

Cenozoic deposits of South Africa

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PREFACE

Acknowledgements

Firstly I want to thank God my saviour and Father in heaven by quoting Ephesians 3:20: „Now to Him who is able to do immeasurably more than all we ask or imagine, according to His power that is at work within us,²¹ to Him be glory”

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ABSTRACT

The Cenozoic Era comprises the last 65 million years of Earth's history, which is divided into the Tertiary and Quaternary Periods. The deposits of the Cenozoic Era are reflected in many surface features covering South Africa including; 1) palaeosols; 2) clastic sedimentary deposits such as cave sediments, gravel deposits, the Pebble Marker; periglacial deposits, redistributed sand deposits and drainage depressions; 3) pedogenic deposits such as calcrete, silcrete, dorbanks, ferricrete, manganocrete, phoscrete, gypcrete and intergrade pedocretes. Each feature linked to the Cenozoic Era reflects certain characteristics of specific palaeoenvironmental conditions or palaeoclimatic change. The extent and the characteristics of the respective Cenozoic features differ considerably.

The Cenozoic deposits cover vast surface areas over South Africa therefore modern society frequently interacts with these materials. This said the objectives were to assimilate information regarding the Cenozoic sediments and pedogenic material with respect to its geotechnical, economical, agricultural and tourism potential. The aims were to compile a distribution map of the South African terrestrial Cenozoic deposits as well as a basic chronostratigraphic timeline.

Physical analyses included angle of repose, atterberg limits, particle size distribution, water retention and loss on ignition, amongst others. Geochemical analyses included, but were not limited to, pH, electrical conductivity, cation exchange capacity and X-ray fluorescence. Mineralogical analyses included scanning electron microscopy and X-ray diffraction. These methods were used to comply with the aims and objectives of the study.

The selected palaeosol localities at Florisbad and Cornelia were mainly used to gain more information on the horizon characteristics. The determined geochemical results were used to compare with previous literature, regarding the palaeoenvironmental conditions which were linked to these deposits. The geochemical analyses supported the palaeoenvironments discussed in literature. The fauna evolutionary stages linked to these sites e.g. the Cornelian Land Mammal Age and Florisian Land Mammal Age were used in the chronostratigraphic timeline.

The clastic sediment results illuminated the variation that occurs in different caves with regards to geochemistry and microbial activity. The main geochemical components were phosphate, nitrate and ammonium and the microbial activity were ascribed to the presence of bats. The bat guano can contribute to the economic potential of the Cenozoic deposits in the form of fertilizers. Information obtained from literature regarding known caves, such as Sterkfontein and Makepansgat, were used in the chronostratigraphic timeline.

The gravel deposits from Windsorton were used as an example of gravel terraces associated with palaeodrainage systems. These gravel deposits were linked to the Riverton and Rietsputs alluvial gravel deposits obtained from literature. The gravel deposits indicated fluvial episodes linked to the Pleistocene Epoch, and can indirectly refer to wetter palaeoenvironmental conditions that existed.

The Pebble Marker was investigated at two selected sites and indicated that the sediments in this „gravel layer“ were not uniform with respect to the gradation and composition. The origin of the Pebble Marker was stated to be associated with ancient river systems or formed by termites as hypothesised by Brink (1985). An alternative hypothesis is used in this research as being formed during periglacial environmental conditions. The age of approximately 19 000 years was proposed for the Pebble Marker from dated fossilised giraffe bones present in this layer.

A periglacial deposit was investigated close to Groot Marico in the North-West province and was linked to a Period between 300 000 years - 1.7 million ago, as Acheulean stone tools were found in the deposit. This indicated that colder periglacial palaeoenvironmental conditions existed during the Late Pliocene and Pleistocene Epochs.

The terrestrial sand deposits were divided into the Kalahari sand deposit and the redistributed coastal sands. The Kalahari Group stratigraphy observed from three borehole logs were compared with the stratigraphy by Thomas (1981) and correlated well. The geochemical analysis of the Kalahari and coastal deposits mainly indicated that SiO_2 was the dominant mineral. The Scanning Electron Microscope interpretation of selected samples indicated that wind was the mode of transportation. The geotechnical analysis indicated that the sand deposits may have the potential to collapse when used as base foundation. The agricultural potential was low due to a low water retention potential and cation exchange capacity.

