)	43.00	23.38	18.18	53.52	73.19	54.82
Mn (mg/kg)	12.30	21.68	17.98	4.90	130.74	119.95
Zn (mg/kg)	0.25	0.23	0.28	0.23	3.23	1.46
Al (cmol _c /kg)	1.594	1.775	0.160	0.164	0	0.119
Resistance (Ohm)	6000	5400	3400	2000	1800	2800

C%	0.14	0.15	0.19	0.06	0.44	0.70
Total N%	0.033	0.036	0.018	0.010	0.044	0.065
S (mg/kg)	7.53	17.76	1.63	4.11	15.12	11.02
CEC (cmol _e /kg)	9.25	10.35	10.93	7.69	8.675	5.183
Distinct Tree Species	1. Ficus ingens 2. Acacia karroo	1. Ficus ingens 2. Acacia karroo	1. Zanthoxylum capense 2. Ximenia caffra 3. Acacia karroo	1. Zanthoxylum capense 2. Ximenia caffra 3. Acacia karroo	1. Zanthoxylum capense 2. Ximenia caffra 3. Acacia karroo	1. Zanthoxylum capense 2. Ximenia caffra 3. Acacia karroo
Average rooting depth of the indicated species (m)	12 - 50	12 - 50	5 - 50	5 - 50	5 - 50	5 - 50
Average depth of weathering (m)	1.4	1.4	1.9	1.9	1.7	1.7
Geomorphology	Mountainous	Mountainous	Hills and valleys	Hills and valleys	Plain and ridges	Plain and ridges
Geophysical instrumentation used	Electromagnetics	Electromagnetics	Electromagnetics & Magnetics	Electromagnetics & Magnetics	Electromagnetics	Electromagnetics
Water features present?	Yes-dry river bed	Yes-dry river bed	Yes-dry river bed	Yes-dry river bed	No	No
Aquifer Yield (l/h)	17 000	17 000	5 500	5 500	4 250	4 250
Borehole Depth (m)	60	60	75	75	80	80
Depth of Water Strike (m)	31	31	52	52	54	54
Static Water Level (m)	16	16	19	19	27	27

Average Aquifer Yield (l/h)	1 800	1 800	1 800	1 800	1 800	1 800
Average Borehole Depth (m)	38	38	38	38	38	38
Average Depth of Water Strike (m)	43	43	43	43	43	43
Average Static Water Level (m)	21	21	21	21	21	21
Land Type Series	Fa274a Glenrosa	Fa274a Glenrosa	Ac68a Clovelly	Ac68a Clovelly	Fa4k Clovelly	Fa4k Clovelly
Profile No	P759	P759	P1366	P1366	P755	P755
Depth Sampled	800 – 1090 mm	800 – 1090 mm	300 – 1200 mm	300 – 1200 mm	100 – 520 mm	100 – 520 mm
Gravel %	2	2	1	1	3	3
Sand %	67	67	81	81	87	87
Silt %	8	8	4	4	4	4
Clay %	23	23	14	14	6	6
pH (H ₂ O)	7.1	7.1	5.5	5.5	6.0	6.0
P (mg/kg)	5.2	5.2	0.7	0.7	1.3	1.3
Ca (mg/kg)	2140	2140	200	200	160	160
Mg (mg/kg)	264	264	36	36	84	84
K (mg/kg)	80	80	78	78	156	156
Na (mg/kg)	23	23	22	22	25	25
Fe (mg/kg)	-	-	-	-	-	-
Mn (mg/kg)	309.9	309.9	0.7	0.7	15.4	15.4
Zn (mg/kg)	0.33	0.33	0.01	0.01	0.35	0.35
Resistance (Ohm)	480	480	6000	6000	4300	4300
C%	0.2	0.2	0.2	0.2	0.4	0.4

CEC (cmol _c /kg)	107	107	20	20	30	30
Veld Type	19/20 Sourish Mixed Bushveld/Sour Bushveld	19/20 Sourish Mixed Bushveld/Sour Bushveld	20 Sour Bushveld	20 Sour Bushveld	19/20 Sourish Mixed Bushveld/Sour Bushveld	19/20 Sourish Mixed Bushveld/Sour Bushveld
Hydrogeological Unit	D2	D2	D2	D2	D2	D2

Information obtained from the veld type maps from Acocks (1988) and hydrogeological information from DWAF: Polokwane (2003). Soil colour was identified and classified in the veld according to the Corstor Colour Gauge that lists 168 different soil colours. Average borehole depth was obtained from Bonsma (1976), while other geohydrological parameters were derived from Frommurze (1937). Information obtained from the land type maps and accompanying memoir is from Land Type Survey Staff (1988). Average weathering depth is extracted from the indicated Land Type Survey Staff and average rooting depth of the geobotanical indicators is referenced from Canadell *et al.* (1996).

Table A1.19b (i). Mogolian Eonothem: Nebo Granite - Warmbaths Area: intrusive contact absent.

	Droogekloof 471KR		Kareefontein 432KR		Zandfontein 476KQ	
Geological Formation	Granite and sandstone	Granite and sandstone	Granite	Granite	Granite	Granite
Depth Sampled	0.5m	1.2m	0.5m	1.2m	0.5m	1.2m
Borehole Co-ordinates:						
S.L.	24°50.239'	24°50.239'	24°42.052'	24°42.052'	24°40.466'	24°40.466'
E.L.	28°08.787'	28°08.787'	28°01.359'	28°01.359'	27°50.332'	27°50.332'
Soil colour	Moderate yellowish brown	Moderate brown	Strong brown	Moderate brown	Strong brown	Strong brown
Soil texture description	Clayey silt	Silt	Silt	Silt	Quartz sand	Quartz sand
pH	4.78	4.83	5.62	5.26	6.67	6.47
P (mg/kg)	27.92	3.86	11.78	10.17	1.94	0.85
Ca (mg/kg)	137	130	315	279	279	389
Mg (mg/kg)	50	47	93	108	66	69
K (mg/kg)	35	25	68	47	42	49
Na (mg/kg)	34	8	16	3	4	22
Fe (mg/kg)	70.76	71.90	64.79	49.88	12.56	75.72
Mn (mg/kg)	1.23	0.69	142.31	94.28	58.26	97.45
Zn (mg/kg)	0.28	0.37	0.65	1.14	0.38	0.13
Al (cmol _c /kg)	2.630	1.741	0.184	0.429	0	0
Resistance (Ohm)	9600	8800	5600	4400	9800	3800

C%	0.64	0.19	0.84	0.56	0.18	0.34
Total N%	0.058	0.021	0.080	0.045	0.017	0.044
S (mg/kg)	8.66	8.02	11.77	23.23	5.79	4.40
CEC (cmol _e /kg)	4.95	4.72	4.900	4.128	2.334	3.673
Distinct Tree Species	1. Ficus ingens 2. Acacia karroo	1. Ficus ingens 2. Acacia karroo	1. Zanthoxylum capense 2. Ximenia caffra 3. Acacia karroo	1. Zanthoxylum capense 2. Ximenia caffra 3. Acacia karroo	1. Zanthoxylum capense 2. Ximenia caffra 3. Acacia karroo	1. Zanthoxylum capense 2. Ximenia caffra 3. Acacia karroo
Average rooting depth of the indicated species (m)	12 - 50	12 - 50	5 - 50	5 - 50	5 - 50	5 – 50
Average depth of weathering (m)	1.4	1.4	1.9	1.9	1.7	1.7
Geomorphology	Mountainous	Mountainous	Hills and valleys	Hills and valleys	Plain and ridges	Plain and ridges
Geophysical instrumentation used	Electromagnetics	Electromagnetics	Electromagnetics & Magnetics	Electromagnetics & Magnetics	Electromagnetics	Electromagnetics
Water features present?	Yes-dry river bed	Yes-dry river bed	Yes-dry river bed	Yes-dry river bed	No	No
Aquifer Yield (l/h)	17 000	17 000	5 500	5 500	4 250	4 250
Borehole Depth (m)	60	60	75	75	80	80
Depth of Water Strike (m)	31	31	52	52	54	54
Static Water Level (m)	16	16	19	19	27	27

Average Aquifer Yield (l/h)	1 800	1 800	1 800	1 800	1 800	1 800
Average Borehole Depth (m)	38	38	38	38	38	38
Average Depth of Water Strike (m)	43	43	43	43	43	43
Average Static Water Level (m)	21	21	21	21	21	21
Land Type Series	Fa274a Glenrosa	Fa274a Glenrosa	Ac68a Clovelly	Ac68a Clovelly	Fa4k Clovelly	Fa4k Clovelly
Profile No	P759	P759	P1366	P1366	P755	P755
Depth Sampled	800 – 1090 mm	800 – 1090 mm	300 – 1200 mm	300 – 1200 mm	100 – 520 mm	100 – 520 mm
Gravel %	2	2	1	1	3	3
Sand %	67	67	81	81	87	87
Silt %	8	8	4	4	4	4
Clay %	23	23	14	14	6	6
pH (H ₂ O)	7.1	7.1	5.5	5.5	6.0	6.0
P (mg/kg)	5.2	5.2	0.7	0.7	1.3	1.3
Ca (mg/kg)	2140	2140	200	200	160	160
Mg (mg/kg)	264	264	36	36	84	84
K (mg/kg)	80	80	78	78	156	156
Na (mg/kg)	23	23	22	22	25	25
Fe (mg/kg)	-	-	-	-	-	-
Mn (mg/kg)	309.9	309.9	0.7	0.7	15.4	15.4
Zn (mg/kg)	0.33	0.33	0.01	0.01	0.35	0.35

Resistance (Ohm)	480	480	6000	6000	4300	4300
C%	0.2	0.2	0.2	0.2	0.4	0.4
CEC (cmol _c /kg)	107	107	20	20	30	30
Veld Type	19/20 Sourish Mixed Bushveld/Sour Bushveld	19/20 Sourish Mixed Bushveld/Sour Bushveld	20 Sour Bushveld	20 Sour Bushveld	19/20 Sourish Mixed Bushveld/Sour Bushveld	19/20 Sourish Mixed Bushveld/Sour Bushveld
Hydrogeological Unit	D2	D2	D2	D2	D2	D2

Information obtained from the veld type maps from Acocks (1988) and hydrogeological information from DWAF: Polokwane (2003). Soil colour was identified and classified in the veld according to the Corstor Colour Gauge that lists 168 different soil colours. Average borehole depth was obtained from Bonsma (1976), while other geohydrological parameters were derived from Frommurze (1937). Information obtained from the land type maps and accompanying memoir is from Land Type Survey Staff (1988). Average weathering depth is extracted from the indicated Land Type Survey Staff and average rooting depth of the geobotanical indicators is referenced from Canadell *et al.* (1996).

Table A1.19a (ii). Mogolian Eonothem: Nebo Granite - Verena Area: along intrusive contact.

Parameter	Klipfontein 258JS		Zusterstroom 447JR	
	Weathered diabase contact and deep weathering profile	Weathered diabase contact and deep weathering profile	Weathered diabase contact	Weathered diabase contact
Depth Sampled	0.5m	1.2m	0.5m	1.2m
Borehole Co-ordinates:				
S.L.	25°36.183'	25°36.183'	25°35.657'	25°35.657'
E.L.	29°03.022'	29°03.022'	29°00.619'	29°00.619'
Soil colour	Greyish orange	Pale red	Yellowish brown	Moderate orange pink
Soil texture description	Clayey silt	Clay	Silty clay	Clayey silt
pH	6.76	6.10	5.80	6.00
P (mg/kg)	16.27	15.42	12.88	10.28
Ca (mg/kg)	681	1452	849	1488
Mg (mg/kg)	136	288	775	1593
K (mg/kg)	49	131	39	80
Na (mg/kg)	77	533	96	72
Fe (mg/kg)	34.35	221.43	45.85	56.45
Mn (mg/kg)	50.58	857.58	52.75	65.27
Zn (mg/kg)	0.34	2.86	0.25	3.47
Al (cmol _c /kg)	0	0	1.080	0.894
Resistance (Ohm)	3400	1300	2600	3000
C%	0.16	0.29	0.03	0.04
Total N%	0.020	0.027	0.008	0.013
S (mg/kg)	9.01	48.11	26.29	21.40
CEC (cmol _c /kg)	5.503	12.107	16.624	22.096

Distinct Tree Species	1. Combretum erythrophyllum	1. Combretum erythrophyllum	1. Combretum erythrophyllum 2. Acacia karroo	1. Combretum erythrophyllum 2. Acacia karroo
Average rooting depth of the indicated species (m)	12	12	12 - 50	12 - 50
Average depth of weathering (m)	0.8	0.8	0.8	0.8
Geomorphology	Plain with scattered tors	Plain with scattered tors	Plain	Plain
Geophysical instrumentation used	Electromagnetics, Magnetism & Schlumberger soundings	Electromagnetics, Magnetism & Schlumberger soundings	Electromagnetics, Magnetism & Schlumberger soundings	Electromagnetics, Magnetism & Schlumberger soundings
Water features present?	Yes, river 400m south	Yes, river 400m south	No	No
Aquifer Yield (l/h)	55 000	55 000	18 000	18 000
Borehole Depth (m)	60	60	60	60
Depth of Water Strike (m)	18	18	15	15
Static Water Level (m)	8	8	12	12
Average Aquifer Yield (l/h)	3 750	3 750	3 750	3 750
Average Borehole Depth (m)	37	37	37	37
Average Depth of Water Strike (m)	23	23	23	23
Average Static Water Level (m)	9	9	9	9
Land Type Series	Bb10a Mispah, Avalon, Glenrosa	Bb10a Mispah, Avalon, Glenrosa	Bb10a Mispah, Avalon, Glenrosa	Bb10a Mispah, Avalon, Glenrosa
Profile No	P67	P67	P67	P67
Depth Sampled	200-450mm	200-450mm	200-450mm	200-450mm

Gravel %	2	2	2	2
Sand %	62	62	62	62
Silt %	8	8	8	8
Clay %	28	28	28	28
PH (H ₂ O)	4.9	4.9	4.9	4.9
P (mg/kg)	1.1	1.1	1.1	1.1
Ca (mg/kg)	400	400	400	400
Mg (mg/kg)	50	50	50	50
K (mg/kg)	290	290	290	290
Na (mg/kg)	10	10	10	10
Fe (mg/kg)	-	-	-	-
Mn (mg/kg)	10.3	10.3	10.3	10.3
Zn (mg/kg)	0.65	0.65	0.65	0.65
Resistance (Ohm)	5900	5900	5900	5900
C%	0.3	0.3	0.3	0.3
CEC (cmol _c /kg)	15.0	15.0	15.0	15.0
Veld Type	18 Mixed Bushveld	18 Mixed Bushveld	18 Mixed Bushveld	18 Mixed Bushveld
Hydrogeological Unit	D3	D3	D3	D3

Information obtained from the veld type maps from Acocks (1988) and hydrogeological information from DWAF: Johannesburg (1999). Soil colour was identified and classified in the veld according to the Corstor Colour Gauge that lists 168 different soil colours. Geohydrological parameters were derived from Frommurze (1937). Information obtained from the land type maps and accompanying memoir is from Land Type Survey Staff (1987). Average weathering depth is extracted from the indicated Land Type Survey Staff and average rooting depth of the geobotanical indicators is referenced from Canadell *et al.* (1996).

Table A1.19b (ii). Mogolian Eonothem: Nebo Granite - Verena Area: intrusive contact absent.

Parameter	Klipfontein 258JS		Zusterstroom 447JR	
	Granite	Granite	Granite	Granite
Geological Formation	Granite	Granite	Granite	Granite
Depth Sampled	0.5m	1.2m	0.5m	1.2m
Borehole Co-ordinates:				
S.L.	25°36.183'	25°36.183'	25°35.657'	25°35.657'
E.L.	29°03.022'	29°03.022'	29°00.619'	29°00.619'
Soil colour	Light brown	Dark yellowish orange	Dark yellowish orange	Moderate brown
Soil texture description	Quartz sand	Quartz clayey silt	Silty sand	Silty sand
pH	7.00	5.40	5.44	5.12
P (mg/kg)	0.92	0.88	15.08	13.13
Ca (mg/kg)	367	493	117	107
Mg (mg/kg)	159	234	47	42
K (mg/kg)	144	153	33	16
Na (mg/kg)	21	43	14	12
Fe (mg/kg)	44.73	137.99	8.02	7.98
Mn (mg/kg)	63.83	141.77	2.05	1.85
Zn (mg/kg)	0.33	0.44	0.17	0.33
Al (cmol _c /kg)	0	0.950	0.340	0.298
Resistance (Ohm)	7200	3000	30000	26000
C%	0.12	0.09	0.29	0.29
Total N%	0.024	0.023	0.020	0.022
S (mg/kg)	29.01	79.75	19.89	12.92
CEC (cmol _c /kg)	15.21	29.25	8.464	9.836

Distinct Tree Species	1. Combretum erythrophyllum	1. Combretum erythrophyllum	1. Combretum erythrophyllum 2. Acacia karroo	1. Combretum erythrophyllum 2. Acacia karroo
Average rooting depth of the indicated species (m)	12	12	12 - 50	12 - 50
Average depth of weathering (m)	0.8	0.8	0.8	0.8
Geomorphology	Plain with scattered tors	Plain with scattered tors	Plain	Plain
Geophysical instrumentation used	Electromagnetics, Magnetics & Schlumberger soundings	Electromagnetics, Magnetics & Schlumberger soundings	Electromagnetics, Magnetics & Schlumberger soundings	Electromagnetics, Magnetics & Schlumberger soundings
Water features present?	Yes, river 400m south	Yes, river 400m south	No	No
Aquifer Yield (l/h)	55 000	55 000	18 000	18 000
Borehole Depth (m)	60	60	60	60
Depth of Water Strike (m)	18	18	15	15
Static Water Level (m)	8	8	12	12
Average Aquifer Yield (l/h)	3 750	3 750	3 750	3 750
Average Borehole Depth (m)	37	37	37	37
Average Depth of Water Strike (m)	23	23	23	23
Average Static Water Level (m)	9	9	9	9
Land Type Series	Bb10a Mispah, Avalon, Glenrosa	Bb10a Mispah, Avalon, Glenrosa	Bb10a Mispah, Avalon, Glenrosa	Bb10a Mispah, Avalon, Glenrosa
Profile No	P67	P67	P67	P67
Depth Sampled	200-450mm	200-450mm	200-450mm	200-450mm
Gravel %	2	2	2	2
Sand %	62	62	62	62

Silt %	8	8	8	8
Clay %	28	28	28	28
PH (H ₂ O)	4.9	4.9	4.9	4.9
P (mg/kg)	1.1	1.1	1.1	1.1
Ca (mg/kg)	400	400	400	400
Mg (mg/kg)	50	50	50	50
K (mg/kg)	290	290	290	290
Na (mg/kg)	10	10	10	10
Fe (mg/kg)	-	-	-	-
Mn (mg/kg)	10.3	10.3	10.3	10.3
Zn (mg/kg)	0.65	0.65	0.65	0.65
Resistance (Ohm)	5900	5900	5900	5900
C%	0.3	0.3	0.3	0.3
CEC (cmol _c /kg)	15.0	15.0	15.0	15.0
Veld Type	18 Mixed Bushveld	18 Mixed Bushveld	18 Mixed Bushveld	18 Mixed Bushveld
Hydrogeological Unit	D3	D3	D3	D3

Information obtained from the veld type maps from Acocks (1988) and hydrogeological information from DWAF: Johannesburg (1999). Soil colour was identified and classified in the veld according to the Corstor Colour Gauge that lists 168 different soil colours. Geohydrological parameters were derived from Frommurze (1937). Information obtained from the land type maps and accompanying memoir is from Land Type Survey Staff (1987). Average weathering depth is extracted from the indicated Land Type Survey Staff and average rooting depth of the geobotanical indicators is referenced from Canadell *et al.* (1996).

25. Droogekloof 471KR

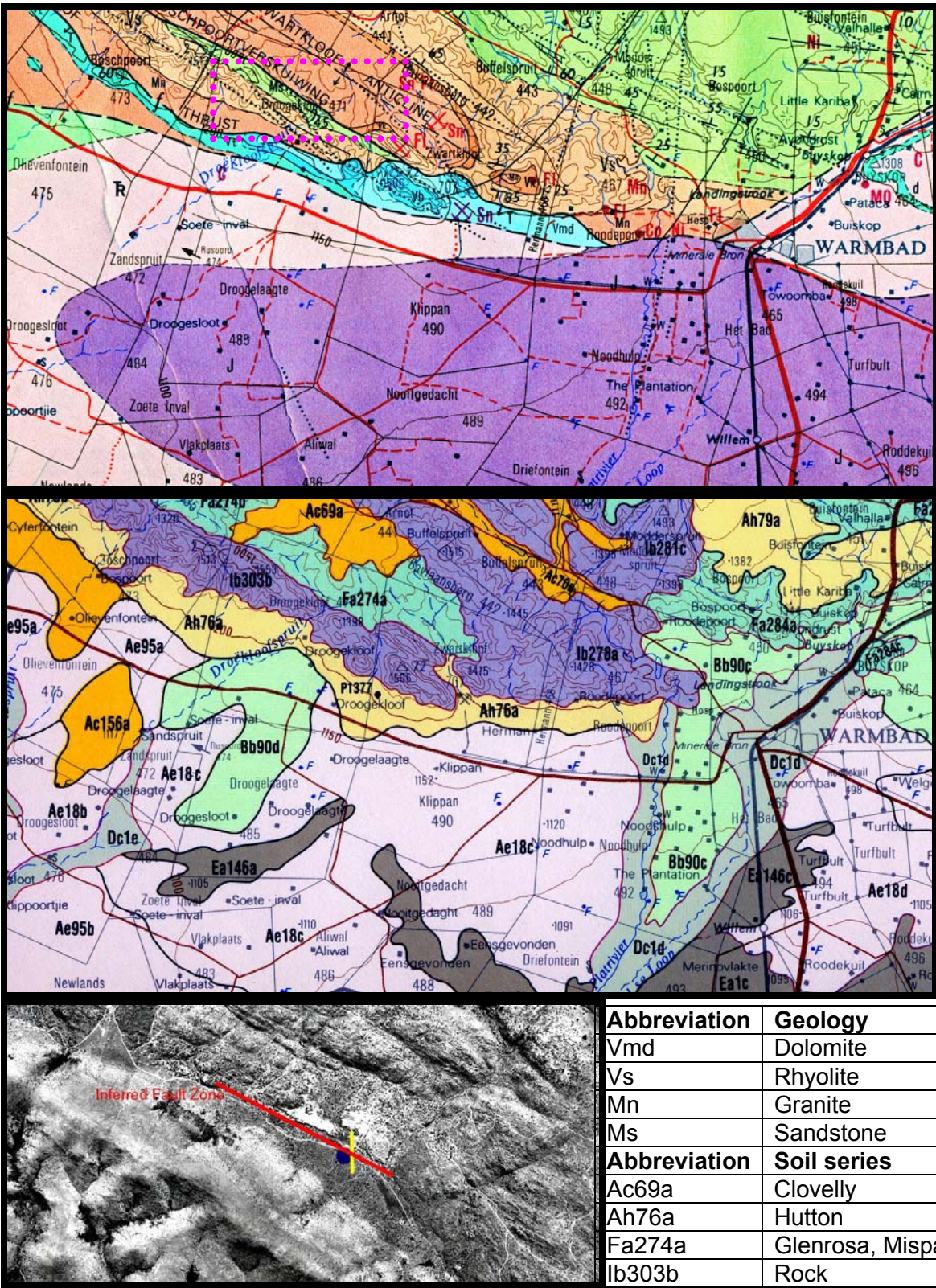


Figure A1.25. The geology (top), land type (middle) and aerial photograph (bottom) of Droogekloof 471KR. The blue circle denotes the position of the borehole and the yellow line indicates the electromagnetic profile. The area covered by the aerial photograph is indicated by the purple shape in the geological map.

The farm Droogekloof was previously visited (Chapter 4, case study 6), although this portion of the farm is north of the mountain range that divides the Springbok Flats from the Waterberg interior. Droogekloof is approximately 10 km to the west of Warmbaths.

26. Kareefontein 432KR

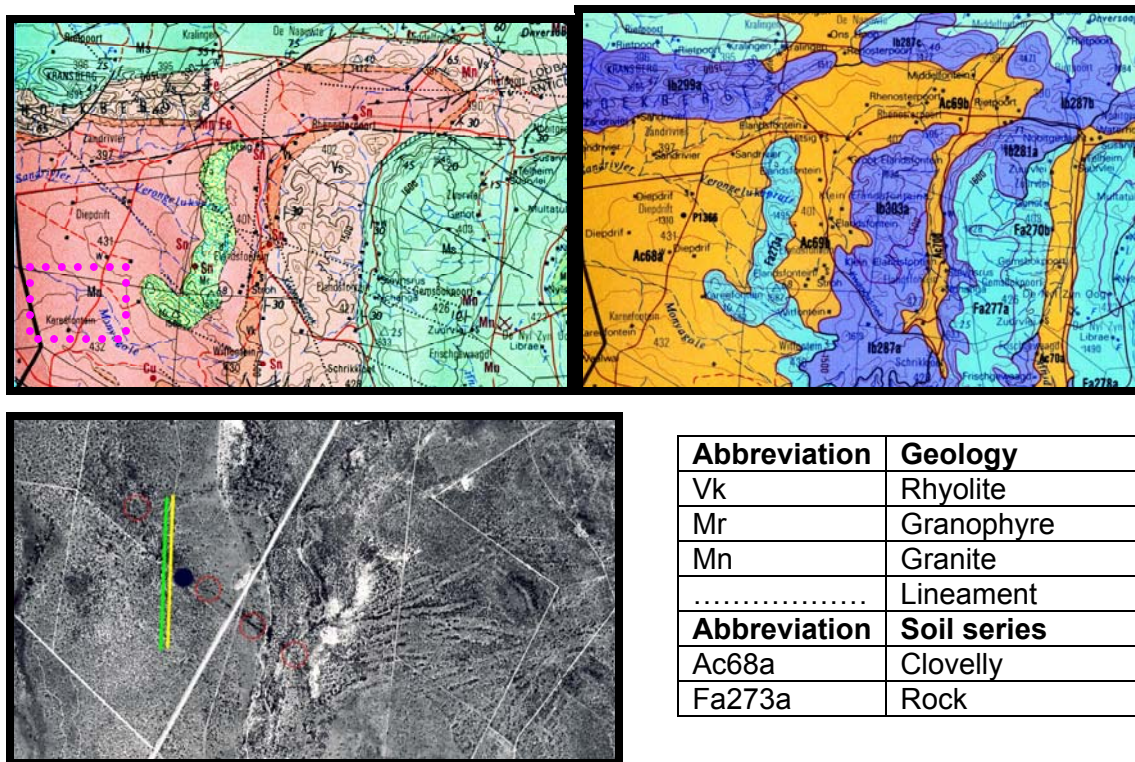


Figure A1.26. The geology (top left), land type (top right) and aerial photograph (bottom) of Kareefontein 432KR. The blue circle denotes the position of the borehole, the green line the orientation of the magnetic profile and the yellow line indicates the electromagnetic profile. The area covered by the aerial photograph is indicated by the purple shape in the geological map. The lineament is indicated by the red circles in the aerial photograph.

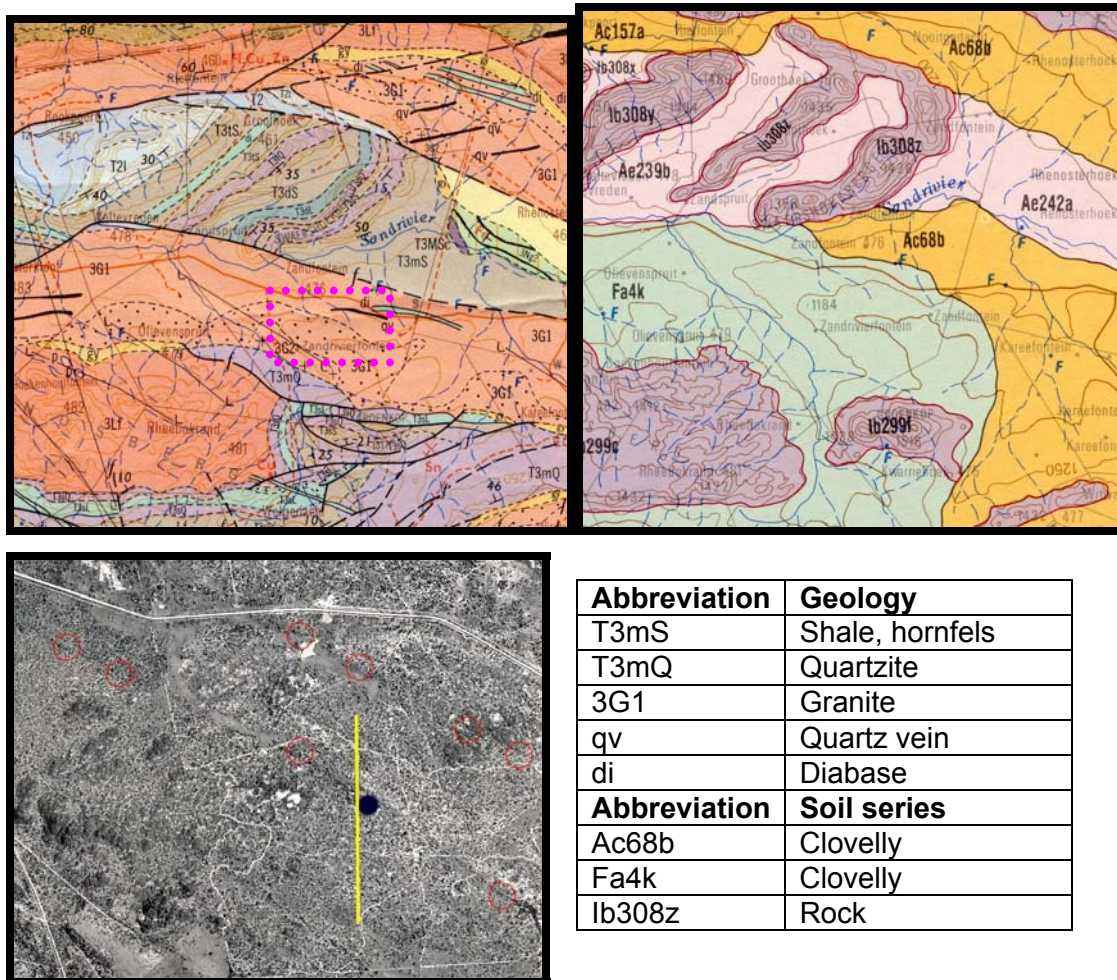
27. Zandfontein 476KQ

Figure A1.27. The geology (top left), land type (top right) and aerial photograph (bottom) of Zandfontein 476KQ. The blue circle denotes the position of the borehole and the yellow line indicates the electromagnetic profile direction. The area covered by the aerial photograph is indicated by the purple shape in the geological map. The lineaments are indicated by the red circles in the aerial photograph, although the upper circles can represent the quartz vein as indicated on the geological map.

28. Klipfontein 256JS

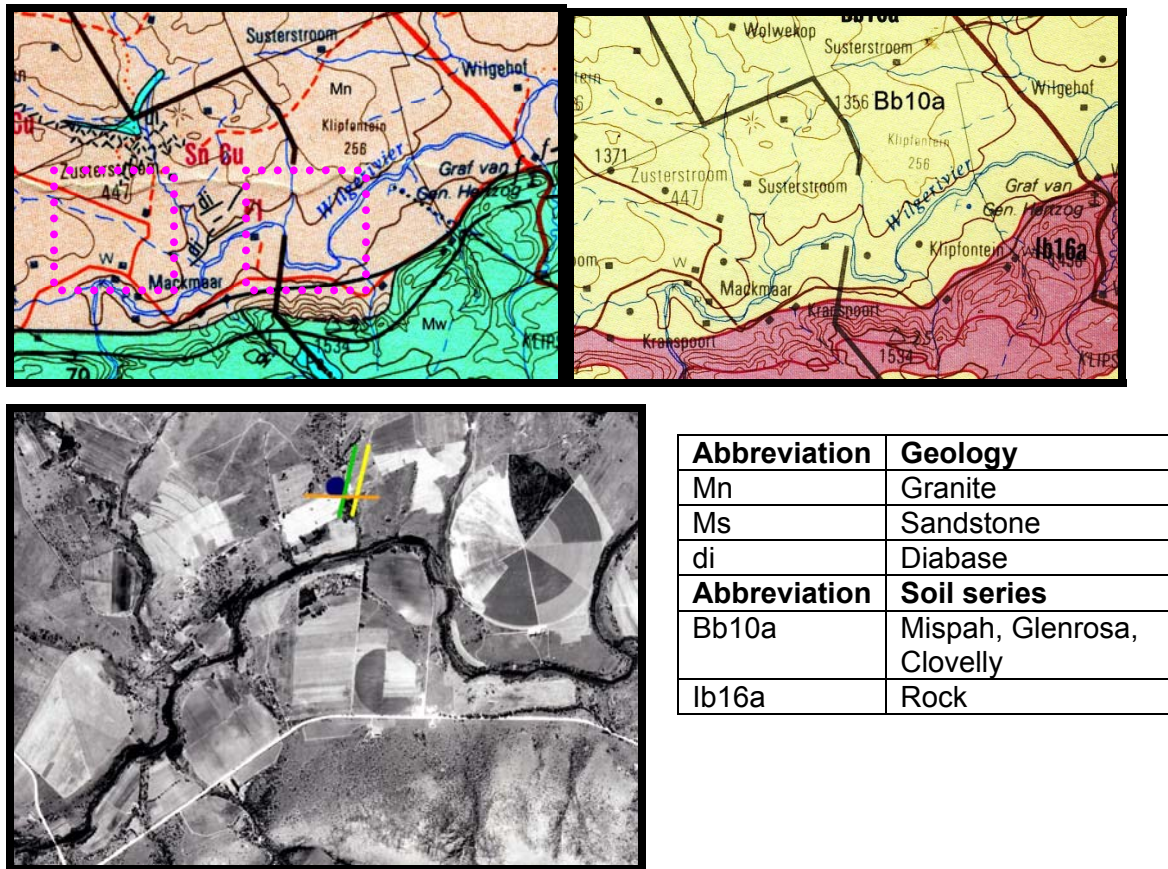


Figure A1.28. The geology (top left), land type (top right) and aerial photograph (bottom) of Klipfontein 256JS. The blue circle denotes the position of the borehole, the green line the orientation of the magnetic profile, the yellow line indicates the electromagnetic profile and the orange line the direction of the Schlumberger sounding. The area covered by the aerial photograph is indicated by the right purple shape in the geological map.

29. Zusterstroom 447JR



Figure A1.29. The geology (top left, Figure A1.28), land type (top right, Figure A1.28) and aerial photograph of Zusterstroom 447JR. The blue circle denotes the position of the borehole, the green line the orientation of the magnetic profile, the yellow line indicates the electromagnetic profile and the orange line the direction of the Schlumberger sounding. The area covered by the aerial photograph is indicated by the left purple shape in the geological map (Figure A1.28).

Zusterstroom 447JR is in close proximity of the case study Klipfontein 256JS, some 5 km to the west. The Wilge River is a bit further away from this farm and subsequently no irrigation practices from the river are taken place.

**A1.10 MOGOLIAN EONOTHEM: THE WATERBERG GROUP IN THE WATERBERG AND
MIDDELBURG AREAS**

Sedimentary rocks forming part of the Waterberg Group are exposed in the vast Waterberg wilderness, around the village of Vaalwater towards the Soutpansberg in the north. A localised outcrop is prominent east of Pretoria extending till Middelburg, some 150 km east of Pretoria. The Waterberg Group is composed primarily of arenaceous rocks, implying sandstone. Sandstone does not weather easily and a resulting positive topography is experienced, not always suitable to land farming practices, depending of the soil depth. In most cases the soil is sandy in the absence of any intrusions and poor in nutrients. Extensive cattle farming, game ranching, nature reserves and wilderness areas are quite common activities encountered in the Waterberg Group. The Waterberg Group is one of the final stages of geological development in the northern parts of South Africa, as some time elapsed to the next and last major geological event that encapsulated southern Africa, namely the developing of the Karoo Supergroup (see Chapter 4).