The drainage depressions indicated a variation in mineral compositions and in some occurrences were relatively saline. This may be due to the drainage depressions being contaminated or the salt being concentrated after evaporation takes place. The geotechnical evaluation indicated that the drainage depressions sediments have a high shrink and swell potential and are not suitable to build on. The drainage depressions were not suited for agricultural purposes due to the high water retention potential resulting in an insufficient amount of water available for plants.

The pedogenic deposits were linked to certain climatic conditions, and were compared to the Climatic N-value map of Weinert (1980). Calcrete, silcrete and ferricrete correlated well and indicated that calcrete and silcrete formed under semi-arid to arid conditions and ferricrete under humid conditions. Literature obtained stated gypcrete formed under very arid conditions.

Intergrade pedocretes are mixtures of different dominant geochemical components such as silica and iron-oxides, and were interpreted as being formed during rapid environmental change or microenvironmental change. The distribution of the calcrete, silcrete and dorbanks, and ferricrete were also compared to the distribution of calcic, silicic, and oxidic soils in South Africa, respectively (Fey, 2010). Calcrete correlated well to the distribution of calcic soils, silcrete correlated poorly to silicic soils, but dorbanks correlated well with silicic soils and ferricrete correlated well with the distribution of oxidic soils. The distribution and geochemical analyses of phoscrete and gypcrete deposits correlated well with literature. The intergrade pedocretes correlated well with the Cenozoic deposit distribution map. The geochemical compositions were determined for selected samples of all the pedogenic material and overall correlated well with the minimum requirements stated by literature. The geotechnical implications of the pedogenic deposits were mainly dependent on the stage of development and therefore are very inconsistent due to variability in the deposit.

It was found that the Cenozoic deposits have high economic potential such as the alluvial diamond bearing gravel deposits; calcrete, silcrete and ferricrete used for road construction material; and phoscrete as fertilizer, amongst others. These deposits also contribute to the tourism industry by allowing the public to access selected caves sites, such as the Sterkfontein and Cango cave and the Langebaan Fossil Park, to name a few.

The compilation map of the Cenozoic deposits obtained from this research was compared to a Geological Map from the CGS (2004). The sample localities overlap the Cenozoic deposits from the Geoscience map but also extended the distribution indicated in the CGS map. This implies that the terrestrial Cenozoic deposits cover wider areas of South Africa in comparison to the deposits indicated in the CGS map. The basic chronostratigraphic timeline indicated that various climatic changes existed in the last 65 million years and is reflected in the different Cenozoic deposits.

The conclusion was made that the standard Cenozoic deposit map of South Africa was an underestimation of the extent of the Cenozoic deposits, and that further research is needed to compile a detailed map and chronostratigraphic timeline.

Keywords: Cenozoic Era, Quaternary, Tertiary, palaeoenvironment, stratigraphy, palaeosols, caves, gravels deposits, pedogenic material, Pebble Marker, periglacial, sand and drainage depressions

OPSOMMING

Die Senosoïse Era bestaan uit die laaste 65 miljoen jaar van die aarde se geologiese geskiedenis, en is verdeel in die Tertiêre en Kwarternêre tydperke. Die Senosoïse Era word weerspieël in baie oppervlak kenmerke wat Suid-Afrika bedek insluitend; 1) palaeosols, 2) klastiese sedimentêre afsettings soos grot sedimente, gruis afsettings, die Pebble Marker, periglasiale afsettings, herverspreide sand afsettings en dreineringsdepressies; 3) pedogeniese materiaal soos kalkrete, silkrete, dorbanke, ferikrete, manganokrete, foskrete, gipskrete en geïntegreerde pedokrete. Elke afsetting geassosieer met die Senosoïse Era bevat sekere eienskappe wat verband hou met palaeo-omgewingskondisies of palaeo-omgewingsveranderinge. Die verspreiding en die eienskappe van die onderskeie Senosoïse kenmerke verskil aansienlik van mekaar.

Die wye verspreiding van die Senosoïse afsettings oor Suid-Afrika het tot gevolg dat die moderne samelewing gereeld in aanraking kom met hierdie materiale. Dit het gelei tot die volgende doelwitte wat gestel is in die studie nl: om inligting te versamel rakende die geotegniese, ekonomiese, landbou en toerisme potentiaal van die Senosoïse sedimente en pedogeniese materiaal. Die hoofdoel was om „n verspreidingskaart van die Suid-Afrikaanse, terrestriële Senosoïse afsettings op te stel asook om „n basiese chronostratigrafiese tydlyn.