A1.10.1 CASE STUDY AREA

A large number of case studies are presented from the Wilgerivier Formation, around the towns of Bronkhorstspuit, Witbank and Middelburg. The Waterberg Group around Alma and Baltimore in the Limpopo Province is also investigated and listed. Due to the small amount of case studies available in the latter region, they are included with the former case studies of the Wilgerivier Formation, part of the Waterberg Group.

A1.10.2 CLIMATE AND VELD TYPES

The climatic conditions vary considerably in the case study areas, becoming moist and colder towards the southeast. The altitude in the Baltimore area ranges from 800 m to 1200 meter. The Waterberg plateau and Wilgerivier Formation is on average elevated 1200 m to 1600 m above sea level, one of the reasons for the higher rainfall and isolated climatic conditions than the surrounding lower lying areas around the Waterberg plateau (see Table A1.20). Few areas are in excess of 1600 meter above sealevel. Rainfall is characteristic continental as the winters are dry and cool to cold in the southeast and hot

and wet summers. The wet season lasts approximately from October to April with rainfall occurring mostly as heavy thunderstorms.

The veld types that occur (see also Table A1.21a) are Mixed Bushveld in the lower regions of the Waterberg area and Sour Bushveld in the ridges and elevated areas in the Waterberg area. Sourish Mixed Bushveld occurs in the northern localities of the Wilgerivier Formation basin and Bankenveld towards the south of the basin (Acocks, 1988). The following tree species are eminent of these veld types (after Bonsma, 1976, Acocks, 1988 and Van Wyk & Van Wyk, 1997), all veld types are part of the savanna biome, except the Bankenveld veld type which represents a transgression between the grassland and savanna biomes:

- Mixed Bushveld: *Acacia caffra* (common hook-thorn), *Burkea africana* (wild seringa), *Combretum apiculatum* (red bushwillow), *C. imberbe* (leadwood), *Grewia flava* (velvet raisin) and *Mundulea sericea* (cork bush).
- Arid Sweet Bushveld: *Adansonia digitata* (baobab), *Grewia flava* (velvet raisin) and *Acacia mellifera* (black thorn).
- Sourish Mixed Bushveld: *Acacia caffra* (common hook-thorn), *A. karroo* (sweet thorn), *A. robusta subsp. robustu* (brack thorn) & *A. tortillis subsp. heteracantha* (umbrella thorn), *Pappea capensis* (jacket-plum), *Peltophorum africanum* (weeping wattle), *Rhus gueinzii* (thorny karree) and *Ziziphus mucronata* (buffalo-thorn).
- Sour Bushveld: *Acacia caffra* (common hook-thorn), *Combretum molle* (velvet bushwillow) & *C. apiculatum* (red bushwillow) & *C. zeyheri* (large-fruited bushwillow), *Euclea crispa* (blue guarri), *Faurea saligna* (Transvaal beech), *Burkea africana* (wild seringa), *Ochna pulchra* (peeling plane), *Olea europaea subsp. africana* (wild olive), *Ficus ingens* (red-leaved fig) and *Strychnos pungens* (spine-leaved monkey orange).
- Bankenveld: *Acacia caffra* (common hook-thorn), *Celtis africana* (white stinkwood) and *Protea caffra* (common sugarbush).

Geobotanical investigations on the included case studies will indicate other occurring tree species as well and the marker tree species (geobotanic indicators) that can be utilised for groundwater exploration.

Table A1.20. Climatic Data of the Waterberg and Bronkhorstspuit-Middelburg Areas
(Bonsma, 1976, Schulze, 1997, Johannesburg, 1999 & Polokwane, 2003).

	Quantity: Waterberg Area	Quantity: Bronkhorstspuit- Middelburg Area
Average Yearly Temperature (°C)	16-20	14-18
Mean Minimum Temperature (°C) in July	2-6	2-4
Mean Maximum Temperature (°C) in January	27.5-32.5	25.0-27.5
Average Yearly Rainfall (mm)	400-800	600-800
Elevation (m)	800-1600	1200-1600
Evaporation (mm/year)	2250-2500	1750-2250
Frost area?	None to <150 days a year	150-175 days a year

A1.10.3 GEOLOGY AND HYDROGEOLOGICAL CLASSIFICATION

(a) Waterberg Area

The Waterberg basin around Alma and Vaalwater occupies the north-western portion of the Bushveld region and consists of two overlapping basins. In the deep basin in the south (Alma trough) beds of the Swaershoek, Alma and Sterkrivier Formation were laid down. The Schilpadkop and locally the Makgabeng Formation form the base of the succession in the younger, larger, but shallower basin. The entire succession is predominantly arenaceous, but the Aasvoëlkop and Vaalwater Formations are in part argillaceous and the Alma and Vaalwater Formations are also partly arkosic. The oldest subdivision, the lower portion of the Swaershoek Formation, is of late-Bushveld age and confined to protobasins of which the largest coincides approximately with the Nylstroom syncline. The Alma, Schilpadkop and Aasvoëlkop Formations are poorly exposed, as a rule only the conglomeratic beds are seen. The Alma Formation becomes less feldspatic to the east and the partly argillaceous Aasvoëlkop Formation grades into the arenaceous Makgabeng Formation (Nylstroom, 1978).

Prominent structural structures are displayed in the Alma trough, namely the Swaershoekberge anticlinorium and the Nylstroom syncline, with accompanying anticlinal structures (Loubad and Zwartkloof anticlines). Their origin and original non-

linear pattern are attributed to late-magmatic Bushveld activity during their embryonic stage. Subsequent folding, flexing and faulting during Waterberg and post-Waterberg times transformed the embryonic structures into their present shape and locally their limbs were tilted to the vertical or over-turned. Block-faulting took place in early Waterberg times and gentle folding after deposition of the Alma Formation. To the north the succession in the late-Waterberg basin was hardly affected, with the exception of the area north of the Swaershoek Mountains, where beds of the Schilpadkop Formation are tilted to the vertical and of the Sandriviersberg Formation by 30°. Post-Waterberg tensional faults and fractures are frequently intruded by diabase dykes (Nylstroom, 1978).

In the Baltimore area, close to the Limpopo River and Botswana border, the rocks of the Waterberg Group, a mainly sedimentary succession, underlie the area where they form a conspicuous plateau intersected by narrow steep valleys. The rocks were deposited in the northern portion of the so-called late-Waterberg basin (Jansen, 1975) a large shallow intracratonic depression whose northern boundary was structurally controlled. The Mogalakwena Formation rests with a mainly conformable contact on the Makgabeng Sandstone Formation. It reaches a thickness of about 1 500 m and consists of purplish brown, coarse-grained sandstone with interbedded conglomerate and boulder conglomerate. The conglomerates occur mainly at three stratigraphic levels and form units up to 100 m thick. The well-rounded clasts may attain a diameter of 80 cm, but in general they measure between 3 and 10 cm. They consist largely of those rocks present in the Limpopo Mobile Belt (Brandl, 1986). According to Tickell (1975) the coarse arenaceous succession resembles deposition in braided streams. Palaeocurrent directions inferred from cross-bed attitudes in the sandstone indicate that most of the sediments were carried from a source lying north-east and east of the Waterberg basin.

Along the Melinda Fault the Waterberg rocks were downthrown to the south in pre-Karoo times. Vertical displacement was about 1 000 m. In post-Karoo times the fault was reactivated with a downthrow to the north. The throw was at least several hundred meters (Brandl, 1986).

(b) Bronkhorstspuit-Middelburg Area

The Waterberg Group is represented in this area by the Wilgerivier Formation. The Formation consists of a thick continuous sequence, about 2 000 m thick, of red to red-brown arenaceous sediments including quartzite, grit and sandstone (SACS, 1980 & Visser, 1989). Crossbedding occurs frequently. The Formation is separated from the underlying rocks by a prominent unconformity and it also rests with a sedimentary contact on the Nebo Granite. Its age is consequently less than $1\,920 \pm 30$ Ma (Pretoria, 1978). This sedimentary basin is probably a protobasin of early Waterberg age and displays dips of about five degrees to the centre of the basin. The entire basin was subsequently transformed into a broad asymmetrical syncline, but around and east of Rhenosterkop (Chapter 4) the strata in the northern limb were faulted, thrust and tilted, probably also along reactivated boundary faults of the basin (Pretoria, 1978). Numerous diabase sills and dykes intrude the Formation. Inspection of borehole logs indicates that the sills can vary in thickness from less than a metre to more than 150 meters. The sills are usually weathered on the contact with the country rock. Geophysical measurements found dykes as thin as 10 m and as wide as 150 m in the study area. Although weathering of the dyke/country contact rock is the norm, exceptions do occur (Meulenbeld & Hattingh, 1999).

(c) Hydrogeological classification

Groundwater in sedimentary rocks is generally encountered in cracks, fissures, bedding planes, pore space and contact zones with intrusions (Hattingh, 1996). Sedimentary rocks of the Wilgerivier Formation are generally weak aquifers. These rocks are classified as predominantly arenaceous rocks (sandstone, feldspathic sandstone, arkose, shale and grit) and act as fractured aquifers (Johannesburg, 1999). Palaeo-weathering, deeply weathered overburden, fissures and cracks in intrusive rocks are the main aquifers found in the Wilgerivier Formation in the study area (Meulenbeld & Hattingh, 1999). Fissures, cracks, intergranular and fractured pores and rock are associated with Karoo overburden that overlies sedimentary rocks of the Wilgerivier Formation at some localities, normally the Dwyka Formation (Johannesburg, 1999). Subsequently the average yield of the arenaceous rocks is 360-1800 l/h that can be increased if associated with weathered diabase contact zones to average yields between 1800-7200 l/h (Meulenbeld, 1998) and with a Karoo overburden to an average yield of 360-7200 l/h (Johannesburg, 1999). The average yield of the arenaceous rocks

in the Waterberg area (Vaalwater-Baltimore) is around 1800-7200 l/h (Polokwane, 2003).

A1.10.4 GEOPHYSICAL AND GEOBOTANICAL INFORMATION

Meulenbeld (1998) has studied the Wilgerivier Formation in the past in some depth and Meulenbeld & Hattingh (1999) published a paper dealing solemnly with groundwater exploration in the Wilgerivier Formation. These studies deal with applicable geophysical methods to be utilised in this formation together with some notes on geobotany and geohydrology. Some of the case studies published by Meulenbeld (1998) are included in this study with information relating to this specific research. As this section contains numerous Schlumberger depth sounding models, Meulenbeld (1998) reckons that a H-type curve is a reasonable indicator for confined aquifers. Sounding curves that are preferable to locate aquifers are KH, HA and QH, or a combination of them. Van Zijl (1987) discusses definitions and examples of sounding type curves. In the study of Meulenbeld (1998) it was noted that species like *Acacia* prefer clay soils derived from weathered diabase intrusions and hence a distinction can be made in the field based on geobotany relating to soil differences; sand soil derived from weathered sandstone and clay soil covered with *Acacia* trees derived from weathered diabase. Weathered diabase intrusions are encountered frequently in the Wilgerivier Formation and are preferable aquifers. The Waterberg Group hosts also diabase intrusions, but on a more restricted scale than found in the Wilgerivier Formation.

The following observation by Bonsma (1976) need consideration. Thorn tree roots have nodule growth on their roots, like cycads, that are responsible for nitrogen assimilation and fixation. Nitrogen, together with other macro-nutrients like carbon, sulphur, phosphorus and potassium, are important to feed *in situ* microorganisms that are associated with the nodules (for instance a blue-green alga *Anabaena* in the case of cycads) and to supply the kind of vegetation with carbohydrates, lipids, proteins and nucleic acids (Giddy, 1974 & Cloete, 2002). Occurrence of thorn trees, like in this instance, is indicative of a higher soil pH and a resultant higher availability of available calcium and phosphorus to the nodules of root systems (although the pH-P relationship is not always clear as reflected in the study's soil sample geochemical analysis, but rather a distinct relationship between CEC-Ca,Mg-values). Hence, nitrogen fixation can

occur. A resultant of this is that grasses that grow in association with thorn trees obtain also a share of the available nitrogen (like fertiliser) and grow taller and appear darker/bluer in appearance than the surrounding grasses. Such grass is called sweet grass. In cases where the pH drops (sandy soil not in association with an intrusion), the calcium and phosphorus content decrease with an increase in the iron content. Nitrogen fixation is low and consequently nitrogen availability to plants and grass also. In this instance such type of grass is called sour grass (Bonsma, 1976).

In addition to the above on geobotanical information, Walker & Bothma (2005) describe the Waterberg area as follows. Most areas of the Waterberg Mountain range are underlain by sandstone, shale and quartzite. Soils derived from these sources are usually nutrient-poor, sandy or sandy-loam soils, with a poor water-holding capacity and rapid water infiltration. They vary from shallow to deep. The vegetation on such soils is usually dominated by broad-leaved trees which are generally taller than the more fine-leaved trees such as the ana tree *Faidherbia albida* and various *Acacia* species which by preference grow on the more clay soils produced from granitic (magmatic) parent rock material. These clay soils have a higher nutrient status, and water percolates slowly through it. The grazing there remains palatable and nutritious in the winter.

A1.10.5 SOIL SAMPLING AND RESULTS PRESENTATION

The soil analysis of the case studies are presented in Tables A1.21(a&b) i-iv. Soil samples were taken at depths of 0.5 and 1.2 m respectively at the site of the borehole and geobotanical indicator and the remaining sample some distance removed from it, not near such a geobotanical indicator. Two farms in the Waterberg (Vaalwater-Baltimore) area were visited and ten farms in the Bronkhorstspruit-Middelburg area, representing the Wilgerivier Formation of the Waterberg Group.

Table A1.21a (i). Mogolian Eonothem: Waterberg Group – Vaalwater-Baltimore Area: along intrusive contact.

Parameter	Hartbeesfontein 394KR		Pennsylvania 336LR	
	Lineament in the Schilpadkop Formation	Lineament in the Schilpadkop Formation	Lineament in the Mogalakwena Formation	Lineament in the Mogalakwena Formation
Depth Sampled	0.5m	1.2m	0.5m	1.2m
Borehole Co-ordinates:				
S.L.	24°34.687'	24°34.687'	23°15.459'	23°15.459'
E.L.	28°06.612'	28°06.612'	28°30.117'	28°30.117'
Soil colour	Dark reddish brown	Moderate reddish brown	Dark reddish brown	Dark red
Soil texture description	Clayey silt	Silty clay	Loam	Loamy sand
pH	5.50	5.06	5.70	6.24
P (mg/kg)	3.07	2.69	2.56	2.19
Ca (mg/kg)	168	111	259	282
Mg (mg/kg)	69	40	104	83
K (mg/kg)	46	31	47	31
Na (mg/kg)	4	9	8	32
Fe (mg/kg)	31.44	30.20	21.32	11.00
Mn (mg/kg)	193.71	25.68	197.53	86.34
Zn (mg/kg)	0.28	0.41	0.38	0.39
Al (cmol _c /kg)	0.408	0.559	0	0
Resistance (Ohm)	7000	9900	14000	16000
C%	0.15	0.31	0.21	0.06
Total N%	0.020	0.029	0.018	0.008
S (mg/kg)	23.28	12.25	22.58	7.21
CEC (cmol _c /kg)	4.433	3.399	3.754	2.620

Distinct Tree Species	1. Acacia karroo 2. Rhus lancea 3. Strychnos pungens 4. Ximenia caffra	1. Acacia karroo 2. Rhus lancea 3. Strychnos pungens 4. Ximenia caffra	1. Combretum imberbe	1. Combretum imberbe
Average rooting depth of the indicated species (m)	4 - 50	4 - 50	20	20
Average depth of weathering (m)	2.7	2.7	2.2	2.2
Geomorphology	Gentle northern slope towards stream	Gentle northern slope towards stream	Plain	Plain
Geophysical instrumentation used	Electromagnetics & Magnetics	Electromagnetics & Magnetics	Magnetics	Magnetics
Water features present?	Yes, stream 700m north	Yes, stream 700m north	No	No
Aquifer Yield (l/h)	15 000	15 000	8 000	8 000
Borehole Depth (m)	64	64	70	70
Depth of Water Strike (m)	37	37	41	41
Static Water Level (m)	18	18	25	25
Average Aquifer Yield (l/h)	2 600	2 600	4 000	4 000
Average Borehole Depth (m)	56	56	43	43
Average Depth of Water Strike (m)	34	34	38	38
Average Static Water Level (m)	17	17	22	22
Land Type Series	Ac 153a Hutton	Ac 153a Hutton	Bc51a Hutton	Bc51 Hutton
Profile No	P1367	P1367	P1823	P1823
Depth Sampled	1000 – 1200 mm	1000 – 1200 mm	200 – 1000 mm	200 – 1000 mm
Gravel %	0	0	1.1	1.1
Sand %	92	92	57.6	57.6
Silt %	1	1	6.6	6.6

Clay %	7	7	34.7	34.7
pH (H ₂ O)	4.3	4.3	6.68	6.68
P (mg/kg)	1.8	1.8	2.40	2.40
Ca (mg/kg)	20	20	64	64
Mg (mg/kg)	9	9	38	38
K (mg/kg)	37	37	8	8
Na (mg/kg)	4	4	21	21
Fe (mg/kg)	-	-	-	-
Mn (mg/kg)	0.7	0.7	19.70	19.70
Zn (mg/kg)	0.14	0.14	0.10	0.10
Resistance (Ohm)	6200	6200	180	180
C%	0.1	0.1	0.13	0.13
CEC (cmol _c /kg)	12	12	8.00	8.00
Veld Type	18/20 Mixed/Sour Bushveld	18/20 Mixed/Sour Bushveld	14/18 Arid Sweet/Mixed Bushveld	14/18 Arid Sweet/Mixed Bushveld
Hydrogeological Unit	B3	B3	B3	B3

Information obtained from the veld type maps from Acocks (1988) and hydrogeological information from DWAF: Polokwane (2003).

Soil colour was identified and classified in the veld according to the Corstor Colour Gauge that lists 168 different soil colours.

Geohydrological parameters were derived from Frommurze (1937). Information obtained from the land type maps and accompanying memoir is from Land Type Survey Staff (1988, 2005). Average weathering depth is extracted from the indicated Land Type Survey Staff and average rooting depth of the geobotanical indicators is referenced from Canadell *et al.* (1996).

Table A1.21b (i). Mogolian Eonothem: Waterberg Group – Vaalwater-Baltimore Area: intrusive contact absent.

Parameter	Hartbeesfontein		Pennsylvania	
	394KR		336LR	
Geological Formation	Schilpadkop Formation sandstone	Schilpadkop Formation sandstone	Sandstone of the Mogalakwena Formation and alluvium	Sandstone of the Mogalakwena Formation and alluvium
Depth Sampled	0.5m	1.2m	0.5m	1.2m
Borehole Co-ordinates:				
S.L.	24°34.687'	24°34.687'	23°15.459'	23°15.459'
E.L.	28°06.612'	28°06.612'	28°30.117'	28°30.117'
Soil colour	Pale reddish brown	Dark reddish brown	Light brown	Weak red
Soil texture description	Sand	Silty sand	Sand	Sand
pH	5.76	6.02	4.85	4.93
P (mg/kg)	2.44	1.94	5.24	3.74
Ca (mg/kg)	175	190	82	87
Mg (mg/kg)	71	76	31	31
K (mg/kg)	44	40	10	10
Na (mg/kg)	48	18	18	5
Fe (mg/kg)	10.37	7.95	54.53	9.30
Mn (mg/kg)	59.19	49.93	0.77	0.85
Zn (mg/kg)	0.46	0.29	0.18	0.40
Al (cmol _c /kg)	0	0	0.936	0.520
Resistance (Ohm)	18000	24000	18000	22000
C%	0.09	0.06	0.55	0.14
Total N%	0.013	0.009	0.023	0.020
S (mg/kg)	9.20	8.46	10.19	16.67
CEC (cmol _c /kg)	2.759	2.283	2.799	1.673

Distinct Tree Species	1. Acacia karroo 2. Rhus lancea 3. Strychnos pungens 4. Ximenia caffra	Acacia karroo Rhus lancea Strychnos pungens Ximenia caffra	1. Combretum imberbe	1. Combretum imberbe
Average rooting depth of the indicated species (m)	4 - 50	4 - 50	20	20
Average depth of weathering (m)	2.7	2.7	2.2	2.2
Geomorphology	Gentle northern slope towards stream	Gentle northern slope towards stream	Plain	Plain
Geophysical instrumentation used	Electromagnetics & Magnetics	Electromagnetics & Magnetics	Magnetics	Magnetics
Water features present?	Yes, stream 700m north	Yes, stream 700m north	No	No
Aquifer Yield (l/h)	15 000	15 000	8 000	8 000
Borehole Depth (m)	64	64	70	70
Depth of Water Strike (m)	37	37	41	41
Static Water Level (m)	18	18	25	25
Average Aquifer Yield (l/h)	2 600	2 600	4 000	4 000
Average Borehole Depth (m)	56	56	43	43
Average Depth of Water Strike (m)	34	34	38	38
Average Static Water Level (m)	17	17	22	22
Land Type Series	Ac 153a Hutton	Ac 153a Hutton	Bc51a Hutton	Bc51a Hutton
Profile No	P1367	P1367	P1823	P1823
Depth Sampled	1000 – 1200 mm	1000 – 1200 mm	200 – 1000 mm	200 – 1000 mm
Gravel %	0	0	1.1	1.1
Sand %	92	92	57.6	57.6
Silt %	1	1	6.6	6.6

Clay %	7	7	34.7	34.7
pH (H ₂ O)	4.3	4.3	6.68	6.68
P (mg/kg)	1.8	1.8	2.40	2.40
Ca (mg/kg)	20	20	64	64
Mg (mg/kg)	9	9	38	38
K (mg/kg)	37	37	8	8
Na (mg/kg)	4	4	21	21
Fe (mg/kg)	-	-	-	-
Mn (mg/kg)	0.7	0.7	19.70	19.70
Zn (mg/kg)	0.14	0.14	0.10	0.10
Resistance (Ohm)	6200	6200	180	180
C%	0.1	0.1	0.13	0.13
CEC (cmol _c /kg)	12	12	8.00	8.00
Veld Type	18/20 Mixed/Sour Bushveld	18/20 Mixed/Sour Bushveld	14/18 Arid Sweet/Mixed Bushveld	14/18 Arid Sweet/Mixed Bushveld
Hydrogeological Unit	B3	B3	B3	B3

Information obtained from the veld type maps from Acocks (1988) and hydrogeological information from DWAF: Polokwane (2003).

Soil colour was identified and classified in the veld according to the Corstor Colour Gauge that lists 168 different soil colours.

Geohydrological parameters were derived from Frommurze (1937). Information obtained from the land type maps and accompanying memoir is from Land Type Survey Staff (1988, 2005). Average weathering depth is extracted from the indicated Land Type Survey Staff and average rooting depth of the geobotanical indicators is referenced from Canadell *et al.* (1996).

Table A1.21a (ii). Mogolian Eonothem: Waterberg Group – Bronkhorstspruit Area: along intrusive contact.

Parameter	Elandsfontein 493JR		Leeuwfontein 492JR		Onspoed 500JR	
Geological Formation	Deep weathering	Deep weathering	Weathered diabase contact	Weathered diabase contact	Weathered diabase dyke/lineament	Weathered diabase dyke/lineament
Depth Sampled	0.5m	1.2m	0.5m	1.2m	0.5m	1.2m
Borehole Co-ordinates:						
S.L.	25°42.707'	25°42.707'	25°43.903'	25°43.903'	25°46.311'	25°46.311'
E.L.	28°56.652'	28°56.652'	28°51.929'	28°51.929'	28°52.134'	28°52.134'
Soil colour	Dusky red	Moderate brown	Dusky red	Dark red	Dark brown	Greyish brown
Soil texture description	Clay	Silty clay	Silty clay	Silty clay	Clay	Clay
pH	6.10	6.24	5.88	6.29	6.50	6.58
P (mg/kg)	1.26	1.18	1.45	1.41	1.18	0.84
Ca (mg/kg)	1285	1200	952	1078	1940	1760
Mg (mg/kg)	381	509	448	560	727	755
K (mg/kg)	70	58	76	76	53	48
Na (mg/kg)	10	27	40	25	25	59
Fe (mg/kg)	61.18	66.11	41.59	69.36	68.97	131.49
Mn (mg/kg)	266.28	152.69	180.74	230.46	320.55	478.92
Zn (mg/kg)	0.58	0.37	0.33	0.34	0.32	0.32
Al (cmol _c /kg)	0	0	0.154	0.118	0	0
Resistance (Ohm)	2600	2200	2000	2800	900	2000
C%	1.57	1.46	1.14	1.00	1.20	1.98
Total N%	0.112	0.094	0.078	0.074	0.089	0.133

S (mg/kg)	10.85	14.92	31.25	10.79	12.44	15.89
CEC (cmol _c /kg)	12.04	13.18	14.83	15.53	19.01	13.00
Distinct Tree Species	Acacia karroo Combretum erythro- phyllum 3. Euclea crispa 4. Zanthoxylum capense	1. Acacia karroo 2. Combretum erythro- phyllum 3. Euclea crispa 4. Zanthoxylum capense	1. Acacia karroo	1. Acacia karroo	1. Acacia karroo 2. Burkea africana	1. Acacia karroo 2. Burkea africana
Average rooting depth of the indicated species (m)	4 - 50	4 - 50	50	50	2 - 50	2 - 50
Average depth of weathering (m)	2.1	2.1	2.1	2.1	0.6	0.6
Geomorphology	Typical Bankenveld: ridges and valleys	Typical Bankenveld: ridges and valleys	Gently undulating terrain	Gently undulating terrain	Valley surrounded by cliffs	Valley surrounded by cliffs
Geophysical instrumentation used	Schlumberger depth sounding	Schlumberger depth sounding	Magnetics & Schlumberger depth soundings	Magnetics & Schlumberger depth soundings	Magnetics, Electromagnetics and Schlumberger depth soundings	Magnetics, Electromagnetics and Schlumberger depth soundings

Water features present?	No	No	No	No	Yes, Wilge River 500m north	Yes, Wilge River 500m north
Aquifer Yield (l/h)	11 000	11 000	5 000	5 000	22 500	22 500
Borehole Depth (m)	45	45	60	60	180	180
Depth of Water Strike (m)	23	23	25	25	18	18
Static Water Level (m)	4	4	7	7	5	5
Average Aquifer Yield (l/h)	3 000	3 000	3 000	3 000	3 000	3 000
Average Borehole Depth (m)	55	55	55	55	55	55
Average Depth of Water Strike (m)	20	20	20	20	20	20
Average Static Water Level (m)	15	15	15	15	15	15
Land Type Series	Ba13c Hutton, Avalon, Glencoe	Ba13c Hutton, Avalon, Glencoe	Ba13c Hutton, Avalon, Glencoe	Ba13c Hutton, Avalon, Glencoe	Ib15a Rock, Mispah	Ib15a Rock, Mispah
Profile No	P65	P65	P65	P65	No Data	No Data
Depth Sampled	660-980mm	660-980mm	660-980mm	660-980mm	-	-
Gravel %	3	3	3	3	-	-
Sand %	26	26	26	26	-	-
Silt %	15	15	15	15	-	-
Clay %	56	56	56	56	-	-
pH (H ₂ O)	6.1	6.1	6.1	6.1	-	-

P (mg/kg)	0.0	0.0	0.0	0.0	-	-
Ca (mg/kg)	6950	6950	6950	6950	-	-
Mg (mg/kg)	4120	4120	4120	4120	-	-
K (mg/kg)	390	390	390	390	-	-
Na (mg/kg)	450	450	450	450	-	-
Fe (mg/kg)	-	-	-	-	-	-
Mn (mg/kg)	65.8	65.8	65.8	65.8	-	-
Zn (mg/kg)	0.35	0.35	0.35	0.35	-	-
Resistance (Ohm)	1200	1200	1200	1200	-	-
C%	0.9	0.9	0.9	0.9	-	-
CEC (cmol _c /kg)	109	109	109	109	-	-
Veld Type	61 Bankenveld	61 Bankenveld	61 Bankenveld	61 Bankenveld	61 Bankenveld	61 Bankenveld
Hydrogeological Unit	B2	B2	B2	B2	B2	B2

Information obtained from the veld type maps from Acocks (1988) and hydrogeological information from DWAF: Johannesburg (1999). Information obtained from the land type maps and accompanying memoir is from Land Type Survey Staff (1987). Soil colour was identified and classified in the veld according to the Corstor Colour Gauge that lists 168 different soil colours. Geohydrological parameters were derived from Frommurze (1937) and Meulenbeld (1998). Average weathering depth is extracted from the indicated Land Type Survey Staff and average rooting depth of the geobotanical indicators is referenced from Canadell *et al.* (1996).

Table A1.21b (ii). Mogolian Eonothem: Waterberg Group – Bronkhorstspuit Area: intrusive contact absent.

Parameter	Elandsfontein 493JR		Leeuwfontein 492JR		Onspoed 500JR	
Geological Formation	Partially weathered sandstone	Partially weathered sandstone	Unweathered sandstone	Unweathered sandstone	Unweathered sandstone	Unweathered sandstone
Depth Sampled	0.5m	1.2m	0.5m	1.2m	0.5m	1.2m
Borehole Co-ordinates:						
S.L.	25°42.707'	25°42.707'	25°43.903'	25°43.903'	25°46.311'	25°46.311'
E.L.	28°56.652'	28°56.652'	28°51.929'	28°51.929'	28°52.134'	28°52.134'
Soil colour	Dusky red	Dark reddish brown	Strong brown	Moderate brown	Moderate brown	Strong brown
Soil texture description	Sand	Silty sand	Sand	Sandy silt	Sandy silt	Silty sand
pH	5.80	4.68	5.72	5.79	4.94	4.62
P (mg/kg)	1.75	0.96	3.68	1.90	2.13	0.92
Ca (mg/kg)	154	128	222	189	177	210
Mg (mg/kg)	54	49	80	68	72	95
K (mg/kg)	17	29	56	45	42	71
Na (mg/kg)	17	32	6	8	11	52
Fe (mg/kg)	8.07	45.90	30.89	21.25	21.19	25.25
Mn (mg/kg)	4.63	1.79	23.99	18.48	113.43	80.66
Zn (mg/kg)	0.47	0.34	0.78	0.47	0.40	0.50
Al (cmol _c /kg)	0.548	0.783	0.271	0.114	0.957	0.316
Resistance (Ohm)	20000	4200	4600	5400	3600	920

C%	0.12	0.46	0.87	0.53	0.65	0.23
Total N%	0.016	0.043	0.063	0.034	0.055	0.027
S (mg/kg)	5.78	37.96	14.51	16.15	71.71	150.19
CEC (cmol _c /kg)	3.38	3.60	3.06	2.62	4.20	7.53
Distinct Tree Species	1. Acacia karroo 2. Combretum erythro-phyllum 3. Euclea crispa 4. Zanthoxylum capense	1. Acacia karroo 2. Combretum erythro-phyllum 3. Euclea crispa 4. Zanthoxylum capense	1. Acacia karroo	1. Acacia karroo	1. Acacia karroo 2. Burkea africana	1. Acacia karroo 2. Burkea africana
Average rooting depth of the indicated species (m)	4 - 50	4 - 50	50	50	2 - 50	2 - 50
Average depth of weathering (m)	2.1	2.1	2.1	2.1	0.6	0.6
Geomorphology	Typical Bankenveld: ridges and valleys	Typical Bankenveld: ridges and valleys	Gently undulating terrain	Gently undulating terrain	Valley surrounded by cliffs	Valley surrounded by cliffs

Geophysical instrumentation used	Schlumberger depth sounding	Schlumberger depth sounding	Magnetics & Schlumberger depth soundings	Magnetics & Schlumberger depth soundings	Magnetics, Electromagnetics and Schlumberger depth soundings	Magnetics, Electromagnetics and Schlumberger depth soundings
Water features present?	No	No	No	No	Yes, Wilge River 500m north	Yes, Wilge River 500m north
Aquifer Yield (l/h)	11 000	11 000	5 000	5 000	22 500	22 500
Borehole Depth (m)	45	45	60	60	180	180
Depth of Water Strike (m)	23	23	25	25	18	18
Static Water Level (m)	4	4	7	7	5	5
Average Aquifer Yield (l/h)	3 000	3 000	3 000	3 000	3 000	3 000
Average Borehole Depth (m)	55	55	55	55	55	55
Average Depth of Water Strike (m)	20	20	20	20	20	20
Average Static Water Level (m)	15	15	15	15	15	15
Land Type Series	Ba13c Hutton, Avalon, Glencoe	Ba13c Hutton, Avalon, Glencoe	Ba13c Hutton, Avalon, Glencoe	Ba13c Hutton, Avalon, Glencoe	Ib15a Rock, Mispah	Ib15a Rock, Mispah
Profile No	P65	P65	P65	P65	No Data	No Data
Depth Sampled	660-980mm	660-980mm	660-980mm	660-980mm	-	-
Gravel %	3	3	3	3	-	-

Sand %	26	26	26	26	-	-
Silt %	15	15	15	15	-	-
Clay %	56	56	56	56	-	-
pH (H ₂ O)	6.1	6.1	6.1	6.1	-	-
P (mg/kg)	0.0	0.0	0.0	0.0	-	-
Ca (mg/kg)	6950	6950	6950	6950	-	-
Mg (mg/kg)	4120	4120	4120	4120	-	-
K (mg/kg)	390	390	390	390	-	-
Na (mg/kg)	450	450	450	450	-	-
Fe (mg/kg)	-	-	-	-	-	-
Mn (mg/kg)	65.8	65.8	65.8	65.8	-	-
Zn (mg/kg)	0.35	0.35	0.35	0.35	-	-
Resistance (Ohm)	1200	1200	1200	1200	-	-
C%	0.9	0.9	0.9	0.9	-	-
CEC (cmol _c /kg)	109	109	109	109	-	-
Veld Type	61 Bankenveld	61 Bankenveld	61 Bankenveld	61 Bankenveld	61 Bankenveld	61 Bankenveld
Hydrogeological Unit	B2	B2	B2	B2	B2	B2

Information obtained from the veld type maps from Acocks (1988) and hydrogeological information from DWAF: Johannesburg (1999). Information obtained from the land type maps and accompanying memoir is from Land Type Survey Staff (1987). Soil colour was identified and classified in the veld according to the Corstor Colour Gauge that lists 168 different soil colours. Geohydrological parameters were derived from Frommurze (1937) and Meulenbeld (1998). Average weathering depth is extracted from the indicated Land Type Survey Staff and average rooting depth of the geobotanical indicators is referenced from Canadell *et al.* (1996).

Table A1.21a (iii). Mogolian Eonothem: Waterberg Group – Bronkhorstspuit Area: along intrusive contact.