Fisiese analyses het onder andere bepaling van die rushoek, Atterberg grense, deeltjie grootte verspreiding, water retensie en koolstof toetse ingesluit. Die geochemiese analyses het die pH, elektriese geleidingsvermoë, katioon uitruilbaarheid en X-straal fluoresensie, om „n paar te noem, ingesluit. Die mineralogiese analyses het skanderingslektronmikroskopie en X-straal diffraksie ingesluit. Hierdie metodes is gebruik om te voldoen aan die doelwitte asook die hoofdoel van die projek.

Spesifieke palaeosol lokaliteite nl. Florisbad en Cornelia is gekies om inligting te versamel oor die eienskappe van die verskillende horisonte in die grondprofile. Die geochemiese resultate is vergelyk met literatuur studies, rakende die palaeo-omgewingstoestande wat veroorsaak het dat die grondprofile vorm, en het goed gekorreleer. Die fauna evolutionêre fases wat met die palaeosol afsettings geassosieer word nl. die Cornelia Land Soogdier Ouderdom en die Florisbad Land Soogdier Ouderdom, is in die chronostratigrafiese tydlyn gebruik.

Die resultate wat verband hou met die klastiese sedimente het die variasie in verskeie grotte aangedui ten opsigte van die geochemiese en mikrobiële aktiwiteit. Die hoof geochemiese komponente wat teenwoordig was, was fosfate, nitrate en ammonium. Die mikrobiële aktiwiteit is toegeskryf aan die teenwoordigheid van vlermuise. Die vlermuiscuano dra by tot die ekonomiese potentiaal van die Senosoïse afsettings in die vorm van kunsmis. Inligting verkry uit

literatuur rakende bekende grotte soos byvoorbeeld Sterkfontein, is gebruik in die chronostratigrafiese tydlyn.

Die gruis afsetting van Windsorton was gebruik as „n voorbeeld van „n gruis afsetting wat geassosieer kan word met palaeodreineringsisteme. Hierdie gruis afsetting is gekoppel aan die Riverton en Rietsput alluviale gruis afsettings verkry uit literatuur. Die gruis afsettings dui op fluviale episodes en is gekoppel aan die Pleistoseen Epog. Dit kan indirek dui op natter palaeo-omgewings toestande in daardie tydperk.

Die *Pebble Marker* (Rolsteenmerker/Gruislaag) is ondersoek by twee lokaliteite en het aangedui dat die sediment in die laag nie uniform is ten opsigte van die gradering en die samestelling nie. Die oorsprong van die Rolsteenmerker is oorspronklik geassosieer met ou riviersisteme of is deur termiete gevorm soos Brink (1985) voorgestel het. „n Alternatiewe hipotese is dus voorgestel in hierdie navorsingsprojek wat lui dat die Rolsteenmerker gevorm het as gevolg van periglasiale toestande. Die ouderdom van die Rolsteenmerker is gekoppel aan „n ouderdom van ongeveer 19 000 jaar, deur kameelperd bene te dateer wat in die laag aangetref is.

„n Periglasiale afsetting is besoek naby Groot Marico in die Noord-Wes Provinsie en is gekoppel aan „n tydperk tussen 300 000 – 1.7 miljoen jaar gelede deur aanleiding van Achaulean handwerktuie wat in die afsetting gevind is. Dit dui daarop dat kouer periglasiale palaeo-omgewingstoestande in die Laat Plioseen en Pleistoseen Epogs bestaan het.

Die terrestriële sand afsettings is verdeel in die Kalahari sand afsetting en die herverspreide kussande. Die stratigrafie van die Kalahari Groep waargeneem uit drie boorgat logs is vergelyk met die stratigrafie opgestel deur Thomas (1981) en het goed gekorreleer. Die geochemiese analyses van die Kalahari en die kussand afsettings het aangedui dat SiO_2 die dominante mineraal is. Die skanderingselektronmikroskopie analyses het aangedui dat die sand meestal deur wind getranspoteer is. Die geotegniese analyses het aangedui dat die sand afsettings „n hoë potensiaal het om te swig wanneer daarop gebou word. Die landboupotensiaal van die sand afsettings is laag as gevolg van die lae waterhouvermoë en katioon uitruilbaarheid.