Parameter	Onverwacht 532JR		Trigaardspoort 451JR		Vlakfontein 453JR	
Geological Formation	Weathered diabase contact	Weathered diabase contact	Weathered diabase contact	Weathered diabase contact	Weathered diabase dyke/lineament	Weathered diabase dyke/lineament
Depth Sampled	0.5m	1.2m	0.5m	1.2m	0.5m	1.2m
Borehole Co-ordinates:						
S.L.	25°50.779'	25°50.779'	25°39.854'	25°39.854'	25°41.223'	25°41.223'
E.L.	28°53.187'	28°53.187'	28°55.455'	28°55.455'	28°52.426'	28°52.426'
Soil colour	Dark reddish brown	Moderate brown	Strong brown	Dark reddish brown	Dusky red	Moderate brown
Soil texture description	Clay	Silty clay	Clay	Clay	Loam	Loam
pH	5.65	5.76	6.63	6.18	6.04	6.47
P (mg/kg)	1.11	1.07	1.45	1.14	29.32	0.89
Ca (mg/kg)	910	890	1140	1105	535	684
Mg (mg/kg)	367	406	339	313	152	216
K (mg/kg)	59	90	52	61	218	137
Na (mg/kg)	12	31	29	13	25	12
Fe (mg/kg)	48.39	51.08	88.13	99.53	79.45	88.10
Mn (mg/kg)	90.47	61.72	205.13	186.29	161.58	49.24
Zn (mg/kg)	0.42	0.35	0.29	0.36	3.63	0.44
Al (cmol _c /kg)	0.145	0.164	0	0	0	0
Resistance (Ohm)	2000	2600	2400	2600	2800	2600
C%	1.28	1.46	1.95	1.25	1.00	0.84

Total N%	0.088	0.096	0.125	0.088	0.068	0.080
S (mg/kg)	71.53	34.80	13.36	24.44	8.70	6.08
CEC (cmol _c /kg)	9.98	10.62	13.21	20.83	6.635	7.240
Distinct Tree Species	1. Acacia karroo 2. Euclea crispa 3. Strychnos pungens	1. Acacia karroo 2. Euclea crispa 3. Strychnos pungens	1. Euclea crispa	1. Euclea crispa	1. Combretum erythrophyllum	1. Combretum erythrophyllum
Average rooting depth of the indicated species (m)	4 - 50	4 - 50	4	4	12	12
Average depth of weathering (m)	1.4	1.4	1.9	1.9	2.1	2.1
Geomorphology	Terraces among sandstone ridges	Terraces among sandstone ridges	Gently undulating terrain	Gently undulating terrain	Gently undulating terrain	Gently undulating terrain
Geophysical instrumentation used	Magnetics & Schlumberger depth sounding	Magnetics & Schlumberger depth sounding	Magnetics, Electromagnetics and Schlumberger depth sounding	Magnetics, Electromagnetics and Schlumberger depth sounding	Magnetics & Electromagnetics	Magnetics & Electromagnetics
Water features present?	No	No	Yes, spring 40m north	Yes, spring 40m north	No	No
Aquifer Yield (l/h)	3 000	3 000	3 500	3 500	18 000	18 000
Borehole Depth (m)	40	40	70	70	60	60

Depth of Water Strike (m)	23	23	3, 28	3, 28	18	18
Static Water Level (m)	12	12	2	2	12	12
Average Aquifer Yield (l/h)	3 000	3 000	3 000	3 000	3 000	3 000
Average Borehole Depth (m)	55	55	55	55	55	55
Average Depth of Water Strike (m)	20	20	20	20	20	20
Average Static Water Level (m)	15	15	15	15	15	15
Land Type Series	Bb12c Clovelly, Glencoe, Avalon	Bb12c Clovelly, Glencoe, Avalon	Bb17b Mispah, Clovelly, Hutton, Avalon, Rock	Bb17b Mispah, Clovelly, Hutton, Avalon, Rock	Ba13c Hutton, Avalon, Glencoe	Ba13c Hutton, Avalon, Glencoe
Profile No	P58	P58	P58	P58	P65	P65
Depth Sampled	180-560mm	180-560mm	180-560mm	180-560mm	660-980mm	660-980mm
Gravel %	0	0	0	0	3	3
Sand %	88	88	88	88	26	26
Silt %	2	2	2	2	15	15
Clay %	10	10	10	10	56	56
pH (H ₂ O)	5.2	5.2	5.2	5.2	6.1	6.1
P (mg/kg)	1.2	1.2	1.2	1.2	0.0	0.0
Ca (mg/kg)	400	400	400	400	6950	6950
Mg (mg/kg)	50	50	50	50	4120	4120

K (mg/kg)	775	775	775	775	390	390
Na (mg/kg)	40	40	40	40	450	450
Fe (mg/kg)	-	-	-	-	-	-
Mn (mg/kg)	7.0	7.0	7.0	7.0	65.8	65.8
Zn (mg/kg)	0.98	0.98	0.98	0.98	0.35	0.35
Resistance (Ohm)	8900	8900	8900	8900	1200	1200
C%	0.5	0.5	0.5	0.5	0.9	0.9
CEC (cmol _c /kg)	32	32	32	32	109	109
Veld Type	61 Bankenveld	61 Bankenveld	61 Bankenveld	61 Bankenveld	61 Bankenveld	61 Bankenveld
Hydrogeological Unit	B2	B2	B2	B2	B2/D2	B2/D2

Information obtained from the veld type maps from Acocks (1988) and hydrogeological information from DWAF: Johannesburg (1999). Information obtained from the land type maps and accompanying memoir is from Land Type Survey Staff (1987). Soil colour was identified and classified in the veld according to the Corstor Colour Gauge that lists 168 different soil colours. Geohydrological parameters were derived from Frommurze (1937) and Meulenbeld (1998). Average weathering depth is extracted from the indicated Land Type Survey Staff and average rooting depth of the geobotanical indicators is referenced from Canadell *et al.* (1996).

Table A1.21b (iii). Mogolian Eonothem: Waterberg Group – Bronkhorstspuit Area: intrusive contact absent.

Parameter	Onverwacht 532JR		Trigaardspoor 451JR		Vlakfontein 453JR	
Geological Formation	Unweathered sandstone	Unweathered sandstone	Unweathered sandstone	Unweathered sandstone	Unweathered sandstone and diabase	Unweathered sandstone and diabase
Depth Sampled	0.5m	1.2m	0.5m	1.2m	0.5m	1.2m
Borehole Co-ordinates:						
S.L.	25°50.779'	25°50.779'	25°39.854'	25°39.854'	25°41.223'	25°41.223'
E.L.	28°53.187'	28°53.187'	28°55.455'	28°55.455'	28°52.426'	28°52.426'
Soil colour	Moderate brown	Dark reddish brown	Moderate brown	Strong brown	Strong brown	Dark reddish brown
Soil texture description	Sand	Sand	Sandy silt	Silty sand	Loam	Loam
pH	5.30	4.69	4.87	5.47	5.90	5.80
P (mg/kg)	3.19	1.75	2.77	2.20	2.81	30.32
Ca (mg/kg)	223	139	139	198	382	481
Mg (mg/kg)	56	47	46	61	147	130
K (mg/kg)	70	43	28	31	53	175
Na (mg/kg)	70	5	4	16	0	20
Fe (mg/kg)	29.80	71.12	26.36	30.99	24.17	39.83
Mn (mg/kg)	33.92	6.99	58.50	182.65	17.64	93.96
Zn (mg/kg)	0.49	0.48	0.37	0.41	0.53	5.49
Al (cmol _c /kg)	0.449	0.634	1.064	0.381	0	0
Resistance (Ohm)	5000	6200	9200	30000	2200	1800

C%	0.37	0.28	0.89	0.52	0.64	0.64
Total N%	0.035	0.026	0.067	0.042	0.054	0.054
S (mg/kg)	8.41	17.59	23.13	24.29	12.41	8.42
CEC (cmol _c /kg)	3.70	2.12	5.30	3.38	3.688	4.396
Distinct Tree Species	1. Acacia karroo 2. Euclea crispa 3. Strychnos pungens	1. Acacia karroo 2. Euclea crispa 3. Strychnos pungens	1. Euclea crispa	1. Euclea crispa	1. Combretum erythrophyllum	1. Combretum erythrophyllum
Average rooting depth of the indicated species (m)	4 - 50	4 - 50	4	4	12	12
Average depth of weathering (m)	1.4	1.4	1.9	1.9	2.1	2.1
Geomorphology	Terraces among sandstone ridges	Terraces among sandstone ridges	Gently undulating terrain	Gently undulating terrain	Gently undulating terrain	Gently undulating terrain
Geophysical instrumentation used	Magnetics & Schlumberger depth sounding	Magnetics & Schlumberger depth sounding	Magnetics, Electromagnetics and Schlumberger depth sounding	Magnetics, Electromagnetics and Schlumberger depth sounding	Magnetics & Electromagnetics	Magnetics & Electromagnetics
Water features present?	No	No	Yes, spring 40m north	Yes, spring 40m north	No	No
Aquifer Yield (l/h)	3 000	3 000	3 500	3 500	18 000	18 000

Borehole Depth (m)	40	40	70	70	60	60
Depth of Water Strike (m)	23	23	3, 28	3, 28	18	18
Static Water Level (m)	12	12	2	2	12	12
Average Aquifer Yield (l/h)	3 000	3 000	3 000	3 000	3 000	3 000
Average Borehole Depth (m)	55	55	55	55	55	55
Average Depth of Water Strike (m)	20	20	20	20	20	20
Average Static Water Level (m)	15	15	15	15	15	15
Land Type Series	Bb12c Clovelly, Glencoe, Avalon	Bb12c Clovelly, Glencoe, Avalon	Bb17b Mispah, Clovelly, Hutton, Avalon, Rock	Bb17b Mispah, Clovelly, Hutton, Avalon, Rock	Ba13c Hutton, Avalon, Glencoe	Ba13c Hutton, Avalon, Glencoe
Profile No	P58	P58	P58	P58	P65	P65
Depth Sampled	180-560mm	180-560mm	180-560mm	180-560mm	660-980mm	660-980mm
Gravel %	0	0	0	0	3	3
Sand %	88	88	88	88	26	26
Silt %	2	2	2	2	15	15
Clay %	10	10	10	10	56	56
pH (H ₂ O)	5.2	5.2	5.2	5.2	6.1	6.1
P (mg/kg)	1.2	1.2	1.2	1.2	0.0	0.0
Ca (mg/kg)	400	400	400	400	6950	6950

Mg (mg/kg)	50	50	50	50	4120	4120
K (mg/kg)	775	775	775	775	390	390
Na (mg/kg)	40	40	40	40	450	450
Fe (mg/kg)	-	-	-	-	-	-
Mn (mg/kg)	7.0	7.0	7.0	7.0	65.8	65.8
Zn (mg/kg)	0.98	0.98	0.98	0.98	0.35	0.35
Resistance (Ohm)	8900	8900	8900	8900	1200	1200
C%	0.5	0.5	0.5	0.5	0.9	0.9
CEC (cmol _c /kg)	32	32	32	32	109	109
Veld Type	61 Bankenveld	61 Bankenveld	61 Bankenveld	61 Bankenveld	61 Bankenveld	61 Bankenveld
Hydrogeological Unit	B2	B2	B2	B2	B2/D2	B2/D2

Information obtained from the veld type maps from Acocks (1988) and hydrogeological information from DWAF: Johannesburg (1999). Information obtained from the land type maps and accompanying memoir is from Land Type Survey Staff (1987). Soil colour was identified and classified in the veld according to the Corstor Colour Gauge that lists 168 different soil colours. Geohydrological parameters were derived from Frommurze (1937) and Meulenbeld (1998). Average weathering depth is extracted from the indicated Land Type Survey Staff and average rooting depth of the geobotanical indicators is referenced from Canadell *et al.* (1996).

Table A1.21a (iv). Mogolian Eonothem: Waterberg Group – Middelburg Area: along intrusive contact.

Parameter	Bankfontein 264JS		Bankplaas 239JS		Buffelskloof 342JS		Goedehoop 244JS	
Geological Formation	Weathered diabase contact	Weathered diabase contact	Weathered diabase contact	Weathered diabase contact	Weathered diabase sill, +20m below surface	Weathered diabase sill, +20m below surface	Weathered diabase sill, close to surface	Weathered diabase sill, close to surface
Depth Sampled	0.5m	1.2m	0.5m	1.2m	0.5m	1.2m	0.5m	1.2m
Borehole Co-ordinates:								
S.L.	25°38.893'	25°38.893'	25°31.255'	25°31.255'	25°32.207'	25°32.207'	25°35.057'	25°35.057'
E.L.	29°19.297'	29°19.297'	29°20.128'	29°20.128'	29°34.194'	29°34.194'	29°29.622'	29°29.622'
Soil colour	Strong brown	Dark reddish brown	Strong brown	Moderate reddish brown	Dark reddish brown	Dusky yellowish brown	Strong brown	Moderate brown
Soil texture description	Clay	Clay	Clayey silt	Clay	Clay	Silty clay	Clay	Clay
pH	5.85	5.90	5.37	6.37	6.26	6.37	6.14	5.97
P (mg/kg)	2.24	1.79	1.56	1.37	1.58	1.38	3.19	0.96
Ca (mg/kg)	546	526	263	1066	1080	1363	323	342
Mg (mg/kg)	217	216	84	446	763	1454	245	188
K (mg/kg)	264	245	33	40	72	89	82	106
Na (mg/kg)	33	12	21	32	18	58	21	30
Fe (mg/kg)	66.23	72.92	46.62	38.94	47.41	64.95	66.61	35.77
Mn (mg/kg)	187.09	148.97	198.39	111.79	76.36	95.64	229.04	133.95
Zn (mg/kg)	0.82	0.48	0.39	0.11	0.22	0.42	0.68	0.76
Al (cmol _c /kg)	0.184	0.174	0.321	0	0	0	0	0.135
Resistance (Ohm)	3000	3200	2650	2020	1110	740	2900	3400

C%	1.99	2.01	0.83	1.39	1.22	1.38	0.37	0.58
Total N%	0.128	0.119	0.058	0.063	0.074	0.071	0.038	0.051
S (mg/kg)	23.24	18.99	28.41	10.15	10.15	21.45	19.33	20.54
CEC (cmol _e /kg)	9.16	10.31	6.36	13.02	14.99	22.54	8.03	7.69
Distinct Tree Species	1. Acacia karroo 2. Euclea crispa	1. Acacia karroo 2. Euclea crispa	1. Acacia karroo 2. Euclea crispa	1. Acacia karroo 2. Euclea crispa	1. Acacia karroo 2. Burkea africana 3. Euclea crispa	1. Acacia karroo 2. Burkea africana 3. Euclea crispa	1. Acacia karroo 2. Euclea crispa	1. Acacia karroo 2. Euclea crispa
Average rooting depth of the indicated species (m)	4 - 50	4 - 50	4 - 50	4 - 50	2 - 50	2 - 50	4 - 50	4 - 50
Average depth of weathering (m)	1.5	1.5	1.7	1.7	1.9	1.9	2.2	2.2
Geomorphology	Typical Bankenveld: sandstone ridges and terraces	Typical Bankenveld: sandstone ridges and terraces	Typical Bankenveld: sandstone ridges and terraces	Typical Bankenveld: sandstone ridges and terraces	Plain	Plain	Broad valley	Broad valley
Geophysical instrumentation used	Magnetics, Electromagnetics and Schlumberger depth sounding	Magnetics, Electromagnetics and Schlumberger depth sounding	Magnetics, Electromagnetics and Schlumberger depth sounding	Magnetics, Electromagnetics and Schlumberger depth sounding	Magnetics, Electromagnetics and Schlumberger depth sounding	Magnetics, Electromagnetics and Schlumberger depth sounding	Schlumberger depth soundings	Schlumberger depth soundings

Water features present?	No	No	No	No	No	No	Yes, stream 500m south	Yes, stream 500m south
Aquifer Yield (l/h)	3 800	3 800	3 250	3 250	3 500	3 500	2 700	2 700
Borehole Depth (m)	65	65	59	59	50	50	32	32
Depth of Water Strike (m)	10, 24	10, 24	26	26	21	21	15	15
Static Water Level (m)	8	8	14	14	8	8	6	6
Average Aquifer Yield (l/h)	3 000	3 000	3 000	3 000	3 000	3 000	3 000	3 000
Average Borehole Depth (m)	55	55	55	55	55	55	55	55
Average Depth of Water Strike (m)	20	20	20	20	20	20	20	20
Average Static Water Level (m)	15	15	15	15	15	15	15	15
Land Type Series	Bb16f Clovelly, Mispah, Hutton, Rock	Bb16f Clovelly, Mispah, Hutton, Rock	Ba15a/Bb16f Hutton, Clovelly, Avalon, Mispah, Rock	Ba15a/Bb16f Hutton, Clovelly, Avalon, Mispah, Rock	Ba37a/Bb16g Hutton, Clovelly, Mispah, Rock	Ba37a/Bb16g Hutton, Clovelly, Mispah, Rock	Ba37a Hutton	Ba37a Hutton
Profile No	No Data	No Data	P77	P77	P68	P68	P78	P78
Depth Sampled	-	-	650-1100mm	650-1100mm	270-740mm	270-740mm	330-690mm	330-690mm
Gravel %	-	-	1	1	1	1	0	0
Sand %	-	-	34	34	57	57	84	84

Silt %	-	-	12	12	7	7	4	4
Clay %	-	-	53	53	35	35	12	12
pH (H ₂ O)	-	-	6.5	6.5	6.1	6.1	5.2	5.2
P (mg/kg)	-	-	0.3	0.3	1.6	1.6	1.2	1.2
Ca (mg/kg)	-	-	10500	10500	800	800	400	400
Mg (mg/kg)	-	-	4000	4000	47	47	50	50
K (mg/kg)	-	-	380	380	390	390	15	15
Na (mg/kg)	-	-	230	230	660	660	10	10
Fe (mg/kg)	-	-	-	-	-	-	-	-
Mn (mg/kg)	-	-	222.5	222.5	0.4	0.4	0.4	0.4
Zn (mg/kg)	-	-	0.40	0.40	0.70	0.70	0.25	0.25
Resistance (Ohm)	-	-	1600	1600	6100	6100	6000	6000
C%	-	-	0.8	0.8	0.6	0.6	0.5	0.5
CEC (cmol _c /kg)	-	-	140		68	68	28	28
Veld Type	61/19 Bankenveld/ Sourish Mixed Bushveld	61/19 Bankenveld/ Sourish Mixed Bushveld	61/19 Bankenveld/ Sourish Mixed Bushveld	61/19 Bankenveld/ Sourish Mixed Bushveld	61/19 Bankenveld/ Sourish Mixed Bushveld	61/19 Bankenveld/ Sourish Mixed Bushveld	61 Bankenveld	61 Bankenveld
Hydrogeological Unit	B2	B2	B2	B2	B2	B2	B2	B2

Information obtained from the veld type maps from Acocks (1988) and hydrogeological information from DWAF: Johannesburg (1999). Information obtained from the land type maps and accompanying memoir is from Land Type Survey Staff (1987). Soil colour was identified and classified in the veld according to the Corstor Colour Gauge that lists 168 different soil colours. Geohydrological parameters were derived from Frommurze (1937) and Meulenbeld (1998). Average weathering depth is extracted from the indicated Land Type Survey Staff and average rooting depth of the geobotanical indicators is referenced from Canadell *et al.* (1996).

Table A1.21b (iv). Mogolian Eonothem: Waterberg Group – Middelburg Area: intrusive contact absent.

Parameter	Bankfontein 264JS		Bankplaas 239JS		Buffelskloof 342JS		Goedehoop 244JS	
Geological Formation	Unweathered sandstone	Unweathered sandstone	Unweathered sandstone	Unweathered sandstone	Unweathered sandstone	Unweathered sandstone	Unweathered sandstone	Unweathered sandstone
Depth Sampled	0.5m	1.2m	0.5m	1.2m	0.5m	1.2m	0.5m	1.2m
Borehole Co-ordinates:								
S.L.	25°38.893'	25°38.893'	25°31.255'	25°31.255'	25°32.207'	25°32.207'	25°35.057'	25°35.057'
E.L.	29°19.297'	29°19.297'	29°20.128'	29°20.128'	29°34.194'	29°34.194'	29°29.622'	29°29.622'
Soil colour	Light brown	Yellowish brown	Moderate brown	Moderate brown	Strong brown	Dark yellowish orange	Dusky red	Dark reddish brown
Soil texture description	Silt	Sandy silt	Sand	Sand	Sand	Sand	Sand	Sand
pH	4.93	4.77	5.21	4.89	5.03	5.37	4.50	5.38
P (mg/kg)	2.09	1.41	1.70	1.49	2.85	1.75	2.58	1.94
Ca (mg/kg)	144	152	136	129	126	176	171	153
Mg (mg/kg)	66	59	52	49	46	60	87	66
K (mg/kg)	87	103	18	20	13	15	18	20
Na (mg/kg)	22	12	3	0	10	26	19	29
Fe (mg/kg)	34.54	69.43	32.80	41.62	21.64	20.16	74.79	23.05
Mn (mg/kg)	22.59	233.06	113.20	144.59	2.17	1.40	13.42	23.67
Zn (mg/kg)	0.28	0.50	0.26	0.37	0.24	0.25	0.20	0.23
Al (cmol _c /kg)	0.858	1.471	0.501	0.620	0.651	0.237	0.685	0.412
Resistance (Ohm)	5400	7200	7200	5710	9000	18000	2000	8000
C%	0.91	0.42	0.57	0.69	0.35	0.27	1.02	0.17

Total N%	0.074	0.034	0.033	0.039	0.037	0.053	0.086	0.020
S (mg/kg)	20.39	42.01	45.09	41.57	23.65	41.52	10.81	5.85
CEC (cmol _e /kg)	4.17	6.50	5.10	4.40	4.95	3.52	3.68	2.62
Distinct Tree Species	1. Acacia karroo 2. Euclea crispa	1. Acacia karroo 2. Euclea crispa	1. Acacia karroo 2. Euclea crispa	1. Acacia karroo 2. Euclea crispa	1. Acacia karroo 2. Burkea africana 3. Euclea crispa	1. Acacia karroo 2. Burkea africana 3. Euclea crispa	1. Acacia karroo 2. Euclea crispa	1. Acacia karroo 2. Euclea crispa
Average rooting depth of the indicated species (m)	4 - 50	4 - 50	4 - 50	4 - 50	2 - 50	2 - 50	4 - 50	4 - 50
Average depth of weathering (m)	1.5	1.5	1.7	1.7	1.9	1.9	2.2	2.2
Geomorphology	Typical Bankenveld: sandstone ridges and terraces	Typical Bankenveld: sandstone ridges and terraces	Typical Bankenveld: sandstone ridges and terraces	Typical Bankenveld: sandstone ridges and terraces	Plain	Plain	Broad valley	Broad valley

Geophysical instrumentation used	Magnetics, Electromagnetics and Schlumberger depth sounding	Magnetics, Electromagnetics and Schlumberger depth sounding	Magnetics, Electromagnetics and Schlumberger depth sounding	Magnetics, Electromagnetics and Schlumberger depth sounding	Magnetics, Electromagnetics and Schlumberger depth sounding	Magnetics, Electromagnetics and Schlumberger depth sounding	Schlumberger depth soundings	Schlumberger depth soundings
Water features present?	No	No	No	No	No	No	Yes, stream 500m south	Yes, stream 500m south
Aquifer Yield (l/h)	3 800	3 800	3 250	3 250	3 500	3 500	2 700	2 700
Borehole Depth (m)	65	65	59	59	50	50	32	32
Depth of Water Strike (m)	10, 24	10, 24	26	26	21	21	15	15
Static Water Level (m)	8	8	14	14	8	8	6	6
Average Aquifer Yield (l/h)	3 000	3 000	3 000	3 000	3 000	3 000	3 000	3 000
Average Borehole Depth (m)	55	55	55	55	55	55	55	55
Average Depth of Water Strike (m)	20	20	20	20	20	20	20	20
Average Static Water Level (m)	15	15	15	15	15	15	15	15
Land Type Series	Bb16f Clovelly, Mispah, Hutton, Rock	Bb16f Clovelly, Mispah, Hutton, Rock	Ba15a/Bb16f Hutton, Clovelly, Avalon, Mispah, Rock	Ba15a/Bb16f Hutton, Clovelly, Avalon, Mispah, Rock	Ba37a/Bb16g Hutton, Clovelly, Mispah, Rock	Ba37a/Bb16g Hutton, Clovelly, Mispah, Rock	Ba37a Hutton	Ba37a Hutton

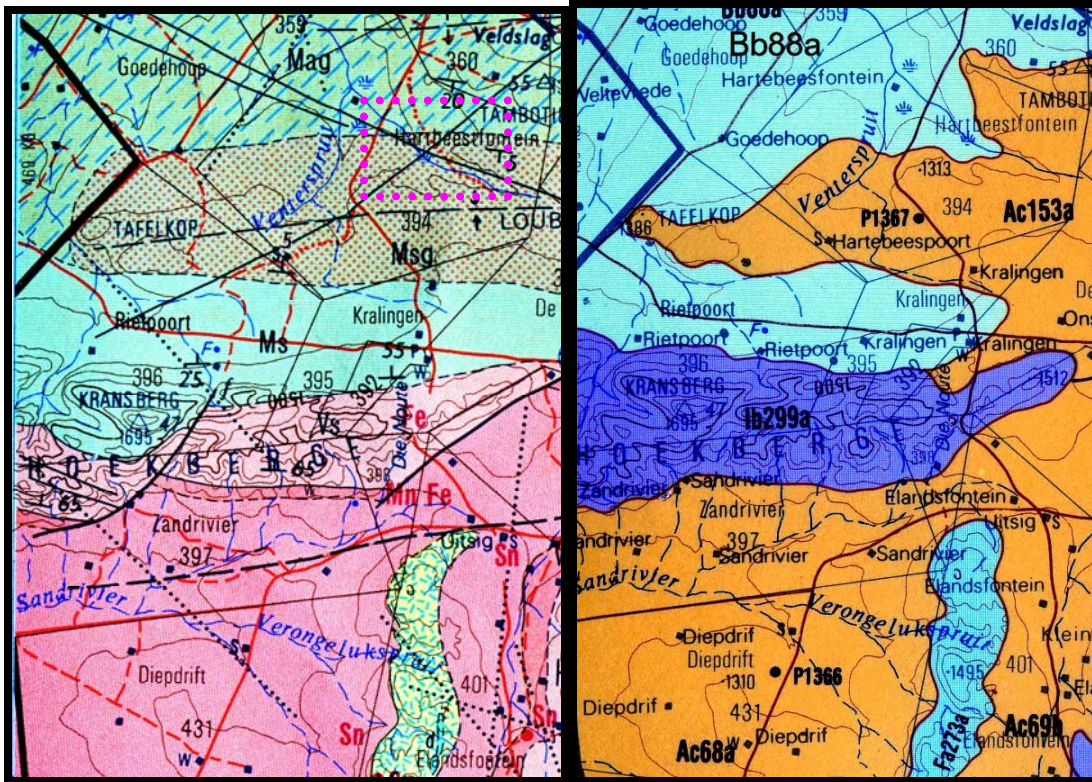
Profile No	No Data	No Data	P77	P77	P68	P68	P78	P78
Depth Sampled	-	-	650-1100mm	650-1100mm	270-740mm	270-740mm	330-690mm	330-690mm
Gravel %	-	-	1	1	1	1	0	0
Sand %	-	-	34	34	57	57	84	84
Silt %	-	-	12	12	7	7	4	4
Clay %	-	-	53	53	35	35	12	12
pH (H ₂ O)	-	-	6.5	6.5	6.1	6.1	5.2	5.2
P (mg/kg)	-	-	0.3	0.3	1.6	1.6	1.2	1.2
Ca (mg/kg)	-	-	10500	10500	800	800	400	400
Mg (mg/kg)	-	-	4000	4000	47	47	50	50
K (mg/kg)	-	-	380	380	390	390	15	15
Na (mg/kg)	-	-	230	230	660	660	10	10
Fe (mg/kg)	-	-	-	-	-	-	-	-
Mn (mg/kg)	-	-	222.5	222.5	0.4	0.4	0.4	0.4
Zn (mg/kg)	-	-	0.40	0.40	0.70	0.70	0.25	0.25
Resistance (Ohm)	-	-	1600	1600	6100	6100	6000	6000
C%	-	-	0.8	0.8	0.6	0.6	0.5	0.5
CEC (cmol _e /kg)	-	-	140		68	68	28	28
Veld Type	61/19 Bankenveld/ Sourish Mixed Bushveld	61/19 Bankenveld/ Sourish Mixed Bushveld	61/19 Bankenveld/ Sourish Mixed Bushveld	61/19 Bankenveld/ Sourish Mixed Bushveld	61/19 Bankenveld/ Sourish Mixed Bushveld	61/19 Bankenveld/ Sourish Mixed Bushveld	61 Bankenveld	61 Bankenveld
Hydrogeological Unit	B2	B2	B2	B2	B2	B2	B2	B2

Information obtained from the veld type maps from Acocks (1988) and hydrogeological information from DWAF: Johannesburg (1999). Information obtained from the land type maps and accompanying memoir is from Land Type Survey Staff (1987). Soil colour

was identified and classified in the veld according to the Corstor Colour Gauge that lists 168 different soil colours. Geohydrological parameters were derived from Frommurze (1937) and Meulenbeld (1998). Average weathering depth is extracted from the indicated Land Type Survey Staff and average rooting depth of the geobotanical indicators is referenced from Canadell *et al.* (1996).

The following case studies are representative of the Waterberg Group in the Waterberg area, see also Table A1.21(a&b) i.

30. Hartbeesfontein 394KR



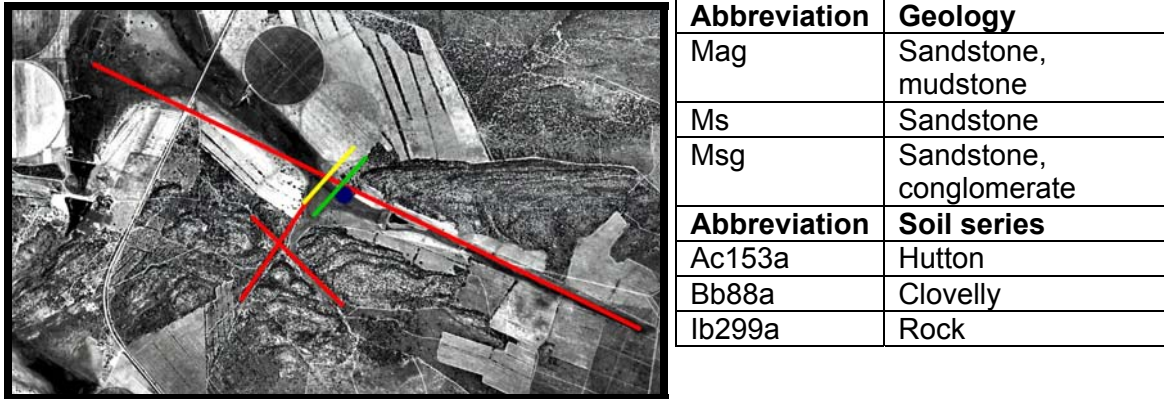


Figure A1.30. The geology (top left), land type (top right) and aerial photograph (bottom) of Hartbeesfontein 394KR. The blue circle denotes the position of the borehole and the green and yellow lines indicates the direction of the magnetic and electromagnetic profiles respectively. The area covered by the aerial photograph is indicated by the purple shape in the geological map. The red lines represent lineaments (compare with the geological map).

The farm is south of Alma, about 32 km south of the village of Vaalwater. The close proximity of streams, namely tributaries of the Venter Spruit, and favourable aquifer conditions due to the presence of structural conditions in the sub-surface, contribute to the diverse agricultural enterprises in this environment. Along the stream some irrigation practices is taken place, where irrigation water is drawn from the stream, dams and boreholes. Further away from the stream, extensive cattle farming practices occur alongside game farming. The change in farming activities stresses the importance of the stream to supply water for irrigation, as the boreholes water quantity must be insufficient to satisfy the water demands of crops in this hot, dry and sandy environment. The hot, dry and sandy environment is hosting typical botanic species that one would associate with this kind of habitat setup. Botanical species like *Burkea africana* (wild seringa), *Combretum molle* (velvet bushwillow), *C. apiculatum* (red bushwillow), *C. zeyheri* (large-fruited bushwillow), *Englerophytum magalismontanum* (Transvaal milkplum), *Euclea crispa* (blue guarri), *Faurea saligna* (Transvaal beech), *Mundulea sericea* (Cork bush), *Ochna pulchra* (Peeling plane) and *Terminalia sericea* (silver cluster-leaf) are representative of this sandy environment due to their broad-leaves and the absence of thorns on the stem and/or twigs.

31. Pennsylvania 336LR

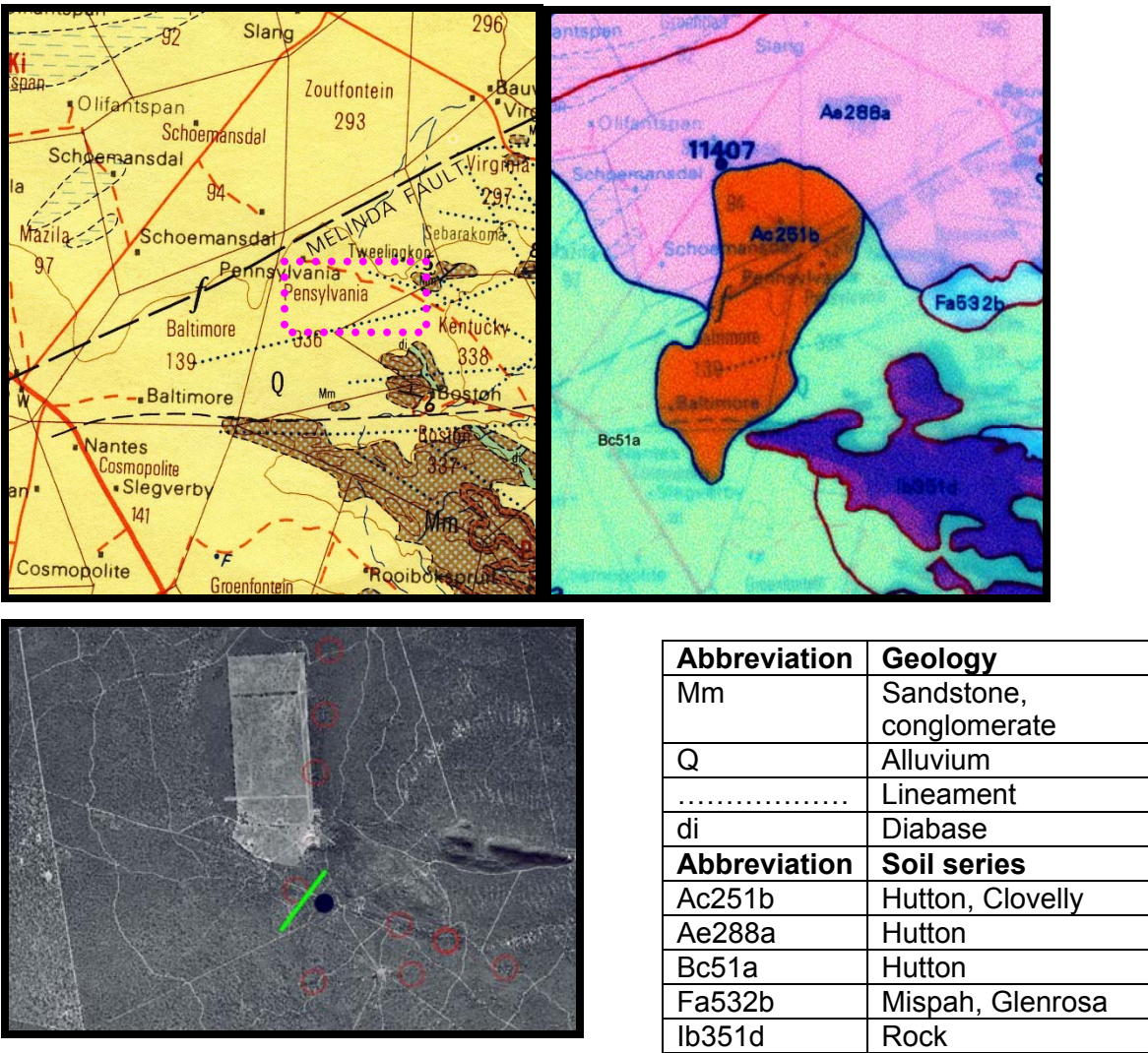
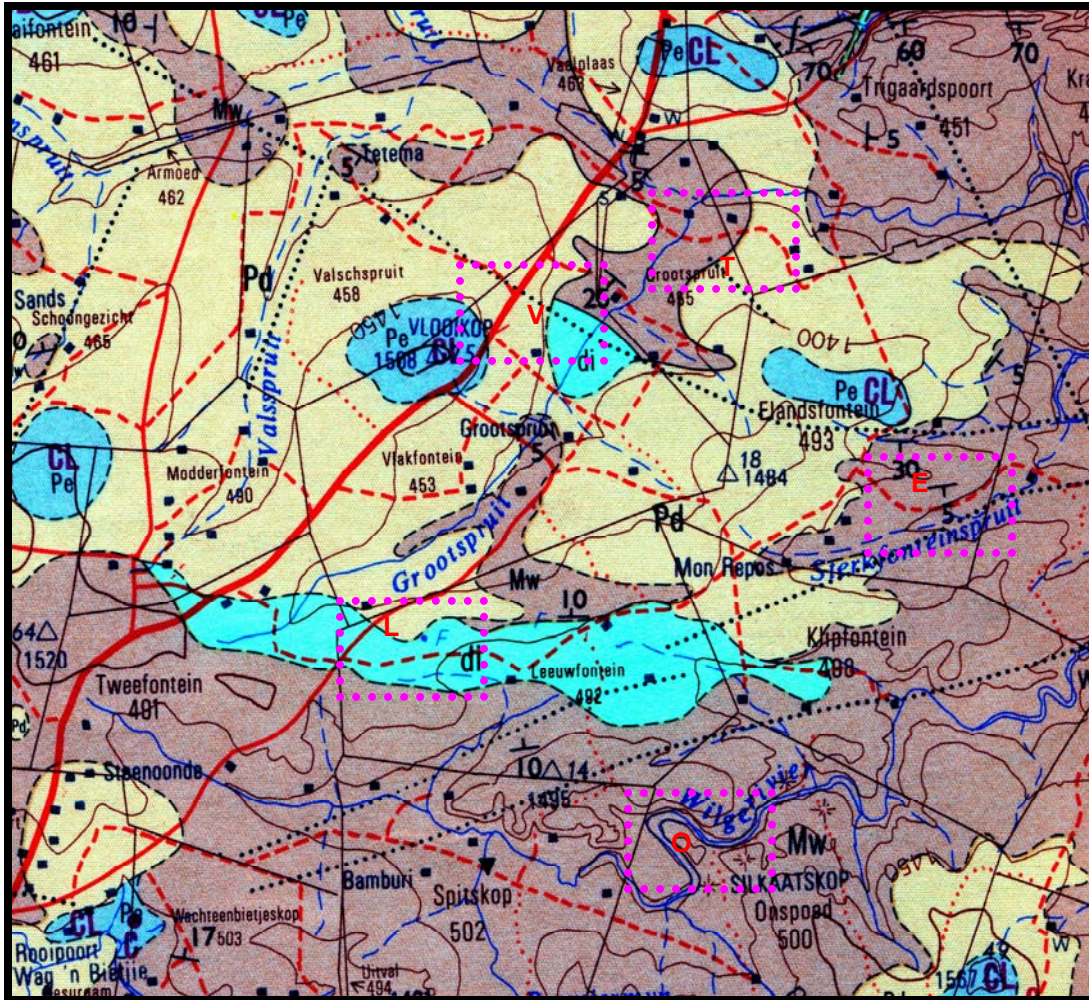
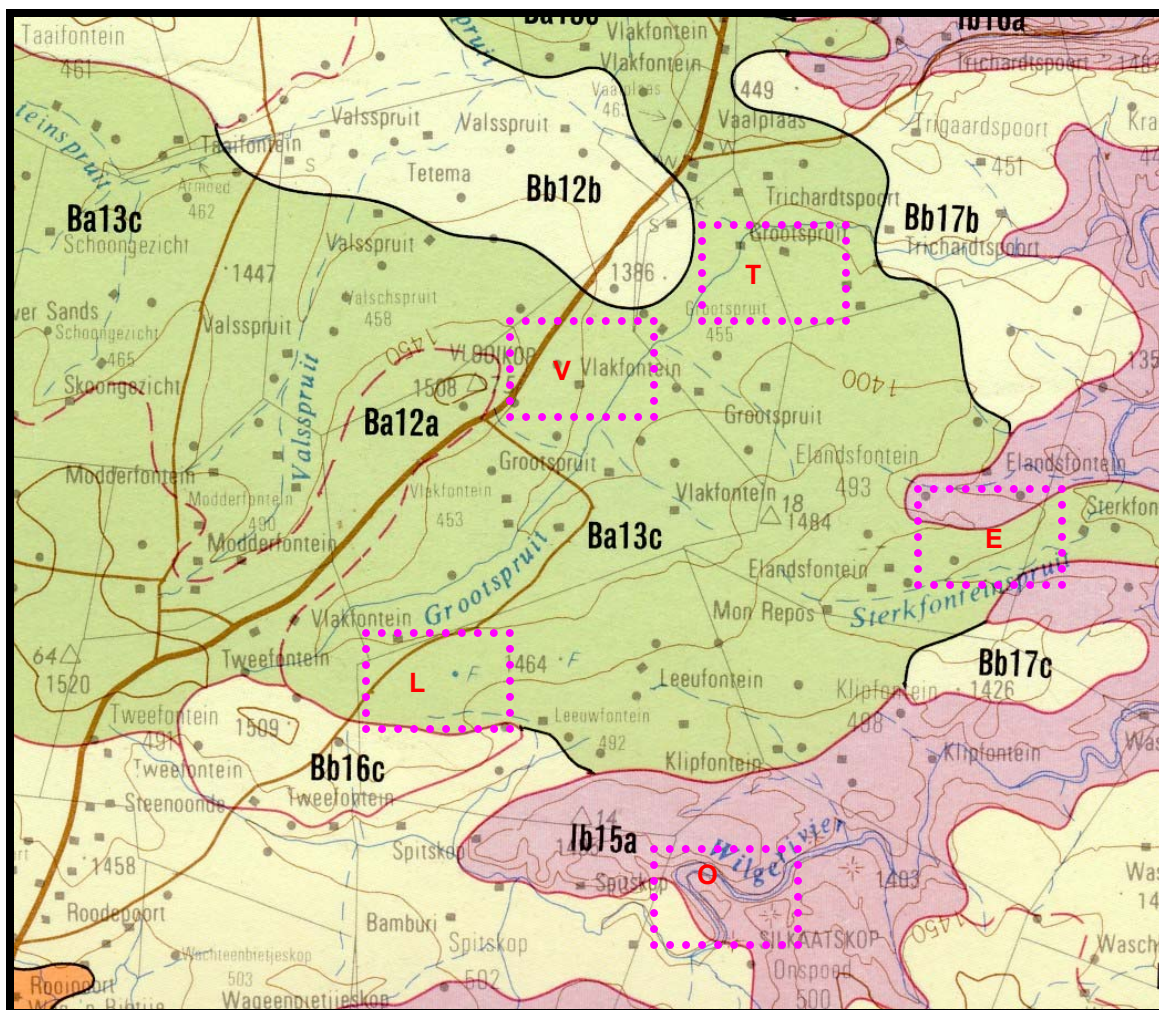


Figure A1.31. The geology (top), land type (middle) and aerial photograph (bottom) of Pennsylvania 336LR. The blue circle denotes the position of the borehole and the green line indicates the magnetic profile direction. Note the linear vegetated features inside the red circles (aerial photograph). The area covered by the aerial photograph is indicated by the purple shape in the geological map.

The following case studies are representative of the Waterberg Group in the Bronkhorstspuit area, see also Tables A1.21(a&b) ii & iii.

32. Elandsfontein 493JR





Abbreviation	Geology
Mw	Sandstone
Pd	Shale
Pe	Shale, sandstone, coal
di	Diabase
Abbreviation	Soil series
Ba13c	Hutton
Bb16c	Mispah, Hutton, Glenrosa
Bb17b,c	Mispah, Clovelly
Ib15a	Rock, Mispah

Figure A1.32. The geology (top), land type (middle) and aerial photograph (bottom) of Elandsfontein 493JR. The blue circle denotes the position of the borehole and the orange line indicates the sounding direction. The area covered by the aerial photograph

is indicated by the purple shape and the letter “E” in the geological and land type maps. Note the linear vegetated feature inside the red circle that crosses the drilled borehole. Elandsfontein 493JR, situated about 30 km from Bronkhorstspuit in a north-eastern direction, is one of the farms that define the eZemvelo Nature Reserve of the Oppenheimer Trust. It is one of the very few nature reserves that protect the biodiversity of the Bankenveld among the rocks of the Wilgerivier Formation. The plains are covered by various grass species, where some valleys and plains consists of diabase and are covered by *Acacia* species, whereas sandstone valleys, gorges and rocky outcrops are mainly covered with broad-leaved, non-thorn bearing, shrubs and trees, very similar to these observed on the farm Hartbeesfontein (case study number 30); *Burkea africana* (wild seringa), *Combretum molle* (velvet bushwillow), *C. apiculatum* (red bushwillow), *Englerophytum magalismontanum* (Transvaal milkplum), *Euclea crispa* (blue guarri), *Faurea saligna* (Transvaal beech), *Mundulea sericea* (Cork bush) and *Ochna pulchra* (Peeling plane).

33. Leeuwfontein 492JR

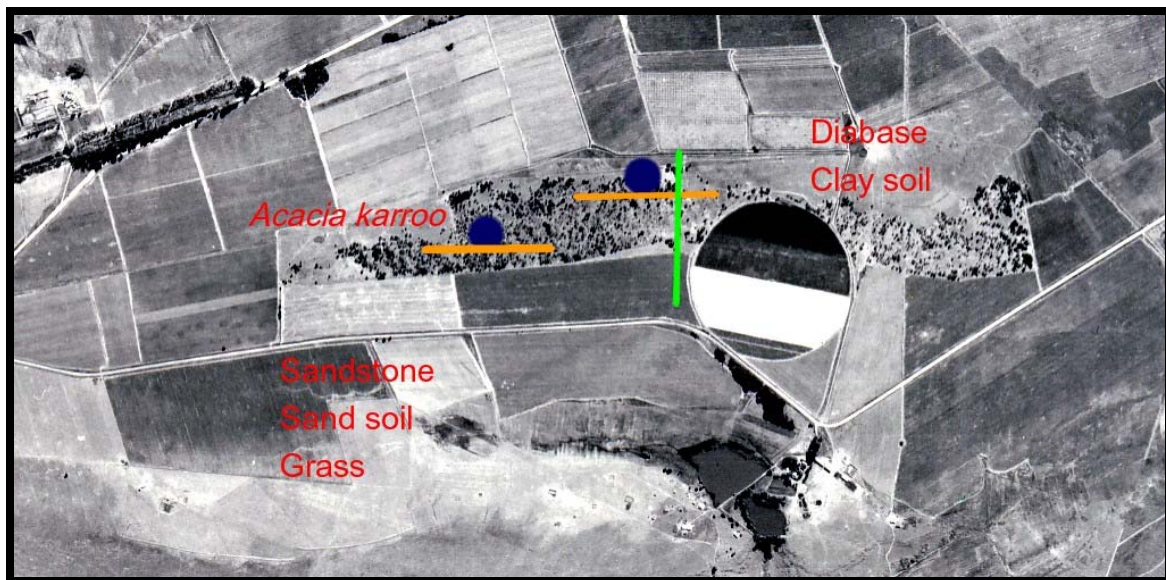


Figure A1.33. Aerial photograph of Leeuwfontein 492JR. The blue circles denotes the position of the boreholes (left = dry and right = yielding), the green line the direction of the magnetic profile and the orange line indicates the sounding direction. The area covered by the aerial photograph is indicated by the purple shape and the letter “L” in the geological and land type maps. The geology and land type are depicted in Figure A1.32.

About 15 km northeast of Bronkhorstspuit, between the town and the farm Elandsfontein 493JR, the farm Leeuwfontein 492JR is situated on a plain of sandstone.

34. Onspoed 500JR

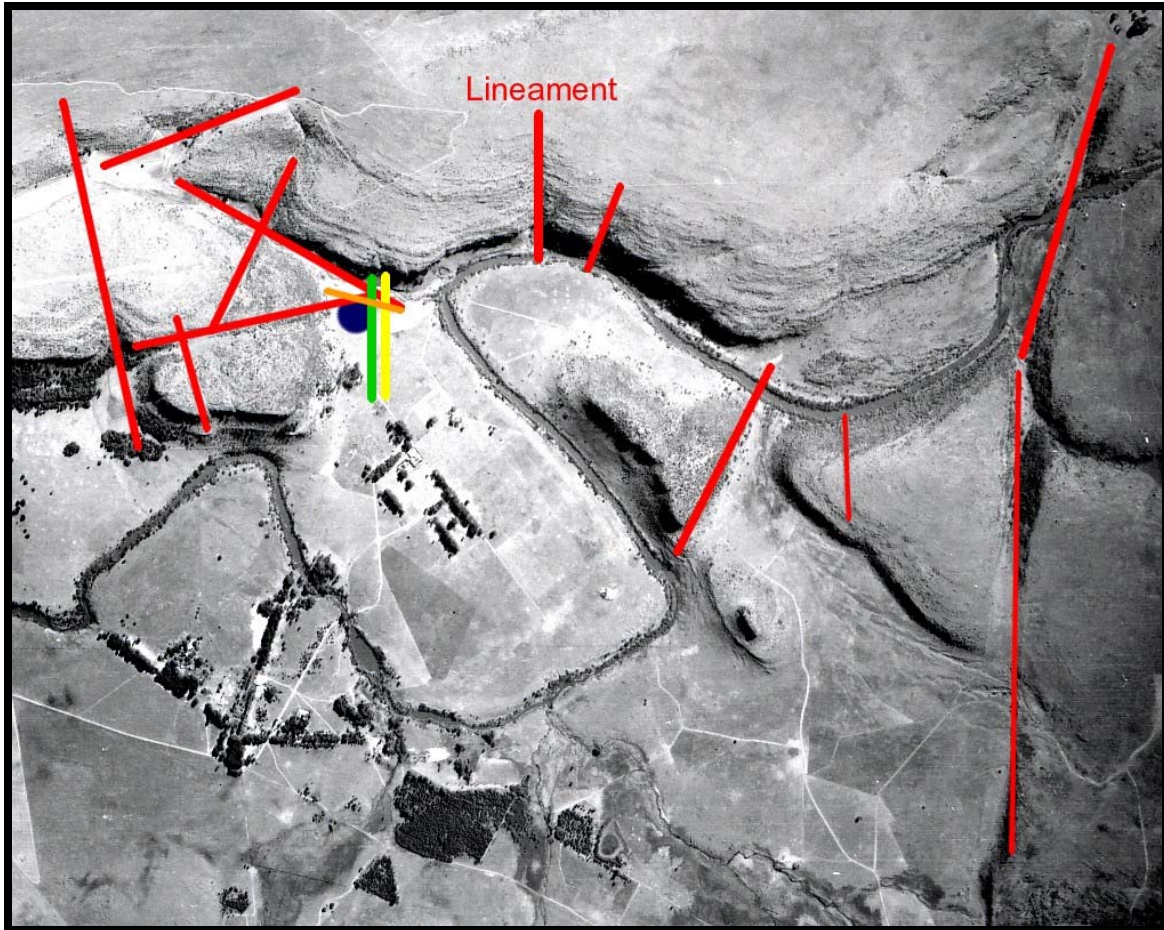


Figure A1.34. Aerial photograph of Onspoed 500JR. The blue circle denotes the position of the borehole, the green line the direction of the magnetic profile, the yellow line the direction of the electromagnetic travers and the orange line indicates the sounding direction. The area covered by the aerial photograph is indicated by the purple shape and the letter “O” in the geological and land type maps. The geology and land type are depicted in Figure A1.32. Note the numerous lineaments in this geological setting.

Nestled among the banks of the Wilge River and enclosed by high sandstone cliffs of the Wilgerivier Formation, the farm Onspoed 500JR is located. The farm has a rich history as Silkaats once occupied it (hence the name of Silkaatskop of a prominent sandstone buttress on the farm). During World War II the farm was used by British Engineering troops, as they were responsible for remaining buildings on the farm, drilling of very deep boreholes and construction of competent steel arch bridges over the Wilge River.

35. Onverwacht 532JR

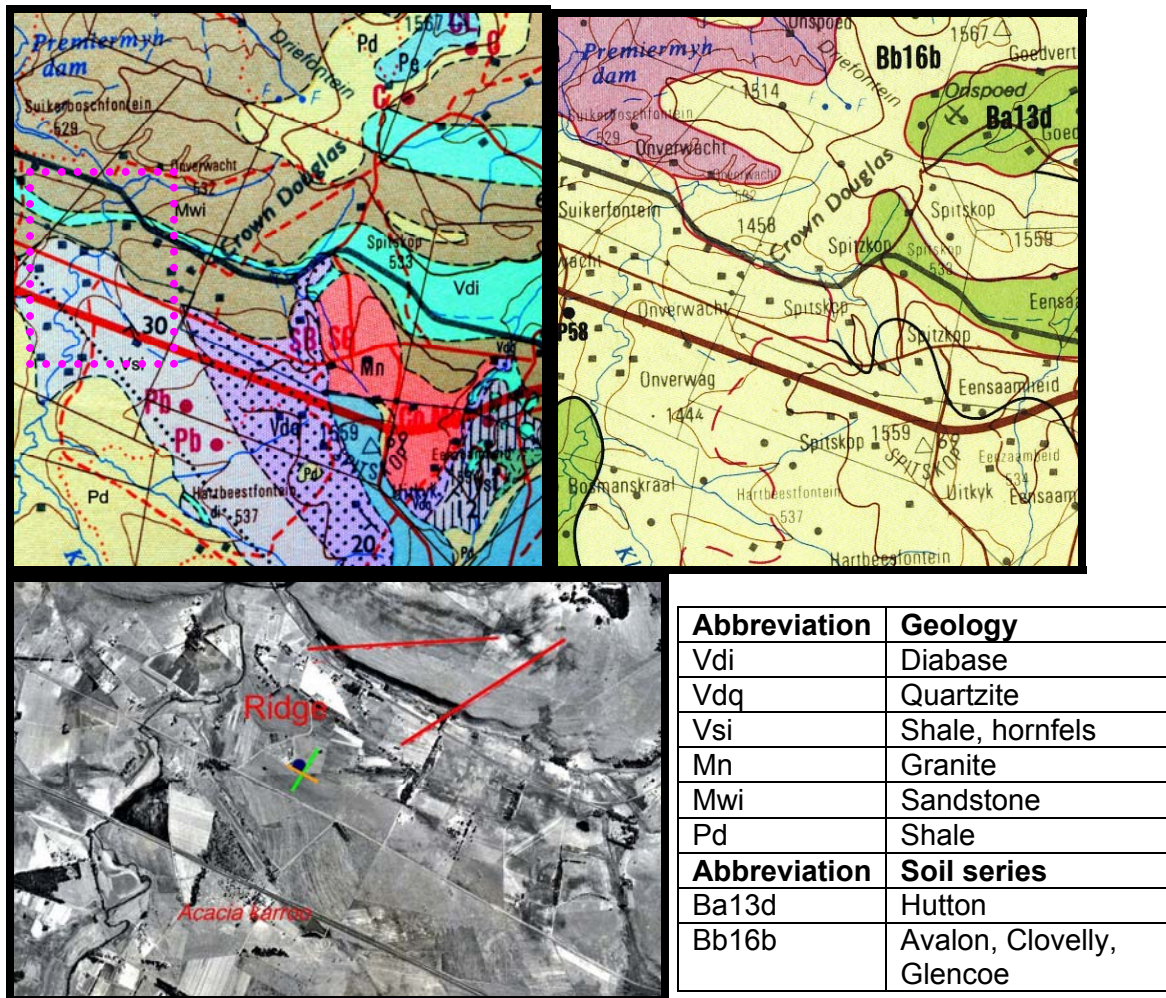


Figure A1.35. The geology (top left), land type (top right) and aerial photograph (bottom) of Onverwacht 532JR. The blue circle denotes the position of the borehole, the green line the direction of the magnetic profile and the orange line indicates the sounding direction. The area covered by the aerial photograph is indicated by the purple shape in the geological map.

The southern edge of the Wilgerivier Formation in contact with shale and hornfels belonging to the Silverton Formation of the Pretoria Group, cuts through the farm Onverwacht 532JR, 15 km east of Bronkhorstspuit. A clearly marked difference in vegetation is observed in this contact zone. The shale and hornfels are covered with *Acacia karroo* species in the clayey parts and furthermore grasses are luxurious. The sandstone hosts a variety shrubs belonging to the Mixed Bushveld veld type, namely *Acacia tortilis* (umbrella thorn), *Combretum molle* (velvet bushwillow), *Englerophytum magalismontanum* (Transvaal milkplum), *Ochna pulchra* (Peeling plane), *Strychnos pungens* (spine-leaved monkey orange), *Tapiphyllum parvifolium* (mountain medlar) and *Vangueria infausta* (wild medlar). However, the farm resides with the Bankenveld veld type. Most of the species are only small shrubs as the plants are exposed to cold spells like frost, wind and at times fire. Due to the numerous sandstone outcrops that define well formed ridges or terraces with intermediate linear grassed areas with little or none sandstone outcrops and sandy plains, the area is suitable for well managed extensive cattle farming in this sour habitat. These linear grassed areas are demarcated by the following species: *Acacia karroo*, *Euclea crispa* and *Strychnos pungens*. The geophysical exploration methods utilised on this farm include the magnetic method for profiling and the Schlumberger depth sounding method, with the results depicted in Figures 4.56 and 4.57.



Figure A1.36. Aerial photograph of Trigaardspoor 451JR. The blue circle denotes the position of the borehole, the green line the direction of the magnetic profile, the yellow line the direction of the electromagnetic travers and the orange line indicates the sounding direction. The area covered by the aerial photograph is indicated by the purple shape and the letter “T” in the geological and land type maps. The geology and land type are depicted in Figure A1.32. Note the linear streams in this geological setting that can indicate the presence of lineaments (weathered diabase).

The farm Trigaardspoor 451JR, approximately 20 km north of Bronkhorstspuit, marks the northern boundary of the Wilgerivier Formation in the Bronkhorstspuit district. Areas underlain by loam and clay soil structures tend to be used for cultivation agricultural practices, whereas these kinds of practices on sand soil are normally marginal productive lands. Areas underlain by the Wilgerivier Formation are mostly used for extensive cattle grazing, as is the case on this farm.

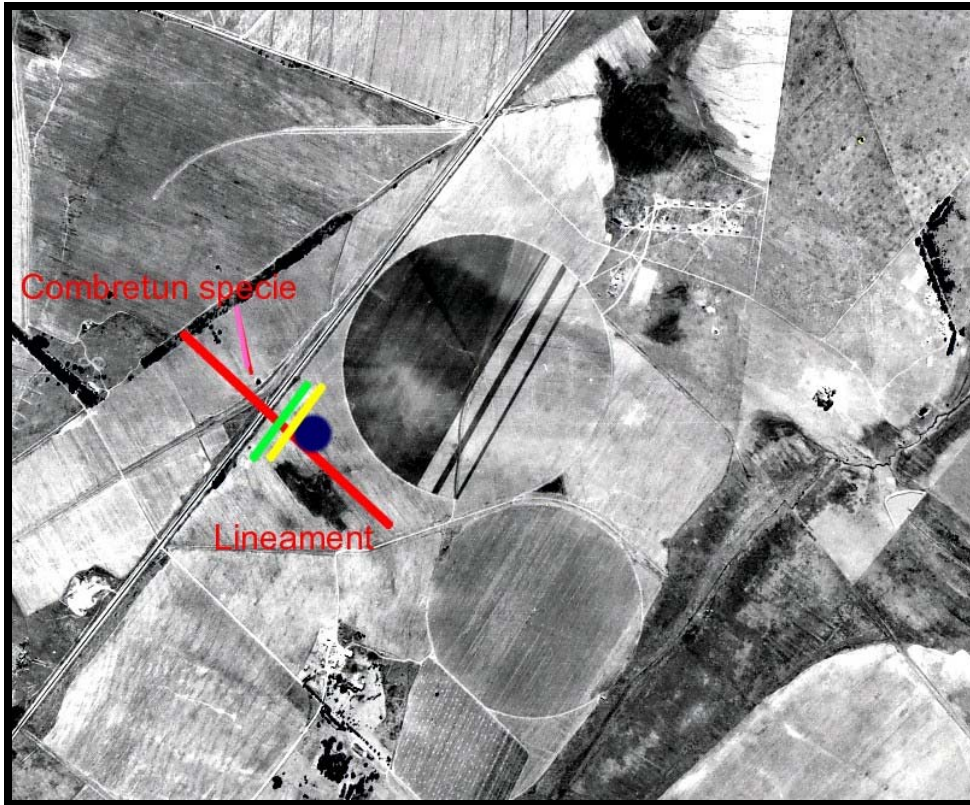
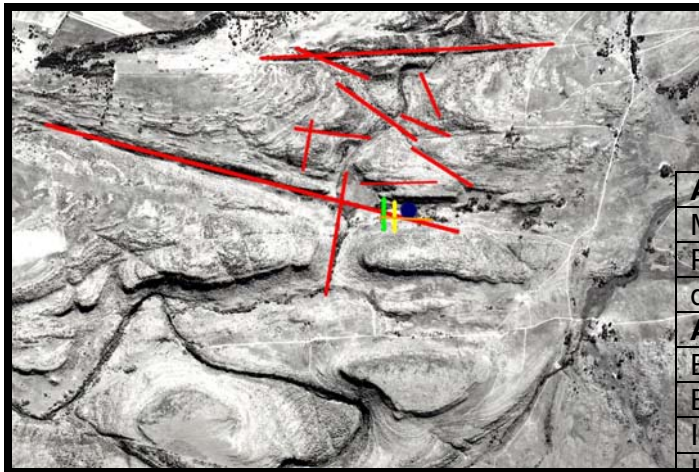


Figure A1.37. Aerial photograph of Vlakfontein 453JR. The blue circle denotes the position of the borehole, the green line the direction of the magnetic profile and the yellow line the direction of the electromagnetic traverse. The area covered by the aerial photograph is indicated by the purple shape and the letter “V” in the geological and land type maps. The geology and land type are depicted in Figure A1.32.

A prominent hill west of the farm, called Vlooi kop, consists of sandstone, grit and coal of the Eccca Group, Karoo Supergroup. The coal deposit was mined in the past. The botanic diversity on Vlooi kop is quite unique for this environment and surroundings as it is covered with *Heteromorpha trifoliata* (parsley tree) and *Protea caffra* (common sugarbush), the former specie only encountered on other Eccca Group outcrops in the region and the latter on sandstone ridges of the Wilgerivier Formation. Due to the variety in rocks, the farm is developed in different production units. The loamy soil of the weathered diabase is used for an orchard and maize irrigation cultivation practices. Land underlain by sandstone of the Wilgerivier Formation is used for cattle grazing and the soil derived from the Karoo sediments is utilised for dry land maize production. The water for irrigation is derived from a local dam, measuring about 50 ha in area.

The following case studies are representative of the Waterberg Group in the Middelburg area, see also Table A1.21(a&b) iv.

38. Bankfontein 264JS



Abbreviation	Geology
Mw	Sandstone
Ed	Shale
di	Diabase
Abbreviation	Soil series
Ea15a	Hutton
Eb16f	Mispah, Rock
Ip15c	Rock
Ip16a	Rock

Figure A1.38. Aerial photograph of Bankfontein 264JS. The blue circle denotes the position of the borehole, the green line the direction of the magnetic profile, the yellow line the direction of the electromagnetic traverse and the yellow line the lay out of the Schlumberger sounding. The area covered by the aerial photograph is indicated by the

lower purple shape in the geological map. Some of the lineaments are indicated by the red lines.

The area surrounding the Olifants River, north of the towns Middelburg and Witbank, is characterised by sandstone terraces, ridges and cliffs. The numerous ridges gives rise to the resemblance of embankments, hence names such as Bankfontein and Bankplaas in the Bankenveld veld type. The vegetation around the Olifants River, gorges, valleys and plains at lower altitudes resemble the savanna biome, as the Bankenveld veld type transforms to the Sourish Mixed Bushveld veld type. The numerous sandstone outcrops of the Wilgerivier Formation are a hindrance for intensive agricultural practices and cultivation of land. As a result most of the area is used for extensive cattle farming, game farms, nature reserves and wilderness areas. This farm hosts the rare *Encephalartos middelburgensis* or Middelburg cycad that is declared as a national monument. The farm Bankfontein 264JS is about 20 km northwest of the town Middelburg.

Due to the various tree species that one can encounter on the farm as a transgression from the Bankenveld to the Sourish Mixed Bushveld veld type occurs, geobotanic prospecting can be done with more ease than in the Bronkhorstspuit area. Superb forests of *Protea caffra* (common sugarbush) can be found on southern slopes and hill tops on this farm. The Sourish Mixed Bushveld veld type hosts tree and shrub species including *Acacia caffra* (common hook-thorn), *A. karroo* (sweet thorn), *A. robusta subsp. robusta* (brack thorn), *Burkea africana* (wild seringa), *Faurea saligna* (Transvaal beech), *Ochna pulchra* (peeling plane), *Pappea capensis* (jacket-plum), *Rhus gueinzii* (thorny karree) and *Ziziphus mucronata* (buffalo-thorn).

39. Bankplaas 239JS

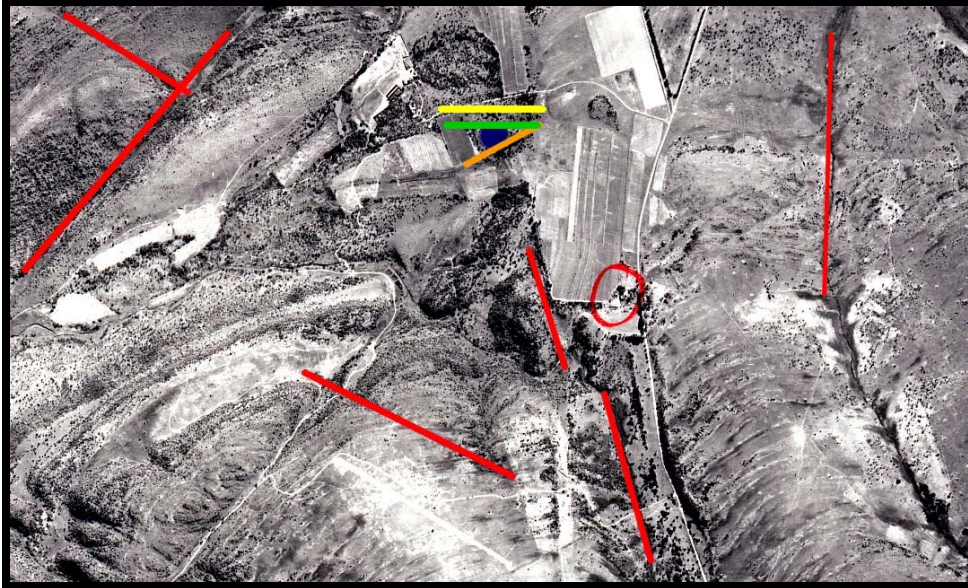


Figure A1.39. Aerial photograph of Bankplaas 239JS. The blue circle denotes the position of the borehole, the green line the direction of the magnetic profile, the yellow line the direction of the electromagnetic traverse and the yellow line the lay out of the Schlumberger sounding. The area covered by the aerial photograph is indicated by the upper purple shape in the geological map (Figure A1.38). Some of the lineaments are indicated by the red lines. Refer to Figure A1.38 for the land type map.

The farm Bankplaas 239JS, or locally referred to as Môrester, is located 30 km northwest of the town Middelburg, close the northern edge of the Wilgerivier Formation basin.

The figure illustrates the geological and soil characteristics of the KwaZulu-Natal coastal plain. It includes a detailed geology map at the top left, an aerial photograph at the top right, and a close-up of a specific site at the bottom left.

Abbreviation	Geology
Vis	Mudstone, rhyolite
Mw	Sandstone
Pd	Shale
di	Diabase

Abbreviation	Soil series
Ba37a	Hutton
Bb16g	Mispah, Rock
Ib15g	Rock

Figure A1.40. Aerial photograph of Buffelskloof 342JS. The blue circle denotes the position of the borehole, the green line the direction of the magnetic profile, the yellow line the direction of the electromagnetic traverse and the yellow line the lay out of the

Schlumberger sounding. The area covered by the aerial photograph is indicated by the right purple shape in the geological map (Figure A1.40).

The farm Buffelskloof 342JS is situated 30 km northeast of the town Middelburg. Temperature conditions are warmer than the area around Middelburg and subsequently Sourish Mixed Bushveld veld type trees occur on this farm and more abundantly and diverse on the neighbouring farm. Agricultural practices are divided into extensive cattle farming in areas underlain by sandstone, which is characterised by numerous sandstone outcrops and the areas underlain by diabase are used for cultivation practices.

41. Goedehoop 244JS

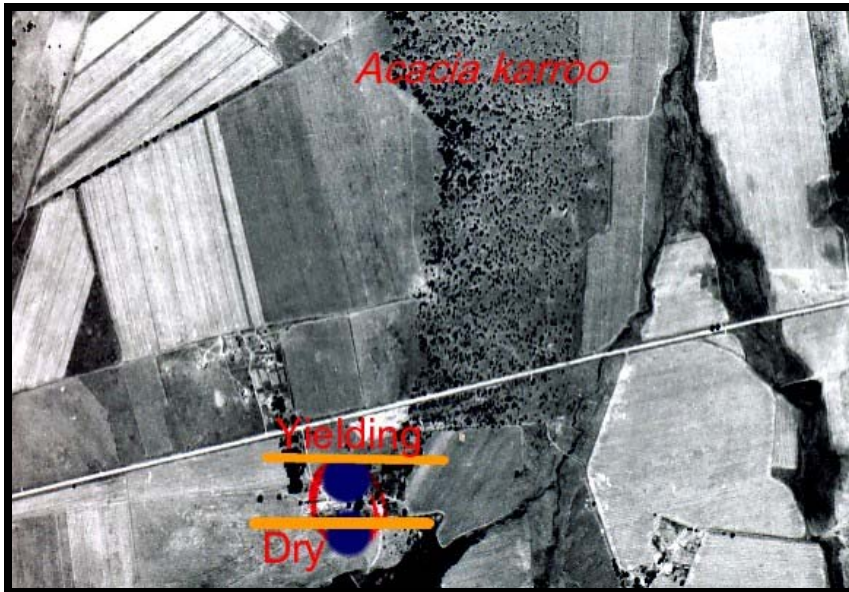


Figure A1.41. Aerial photograph of Goedehoop 244JS. The blue circles denotes the position of the boreholes (dry and yielding) and the yellow line the layout of the Schlumberger sounding. The area covered by the aerial photograph is indicated by the left purple shape in the geological map (Figure A1.40). Refer to Figure A1.40 for the land type map.

Located 22 km north of the town of Middelburg, towards Groblersdal, the farm is one of the most elevated places in the Wilgerivier Formation basin at an altitude above 1 600 meter. Mixed agricultural practices are encountered on this farm, including cattle farming and cultivation of lands.

A1.11 CARBONIFEROUS – PERMIAN EONOTHEMS: SANDSTONE AND SHALE OF THE VRYHEID FORMATION IN THE NIGEL AREA

Vast geological activity came to an end in Southern Africa during the formation of the Karoo Supergroup, which stretches from the Carboniferous Eonothem till the Jurassic Eonothem. This period lasted from 345 Ma to 150 Ma. The Karoo Supergroup covers almost to two-thirds of the South African geological landscape and is prominent in the Freestate and Karoo (Rust & Eriksson, 1996). The Karoo Supergroup consists of sedimentary arenaceous and argillaceous rocks that are frequently intruded by mafic intrusions, like dolerite, and capped by extrusive basalt formations. Some isolated patches of the Karoo Supergroup are located in the northern parts of South Africa as well. This chapter deals with geobotanic indicators associated with the Karoo Supergroup among its various lithological units, namely aquifers associated with the (i) Vryheid (sandstone and shale) Formation, (ii) Irrigasie, Lisbon and Clarens (sandstone, siltstone and shale) Formations and lastly (iii) Letaba (basalt) Formation.