Die dreineringsdepressies (panne) het aangedui dat daar baie variasie in die mineraal samestelling is en dat sommige dreineringsdepressies „n baie hoë soutkonsentrasie gehad het. Die hoë konsentrasie sout kan wees as gevolg van kontaminasie of aandui dat die evaporasietempo hoog is en die sout gekonsentreerd agter gebly het. Die geotegniese ondersoek het aangedui dat die sediment in die dreineringsdepressies „n hoë swel en krimp potensiaal het en dus nie geskik is om op te bou nie. Dreineringsdepressies is ook nie geskik vir landbou doeleindes nie omdat die waterretensie vermoë hoog is en te min water beskikbaar stel vir die plante.

Die pedogeniese afsettings is geassosieer met spesifieke klimaattoestande en is vergelyk met die Klimaat N-waardes kaart van Weinert (1980). Kalkreet, silkrete en ferikreet het goed ooreengestem en dit het dus aangedui dat kalkreet en silkrete in semi-ariëde en ariëde toestande gevorm het en ferikreet in meer humiede toestande. Uit literatuur is dit afgelei dat gipskrete in baie ariëde toestande gevorm het. Geïntegreerde pedokrete bestaan uit verskillende gemengde geochemiese komponente soos silika en yster oksied. Dit dui aan dat vinnige verandering in omgewingstoestande plaasgevind het of verandering in die mikroklimaat in daardie area. Die verspreiding van kalkreet, silkrete en dorbane, en ferikreet is ook vergelyk met die verspreiding van kalsiumryke, silikaryke en ysterryke gronde, onderskeidelik (Fey, 2010). Kalkreet het goed ooreengestem met die verspreiding van kalkryke gronde, silkrete het swak ooreengestel met silika-ryke gronde, maar dorbane het goed ooreengestem met silica-ryke gronde, en ferikreet het goed ooreengestem met die ysterryke gronde. Die verspreiding en geochemiese analyses van foskrete en gipskrete afsettings het goed ooreengestem met literatuur. Die geïntegreerde pedokrete het goed ooreengestem met die verspreiding van die Senosoïse afsettings van Suid-Afrika. Die geochemiese samestellings is bepaal vir geselekteerde monsters van al die pedogeniese materiaal en het oor die algeheel goed ooreengestem met die minimum vereistes voorgestel in literatuur. Die geotegniese gevolge van die pedogeniese materiaal is meestal afhanklik van die fase van ontwikkeling en dus was daar baie variasie in die afsettings.

Daar is bevind dat die Senosoïse afsettings „n hoë ekonomiese potensiaal het weens die alluviale diamantdraende gruis afsettings; kalkreet, silkrete en ferikreet wat gebruik word vir padboumateriaal en foskrete wat gebruik word vir kunsmis, om „n paar voorbeelde te noem. Hierdie afsettings dra ook by tot die toerismebedryf aangesien die publiek grotte soos die Sterkfontein en Cango, asook die Langbaan Fossiel Park kan besoek.

„n Samevattende kaart van die Senosoïse afsettings uit die ondersoek in hierdie navorsingsprojek is vergelyk met die Geologiese Kaart van die CGS (2004). Die lokaliteite waar Senosoïse afsettings gevind is tydens veldwerk het in sommige gevalle ooreenstem met die Senosoïse afsettings van die CGS kaart, maar het ook verder as die verspreiding in die CGS kaart gestrek. Dit impliseer dat die terrestriële Senosoïse afsettings wyer areas in Suid-Afrika dek as wat voorgestel is deur die CGS kaart. Die basiese chronostratigrafiese tydlyn dui aan dat verskeie klimaatsveranderings plaasgevind het in die laaste 65 miljoen jaar en dit word weerspieël in die verskillende Senosoïse afsettings.

Die gevolgtrekking is gemaak dat die standaard kaart wat die Senosoïse afsettings „n onderskatting van die verspreiding van die Senosoïse afsettings is en dat verdere navorsing nodig is om „n gedetailleerde kaart en chronostratigrafiese tydlyn op te stel.

Sleuteltermen: Senosoïse Era, Kwarternêr, Tertiêr, palaeo-omgeving, stratigrafie, palaeosols, grotte, gruis afsettings, pedogeniese materiaal, Pebble Marker, periglasiaal, sand en dreineringsholtes.