The Vryheid Formation (Ecca Group-Permian Eonothem) and some older outcrops of the Carboniferous – Permian aged Dwyka Formation are exposed on the southern Highveld in the area around Nigel and further to the southeast. The area to the east is recognised for its coal mining activities, although gold mining activities occur around Nigel and towards the west – the Witwatersrand Gold Fields.

A1.11.1 CASE STUDY AREA

Three case studies are discussed in this section. The case studies are situated around Nigel and its zone of influence of activities, like towards Delmas and Greylingstad. Most parts of the area are utilised for the cultivation of crops, although wetland areas and shallow soils are utilised for cattle grazing practices. Situated on the Highveld, most of the plains are covered by indigenous grass species and indigenous shrubs and trees only occurring among some isolated rock outcrops or in areas where rocks belonging to other formations and with different lithologies are exposed. No major drainage features are associated with the presented case studies.

A1.11.2 CLIMATE AND VELD TYPES

The Highveld areas of the northern parts of South Africa are elevated 1200 – 2000 m above sea level, with higher altitudes around Nigel and stretching eastwards. The higher altitude areas are situated on a broad dolerite sill and form the watershed between rivers flowing towards the Atlantic and Indian Oceans. The larger tributaries are permanent, but their flow is very small during winter and spring. Due to the high altitude, winters are dry and cold (continental climate) and summers are wet and warm. Thunderstorms are responsible for bringing rain to these parts of the interior. Climatic information is indicated in Table A1.22. The open grass plains and cold spells during winter time, are the drivers behind the treeless landscape of the Highveld, combined with regular burning through veld fires (controlled and uncontrolled). Consequently the following veld types and trees are evident of this area and grassland biome (Acocks, 1988, Van Oudtshoorn, 1994 & Van Wyk & Van Wyk, 1997):

- Bankenveld on the farm Schoongezicht 225 IR: *Acacia caffra* (common hook-thorn), *Celtis africana* (white stinkwood) and *Protea caffra* (common sugarbush).
- *Cymbopogon-Themeda* veld on the farm Holgatfontein 326 IR: tree and shrub less veld type, dominant grass species include *Cymbopogon plurinodis* (narrow-leaved Turpentine Grass) and *Themeda triandra* (Rooigras).
- *Themeda* veld or Turf Highveld and Bankenveld to Turf Highveld Transition on the farm Leeuwkraal 517 IR: dominated by the grass specie *Themeda triandra* (Rooigras) and general absence of indigenous tree and shrub species.

Geobotanical investigations on the included case studies will indicate other occurring tree species as well and the marker tree species (geobotanic indicators) that can be utilised for groundwater exploration.

Table A1.22. Climatic Data of the Nigel Area (Schulze, 1997 & Johannesburg, 1999).

	Quantity
Average Yearly Temperature (°C)	14-16
Mean Minimum Temperature (°C) in July	0-2
Mean Maximum Temperature (°C) in January	25.0-27.5
Average Yearly Rainfall (mm)	600-800
Elevation (m)	1200-2000
Evaporation (mm/year)	2000-2250
Frost area?	150-175 days per year

A1.11.3 GEOLOGY AND HYDROGEOLOGICAL CLASSIFICATION

Generally speaking, the entire study area is covered with rocks belonging to the Vryheid Formation of the Eccca Group, Karoo Supergroup. The Vryheid Formation consists of sandstone, shale and coal beds (East Rand, 1986). The rocks belonging to the Vryheid Formation display not any structural deformation on a large scale and are basically horizontal in layering. Vegter & Ellis (1968) made a detailed study of aquifer conditions and borehole siting in this area, and their findings and views are expressed hereunder.

The Karoo Supergroup which is represented by the two lowermost formations, the Dwyka Formation and the Eccca Group, rests unconformably and more or less horizontally on rocks of the Transvaal Sequence, Ventersdorp Supergroup, Witwatersrand Supergroup and Archaean granite and schist. The basal beds of the Karoo Supergroup, which are nowhere exposed, consist, according to boreholes, of tillite, sandstone, siltstone and shale of the Dwyka Formation. These beds reach a thickness of 30 m in places and are absent in others.

The Lower Eccca Group Stage is either absent or very poorly developed, in which case it consists of sandy and black shale. The Middle Eccca Group Stage is 150 to 250 m thick and comprises mostly sandstone and grit which alternate with sandy and micaceous shale and carry several coal seams. Outliers of the Upper Eccca Group Stage, which consists of blue to dark-grey, black and yellowish shales are formed around Standerton

(Volksrust Formation) where the greatest thickness penetrated in prospecting boreholes for coal is 45 meters.

Dykes and sills of dolerite and olivine dolerite have intruded the Eccca Group. Metamorphism of the country-rock by these intrusions is limited to recrystallisation of sandstone and conversion of shale to hornfels close to the intrusive contact. Microscopic examination of samples of weathered dolerite and olivine dolerite showed that the order of alteration of minerals is olivine, which changes to chlorite; and lastly feldspar (Vegter & Ellis, 1968). Spheroidal and columnar weathering of dolerite has been observed. Dykes, intensely jointed parallel and perpendicular to their contacts, weather to small oblong pieces of dolerite.

Porosities of 7 to 12.8% can be assigned to weathered sandstone beds, whereas the porosity of unweathered sandstone and shale of the Eccca Group is in the order of 2% that can increase to 12% in the case of fractures and large bedding planes (Vegter & Ellis, 1968). The permeability of fracture-free Eccca Group sedimentary rocks is too low for them to yield meaningful supplies of water in boreholes. Dolerite is neither porous nor permeable unless fractured and weathered. In the formation of aquifers, tectonic movements, intrusion of dolerite and processes of weathering have all played a part. Water-yielding structures are the following:

- Weathered and fractured sedimentary rocks not associated with dolerite intrusions.
- Indurated and jointed sedimentary rocks alongside dykes.
- Narrow weathered and fractured dolerite dykes.
- Basins of weathering in dolerite sills and highly jointed sedimentary rocks enclosed by dolerite.
- Weathered and fractured upper contact-zones of dolerite sills.
- Weathered and fractured lower contact-zones of dolerite sills.

According to the Johannesburg (1999) hydrogeological map and corresponding to the work of Vegter & Ellis (1968), the yield of aquifers in the area vary from 360 – 1800 l/h to 1800 – 7200 l/h, depending on the existing geological conditions. Aquifers are classified as intergranular and fractured in a predominantly arenaceous rock environment in association with ultramafic/mafic extrusive rock (andesite) and ultramafic/mafic intrusive rocks (dolerite).

A1.11.4 GEOPHYSICAL AND GEOBOTANICAL INFORMATION

The work of Vegter & Ellis (1968) present and discuss a number of direct current resistivity soundings and magnetometer profiles in the study area. Successful boreholes' (average yield up to 7200 l/h) aquifer resistivity is between 50 – 185 Ω .m. and corresponds favourably with the results presented by Meulenbeld (1998), where the modelled aquifer resistivity value is below 100 Ω .m. and boreholes are not deeper than 85 m on average. Other geophysical work is available as confidential reports issued to mines in the area and these sources won't be referenced. From the geophysical work available, published and unpublished, it is clear that the magnetic method is of superior value due to the numerous dolerite intrusions in the area. Electromagnetic profiling is an aid to establish weathered contact zones along an intrusion. The utilisation of the electromagnetic method over areas of weathered, clayey sedimentary material is not advocated as the clay restricts signal penetration to deeper layers as it is a conductor and erroneous interpretations can be made. Schlumberger depth soundings can be a valuable tool in the presence of weathering basins and lateral sedimentary layers intruded or not by dolerite.

Geobotanical indicators of the area listed by Meulenbeld (1998) include only two species, one tree and one grass specie; *Acacia karroo* (sweet thorn) and *Fingerhuthia sesleriiformis* (thimble grass). Kent and Enslin (1965) and Vegter and Ellis (1968) point out the relevance of the specie *Fingerhuthia sesleriiformis* as a geobotanic indicator. Due to the climatic conditions of the area, regular burning of veld and gently undulating nature of the tufted grassy plains of the area, trees and shrubs do not occur frequently compared to the previous case studies. The included case studies will, although, include some tree and shrub species that occur as a result of changes in geology.

A1.11.5 SOIL SAMPLING AND RESULTS PRESENTATION

Soil sampling compares to the already included and mentioned case studies. Soil samples were analysed for available cations and nutrients in addition to pH, resistance and a few other parameters. Soil samples were taken at depths of 0.5 and 1.2 m respectively at the site of the borehole and geobotanical indicator and the remaining

sample some distance removed from it, not near such a geobotanical indicator. This section deals with three case studies, Table A1.23(a&b).

Table A1.23 (a). Carboniferous - Jura Eonothems: Vryheid Formation - Nigel Area: along intrusive contact.

Parameter	Holgatfontein 326IR		Leeuwkraal 517IR		Schoongezicht 225IR	
Geological Formation	Dolerite intrusion among Vryheid Formation rocks	Dolerite intrusion among Vryheid Formation rocks	Basalt/Dolerite intrusions among Vryheid Formation rocks	Basalt/Dolerite intrusions among Vryheid Formation rocks	Buried diabase (Vaalium age) under the Vryheid Formation	Buried diabase (Vaalium age) under the Vryheid Formation
Depth Sampled	0.5m	1.2m	0.5m	1.2m	0.5m	1.2m
Borehole Co-ordinates:						
S.L.	26°24.058'	26°24.058'	26°37.438'	26°37.438'	26°05.639'	26°05.639'
E.L.	28°32.271'	28°32.271'	28°44.250'	28°44.250'	28°48.343'	28°48.343'
Soil colour	Greyish red	Dark grey	Dark grey	Blackish red	Moderate brown	Dark yellowish orange
Soil texture description	Clay	Clay	Clay	Clay	Silty clay	Silty clay
pH	6.39	6.79	6.47	6.56	5.62	5.73
P (mg/kg)	8.33	2.62	3.24	1.86	0.96	0.48
Ca (mg/kg)	2166	1980	1442	1844	1320	2302
Mg (mg/kg)	774	697	521	669	835	1368
K (mg/kg)	186	151	166	97	89	136
Na (mg/kg)	62	47	17	20	37	62
Fe (mg/kg)	223.36	329.13	112.46	123.76	104.27	177.63
Mn (mg/kg)	288.22	246.87	285.07	253.21	248.65	407.54
Zn (mg/kg)	2.33	1.11	1.40	1.29	0.41	1.41
Al (cmol _c /kg)	0	0	0.095	0.086	0.086	0.198
Resistance (Ohm)	1400	2000	1400	1600	1600	1600

C%	1.28	1.12	1.48	1.34	0.42	0.23
Total N%	0.069	0.068	0.088	0.079	0.040	0.029
S (mg/kg)	8.46	6.70	12.04	16.70	144.78	66.16
CEC (cmol _c /kg)	20.94	18.15	14.510	18.248	28.691	28.430
Distinct Tree Species	Acacia karroo	Acacia karroo	1.Acacia karroo 2.Euclea crispa	1. Acacia karroo 2. Euclea crispa	Acacia karroo (<i>Fingerhuthia sesleriiformis</i>)	Acacia karroo (<i>Fingerhuthia sesleriiformis</i>)
Average rooting depth of the indicated species (m)	50	50	4 - 50	4 - 50	2 - 50	2 – 50
Average depth of weathering (m)	2.2	2.2	1.8	1.8	2.5	2.5
Geomorphology	Plain with a hill	Plain with a hill	Plain and hills	Plain and hills	Plain	Plain
Geophysical instrumentation used	Electromagnetics & Magnetism	Electromagnetics & Magnetism	Electromagnetics & Magnetism	Electromagnetics & Magnetism	Electromagnetics, Magnetism & Schlumberger soundings	Electromagnetics, Magnetism & Schlumberger soundings
Water features present?	Yes-small stream and wetland	Yes-small stream and wetland	No	No	Yes-wetland	Yes-wetland
Aquifer Yield (l/h)	7 000	7 000	6 800	6 800	9 000	9 000
Borehole Depth (m)	60	60	65	65	90	90
Depth of Water Strike (m)	26	26	23	23	65	65
Static Water Level (m)	6	6	11	11	9	9

Average Aquifer Yield (l/h)	2 400	2 400	2 400	2 400	2 400	2 400
Average Borehole Depth (m)	52	52	52	52	52	52
Average Depth of Water Strike (m)	29	29	29	29	29	29
Average Static Water Level (m)	11	11	11	11	11	11
Land Type Series	Bb19a Avalon	Bb19a Avalon	Ea20b Arcadia	Ea20b Arcadia	Ba5f Hutton	Ba5f Hutton
Profile No	P136	P136	P124	P124	P154	P154
Depth Sampled	640 – 1200 mm	640 – 1200 mm	760 – 100 mm	760 – 100 mm	600 – 1050 mm	600 – 1050 mm
Gravel %	2	2	1	1	0	0
Sand %	55	55	51	51	52	52
Silt %	6	6	11	11	4	4
Clay %	37	37	37	37	44	44
pH (H ₂ O)	8.8	8.8	5.5	5.5	6.3	6.3
P (mg/kg)	0.3	0.3	0.3	0.3	0.8	0.8
Ca (mg/kg)	1180	1180	1495	1495	920	920
Mg (mg/kg)	864	864	996	996	504	504
K (mg/kg)	78	78	39	39	156	156
Na (mg/kg)	621	621	69	69	207	207
Fe (mg/kg)	-	-	-	-	-	-
Mn (mg/kg)	175.2	175.2	218.93	218.93	133.3	133.3
Zn (mg/kg)	0.00	0.00	0.63	0.63	0.00	0.00
Resistance (Ohm)	360	360	5300	5300	360	360
C%	0.1	0.1	0.3	0.3	0.2	0.2

CEC (cmol _c /kg)	179	179	51	51	122	122
Veld Type	48 <i>Cymbopogon- Themeda</i> veld	48 <i>Cymbopogon- Themeda</i> veld	52/55 <i>Themeda</i> veld or Turf Highveld and Bankenveld	52/55 <i>Themeda</i> veld or Turf Highveld and Bankenveld	61 Bankenveld	61 Bankenveld
Hydrogeological Unit	D2	D2	D2/D3	D2/D3	D2	D2

Information obtained from the veld type maps from Acocks (1988) and hydrogeological information from DWAF: Johannesburg (1999). Soil colour was identified and classified in the veld according to the Corstor Colour Gauge that lists 168 different soil colours. Geohydrological parameters were derived from Frommurze (1937), Vegter & Ellis (1968) and Meulenbeld (1998). Information obtained from the land type maps and accompanying memoir is from Land Type Survey Staff (1985). Average weathering depth is extracted from the indicated Land Type Survey Staff and average rooting depth of the geobotanical indicators is referenced from Canadell *et al.* (1996).

Table A1.23 (b). Carboniferous - Jura Eonothems: Vryheid Formation - Nigel Area: intrusive contact absent.

Parameter	Holgatfontein 326IR		Leeuwkraal 517IR		Schoongezicht 225IR	
Geological Formation	Dolerite intrusion among Vryheid Formation rocks	Dolerite intrusion among Vryheid Formation rocks	Basalt/Dolerite intrusions among Vryheid Formation rocks	Basalt/Dolerite intrusions among Vryheid Formation rocks	Buried diabase (Vaalium age) under the Vryheid Formation	Buried diabase (Vaalium age) under the Vryheid Formation
Depth Sampled	0.5m	1.2m	0.5m	1.2m	0.5m	1.2m
Borehole Co-ordinates:						
S.L.	26°24.058'	26°24.058'	26°37.438'	26°37.438'	26°05.639'	26°05.639'
E.L.	28°32.271'	28°32.271'	28°44.250'	28°44.250'	28°48.343'	28°48.343'
Soil colour	Weak red	Greyish brown	Light brown	Light brown with laterite inclusions	Light brown	Dark red
Soil texture description	Sandy silt	Sandy silt	Silty sand	Silty sand	Silty sand	Clay
pH	5.19	5.10	4.54	4.93	6.27	5.01
P (mg/kg)	2.43	2.39	6.45	2.97	3.69	2.36
Ca (mg/kg)	647	667	148	187	200	472
Mg (mg/kg)	233	259	52	62	69	292
K (mg/kg)	138	192	95	79	63	29
Na (mg/kg)	58	30	11	13	10	29
Fe (mg/kg)	225.18	190.25	28.47	24.06	14.80	62.18
Mn (mg/kg)	141.76	173.77	7.77	13.65	44.91	204.81
Zn (mg/kg)	1.51	1.55	0.56	0.44	0.77	0.34

Al (cmol _c /kg)	0.347	0.400	1.106	0.715	0.100	0.409
Resistance (Ohm)	2000	2400	3000	3600	5200	2390
C%	2.52	2.66	0.62	0.63	0.42	0.27
Total N%	0.176	0.181	0.049	0.049	0.027	0.018
S (mg/kg)	54.36	43.47	88.36	78.29	22.95	9.23
CEC (cmol _c /kg)	9.52	10.56	8.928	7.861	5.452	19.19
Distinct Tree Species	1. Acacia karroo	1. Acacia karroo	1. Acacia karroo 2. Euclea crispa	1. Acacia karroo 2. Euclea crispa	1. Acacia karroo (<i>Fingerhuthia sesleriiformis</i>)	1. Acacia karroo (<i>Fingerhuthia sesleriiformis</i>)
Average rooting depth of the indicated species (m)	50	50	4 - 50	4 - 50	2 - 50	2 – 50
Average depth of weathering (m)	2.2	2.2	1.8	1.8	2.5	2.5
Geomorphology	Plain with a hill	Plain with a hill	Plain and hills	Plain and hills	Plain	Plain
Geophysical instrumentation used	Electromagnetics & Magnetics	Electromagnetics & Magnetics	Electromagnetics & Magnetics	Electromagnetics & Magnetics	Electromagnetics, Magnetics & Schlumberger soundings	Electromagnetics, Magnetics & Schlumberger soundings
Water features present?	Yes-small stream and wetland	Yes-small stream and wetland	No	No	Yes-wetland	Yes-wetland
Aquifer Yield (l/h)	7 000	7 000	6 800	6 800	9 000	9 000
Borehole Depth (m)	60	60	65	65	90	90
Depth of Water Strike (m)	26	26	23	23	65	65

Static Water Level (m)	6	6	11	11	9	9
Average Aquifer Yield (l/h)	2 400	2 400	2 400	2 400	2 400	2 400
Average Borehole Depth (m)	52	52	52	52	52	52
Average Depth of Water Strike (m)	29	29	29	29	29	29
Average Static Water Level (m)	11	11	11	11	11	11
Land Type Series	Bb19a Avalon	Bb19a Avalon	Ea20b Arcadia	Ea20b Arcadia	Ba5f Hutton	Ba5f Hutton
Profile No	P136	P136	P124	P124	P154	P154
Depth Sampled	640 – 1200 mm	640 – 1200 mm	760 – 100 mm	760 – 100 mm	600 – 1050 mm	600 – 1050 mm
Gravel %	2	2	1	1	0	0
Sand %	55	55	51	51	52	52
Silt %	6	6	11	11	4	4
Clay %	37	37	37	37	44	44
pH (H ₂ O)	8.8	8.8	5.5	5.5	6.3	6.3
P (mg/kg)	0.3	0.3	0.3	0.3	0.8	0.8
Ca (mg/kg)	1180	1180	1495	1495	920	920
Mg (mg/kg)	864	864	996	996	504	504
K (mg/kg)	78	78	39	39	156	156
Na (mg/kg)	621	621	69	69	207	207
Fe (mg/kg)	-	-	-	-	-	-
Mn (mg/kg)	175.2	175.2	218.93	218.93	133.3	133.3

Zn (mg/kg)	0.00	0.00	0.63	0.63	0.00	0.00
Resistance (Ohm)	360	360	5300	5300	360	360
C%	0.1	0.1	0.3	0.3	0.2	0.2
CEC (cmol _e /kg)	179	179	51	51	122	122
Land Type Series	No Data	No Data	No Data	No Data	No Data	No Data
Profile No	No Data	No Data	No Data	No Data	No Data	No Data
Veld Type	48 <i>Cymbopogon- Themeda</i> veld	48 <i>Cymbopogon- Themeda</i> veld	52/55 <i>Themeda</i> veld or Turf Highveld and Bankenveld	52/55 <i>Themeda</i> veld or Turf Highveld and Bankenveld	61 Bankenveld	61 Bankenveld
Hydrogeological Unit	D2	D2	D2/D3	D2/D3	D2	D2

Information obtained from the veld type maps from Acocks (1988) and hydrogeological information from DWAF: Johannesburg (1999). Soil colour was identified and classified in the veld according to the Corstor Colour Gauge that lists 168 different soil colours. Geohydrological parameters were derived from Frommurze (1937), Vegter & Ellis (1968) and Meulenbeld (1998). Information obtained from the land type maps and accompanying memoir is from Land Type Survey Staff (1985). Average weathering depth is extracted from the indicated Land Type Survey Staff and average rooting depth of the geobotanical indicators is referenced from Canadell *et al.* (1996).

42. Holgatfontein 326IR

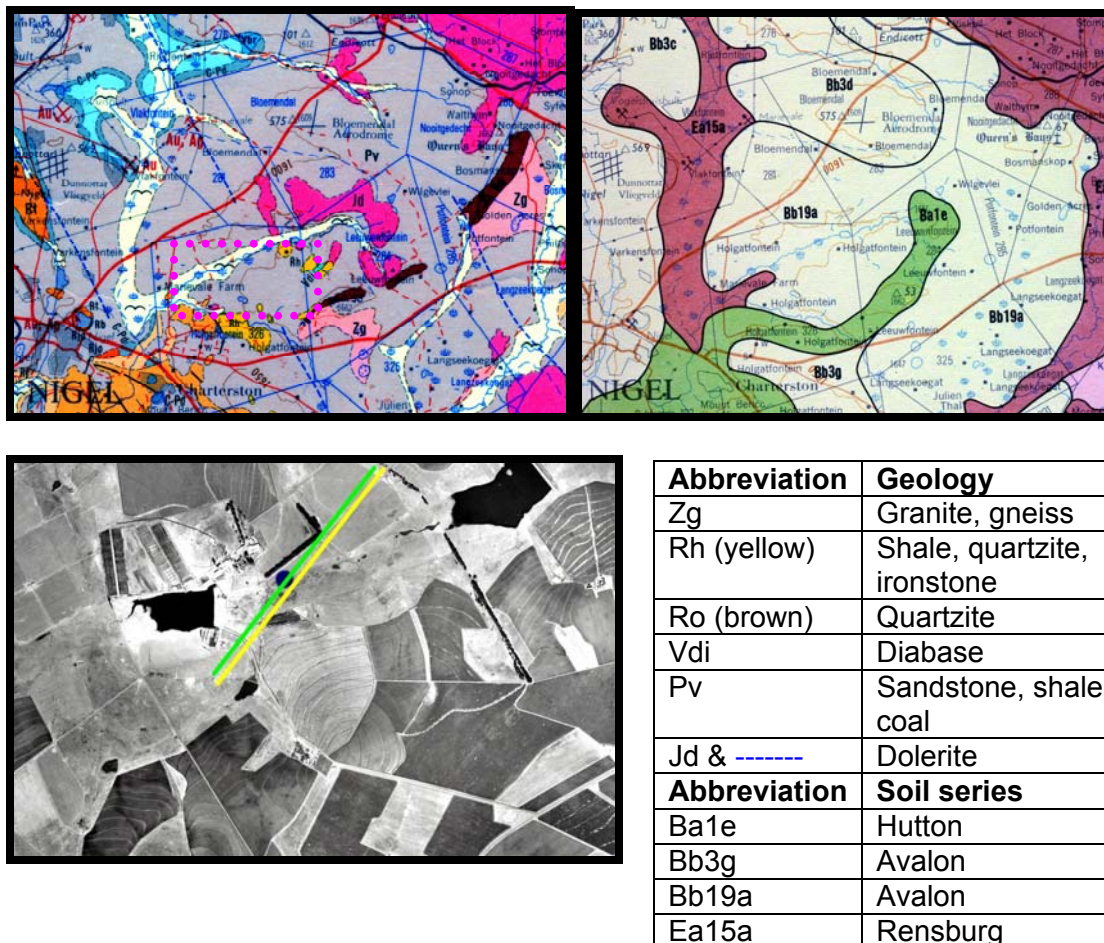


Figure A1.42. The geology (top left), land type (top right) and aerial photograph (bottom) of Holgatfontein 326IR. The blue circle denotes the position of the borehole and the green and yellow lines the direction of the (electro)-magnetic profiles. The area covered by the aerial photograph is indicated by the purple shape in the geological map.

About 12km northeast of Nigel, the farm Holgatfontein 326IR is located. To the northwest of the farm gold mining is taking place on an outcrop of the Malmani Subgroup (Chuniespoort Group, Transvaal Sequence). The gold mine is discharging underground water in the Blesbok Spruit and creates an artificial wetland. The impact of the gold mining activities on the Karoo aquifers on this farm is considered to be insignificant as the Karoo overburden does not outcrop at the mining area and therefore the aquifer's boundaries are confined to the sedimentary rocks of the Karoo Supergroup. Note that the weathered dolerite in the upper part of the land type map defines Rensburg

soil series. Where the Rensburg soil series occur in the southwestern parts of the land type map, this is due to the presence of dolerite, although not mapped as such on the geological map, but rather covered by alluvium. Geophysical profiles indicate the presence of dolerite under the alluvium at Holgatfontein 326IR.

43. Leeuwkraal 517IR

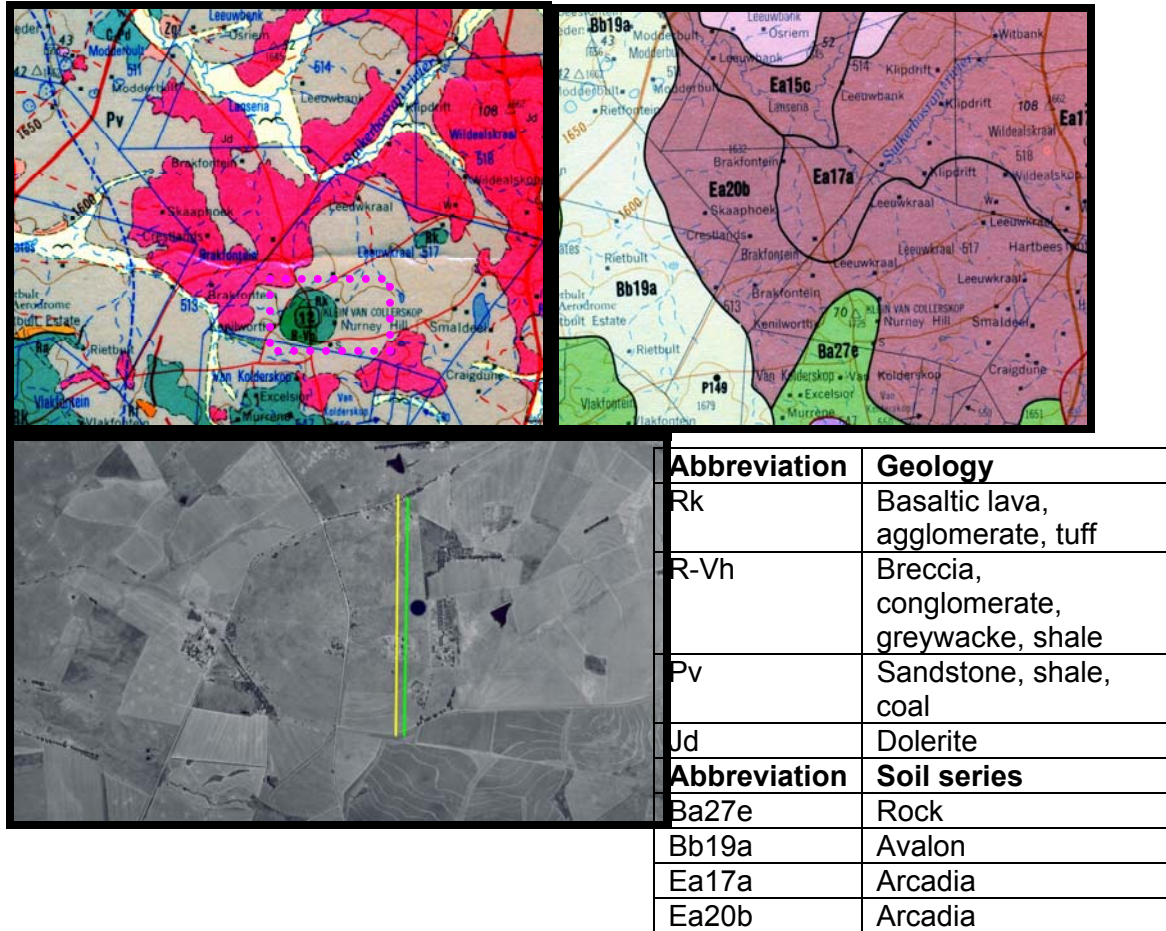


Figure A1.43. The geology (top left), land type (top right) and aerial photograph (bottom) of Leeuwkraal 517IR. The blue circle denotes the position of the borehole and the green and yellow lines the direction of the (electro)-magnetic profiles. The area covered by the aerial photograph is indicated by the purple shape in the geological map.

Leeuwkraal 517IR, about 18 km northeast of Balfour, agricultural practices include maize production and extensive beef cattle farming practices.

44. Schoongezicht 225IR

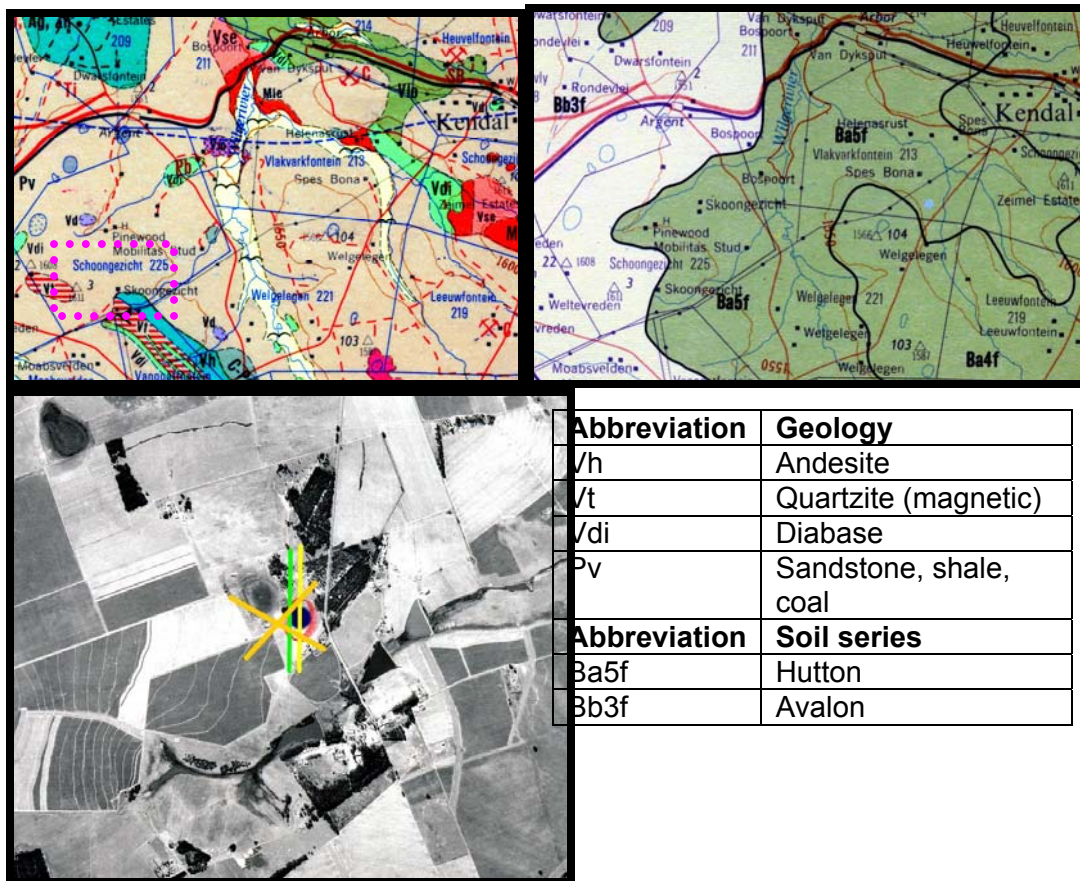


Figure A1.44. The geology (top left), land type (top right) and aerial photograph (bottom) of Schoongezicht 225IR. The blue circle denotes the position of the borehole and the green and yellow lines the direction of the (electro)-magnetic profiles. The various soundings are indicated by the orange lines. The area covered by the aerial photograph is indicated by the purple shape in the geological map.

Being part of the Bankenveld veld type, the farm does not pose the characteristic Bankenveld topography as found in the Wilgerivier Formation area, north of Bronkhorstspuit and Middelburg (Chapter 4), where terraces and ridges are common and hosting a variety of trees and shrubs. The farm Schoongezicht 225IR poses rather a flat, plain topography with some small rock outcrops and local depressions are saturated with water. Most of the natural veld is damaged by agricultural practices for crop production, although some areas are still in its natural condition due to the presence of some rock outcrops.

A1.12 PERMIAN – TRIASSIC EONOTHEMS: ARENACEOUS AND ARGILLACEOUS ROCKS OF THE IRRIGASIE, LISBON AND CLARENS FORMATIONS OF THE KAROO SUPERGROUP IN THE MABULA-WATERBERG AREA

Outcrops of the Karoo Supergroup occur in isolated parts in different regions of the northern parts of South Africa. This section deals with arenaceous and argillaceous rocks (sandstone, grit, siltstone, mudstone and shale) of the Irrigasie, Lisbon and Clarens Formations of the Karoo Supergroup in the area around Mabula and the Waterberg Mountains in the vicinity of Ellisras. These formations were deposited during the Permian-Triassic Eonothems. One feature of the rocks belonging to these formations is that intrusive bodies are rare and structural faulting or fracturing might be more of a norm.

A1.12.1 CASE STUDY AREA

The area southwest of Mabula, between Warmbaths and Thabazimbi, is a flat Bushveld country with occasional hills. Due to the flat terrain, no major drainage structures cross this area. The loamy soils are beneficial for agricultural crop production activities, but groundwater quantity is a concern in certain areas. Numerous farms are used for extensive beef cattle farming and game farming purposes, mainly due to the Bushveld character of the area. The Mabula area hosts two case studies. The remaining case study is located to the north of the Waterberg plateau, east of Ellisras in the Limpopo province.

A1.12.2 CLIMATE AND VELD TYPES

In areas where Bushveld vegetation grows (savanna biome), the climate is mild and even warm to sustain vegetation, as cold spells and winds are destructive powers regarding tree growth and development. The elevation of the area is also lower than the Highveld, as the area is situated 800 – 1200 m above sea level. Winter months are mostly dry and cool, and the summer months are warm and wet with most rainfall occurring as thunderstorms, characteristic of the continental climatic conditions. The rainfall is, however, less than on the Highveld (Table A1.24). Veld types associated within this kind of climatic conditions are (Acocks, 1988 & Van Wyk & Van Wyk, 1997):

- Mixed Bushveld (Waterberg area): *Acacia caffra* (common hook-thorn), *Combretum apiculatum* (red bushwillow), *C. imberbe* (leadwood), *Dichrostachys cinerea* (sickle bush), *Grewia flava* (velvet raisin), *Lannea discolor* (live-long) and *Sclerocarya birrea* subsp. *caffra* (marula).
- Sourish Mixed Bushveld (Mabula area): *Acacia caffra* (common hook-thorn), *A. karroo* (sweet thorn), *A. robusta* subsp. *robustu* (brack thorn) & *A. tortillis* subsp. *heteracantha* (umbrella thorn), *Pappea capensis* (jacket-plum), *Peltophorum africanum* (weeping wattle), *Rhus gueinzii* (thorny karree), *Sclerocarya birrea* subsp. *caffra* (marula) and *Ziziphus mucronata* (buffalo-thorn).

The above-mentioned tree species are frequently found in the veld and their use as geobotanical indicators must only be done with extreme caution through frequency of occurrence and circumscribe mapping.

Table A1.24. Climatic Data of the Mabula-Waterberg Area (Schulze, 1997 & Polokwane, 2003).

	Quantity
Average Yearly Temperature (°C)	18 – 20
Mean Minimum Temperature (°C) in July	2 - 4
Mean Maximum Temperature (°C) in January	30.0 – 32.5
Average Yearly Rainfall (mm)	400 – 600
Elevation (m)	800 – 1200
Evaporation (mm/year)	2250 – 2500
Frost area?	No frost

A1.12.3 GEOLOGY AND HYDROGEOLOGICAL CLASSIFICATION

Three different geological formations occur in the presented case study area. The area around Mabula is covered with rocks from the Permian-Triassic Irrigasie Formation (sandstone, grit, mudstone, siltstone, marl, shale and sporadic sand layers) and Triassic Clarens Formation (fine-grained red to cream sandstone) according to the Nylstroom (1978) geological map. In the Mabula area a large post-Karoo fault-system with a

downtthrow up to 300 m to the south bounds the basin (Nylstroom, 1978). This fault zone runs parallel with the main road from Warmbaths to Thabazimbi and is therefore a difficult groundwater exploration target as it is outside the farm boundaries. Most outcrops are arenaceous rocks, as well in the Waterberg area, where the farm Newcastle 202LQ is positioned. The Lisbon and Clarens Formations (Triassic Eonothem) of the Karoo Sequence occur on this farm, where a localised east-west trending fault separates the two formations. The Lisbon Formation has a constant thickness of 100 to 110 m. The formation comprises a succession of dominantly red massive mudstone with siltstone, and minor silty sandstone and medium- to coarse-grained sandstone with pebble washes. The succession is characterised by cyclically repeated units (five to ten meters thick) consisting of thin sandstone at the base, grading into siltstone or mudstone. The basal contacts of individual units are generally sharp. The Clarens Formation attains a maximum thickness of 130 m. Unlike most of the other formations, rocks of the Clarens Formation form prominent hills or ridges in parts of the Ellisras area. In general, however, most of the area underlain by the Clarens Formation is characterised by fine-grained, light-coloured sand. The formation is composed almost entirely of sandstone which is generally massive, well sorted and fine grained. Medium- to coarse-grained units and thin pebbly horizons are locally developed. The contact between the Clarens Formation and the underlying Lisbon Formation is gradational. The rock is mostly cream coloured or off-white, with a light pink colour occurring locally. The sandstone consists almost entirely of quartz grains which are well rounded. Locally some feldspar grains may be present, and some calcareous concretions occur in its lower part (Brandl, 1996).

Aquifers that can be expected in this geological setting are mostly aquifers due to the existence of two-dimensional weathering, like joints, fractures and fault zones (Hattingh, 1996). Bedding planes as present in arenaceous rocks might also act as an aquifer. The hydrogeological map of Polokwane (2003) classifies the aquifers in the Mabula geological setting as intergranular and fractured in an arenaceous and argillaceous rock environment with a yield of 1800 – 7200 l/h. The Lisbon and Clarens Formations north of the Waterberg are classified as predominantly argillaceous rock that hosts fractured aquifers with a yield of 360 – 1800 l/h.

A1.12.4 GEOPHYSICAL AND GEOBOTANICAL INFORMATION

Information on geophysical studies, relating to the magnetic, electromagnetic and Schlumberger methods, of this area is scarce. A publication by the CSIR (Van Zijl, 1978) presenting results of the Settlers basalt area to the east of the case studies indicate the thickness of the Karoo sediments (predominantly the Clarens Formation) to be around 300 meters. Schlumberger sounding curves obtained (a total of 26) by the study of Van Zijl (1978) are of the four-layered KH-shape, indicating a resistive overburden and conductor in depth. The apparent resistivity of the sediments is between 12-33 Ω .m. and the apparent resistivity of the pre-Karoo floor rocks in excess of 5000 Ω .m., although no Schlumberger depth soundings are presented in this section as the exploration targets were fracture and fault zones that require geophysical profiling techniques for proper definition of the structures, and the dense vegetation limited ordinary usage and accuracy of sounding methods.

To obtain the significance of geobotanical indicators around this area in literature is a fruitless exercise. Geobotanical indicators as listed under the previous case studies will be included. Furthermore, a source of information is local farmers that can provide information once the concept of geobotanical indicators and the presence of termitaria are discussed with them. Although briefly included in the case studies as the locality was never drilled regarding groundwater supply, the area northwest of Marble Hall is situated on Karoo sediments and according to local farmers the tree specie *Boscia foetida* subsp. *rehmanniana* (stink shepherd's tree) is associated with linear termitaria. The linear pattern can be possibly linked to intrusive linear structures in the sub-surface, but has to be confirmed with further research. The species *Boscia albitrunca* (shepherd's tree) and *B. foetida* subsp. *rehmanniana* are sometimes encountered in the study area, but it was not regarded as a geobotanical indicator in the Mabula-Waterberg area thus far.

A1.12.5 SOIL SAMPLING AND RESULTS PRESENTATION

To establish the importance and linkage of soil nutrients, weathered intrusive rocks, aquifers and botanic species, soil samples were taken at depths of 0.5 m and 1.2 meters. The soil chemical analytic results of the three case studies are presented in Table A1.25 (a&b), with the discussion of the case studies thereafter.

Table A1.25 (a). Carboniferous - Jura Eonothems: Irrigasie, Lisbon & Clarens Formations – Mabula-Waterberg Area: along fracture and/or fault contact zone.

Parameter	Droogesloot 476KR		Grootfontein 528KQ		Newcastle 202LQ	
Geological Formation	Fracture among Clarens Formation rocks	Fracture among Clarens Formation rocks	Fracture among Irrigasie Formation rocks	Fracture among Irrigasie Formation rocks	Fault zone along Lisbon and Clarens Formations	Fault zone along Lisbon and Clarens Formations
Depth Sampled	0.5m	1.2m	0.5m	1.2m	0.5m	1.2m
Borehole Co-ordinates: S.L. E.L.	24°54.177' 28°01.823'	24°54.177' 28°01.823'	24°51.354' 27°58.931'	24°51.354' 27°58.931'	23°28.514' 27°53.036'	23°28.514' 27°53.036'
Soil colour	Strong brown	Yellowish brown	Olive brown	Moderate brown	Moderate brown	Dark yellowish orange
Soil texture description	Silt	Loam	Sand	Sand	Loam	Sand
pH	8.23	8.60	7.96	8.29	7.91	7.46
P (mg/kg)	5.89	4.37	12.61	11.98	1.41	1.30
Ca (mg/kg)	5243	4390	5189	6747	2688	3475
Mg (mg/kg)	201	129	616	879	400	490
K (mg/kg)	323	138	162	225	113	256
Na (mg/kg)	29	27	35	59	35	16
Fe (mg/kg)	2.35	2.68	11.77	11.07	69.36	44.47
Mn (mg/kg)	36.08	36.44	47.60	42.50	224.29	176.14
Zn (mg/kg)	0.52	0.33	0.31	0.55	0.53	0.84
Al (cmol _c /kg)	0	0	0	0	0	0
Resistance (Ohm)	2000	2400	2400	2000	2000	800

C%	0.24	0.13	0.14	0.25	0.16	0.48
Total N%	0.035	0.023	0.077	0.021	0.014	0.044
S (mg/kg)	6.94	5.42	8.38	9.57	5.34	5.77
CEC (cmol/kg)	10.39	12.00	20.141	23.116	21.44	16.45
Distinct Tree Species	1. Rhus lancea 2. Strychnos pungens	1. Rhus lancea 2. Strychnos pungens	1. Rhus lancea 2. Strychnos pungens	1. Rhus lancea 2. Strychnos pungens	1. Combretum imberbe 2. Ficus ingens	1. Combretum imberbe 2. Ficus ingens
Average rooting depth of the indicated species (m)	4 - 13	4 - 13	4 - 13	4 - 13	12 - 20	12 - 20
Average depth of weathering (m)	2.8	2.8	2.8	2.8	3.0	3.0
Geomorphology	Plain	Plain	Plain with a hill	Plain with a hill	Plain	Plain
Geophysical instrumentation used	Electromagnetics	Electromagnetics	Electromagnetics & Magnetics	Electromagnetics & Magnetics	Electromagnetics & Magnetics	Electromagnetics & Magnetics
Water features present?	Yes-small stream "Karee Spruit"	Yes-small stream "Karee Spruit"	Yes-small stream "Riet Spruit"	Yes-small stream "Riet Spruit"	No	No
Aquifer Yield (l/h)	6 000	6 000	5 000	5 000	4 500	4 500
Borehole Depth (m)	75	75	65	65	70	70
Depth of Water Strike (m)	33	33	30	30	36	36
Static Water Level (m)	17	17	14	14	20	20
Average Aquifer Yield (l/h)	3 300	3 300	3 300	3 300	2 300	2 300
Average Borehole Depth (m)	60	60	60	60	69	69

Average Depth of Water Strike (m)	37	37	37	37	44	44
Average Static Water Level (m)	23	23	23	23	26	26
Land Type Series	Ae18b Hutton	Ae18b Hutton	Ae95c Hutton	Ae95c Hutton	Ah85a Hutton	Ah85a Hutton
Profile No	P1379	P1379	P1379	P1379	P1447	P1447
Depth Sampled	300 – 700 mm	300 – 700 mm	300 – 700 mm	300 – 700 mm	450 – 800 mm	450 – 800 mm
Gravel %	1	1	1	1	1	1
Sand %	48	48	48	48	51	51
Silt %	7	7	7	7	9	9
Clay %	44	44	44	44	39	39
pH (H ₂ O)	6.5	6.5	6.5	6.5	7.3	7.3
P (mg/kg)	2.8	2.8	2.8	2.8	1.6	1.6
Ca (mg/kg)	780	780	780	780	2910	2910
Mg (mg/kg)	360	360	360	360	520	520
K (mg/kg)	78	78	78	78	250	250
Na (mg/kg)	23	23	23	23	23	23
Fe (mg/kg)	-	-	-	-	-	-
Mn (mg/kg)	250.5	250.5	250.5	250.5	211.5	211.5
Zn (mg/kg)	0.31	0.31	0.31	0.31	0.62	0.62
Resistance (Ohm)	1600	1600	1600	1600	1000	1000
C%	0.5	0.5	0.5	0.5	0.4	0.4
CEC (cmol _c /kg)	72	72	72	72	63	63

Veld Type	19 Sourish Mixed Bushveld	19 Sourish Mixed Bushveld	19 Sourish Mixed Bushveld	19 Sourish Mixed Bushveld	18 Mixed Bushveld	18 Mixed Bushveld
Hydrogeological Unit	D3	D3	D3	D3	B2	B2

Information obtained from the veld type maps from Acocks (1988) and hydrogeological information from DWAF: Polokwane (2003). Soil colour was identified and classified in the veld according to the Corstor Colour Gauge that lists 168 different soil colours. Geohydrological parameters were derived from Frommurze (1937). Information obtained from the land type maps and accompanying memoirs are from Land Type Survey Staff (1988, 2005). Average weathering depth is extracted from the indicated Land Type Survey Staff and average rooting depth of the geobotanical indicators is referenced from Canadell *et al.* (1996).

Table A1.25 (b). Carboniferous - Jura Eonothers: Irrigasie, Lisbon & Clarens Formations – Mabula-Waterberg Area: faulting or fracturing absent.

Parameter	Droogeloot 476KR		Grootfontein 528KQ		Newcastle 202LQ	
Geological Formation	Competent Clarens Formation rocks	Competent Clarens Formation rocks	Competent Irrigasie Formation rocks	Competent Irrigasie Formation rocks	Competent Lisbon and Clarens Formations	Competent Lisbon and Clarens Formations
Depth Sampled	0.5m	1.2m	0.5m	1.2m	0.5m	1.2m
Borehole Co-ordinates:						
S.L.	24°54.177'	24°54.177'	24°51.354'	24°51.354'	23°28.514'	23°28.514'
E.L.	28°01.823'	28°01.823'	27°58.931'	27°58.931'	27°53.036'	27°53.036'
Soil colour	Strong brown	Strong brown	Dark reddish brown	Brown	Brown	Dark brown
Soil texture description	Silt	Silt	Loam	Silty clay	Sand	Silty clay
pH	8.47	8.41	8.51	8.57	7.62	8.10
P (mg/kg)	4.67	3.68	16.66	13.15	6.08	0.99
Ca (mg/kg)	5749	5364	5328	7043	2785	3992
Mg (mg/kg)	211	212	684	586	543	558
K (mg/kg)	208	282	232	214	92	107
Na (mg/kg)	22	20	83	101	26	27
Fe (mg/kg)	3.91	1.06	18.96	8.77	45.53	51.07
Mn (mg/kg)	25.37	34.70	131.49	31.17	93.31	202.25
Zn (mg/kg)	0.40	0.45	0.59	0.22	0.38	0.53
Al (cmol _c /kg)	0	0	0	0	0	0

Resistance (Ohm)	1800	1800	1800	3000	2400	780
C%	0.16	0.20	0.20	0.75	0.07	0.24
Total N%	0.027	0.029	0.018	0.059	0.007	0.023
S (mg/kg)	5.76	6.59	10.15	12.43	4.13	6.14
CEC (cmol _c /kg)	5.53	8.61	22.931	15.885	20.05	11.51
Distinct Tree Species	1. Rhus lancea 2. Strychnos pungens	1. Rhus lancea 2. Strychnos pungens	1. Rhus lancea 2. Strychnos pungens	1. Rhus lancea 2. Strychnos pungens	1. Combretum imberbe 2. Ficus ingens	1. Combretum imberbe 2. Ficus ingens
Average rooting depth of the indicated species (m)	4 - 13	4 - 13	4 - 13	4 - 13	12 - 20	12 - 20
Average depth of weathering (m)	2.8	2.8	2.8	2.8	3.0	3.0
Geomorphology	Plain	Plain	Plain with a hill	Plain with a hill	Plain	Plain
Geophysical instrumentation used	Electromagnetics	Electromagnetics	Electromagnetics & Magnetics	Electromagnetics & Magnetics	Electromagnetics & Magnetics	Electromagnetics & Magnetics
Water features present?	Yes-small stream "Karee Spruit"	Yes-small stream "Karee Spruit"	Yes-small stream "Riet Spruit"	Yes-small stream "Riet Spruit"	No	No
Aquifer Yield (l/h)	6 000	6 000	5 000	5 000	4 500	4 500
Borehole Depth (m)	75	75	65	65	70	70
Depth of Water Strike (m)	33	33	30	30	36	36
Static Water Level (m)	17	17	14	14	20	20

Average Aquifer Yield (l/h)	3 300	3 300	3 300	3 300	2 300	2 300
Average Borehole Depth (m)	60	60	60	60	69	69
Average Depth of Water Strike (m)	37	37	37	37	44	44
Average Static Water Level (m)	23	23	23	23	26	26
Land Type Series	Ae18b Hutton	Ae18b Hutton	Ae95c Hutton	Ae95c Hutton	Ah85a Hutton	Ah85a Hutton
Profile No	P1379	P1379	P1379	P1379	P1447	P1447
Depth Sampled	300 – 700 mm	300 – 700 mm	300 – 700 mm	300 – 700 mm	450 – 800 mm	450 – 800 mm
Gravel %	1	1	1	1	1	1
Sand %	48	48	48	48	51	51
Silt %	7	7	7	7	9	9
Clay %	44	44	44	44	39	39
pH (H ₂ O)	6.5	6.5	6.5	6.5	7.3	7.3
P (mg/kg)	2.8	2.8	2.8	2.8	1.6	1.6
Ca (mg/kg)	780	780	780	780	2910	2910
Mg (mg/kg)	360	360	360	360	520	520
K (mg/kg)	78	78	78	78	250	250
Na (mg/kg)	23	23	23	23	23	23
Fe (mg/kg)	-	-	-	-	-	-
Mn (mg/kg)	250.5	250.5	250.5	250.5	211.5	211.5
Zn (mg/kg)	0.31	0.31	0.31	0.31	0.62	0.62
Resistance (Ohm)	1600	1600	1600	1600	1000	1000

C%	0.5	0.5	0.5	0.5	0.4	0.4
CEC (cmol _c /kg)	72	72	72	72	63	63
Veld Type	19 Sourish Mixed Bushveld	19 Sourish Mixed Bushveld	19 Sourish Mixed Bushveld	19 Sourish Mixed Bushveld	18 Mixed Bushveld	18 Mixed Bushveld
Hydrogeological Unit	D3	D3	D3	D3	B2	B2

Information obtained from the veld type maps from Acocks (1988) and hydrogeological information from DWAF: Polokwane (2003). Soil colour was identified and classified in the veld according to the Corstor Colour Gauge that lists 168 different soil colours. Geohydrological parameters were derived from Frommurze (1937). Information obtained from the land type maps and accompanying memoirs are from Land Type Survey Staff (1988, 2005). Average weathering depth is extracted from the indicated Land Type Survey Staff and average rooting depth of the geobotanical indicators is referenced from Canadell *et al.* (1996).

45. Droogesloot 476KR

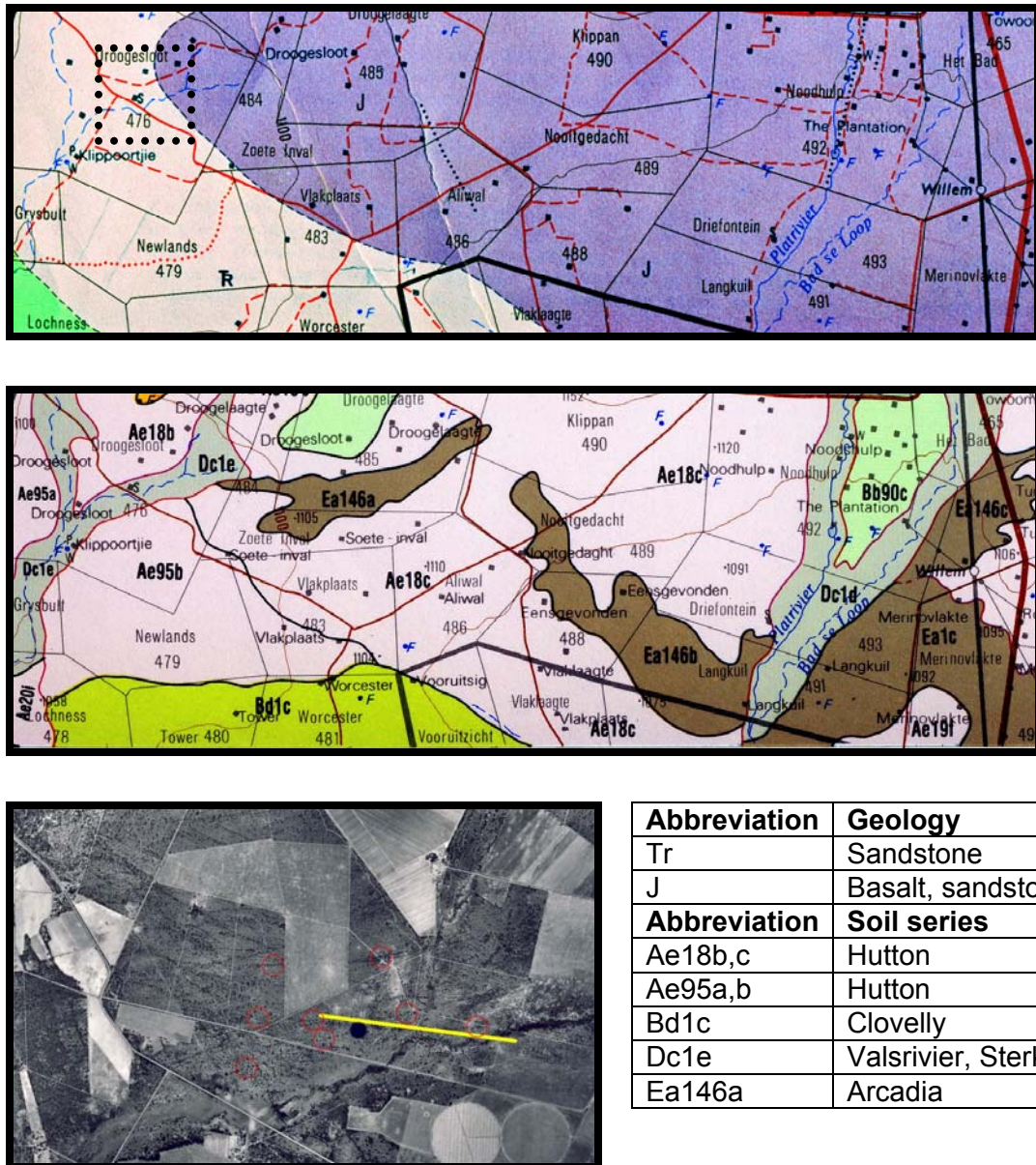
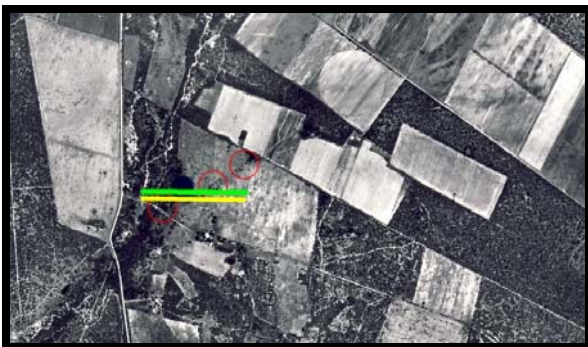
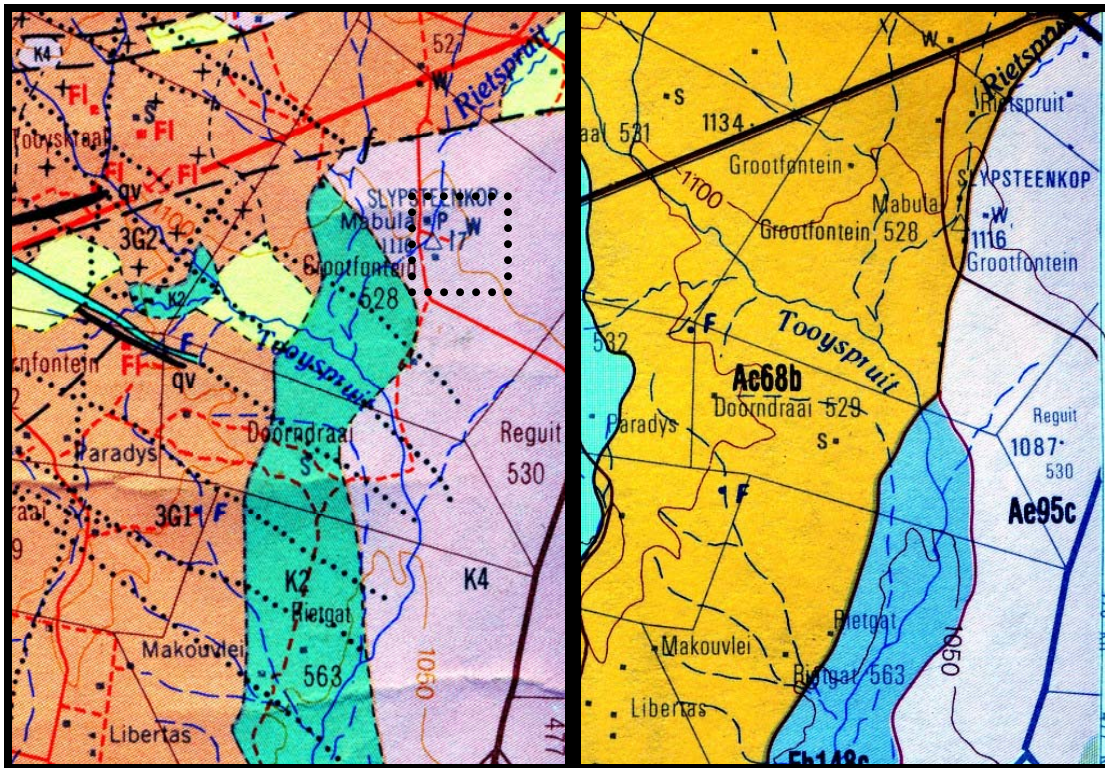


Figure A1.45. The geology (top), land type (middle) and aerial photograph (bottom) of Droogesloot 476KR. The blue circle denotes the position of the borehole and the yellow line the direction of the electromagnetic profile. The area covered by the aerial photograph is indicated by the black shape in the geological map. The red circles in the aerial photograph indicate the position of the fracture zones.

46. Grootfontein 528KQ

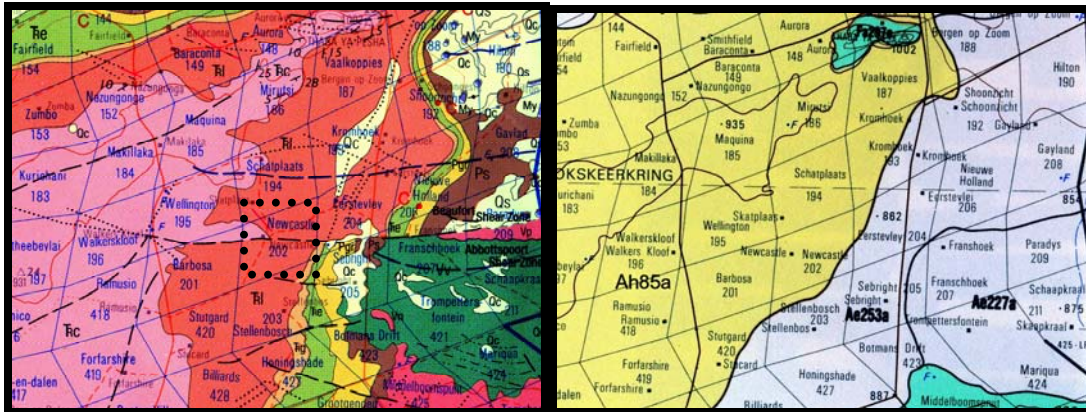


Abbreviation	Geology
3G1	Granite
3G2	Granite
.....	Lineament
K2	Shale, sandstone and grit
K4	Sandstone, marl and shale
-----f	Concealed fault
Abbreviation	Soil series
Ac68b	Clovelly
Ae95c	Hutton

Figure A1.46. The geology (top), land type (middle) and aerial photograph (bottom) of Grootfontein 528KQ. The blue circle denotes the position of the borehole and the green and yellow lines the direction of the (electro)-magnetic profiles. The area covered by the aerial photograph is indicated by the black shape in the geological map. The red circles in the aerial photograph indicate the position of the fracture zone, note the linear vegetated pattern.

About 7 km west of the previous case study (Droogesloot 476KR) the farm Grootfontein 528KQ borders the small village of Mabula. Mabula is about 25 km west of Warmbaths.

47. Newcastle 202LQ



Abbreviation	Geology
Trc	Sandstone
Tre	Shale
Trg	Sandstone, conglomerate
Trl	Mudstone, siltstone
----	Fault
Abbreviation	Soil series
Ae253a	Hutton, Shortlands
Ah85a	Hutton, Clovelly



Figure A1.47. The geology (top left), land type (top right) and aerial photograph (bottom) of Newcastle 202LQ. The blue circle denotes the position of the borehole and the green and yellow lines the direction of the (electro)-magnetic profiles. The area covered by the aerial photograph is indicated by the black shape in the geological map. The red lines in the aerial photograph indicate the position of the fault, although it is not as straight linear as indicated in the geological map.

A1.13 JURASSIC EONOTHEM: BASALT ROCK OF THE LETABA FORMATION AND DOLERITE INTRUSIONS OF THE KAROO SUPERGROUP IN THE SPRINGBOK FLATS AREA

The last deposition sequence of the Karoo Supergroup is concluded with the formation of basalt on top of the arenaceous and argillaceous rocks of the Karoo Supergroup. The extrusive basalt was fed from the magma chamber of the earth through intrusive dolerite bodies, like sills and dykes. These dolerite bodies are nowadays exposed through weathering and erosion processes. Most of the basalt has weathered over time, but outcrops are still evident on the Drakensberg of the interior and isolated patches in the northern parts of South Africa, like in the Springbok Flats area around the town of Settlers.

A1.13.1 CASE STUDY AREA

Basalt and dolerite outcrops in the area around Pienaarsrivier, about 50 km north of Pretoria, are incorporated in the study. A total of three case studies represent this area. The terrain is extremely plain with no major drainage structures, but is densely covered by shrubs and small trees. However, due to the water bearing properties of the basalt aquifers and productive soil, large areas of bush has been cleared to make way for intensive (irrigation) agricultural practices. Other areas are still utilised for extensive beef cattle farming and game lodges.

A1.13.2 CLIMATE AND VELD TYPES

The area covered with basalt and dolerite outcrops is situated at a lower elevation (800-1200 masl) compared to the plains of the Highveld in the south. Consequently a warmer and dryer climate is encountered (see Table A1.26). The basalt plains are extremely flat and therefore no significant microclimates are present that are commonly found on the slopes of mountains or in gorges and host different botanic species. The flat terrain permits radiation and as a result mild frost happens during winter time. However, the basalt plains are luxuriously covered with shrub and tree vegetation, indicating a climate different to that found on the southern Highveld plateau. The luxurious vegetation indicates that the veld types indicative of the basalt and dolerite environment are part of the savanna biome. Veld types associated within this kind of climatic conditions are (Acocks, 1988 & Van Wyk & Van Wyk, 1997):

- Kalahari Thornveld (sand & dolerite): *Acacia erioloba* (camel thorn), *A. luederitzii* (false umbrella thorn), *A. mellifera* (black thorn), *A. tortillis* subsp. *heteracantha* (umbrella thorn), *Boscia albitrunca* (shepherd's tree), *Dichrostachys cinerea* (sickle bush), *Grewia flava* (velvet raisin), *Mundulea sericea* (cork bush), *Peltophorum africanum* (weeping wattle), *Tarchonanthus camphoratus* (wild camphor bush) and *Ziziphus mucronata* (buffalo-thorn).
- Springbok Flats Turf Thornveld (basalt): *Acacia nilotica* subsp. *kraussiana* (scented thorn), *A. tortillis* subsp. *heteracantha* (umbrella thorn), *Dichrostachys cinerea* (sickle bush), *Grewia flava* (velvet raisin) and *Ziziphus mucronata* (buffalo-thorn).
- Mixed Bushveld (dolerite): *Acacia caffra* (common hook-thorn), *Combretum apiculatum* (red bushwillow), *C. imberbe* (leadwood), *Dichrostachys cinerea* (sickle bush), *Grewia flava* (velvet raisin), *Lannea discolor* (live-long) and *Sclerocarya birrea* subsp. *caffra* (marula).

The above-mentioned tree species are frequently found in the veld and their use as geobotanical indicators must only be done with extreme caution through frequency of occurrence and circumscribe mapping.

Table A1.26. Climatic Data of the Springbok Flats Area around Pienaarsrivier-Settlers (Schulze, 1997, Johannesburg, 1999 & Polokwane, 2003).

	Quantity
Average Yearly Temperature (°C)	18 -20
Mean Minimum Temperature (°C) in July	2 - 4
Mean Maximum Temperature (°C) in January	27.5 – 30.0
Average Yearly Rainfall (mm)	400 – 600
Elevation (m)	800 – 1200
Evaporation (mm/year)	2000 – 2250
Frost area?	<150 days a year

A1.13.3 GEOLOGY AND HYDROGEOLOGICAL CLASSIFICATION

The geology of the case study area is relatively simple compared to other geological terrain as presented. Horizontal layered basalt (Letaba Formation, Karoo Supergroup) and dolerite (Karoo Supergroup) of a thickness of about 200 to 300 m (Van Zijl, 1978) covers sedimentary rock of the Karoo Supergroup. No structural phenomena are encountered in the mentioned mafic and ultramafic rocks.

According to Hattingh (1996), Johannesburg (1999) and Polokwane (2003), the intergranular and fractured aquifers associated with the basalt and dolerite rocks are mainly created through joints. The basalt aquifers' yield is above 18 000 l/h. The dolerite outcrop around Pienaarsrivier is surrounded by argillaceous rock belonging to the Irrigasie Formation (see section 4.12) with a possible yield of 1800 – 7200 l/h (Johannesburg, 1999).

A1.13.4 GEOPHYSICAL AND GEOBOTANICAL INFORMATION

The publication by Van Zijl (1978) is a source of vital geophysical information regarding this area. Schlumberger sounding curves obtained (a total of 26) by the study of Van Zijl (1978) are of the four-layered KH-shape, indicating a resistive overburden and conductor in depth. The apparent resistivity of the weathered basalt is between 10-200 Ω .m., the unweathered basalt between 510-1330 Ω .m. and the apparent resistivity of the pre-Karoo floor rocks in excess of 5000 Ω .m., although no Schlumberger depth soundings are presented in this section as the exploration targets were fracture and fault zones that require geophysical profiling techniques for proper definition of the structures and dense vegetation restricted proper, time-efficient conducting of soundings.

Information on geobotanical indicators for groundwater are not known in this case study area, although certain geobotanical species occur in this geological environment that also occur in other geological environments previously included and act as a reconnaissance tool.

A1.13.5 SOIL SAMPLING AND RESULTS PRESENTATION

To establish the importance and linkage of soil nutrients, weathered intrusive rocks, aquifers and botanic species, soil samples were taken at depths of 0.5 m and 1.2 meters. The soil chemical analytic results of the three case studies are presented in Table A1.27(a&b), with the discussion of the case studies thereafter.

Table A1.27 (a). Jurassic Eonothem: Basalt rock of the Letaba Formation and dolerite intrusions of the Karoo Supergroup in the Springbok Flats Area: along contact, weathering and/or fracture zone.