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LIST OF EQUATIONS

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LIST OF ABBREVIATIONS

CGS – Council for Geoscience

EC – Electrical conductivity (mS/m)

GIS – Geographical Information System

ka – thousand years

LMA – Land Mammal Ages

Ma – Million years

mamsl – meters above mean sea level

MSA – Middle Stone Age

OC- Organic carbon

pH – The acidity of a soil (The negative logarithm to the base 10 of the hydrogen ion activity),
Soil Classification Working Group (1991:235)

PXRF – Portable X-ray Diffraction

PSD – Particle size distribution

ppm - parts per million

SEM – Scanning Electron microscope

SOM – Soil organic matter

XRF- X-ray Diffraction

DEFINITIONS

Accummulation: **Absolute:** The addition of an element to a system or regolith (Taylor and Eggleton, 2001).

Relative: The concentration of elements due to the leaching of others (Taylor and Eggleton, 2001).

Calcrete: Carbonate horizon formed due to the precipitation of calcium carbonate in solution in a semi-arid environment. The first stage of formation is nodules and can become laminar or massive and can also be cemented and indurated in result on exposure. Calcretes can also be soft or powder (Oxford Dictionary of Earth Sciences, 2008).

Ferricrete: Also referred to as duricrust. Weathered material which has a dominant mineral such as sesquioxides of iron and aluminium in ferricrete. Ferricrete forms in subtropical or semi-desert environments (Taylor and Eggleton, 2001; Oxford Dictionary of Earth Sciences, 2008).

Intergranular aquifer: An aquifer which has fractures in weathered rock or spaces in between soil particles which groundwater can flow through (DWA, Groundwater Dictionary: 2015)

Lag deposit: Residue layer consisting mainly of coarser grained particles as a result of the removal or transportation of finer particle from the deposit (Oxford Dictionary of Earth Sciences, 2008).

Last Glacial: The last glacial maximum started in the Northern Hemisphere about 18 ka, and ended 10 ka (McCarthy and Rubidge, 2005).

Laterite: Forms in a humid environment as a product of weathered rocks mainly containing hydrated iron and hydroxides, clay minerals and silica (Oxford Dictionary of Earth Sciences, 2008).

Lunette dunes: Also referred to as clay dunes. Aeolian sediment including clay particles found on the margins of some salt pans, (Oxford Dictionary of Earth Sciences, 2008), as well as other pans. In southern Africa lunette dunes are dominant in the south eastern rims of pans and contain abundant CaCO_3 .

Neomineralization: The metamorphism of pre-existing minerals to form new minerals (Oxford Dictionary of Earth Sciences, 2008).

Palaeo: A prefix meaning „ancient“ or „very old“. Palaeo is derived from the Greek word *palaios* (ancient) (Oxford Dictionary of Earth Sciences, 2008).

Palaeobotany: The study of plant fossils (Oxford Dictionary of Earth Sciences, 2008).

Palaeontology: The study of fossils (fauna and/or flora) to gain information on the palaeoenvironmental conditions (Oxford Dictionary of Earth Sciences, 2008).

Palaeosol: Is a soil which formed during an earlier stage of pedogenesis and differs from the present stage of soil formation and could be present on the surface, or buried (Oxford Dictionary of Earth Sciences, 2008).

Particle Size Distribution: Different size fractions of a sediment expressed as percentage after separation of a dispersed sample (Soil Classification Working Group, 1991).

Periglacial: Environmental conditions where the dominant surface feature was freezing and thawing and can also refer to an area adjacent to an ice sheet or glacier. Periglacial conditions can occur at the present but are rather associated with the Pleistocene Period (Oxford Dictionary of Earth Sciences, 2008).

Sedimentology: The study of sediments, sedimentary processes and rocks for classification and interpretation purposes (Oxford Dictionary of Earth Sciences, 2008).

Silcrete: Is one of many duricrusts and is weathered material which has silica as the dominant mineral (Oxford Dictionary of Earth Sciences, 2008).

Soil horizon: A relatively parallel layer of soil at any depth in a soil profile which has distinct mineralogical and organic characteristics which allows the layers to be differentiated for each other, (Oxford Dictionary of Earth Sciences, 2008). The Soil Classification Working Group (1991) is used in South Africa.