Parameter	Kalkheuvel 73 JR		Langkuil 13 JR		Vlakplaats 483 KR	
Geological Formation	Contact zone between dolerite and Irrigasie Formation	Contact zone between dolerite and Irrigasie Formation	Palaeo-channel in weathered basalt	Palaeo-channel in weathered basalt	Fracture zone in Letaba Formation	Fracture zone in Letaba Formation
Depth Sampled	0.5m	1.2m	0.5m	1.2m	0.5m	1.2m
Borehole Co-ordinates:						
S.L.	25°11.077'	25°11.077'	25°00.411'	25°00.411'	24°57.967'	24°57.967'
E.L.	28°20.609'	28°20.609'	28°14.258'	28°14.258'	28°07.129'	28°07.129'
Soil colour	Moderate brown	Strong brown	Moderate brown	Dark brown	Moderate brown	Dusky red
Soil texture description	Silt	Silty sand	Sandy silt	Loam	Loam	Loam
pH	7.78	8.13	6.79	7.16	7.24	7.04
P (mg/kg)	8.79	8.07	1.71	0.99	1.22	0.84
Ca (mg/kg)	4362	3805	5758	5739	2993	2786
Mg (mg/kg)	470	444	2061	2014	858	817
K (mg/kg)	468	486	155	153	132	100
Na (mg/kg)	31	30	72	104	41	27
Fe (mg/kg)	4.81	8.80	63.53	70.63	64.07	86.99
Mn (mg/kg)	77.46	105.74	531.08	405.50	100.86	191.05
Zn (mg/kg)	1.16	1.06	0.31	0.33	0.33	0.41
Al (cmol _c /kg)	0	0	0	0	0	0

Resistance (Ohm)	1600	1800	1700	2200	2800	2400
C%	1.02	0.92	0.01	0.01	0.04	0.08
Total N%	0.097	0.090	0.005	0.008	0.005	0.011
S (mg/kg)	7.67	7.88	4.48	4.33	3.88	4.56
CEC (cmol _c /kg)	9.27	14.94	46.47	40.22	18.39	36.82
Distinct Tree Species	1. Acacia karroo 2. Rhus lancea	1. Acacia karroo 2. Rhus lancea	1. Combretum erythrophyllum	1. Combretum erythrophyllum	1. Acacia karroo 2. Ximenia caffra 3. Zanthoxylum capense	1. Acacia karroo 2. Ximenia caffra 3. Zanthoxylum capense
Average rooting depth of the indicated species (m)	13 - 50	13 - 50	12	12	4 - 50	4 - 50
Average depth of weathering (m)	2.4	2.4	1.9	1.9	2.5	2.5
Geomorphology	Plain	Plain	Plain	Plain	Plain	Plain
Geophysical instrumentation used	Electromagnetics & Magnetism	Electromagnetics & Magnetism	Electromagnetics, Magnetism and Schlumberger soundings	Electromagnetics, Magnetism and Schlumberger soundings	Electromagnetics, Magnetism and Schlumberger sounding	Electromagnetics, Magnetism and Schlumberger sounding
Water features present?	No	No	Yes-small stream "Plat River" 700 m east	Yes-small stream "Plat River" 700 m east	No	No
Aquifer Yield (l/h)	5 500	5 500	8 000	8 000	15 400	15 400
Borehole Depth (m)	60	60	35	35	60	60

Depth of Water Strike (m)	24	24	17	17	22	22
Static Water Level (m)	15	15	8	8	11	11
Average Aquifer Yield (l/h)	5 500	5 500	5 500	5 500	5 500	5 500
Average Borehole Depth (m)	41	41	41	41	41	41
Average Depth of Water Strike (m)	28	28	28	28	28	28
Average Static Water Level (m)	17	17	17	17	17	17
Land Type Series	Ae20b Hutton	Ae20b Hutton	Ea1a Arcadia	Ea1a Arcadia	Ae18c Hutton	Ae18c Hutton
Profile No	P89	P89	P84	P84	P89	P89
Depth Sampled	760 – 1200 mm	760 – 1200 mm	800 – 1000 mm	800 – 1000 mm	760 – 1200 mm	760 – 1200 mm
Gravel %	1	1	6	6	1	1
Sand %	70	70	17	17	70	70
Silt %	4	4	23	23	4	4
Clay %	25	25	54	54	25	25
pH (H ₂ O)	7.4	7.4	8.3	8.3	7.4	7.4
P (mg/kg)	1.7	1.7	0.3	0.3	1.7	1.7
Ca (mg/kg)	1000	1000	8717	8717	1000	1000
Mg (mg/kg)	192	192	1749	1749	192	192
K (mg/kg)	195	195	156	156	195	195
Na (mg/kg)	23	23	460	460	23	23

Fe (mg/kg)	-	-	-	-	-	-
Mn (mg/kg)	83.1	83.1	395.0	395.0	83.1	83.1
Zn (mg/kg)	0.50	0.50	0.49	0.49	0.50	0.50
Resistance (Ohm)	960	960	270	270	960	960
C%	0.2	0.2	0.6	0.6	0.2	0.2
CEC (cmol _c /kg)	67	67	610	610	67	67
Veld Type	16/18 Kalahari Thornveld/ Mixed Bushveld	16/18 Kalahari Thornveld/ Mixed Bushveld	12 Springbok Flats Turf Thornveld	12 Springbok Flats Turf Thornveld	12 Springbok Flats Turf Thornveld	12 Springbok Flats Turf Thornveld
Hydrogeological Unit	D3	D3	D5	D5	B5	B5

Information obtained from the veld type maps from Acocks (1988) and hydrogeological information from DWAF: Johannesburg (1999) & Polokwane (2003). Soil colour was identified and classified in the veld according to the Corstor Colour Gauge that lists 168 different soil colours. Geohydrological parameters were derived from Frommurze (1937). Information obtained from the land type maps and accompanying memoir is from Land Type Survey Staff (1987). Average weathering depth is extracted from the indicated Land Type Survey Staff and average rooting depth of the geobotanical indicators is referenced from Canadell *et al.* (1996).

Table A1.27 (b). Jurassic Eonothem: Basalt rock of the Letaba Formation and dolerite intrusions of the Karoo Supergroup in the Springbok Flats Area: contact, weathering and/or fracture zone absent.

Parameter	Kalkheuvel 73 JR		Langkuil 13 JR		Vlakplaats 483 KR	
Geological Formation	Unweathered dolerite	Unweathered dolerite	Unweathered basalt	Unweathered basalt	Unweathered basalt	Unweathered basalt
Depth Sampled	0.5m	1.2m	0.5m	1.2m	0.5m	1.2m
Borehole Co-ordinates:						
S.L.	25°11.077'	25°11.077'	25°00.411'	25°00.411'	24°57.967'	24°57.967'
E.L.	28°20.609'	28°20.609'	28°14.258'	28°14.258'	28°07.129'	28°07.129'
Soil colour	Moderate reddish brown	Very dark red	Light brown	Strong brown	Dark brown	Dusky yellowish brown
Soil texture description	Clayey silt	Clay	Silty clay	Silty clay	Silty clay	Silty clay
pH	6.79	7.52	7.52	7.11	6.98	6.70
P (mg/kg)	8.10	14.87	1.67	1.11	1.22	0.88
Ca (mg/kg)	1741	2452	3738	1530	4493	1542
Mg (mg/kg)	321	357	1294	367	1511	349
K (mg/kg)	433	470	104	129	155	116
Na (mg/kg)	9	23	35	20	61	46
Fe (mg/kg)	29.55	31.77	70.87	115.17	64.56	136.35
Mn (mg/kg)	226.23	242.79	227.03	228.00	300.13	283.67
Zn (mg/kg)	0.86	2.02	0.33	1.08	0.53	0.85
Al (cmol _c /kg)	0	0	0	0	0	0
Resistance (Ohm)	1600	440	2000	2400	1800	2200

C%	0.96	1.38	0.03	0.23	0.11	0.44
Total N%	0.099	0.127	0.001	0.022	0.016	0.033
S (mg/kg)	16.99	12.69	3.84	5.19	6.67	6.30
CEC (cmol _c /kg)	9.828	7.52	16.86	13.78	9.14	31.40
Distinct Tree Species	1. Acacia karroo 2. Rhus lancea	1. Acacia karroo 2. Rhus lancea	1. Combretum erythrophyllum	1. Combretum erythrophyllum	1. Acacia karroo 2. Ximenia caffra 3. Zanthoxylum capense	1. Acacia karroo 2. Ximenia caffra 3. Zanthoxylum capense
Average rooting depth of the indicated species (m)	13 - 50	13 - 50	12	12	4 - 50	4 - 50
Average depth of weathering (m)	2.4	2.4	1.9	1.9	2.5	2.5
Geomorphology	Plain	Plain	Plain	Plain	Plain	Plain
Geophysical instrumentation used	Electromagnetics & Magnetics	Electromagnetics & Magnetics	Electromagnetics, Magnetics and Schlumberger soundings	Electromagnetics, Magnetics and Schlumberger soundings	Electromagnetics, Magnetics and Schlumberger sounding	Electromagnetics, Magnetics and Schlumberger sounding
Water features present?	No	No	Yes-small stream "Plat River" 700 m east	Yes-small stream "Plat River" 700 m east	No	No
Aquifer Yield (l/h)	5 500	5 500	8 000	8 000	15 400	15 400
Borehole Depth (m)	60	60	35	35	60	60
Depth of Water Strike (m)	24	24	17	17	22	22

Static Water Level (m)	15	15	8	8	11	11
Average Aquifer Yield (l/h)	5 500	5 500	5 500	5 500	5 500	5 500
Average Borehole Depth (m)	41	41	41	41	41	41
Average Depth of Water Strike (m)	28	28	28	28	28	28
Average Static Water Level (m)	17	17	17	17	17	17
Land Type Series	Ae20b Hutton	Ae20b Hutton	Ea1a Arcadia	Ea1a Arcadia	Ae18c Hutton	Ae18c Hutton
Profile No	P89	P89	P84	P84	P89	P89
Depth Sampled	760 – 1200 mm	760 – 1200 mm	800 – 1000 mm	800 – 1000 mm	760 – 1200 mm	760 – 1200 mm
Gravel %	1	1	6	6	1	1
Sand %	70	70	17	17	70	70
Silt %	4	4	23	23	4	4
Clay %	25	25	54	54	25	25
pH (H ₂ O)	7.4	7.4	8.3	8.3	7.4	7.4
P (mg/kg)	1.7	1.7	0.3	0.3	1.7	1.7
Ca (mg/kg)	1000	1000	5758	5739	1000	1000
Mg (mg/kg)	192	192	2061	2014	192	192
K (mg/kg)	195	195	155	153	195	195
Na (mg/kg)	23	23	72	104	23	23
Fe (mg/kg)	-	-	-	-	-	-
Mn (mg/kg)	83.1	83.1	395.0	395.0	83.1	83.1

Zn (mg/kg)	0.50	0.50	0.49	0.49	0.50	0.50
Resistance (Ohm)	960	960	270	270	960	960
C%	0.2	0.2	0.6	0.6	0.2	0.2
CEC (cmol _c /kg)	67	67	610	610	67	67
Veld Type	16/18 Kalahari Thornveld/ Mixed Bushveld	16/18 Kalahari Thornveld/ Mixed Bushveld	12 Springbok Flats Turf Thornveld	12 Springbok Flats Turf Thornveld	12 Springbok Flats Turf Thornveld	12 Springbok Flats Turf Thornveld
Hydrogeological Unit	D3	D3	D5	D5	B5	B5

Information obtained from the veld type maps from Acocks (1988) and hydrogeological information from DWAF: Johannesburg (1999) & Polokwane (2003). Soil colour was identified and classified in the veld according to the Corstor Colour Gauge that lists 168 different soil colours. Geohydrological parameters were derived from Frommurze (1937). Information obtained from the land type maps and accompanying memoirs is from Land Type Survey Staff (1987). Average weathering depth is extracted from the indicated Land Type Survey Staff and average rooting depth of the geobotanical indicators is referenced from Canadell *et al.* (1996).

48. Kalkheuvel 73JR

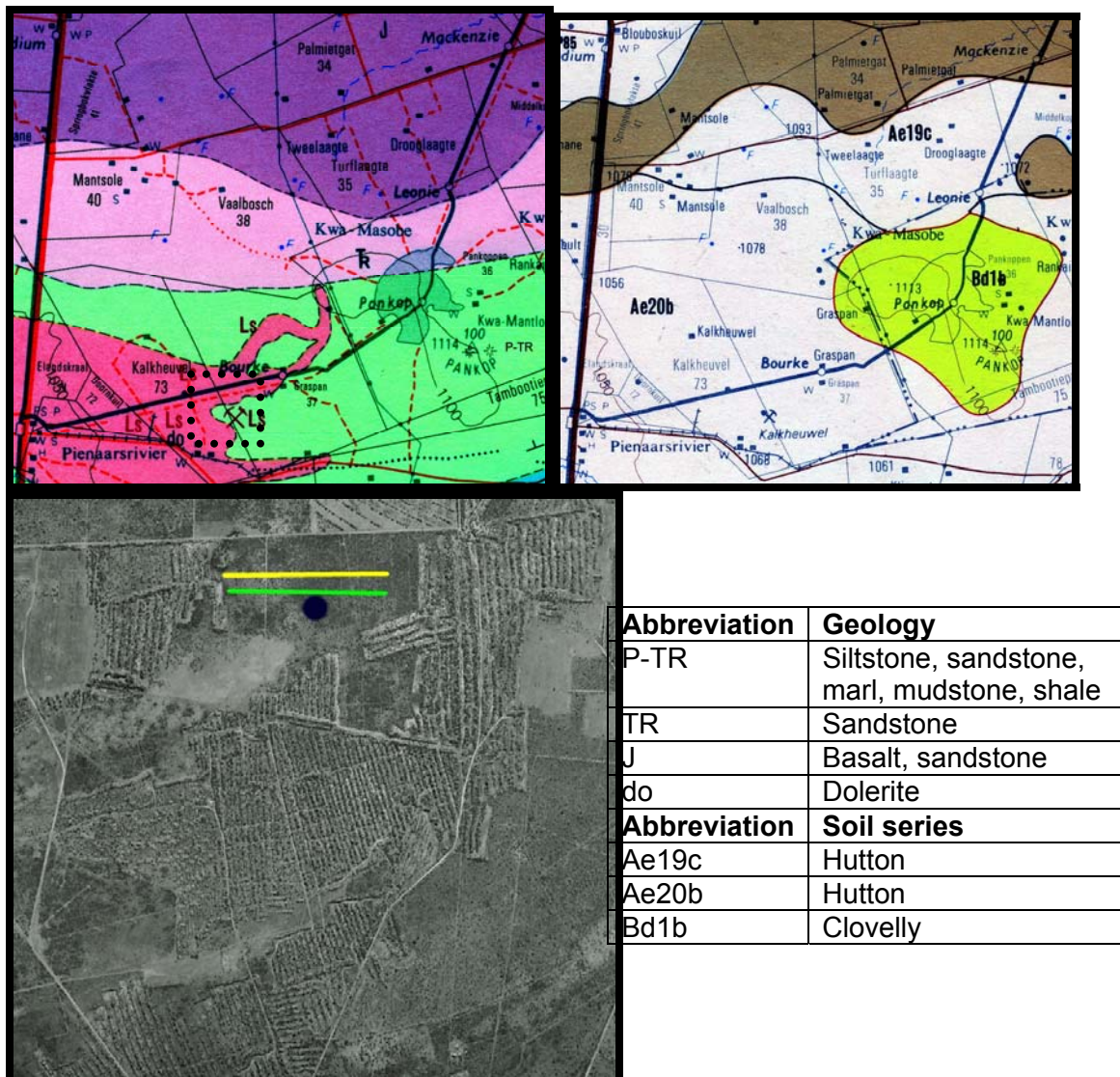


Figure A1.48. The geology (top left), land type (top right) and aerial photograph (bottom) of Kalkheuvel 73JR. The blue circle denotes the position of the borehole and the green and yellow lines the direction of the (electro)-magnetic profiles. The area covered by the aerial photograph is indicated by the black shape in the geological map. Note the disturbed surface on the aerial photograph due to mining activities. No vegetation patterns are easy to recognize.

49. Langkuil 13JR

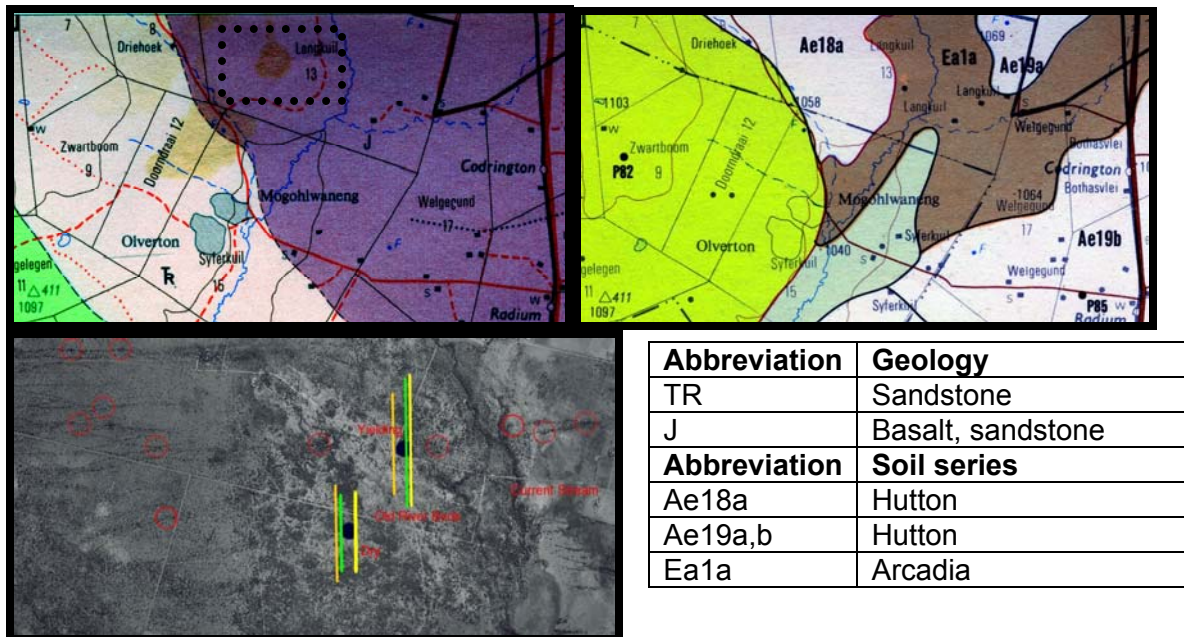


Figure A1.49. The geology (top left), land type (top right) and aerial photograph (bottom) of Langkuil 13JR. The blue circles denote the position of the boreholes (dry and yielding), the green and yellow lines the direction of the (electro)-magnetic profiles and the orange lines the direction of the sounding electrodes. The area covered by the aerial photograph is indicated by the black shape in the geological map. The red circles indicate linear features that were recognized by the magnetometer. The position of the current and past river bed is indicated.

50. Vlakplaats 483KR

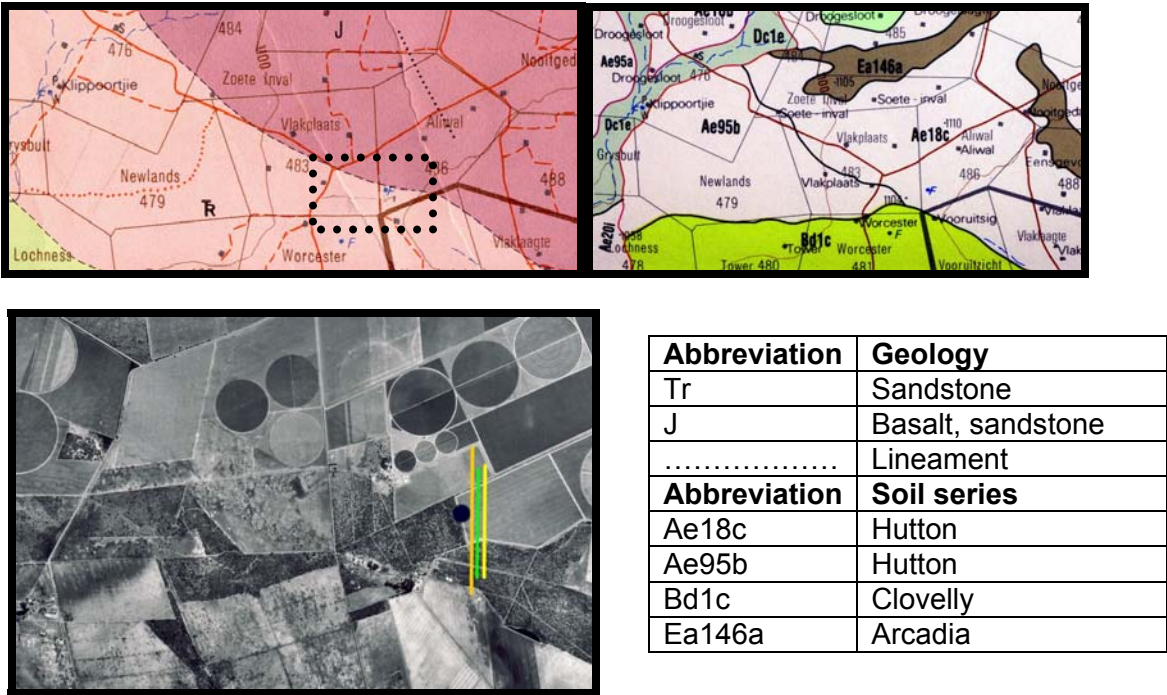


Figure A1.50. The geology (top left), land type (top right) and aerial photograph (bottom) of Vlakplaats 483KR. The blue circle denotes the position of the borehole, the green and yellow lines the direction of the (electro)-magnetic profiles and the orange line the direction of the sounding electrodes. The area covered by the aerial photograph is indicated by the black shape in the geological map. No vegetation patterns are easy to recognize in this cultivated landscape.

ANNEXURE 2: AN OVERVIEW OF THE IDENTIFIED GEOBOTANICAL INDICATORS

This section presents a brief description of the locality, biome and Photographs of the identified geobotanical indicators. The geobotanical indicators that are listed are those that are tabled in Table 5.1, both the recognized (A2.2.1-16) and warrants more study geobotanical indicators (A2.2.17-24). Only the biomes relevant to the research area are mentioned.

A2.1 BIOME OVERSIGHT

The area of the study area is represented in Figure A2.1. This figure indicates the different biomes and the overlap of the different geological units as indicated in Chapter 3. Compare this figure with Figure 3.4.

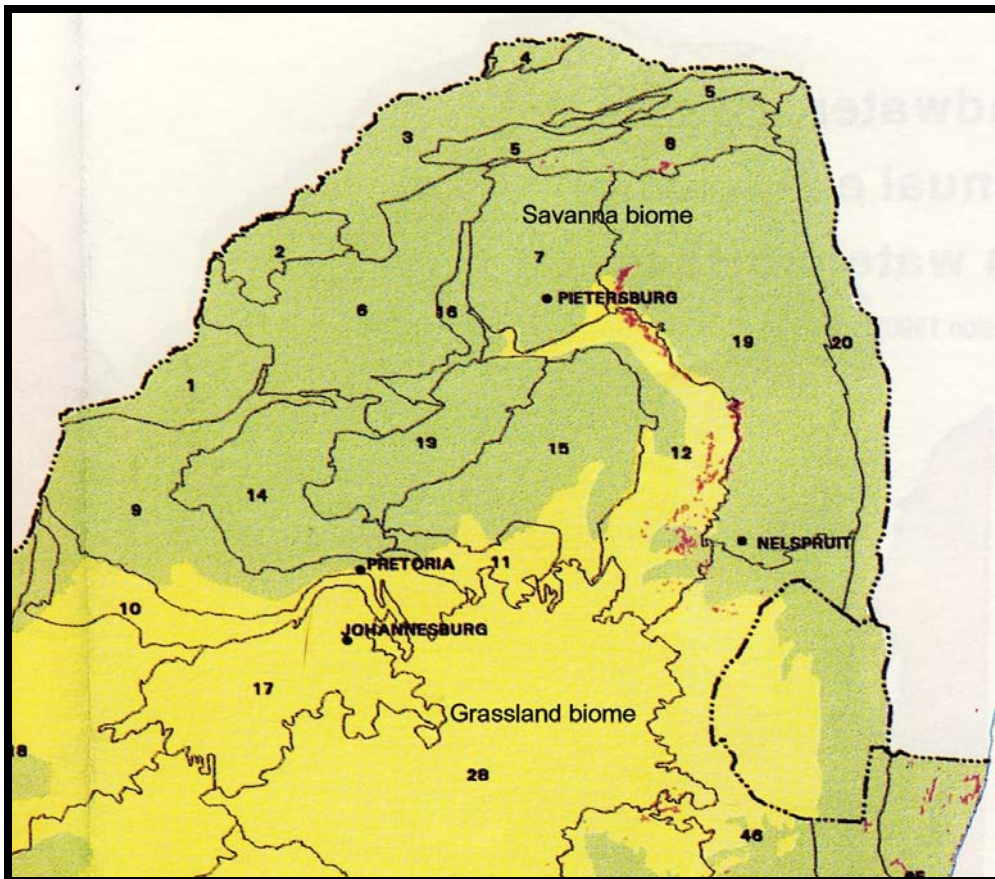


Figure A2.1. Distribution of biomes across the research area and geological units (Vegter, 2001a).

A2.2 IDENTIFIED GEOBOTANICAL INDICATORS

A2.2.1 *Acacia karroo* (Sweet thorn)

Distribution: Grassland and Savanna biomes.

Description: Shrub to medium-sized deciduous tree, variable in shape but typically with a somewhat rounded crown. Spines slender, white, often more prominent on young trees (Van Wyk & Van Wyk, 1997).

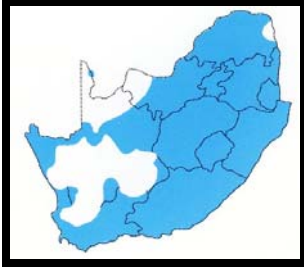


Figure A2.2. Distribution of *Acacia karroo* (Venter & Venter, 2005).



Figure A2.3. Photographs of *Acacia karroo* (appearance, thorns, flowers, seeds, bark and leaves) (Venter & Venter, 2005).

A2.2.2 *Adansonia digitata* (Baobab)

Distribution: Savanna biome.

Description: Grotesque, comparatively short, deciduous tree with hugely swollen trunk; occurring at low altitudes in hot dry bushveld (Van Wyk & Van Wyk, 1997).

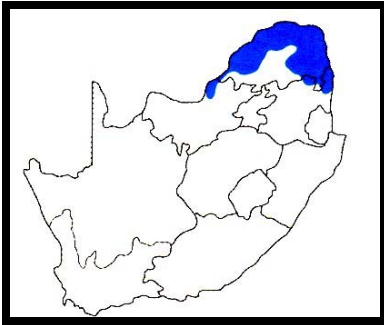


Figure A2.4. Distribution of *Adansonia digitata* (Venter & Venter, 2005).

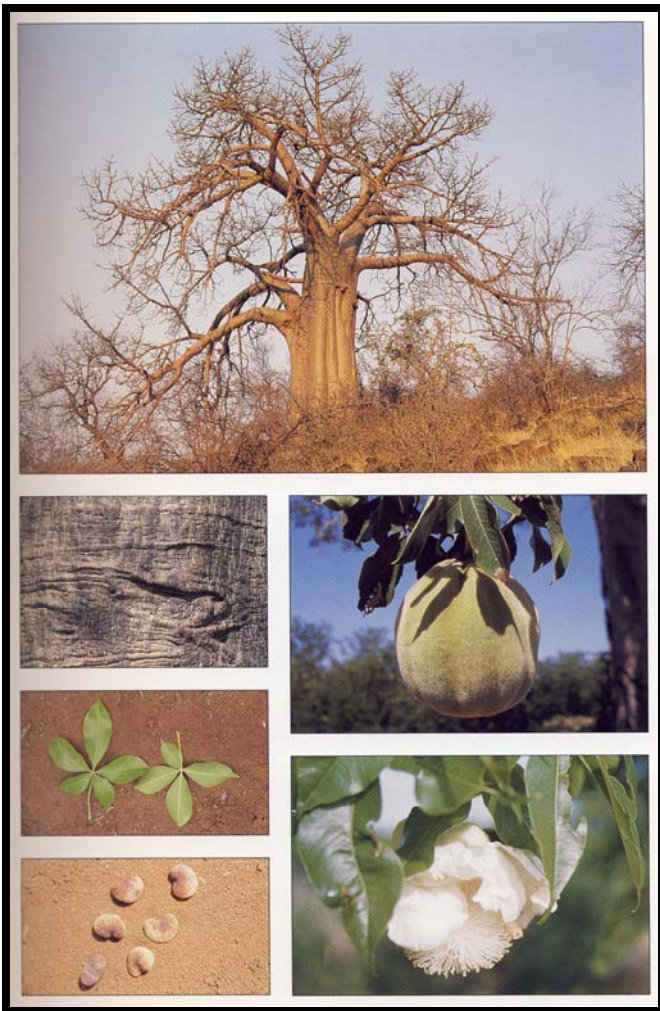


Figure A2.5. Photographs of *Adansonia digitata* (appearance, flowers, seeds, bark and leaves) (Venter & Venter, 2005).

A2.2.3 *Burkea africana* (Wild seringa)

Distribution: Grassland and Savanna biomes.

Description: Medium-sized deciduous tree with a somewhat flattened and spreading crown; occurring often on deep sandy soil (Van Wyk & Van Wyk, 1997).

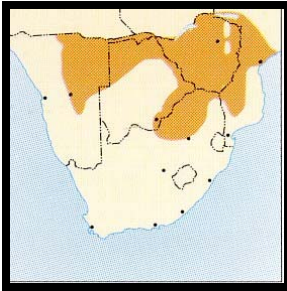


Figure A2.6. Distribution of *Burkea africana* (Van Wyk & Van Wyk, 1997).



Figure A2.7. Photographs of *Burkea africana* (appearance, flowers, seeds, bark and leaves) (Van Wyk, 1986).

A2.2.4 *Dichapetalum cymosum* (Poison leaf/Gifblaar)

Found very often in association with *Burkea Africana*.

Distribution: Grassland and Savanna biomes.

Description: An enormous woody plant that grows underground except for the numerous branch tips that emerges above the ground. The species is easily recognized by the alternate (deciduous) leaves (not opposite) and the same bright green colour of the upper and lower leaf surfaces (Van Wyk *et al.*, 2002).



Figure A2.8. Distribution of *Dichapetalum cymosum* (Van Wyk *et al.*, 2002).



Figure A2.9. Photographs of *Dichapetalum cymosum* (appearance, flowers, seeds and leaves) (Van Wyk *et al.*, 2002).

A2.2.5 *Celtis africana* (White stinkwood)

Distribution: Grassland and Savanna biomes.

Description: Medium to large deciduous tree; occurring often on dolomite (Van Wyk & Van Wyk, 1997).

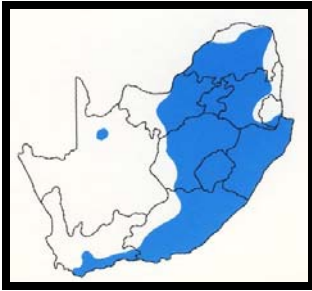


Figure A2.10. Distribution of *Celtis africana* (Venter & Venter, 2005).



Figure A2.11. Photographs of *Celtis africana* (appearance, flowers, seeds, bark and leaves) (Venter & Venter, 2005).

A2.2.6 *Clerodendrum glabrum* (Tinderwood)

Distribution: Grassland and Savanna biomes.

Description: Shrub or small to medium-sized deciduous tree, crown often drooping (Van Wyk & Van Wyk, 1997).

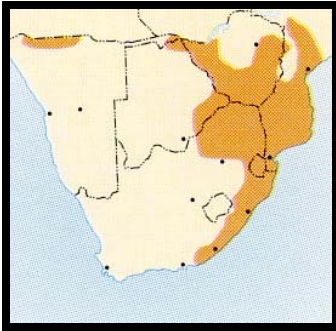


Figure A2.12. Distribution of *Clerodendrum glabrum* (Van Wyk & Van Wyk, 1997).

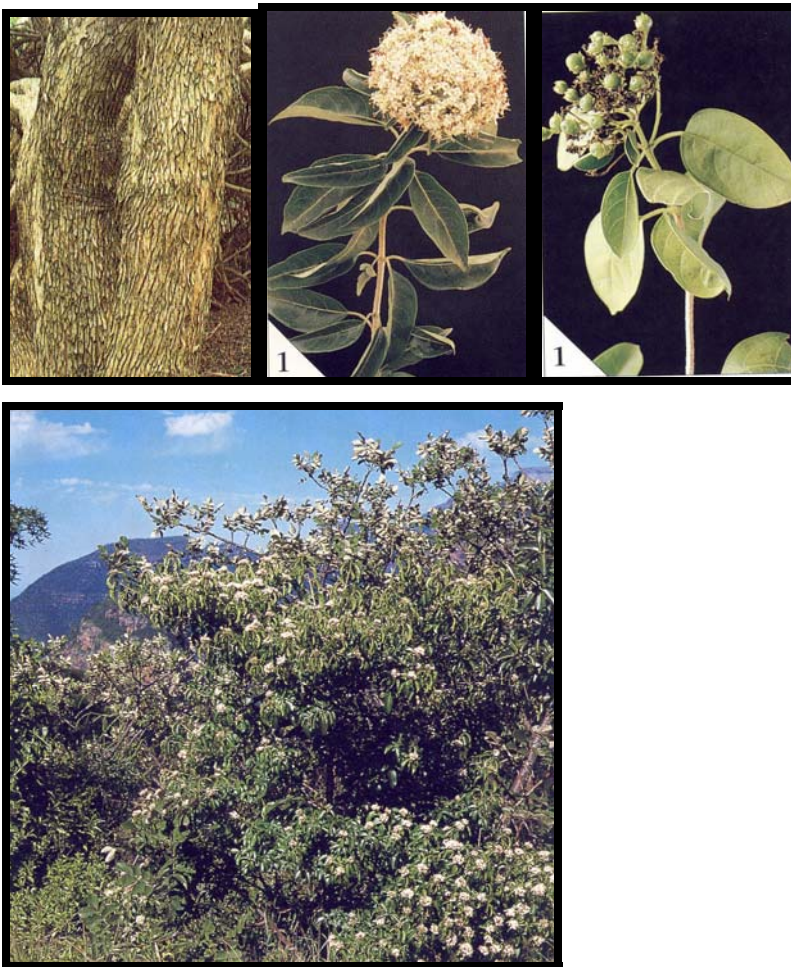


Figure A2.13. Photographs of *Clerodendrum glabrum* (appearance (Grant and Thomas, 2000), seeds (Van Wyk & Van Wyk, 1997), flowers (Van Wyk & Van Wyk, 1997), bark (Pooley, 1997) and leaves (Van Wyk & Van Wyk, 1997)).

A2.2.7 Combretum erythrophyllum (River bush-willow)

Distribution: Grassland and Savanna biomes.

Description: Small to large deciduous tree, with reddish autumn and sometimes whitish spring colours; occurring mainly along the banks of rivers (Van Wyk & Van Wyk, 1997).

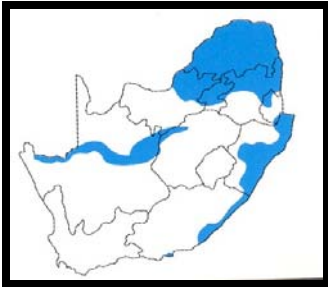


Figure A2.14. Distribution of *Combretum erythrophyllum* (Venter & Venter, 2005).

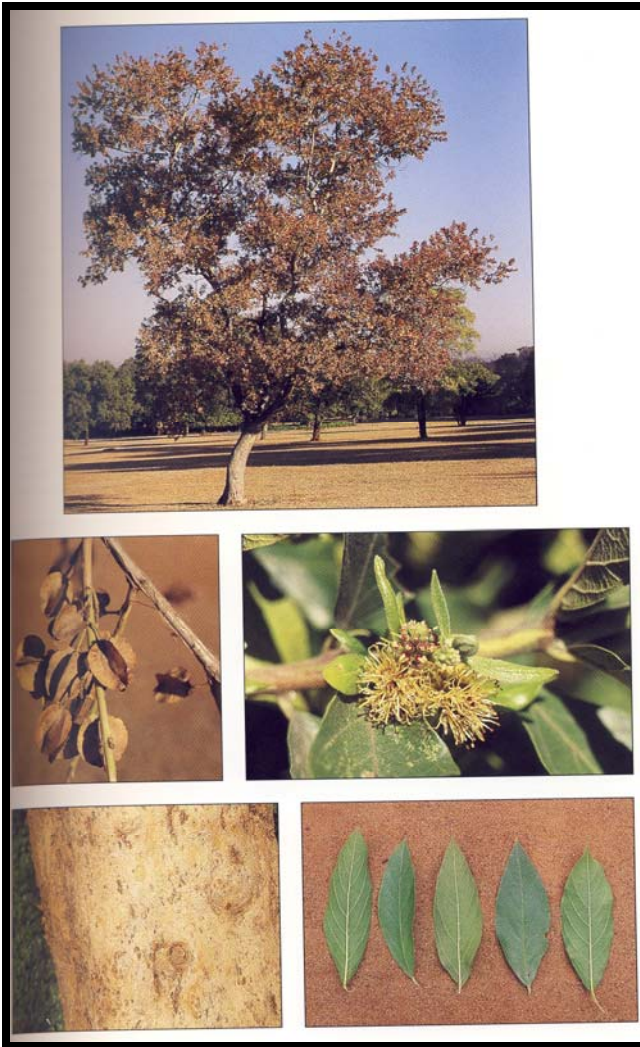


Figure A2.15. Photographs of *Combretum erythrophyllum* (appearance, flowers, seeds, bark and leaves) (Venter & Venter, 2005).

A2.2.8 *Combretum imberbe* (Leadwood)

Distribution: Savanna biome.

Description: Medium to large semi-deciduous tree with a grayish appearance; occurring in bushveld, often on alluvial soils along rivers or dry watercourses (Van Wyk & Van Wyk, 1997).



Figure A2.16. Distribution of *Combretum imberbe* (Venter & Venter, 2005).

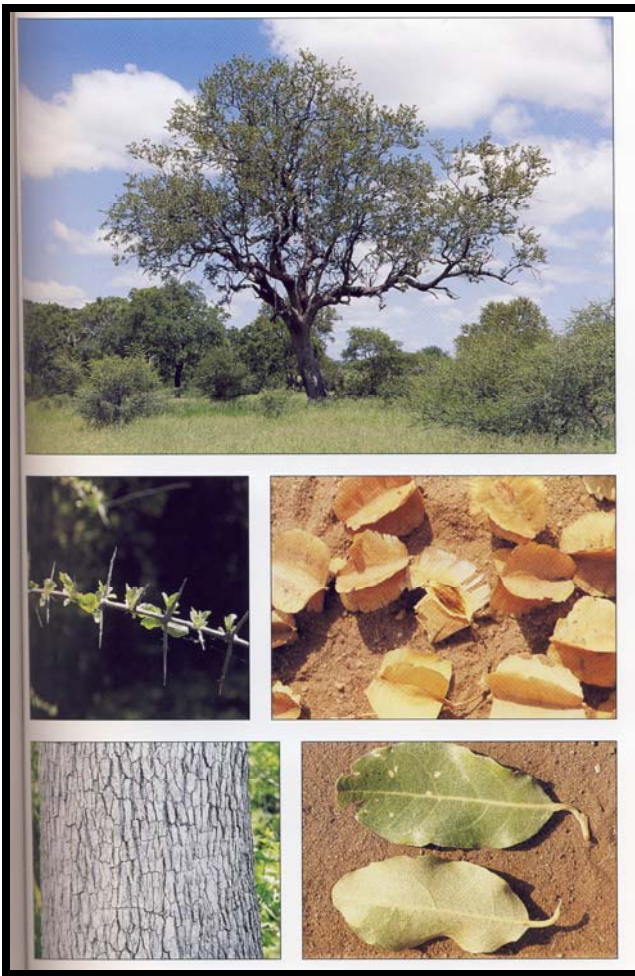


Figure A2.17. Photographs of *Combretum imberbe* (appearance, flowers, seeds, bark and leaves) (Venter & Venter, 2005).

A2.2.9 *Euclea crispa* (Blue guarri)

Distribution: Grassland and Savanna biomes.

Description: Much-branched evergreen shrub or small tree, usually with a dense, grey-green crown; occurring in bushveld, forest margins and sheltered places in grassland, often in rocky places (Van Wyk & Van Wyk, 1997).

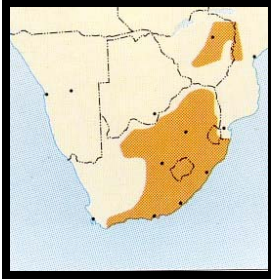


Figure A2.18. Distribution of *Euclea crispa* (Van Wyk & Van Wyk, 1997).



Figure A2.19. Photographs of *Clerodendrum glabrum* (appearance (Grant and Thomas, 2002), seeds (Van Wyk & Van Wyk, 1997), flowers (Van Wyk & Van Wyk, 1997), bark (Pooley, 1997) and leaves (Van Wyk & Van Wyk, 1997)).

A2.2.10 *Ficus ingens* (Red-leaved fig)

Distribution: Grassland and Savanna biomes.

Description: Dwarf spreading shrub or small to medium-sized deciduous tree, often acting as a rock-splitter; occurring in bushveld or frost-protected sites in grassland, usually on rocky hills (Van Wyk & Van Wyk, 1997).



Figure A2.20. Distribution of *Ficus ingens* (Venter & Venter, 2005).

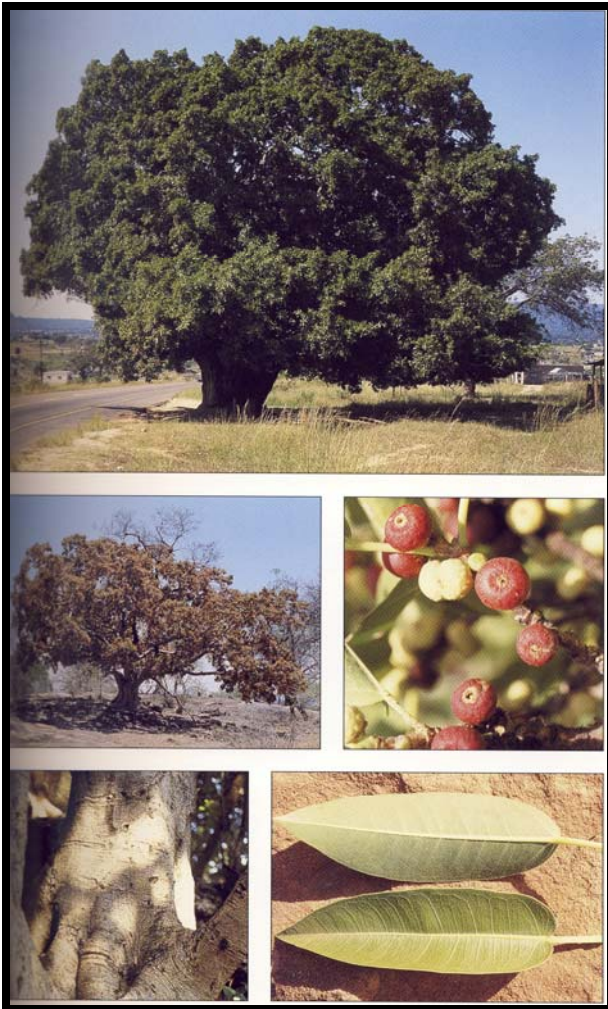


Figure A2.21. Photographs of *Ficus ingens* (appearance, flowers, seeds, bark and leaves) (Venter & Venter, 2005).

A2.2.11 *Fingerhuthia sesleriiformis* (Thimble grass)

Distribution: Grassland and Savanna biomes.

Description: A perennial tuft-grass with unbranched stalks to 0.9 m long; occurring on calc-containing rock outcrops, disturbed areas and in well-drained sand and gravel soils (Van Oudtshoorn, 1994).

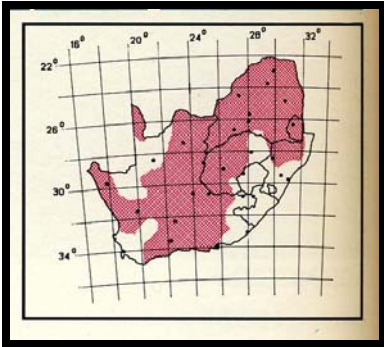


Figure A2.22. Distribution of *Fingerhuthia sesleriiformis* (Van Oudtshoorn, 1994).

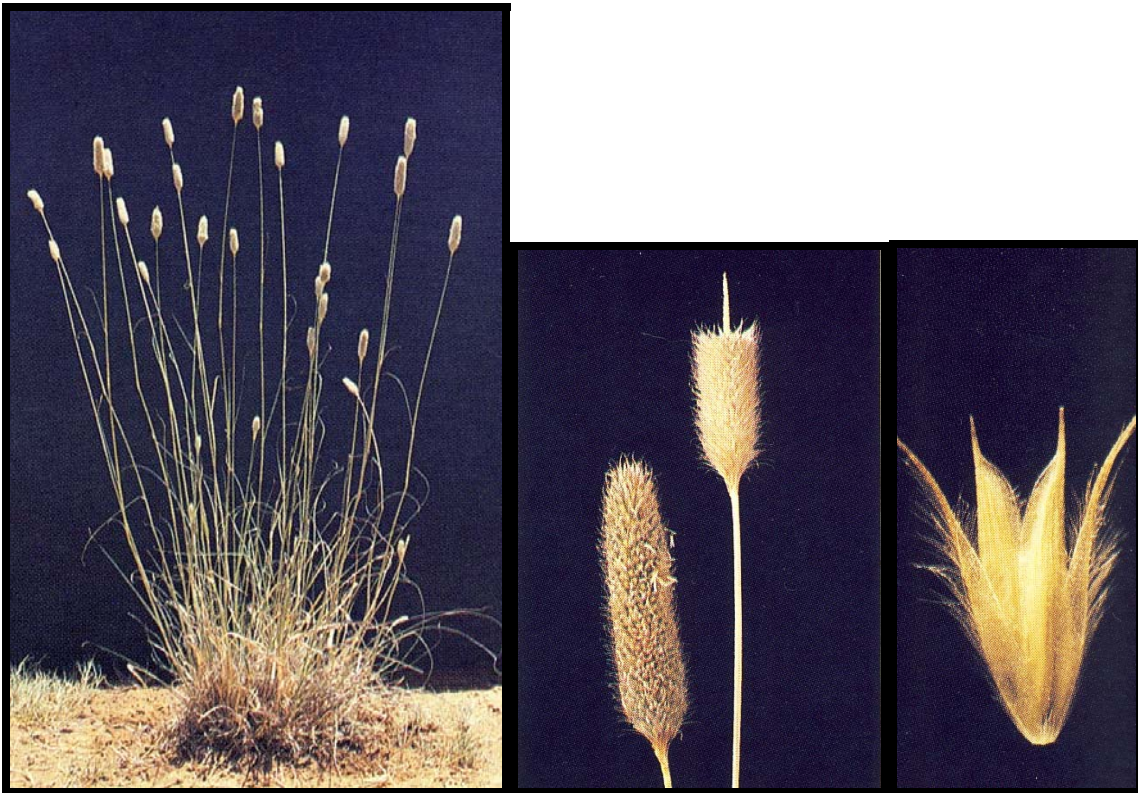


Figure A2.23. Photographs of *Fingerhuthia sesleriiformis* (appearance, flowers, seeds and leaves) (Van Oudtshoorn, 1994).

A2.2.12 *Rhus lancea* (Karee)

Distribution: Grassland and Savanna biomes.

Description: Small to medium-sized evergreen tree; occurring in a wide range of habitats, often on calcareous substrates (Van Wyk & Van Wyk, 1997).

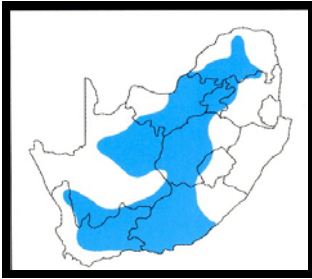


Figure A2.24. Distribution of *Rhus lancea* (Venter & Venter, 2005).



Figure A2.25. Photographs of *Rhus lancea* (appearance, flowers, seeds, bark and leaves) (Venter & Venter, 2005).

A2.2.13 *Strychnos pungens* (Spine-leaved monkey orange)

Distribution: Grassland and Savanna biomes.

Description: Small to medium-sized evergreen tree; occurring in a wide range of habitats, often on calcareous substrates (Van Wyk & Van Wyk, 1997).

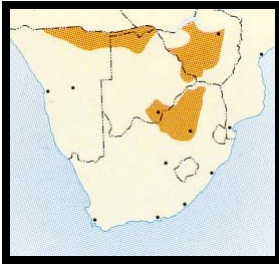


Figure A2.26. Distribution of *Strychnos pungens* (Van Wyk & Van Wyk, 1997).



Figure A2.27. Photographs of *Strychnos pungens* (appearance (Grant and Thomas, 2000), seeds (Van Wyk & Van Wyk, 1997), flowers (Van Wyk & Van Wyk, 1997), bark (Van Wyk, 1986) and leaves (Van Wyk & Van Wyk, 1997)).

A2.2.14 *Ximenia americana* & *X. caffra* (Blue sourplum & Sourplum)

Distribution: Mainly in the Savanna biome.

Description: *Ximenia americana*: Much-branched shrub or small deciduous tree with a blue-green appearance; occurring in bushveld, often in hot, low altitude areas.

Ximenia caffra: Sparsely branched shrub or small deciduous tree with dark green leaves (Van Wyk & Van Wyk, 1997).



Figure A2.28. Distribution of *Ximenia caffra* (Venter & Venter, 2005). The distribution of *Ximenia americana* is similar.



Figure A2.29. Photographs of *Ximenia caffra* (appearance, flowers, seeds, bark and leaves) (Venter & Venter, 2005). The leaves of *Ximenia americana* are blue-green.

A2.2.15 *Zanthoxylum capense* (Small knobwood)

Distribution: Grassland and Savanna biomes.

Description: Shrub or small deciduous tree armed with prickles; occurring in grassland, bushveld and along forest margins, usually associated with bush clumps and rocky places (Van Wyk & Van Wyk, 1997).

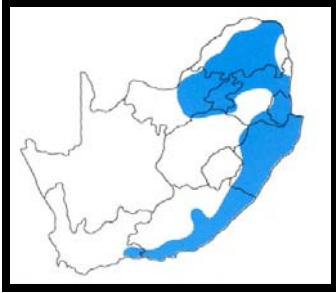


Figure A2.30. Distribution of *Zanthoxylum capense* (Venter & Venter, 2005).

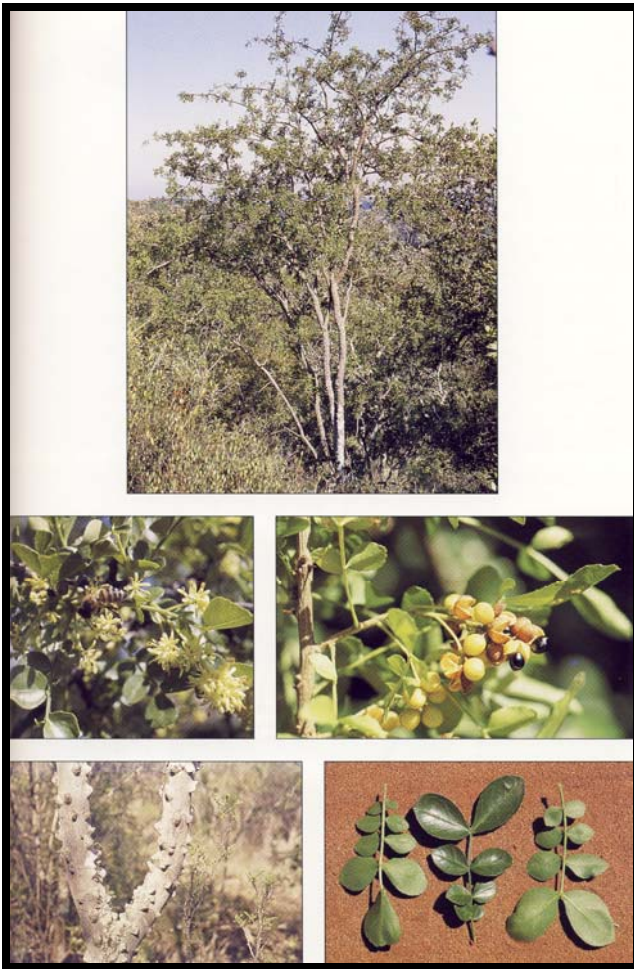


Figure A2.31. Photographs of *Zanthoxylum capense* (appearance, flowers, seeds, thorny bark and leaves) (Venter & Venter, 2005).

A2.2.16 *Ziziphus mucronata* (Buffalo-thorn)

Distribution: Grassland and Savanna biomes.

Description: Shrub or small to medium-sized deciduous tree; occurring in a wide variety of habitats (Van Wyk & Van Wyk, 1997).

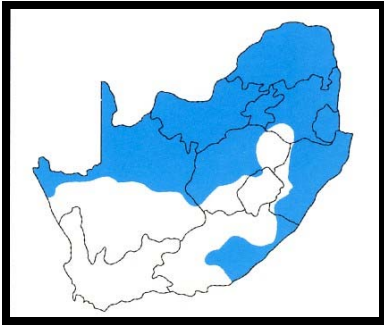


Figure A2.32. Distribution of *Ziziphus mucronata* (Venter & Venter, 2005).



Figure A2.33. Photographs of *Ziziphus mucronata* (appearance, flowers, seeds, thorns, bark and leaves) (Venter & Venter, 2005).

A2.2.17 *Acacia erioloba* (Camel thorn)

Distribution: Grassland and Savanna biomes.

Description: Medium to large tree with a rounded or umbrella-shaped crown; main branches often somewhat contorted in old trees; occurring in bushveld and grassland, usually on deep sandy soils or along watercourses in arid areas (Van Wyk & Van Wyk, 1997).

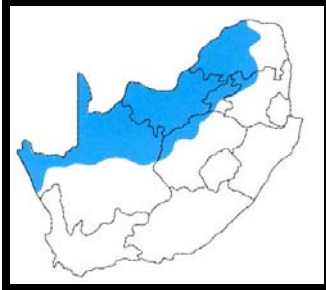


Figure A2.34. Distribution of *Acacia erioloba* (Venter & Venter, 2005).



Figure A2.35. Photographs of *Acacia erioloba* (appearance, flowers, seeds, thorns, bark and leaves) (Venter & Venter, 2005).

A2.2.18 *Boscia albitrunca* & *B. foetida* subsp. *rehmanniana* (Shepherd's tree & Stink shepherd's tree)

Distribution: Mainly in the Savanna biome.

Description: *Boscia albitrunca*: Small tree with a rounded, much-branched crown and rigid branchlets; occurring in semi-desert areas and bushveld, often on termitaria.

B. foetida subsp. *rehmanniana*: Small tree with a single stem, usually starting to branch at least 1 m above the ground; occurring in dry bushveld (restricted to the research area). Leaves are smaller than these of *Boscia albitrunca* (Van Wyk & Van Wyk, 1997).

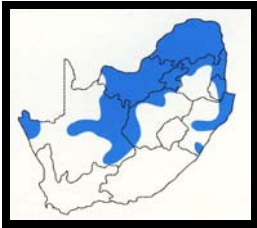


Figure A2.36. Distribution of *Boscia albitrunca* (Venter & Venter, 2005). The distribution of *B. foetida* subsp. *rehmanniana* is restricted to the research area.

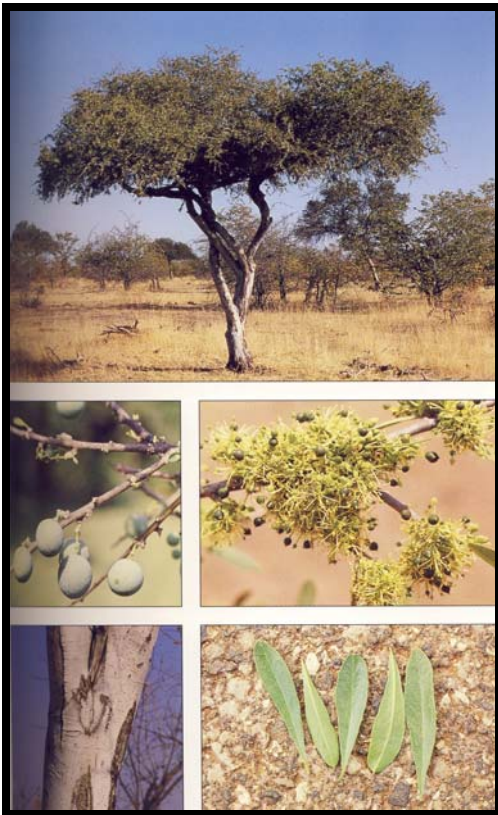


Figure A2.37. Photographs of *Boscia albitrunca* (appearance, flowers, seeds, bark and leaves) (Venter & Venter, 2005). Note that the leaves of *B. foetida* subsp. *rehmanniana* are smaller.

A2.2.19 *Commiphora mollis* (Velvet corkwood)

Distribution: Savanna biome.

Description: Small to medium-sized, deciduous tree; occurring in hot, dry bushveld, often on rocky outcrops (Van Wyk & Van Wyk, 1997).

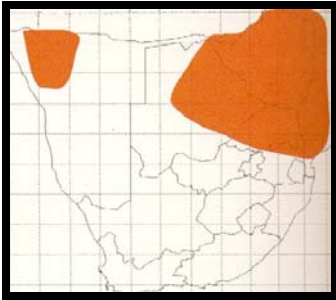


Figure A2.38. Distribution of *Commiphora mollis* (Steyn, 2003).

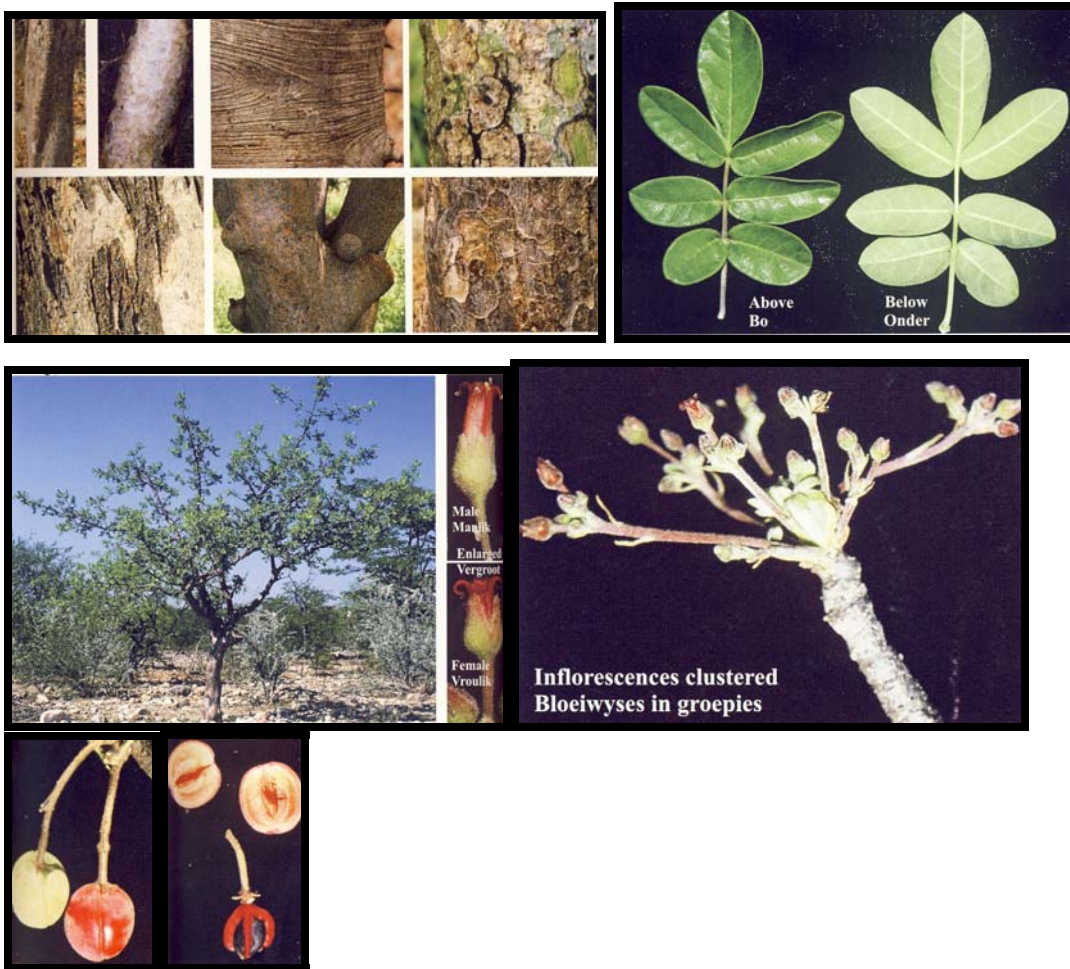


Figure A2.39. Photographs of *Commiphora mollis* (appearance, flowers, seeds, bark and leaves) (Steyn, 2003).

A2.2.20 *Gardenia volkensii* (Savanna gardenia)

Distribution: Savanna biome.

Description: Shrub or small tree, with short, rigid branches; occurring in bushveld (Van Wyk & Van Wyk, 1997).



Figure A2.40. Distribution of *Gardenia volkensii* (Venter & Venter, 2005).

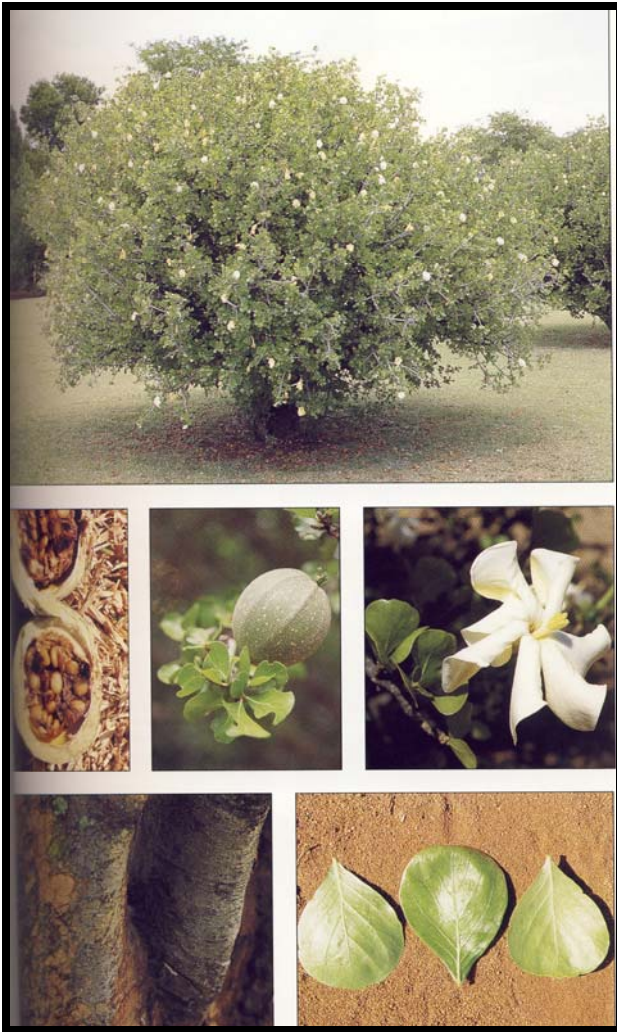


Figure A2.41. Photographs of *Gardenia volkensii* (appearance, flowers, seeds, bark and leaves) (Venter & Venter, 2005).

A2.2.21 *Lonchocarpus capassa* (Apple-leaf)

Distribution: Savanna biome.

Description: Small to medium-sized deciduous or semi-deciduous tree with a rather sparse crown; occurring in bushveld and woodland, often at low altitude along rivers (Van Wyk & Van Wyk, 1997).

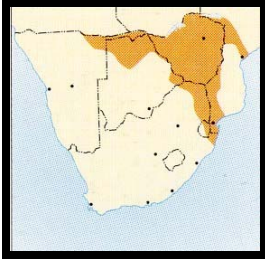


Figure A2.42. Distribution of *Lonchocarpus capassa* (Van Wyk & Van Wyk, 1997).



Figure A2.43. Photographs of *Lonchocarpus capassa* (appearance, flowers, seeds, bark and leaves) (Van Wyk, 1986).

A2.2.22 *Olea europaea* subsp. *africana* (Wild olive)

Distribution: Grassland and Savanna biomes.

Description: Small to medium-sized evergreen tree with a dense rounded crown and grayish green foliage; occurring in a wide range of habitats, usually on rocky hillsides or on stream banks (Van Wyk & Van Wyk, 1997).

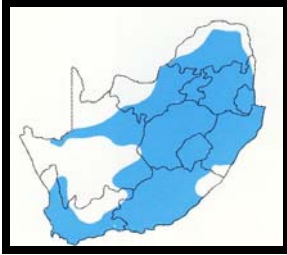


Figure A2.44. Distribution of *Olea europaea* subsp. *africana* (Venter & Venter, 2005).

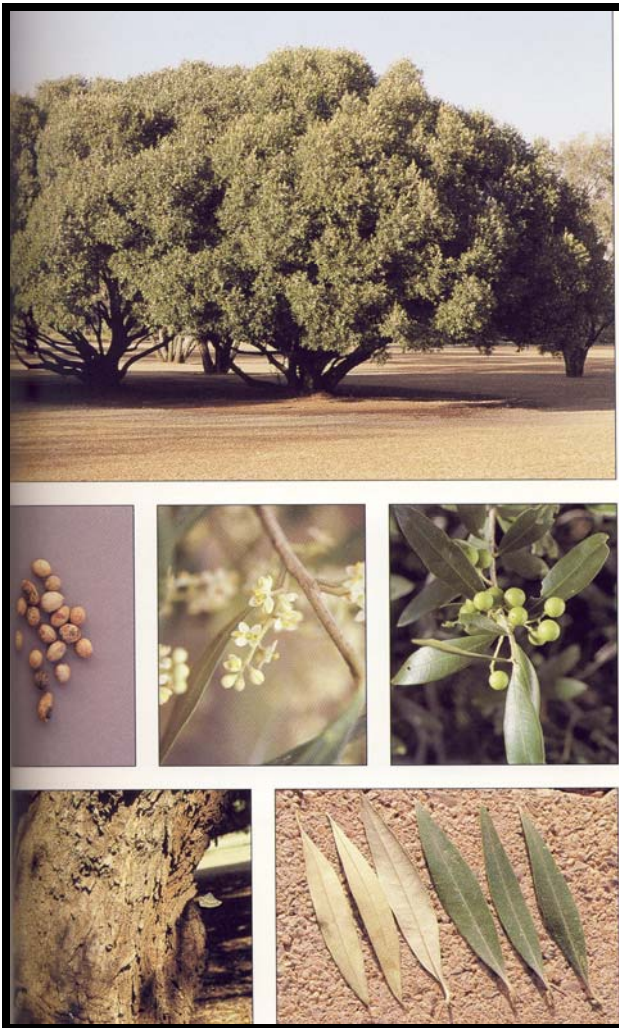


Figure A2.45. Photographs of *Olea europaea* subsp. *africana* (appearance, flowers, seeds, bark and leaves) (Venter & Venter, 2005).

A2.2.23 *Pappea capensis* (Jacket-plum)

Distribution: Grassland and Savanna biomes.

Description: Small to medium-sized deciduous tree with a spreading, often intricately branched crown; occurring in bushveld and wooded grassland (Van Wyk & Van Wyk, 1997).

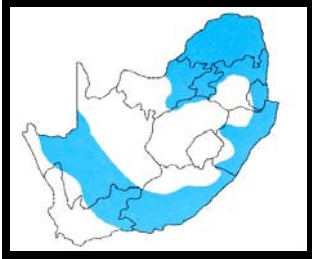


Figure A2.46. Distribution of *Pappea capensis* (Venter & Venter, 2005).

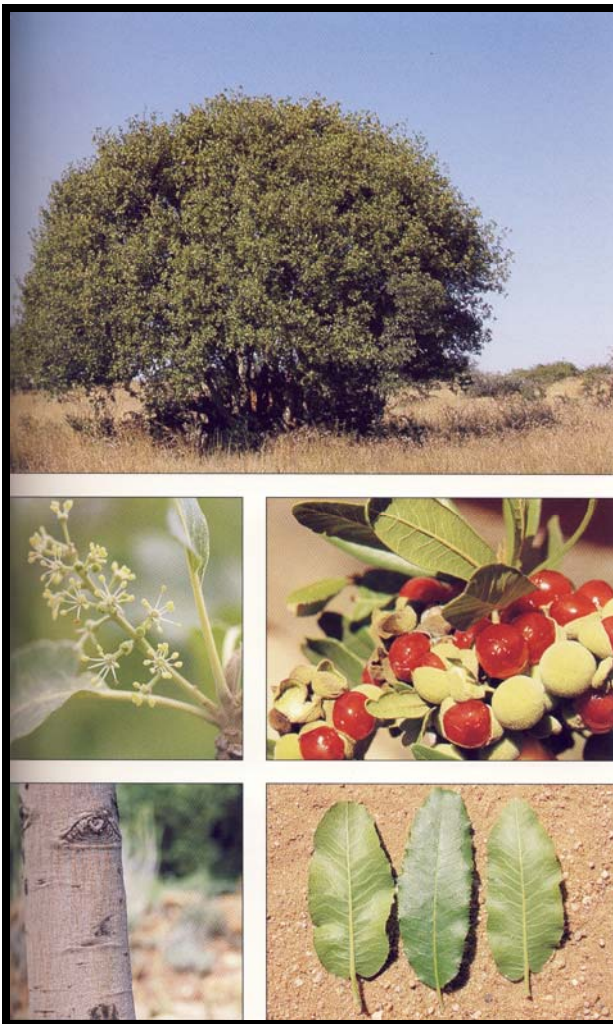


Figure A2.47. Photographs of *Pappea capensis* (appearance, flowers, seeds, bark and leaves) (Venter & Venter, 2005).

A2.2.24 *Spirostachys africana* (Tamboti)

Distribution: Savanna biome.

Description: Medium-sized deciduous tree with a rounded crown and yellow or reddish autumn colours; latex milky; occurring in low-altitude bushveld, often on heavy soils along rivers and streams (Van Wyk & Van Wyk, 1997).

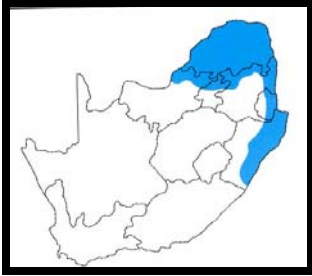


Figure A2.48. Distribution of *Spirostachys africana* (Venter & Venter, 2005).

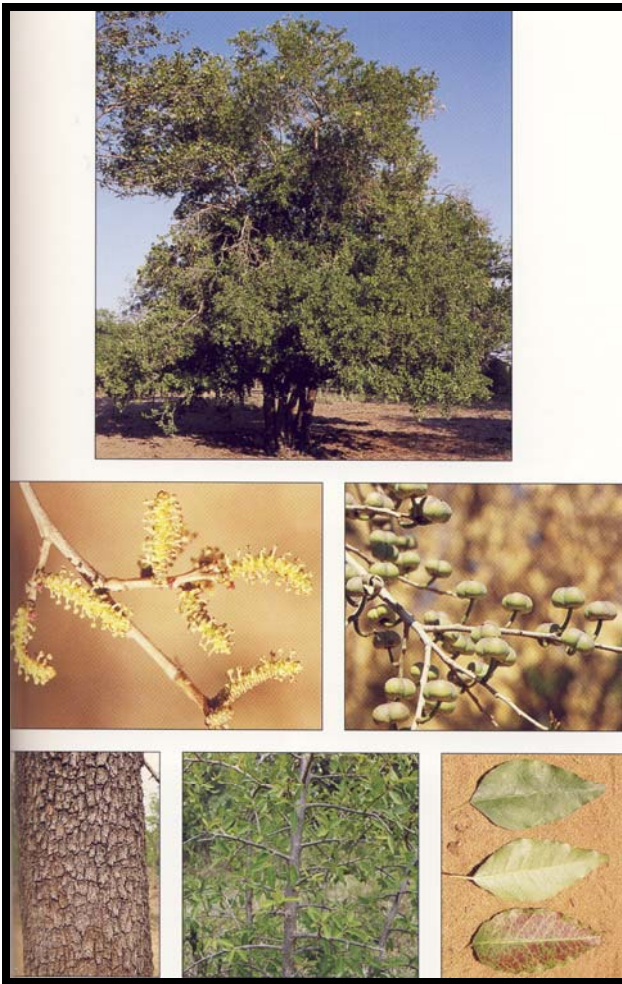


Figure A2.49. Photographs of *Spirostachys africana* (appearance, flowers, seeds, bark and leaves) (Venter & Venter, 2005).