Stratigraphy: The study of stratified rock referring to the time and space. This involves the correlation of rocks from different localities using geological time units (chronostratigraphy), rock units (lithostratigraphy) or fossils (biostratigraphy) (Oxford Dictionary of Earth Sciences, 2008).

Subfossil: The preserved remains of organisms that are younger than 10 ka are referred to as subfossils (Oxford Dictionary of Earth Sciences, 2008).

Taphonomy: The study of the process of fossilization of an organism (Oxford Dictionary of Earth Sciences, 2008)

CHAPTER 1 - INTRODUCTION

1.1 Background

The geological timeline of the Cenozoic Era as seen in Table 1 is divided into the Quaternary and the Tertiary Periods, which are further, subdivided into the Palaeogene and Neogene Series. The Palaeogene is subdivided into the Palaeocene, Eocene and Oligocene Epoch. The Neogene is subdivided into the Miocene, Pliocene, Pleistocene and Holocene Epoch.

Table 1: The basic chronological table of the Cenozoic Era (Johnson *et al.*, 2006).

Era	Period	Series	Epoch	Age (Ma)
Cenozoic	Quaternary	Neogene	Holocene / Recent	0.01
			Pleistocene	1.8
	Tertiary		Pliocene	5
			Miocene	23
		Palaeogene	Oligocene	34
			Eocene	56
			Palaeocene	65

The geology of South Africa, as seen in Figure 1, indicates the Cenozoic deposits in yellow and is the youngest geological sequence in the stratigraphic index. The largest section of the Cenozoic geology is the Kalahari Group in the North West and Northern Cape provinces. The other Cenozoic outcrops are mainly situated along the coastal areas.

The Cenozoic deposits along the coastline of South Africa are mainly thinly distributed and include the marine, fluvial, estuarine, lacustrine and aeolian originated deposits (Figure 2). The lithological units of the coastal deposits have been classified but a few aspects, such as age, fossils present, geomorphology and weathering products, still needs to be taken into account when referring to stratigraphic units (Roberts *et al.*, 2006), see Table 2.

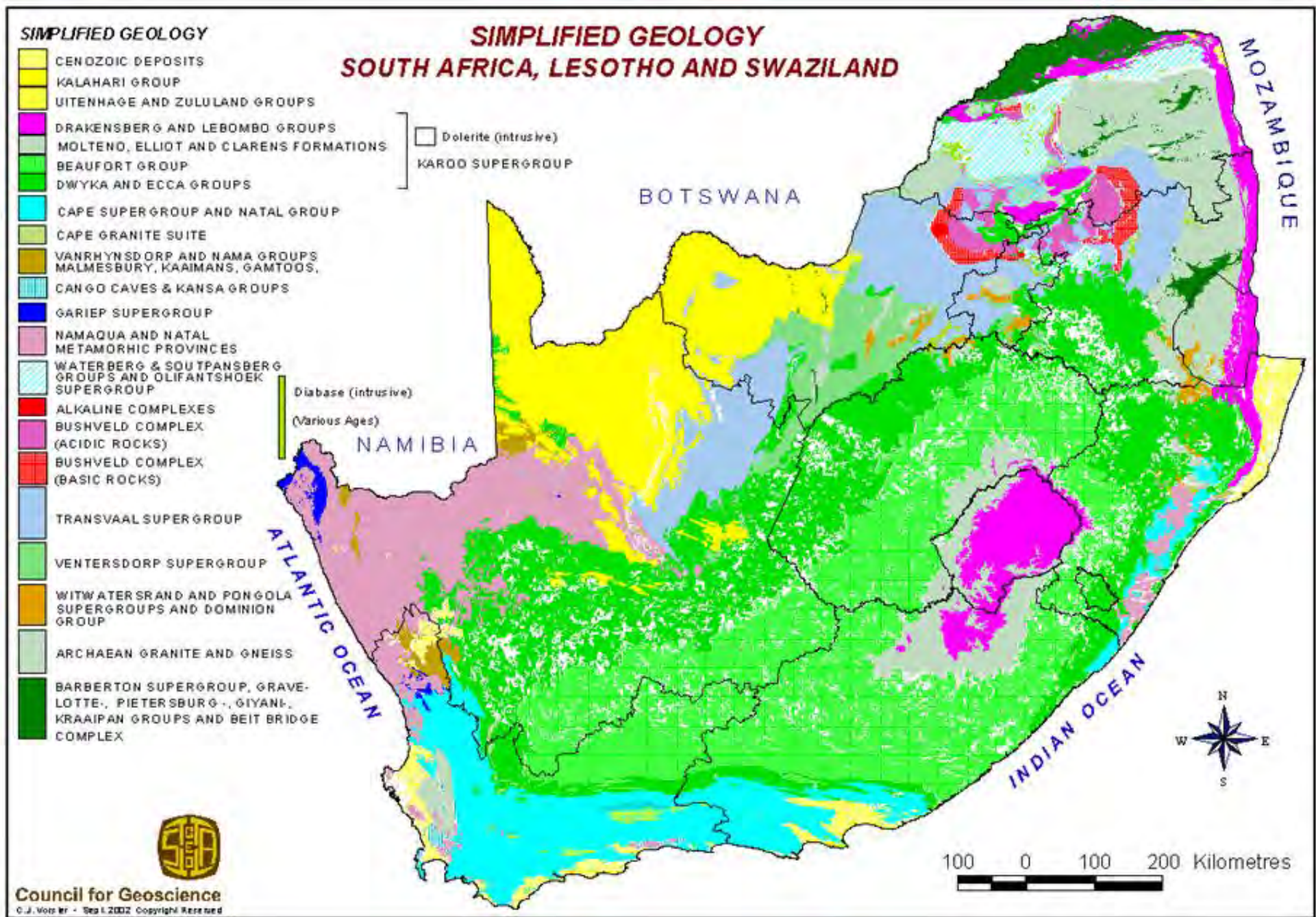


Figure 1: The geology of South Africa, the Cenozoic deposits are indicated in yellow (Vorster, 2002).

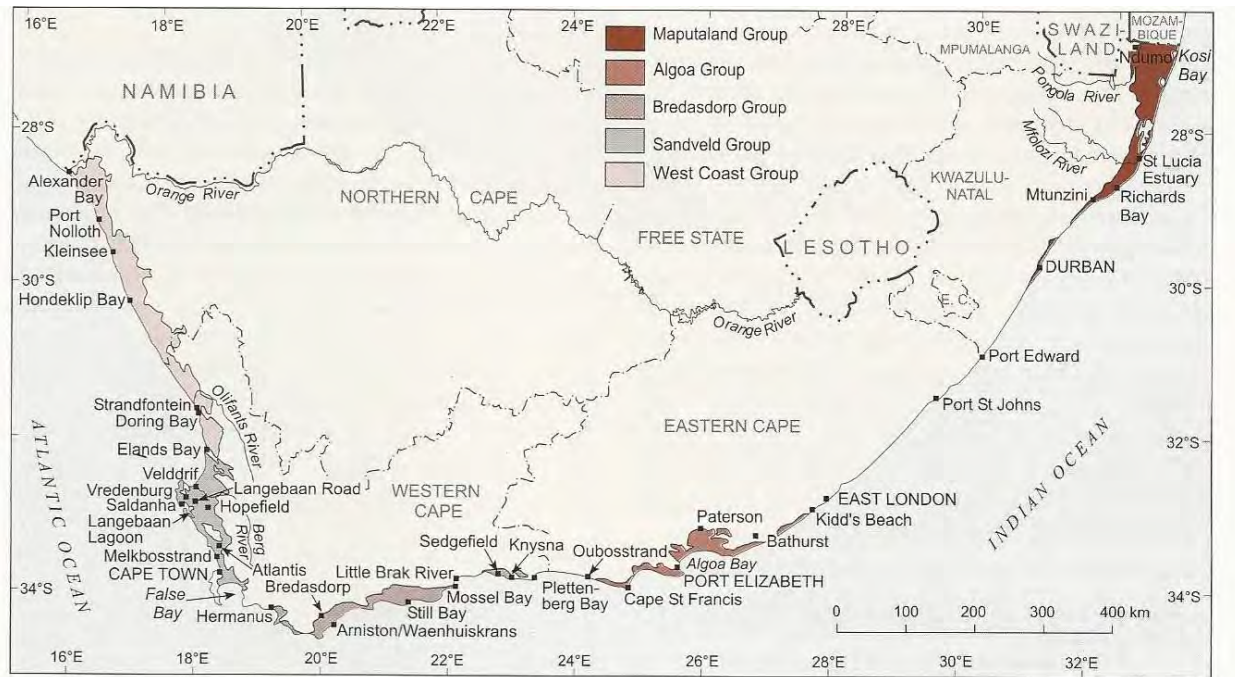


Figure 2: The distribution of the coastal Cenozoic deposits of South Africa (Roberts *et al.*, 2006).

The coastal and inland deposits do overlap in certain areas of South Africa such as the West Cape Group coastal sands and the inland coastal Cenozoic sand deposits.

Cenozoic deposits were studied by various authors which includes Harmse and Hattingh (2012) on the aeolian and gravel deposits, Netterberg (1969) and Goudie (1983) on calcretes, Fey (2010) on the soils of South Africa and De Wet (1991) on the ferricretes. Wilson *et al.* (2007) studied the diamonds associated with gravel deposits. Maud (2012) did a study on the inland as well as the coastal Cenozoic deposits. Many more research was done by various authors including Partridge (1998, 2006) on the evolution of the inland deposits, Visser (1989) on the mineralogical and economical potential, Nash (2012) on the pedogenic material such as silcrete and calcretes as well as the drainage development in the Kalahari desert and Botswana, Lancaster (1988) on the dunes and dune formation and Haddon (2005) on the Kalahari basin.

Table 2: Lithological units of the coastal deposits of South Africa (Roberts *et al.*, 2006).

SANDVELD GROUP	BREDASDORP GROUP	ALGOA GROUP	Age and lithology	MAPUTALAND GROUP	Age and lithology
Witzand Formation	Strandveld Formation	Schelm Hoek Formation	Holocene and recently active dune fields and cordons	Sibayi Formation	Holocene composite accretionary coastal dune cordon
				KwaMbonambi Formation	Late Pleistocene to mid-Holocene inland dunes, diatomite and peat
Springfontyn Formation	Waenhuiskrans Formation	Nahoon Formation	Pleistocene to Holocene calcareous sandstone (aeolianite) with interbedded palaeosols	Isipingo Formation	Latest Middle Pleistocene to Holocene calcified aeolianite and beach deposits
				Kosi Bay Formation	Middle to Late Pleistocene dune sand (generally non-calcareous), lignite, palaeosols and ferricrete
Velddrif Formation	Klein Brak Formation	Salnova Formation	Pleistocene estuarine coquina, calcarenite, sand and conglomerate	Port Durnford Formation	Pleistocene estuarine/lacustrine mud and clayey carbonaceous sand
Langebaan Formation			Late Pliocene to Late Pleistocene aeolianites		
				Berea-type red sand (informal unit)	Weathering product of Mio-Pliocene and Pleistocene calcareous deposits
	Wankoe Formation	Nanaga Formation	Pliocene aeolianite	Umkwelane Formation	Early Pliocene aeolianite and calcarenite
Prospect Hill Formation			Mio-Pliocene aeolianite		
Varswater Formation	De Hoopvlei Formation	Alexandria Formation	Mio-Pliocene littoral and shallow marine sandstone, coquina and conglomerate	Uloa Formation	Mio-Pliocene littoral and shallow marine coquina and sandstone
Elandsfontyn Formation			Miocene fluvial sand and gravels		
		Bathurst Formation	Early to Middle Eocene limestone, calcarenite and conglomerate	Salamanga Formation (Mozambique – not part of Maputaland Group)	Middle to Late Eocene limestone and sandstone

The Cenozoic deposits are of most importance due to the palaeoclimatic changes that are reflected in the different geological formations (Hunter *et al.*, 2006). During the climate fluctuations and epeirogenic activities in the Cenozoic Era most geomorphologic features in southern Africa were formed (Maud, 2012). Barnosky (2005) indicated that various warming and cooling events occurred in the Cenozoic but states that climatic changes during the Quaternary Period, specifically the last 1.8 Ma, were the most drastic climate changes relative to all climate variations in the past. Climate variations that occurred in the Quaternary Period

were both drier and wetter than the present and resulted in changes in river flow patterns, sedimentation processes and vegetation variation (Tooth *et al.*, 2004).

1.2 Study area

The area of this study is very broad and includes most parts of South Africa. Samples were collected in North-West, Free State, Western Cape, Northern Cape and Limpopo provinces. The sites were carefully selected and specific data were recorded per site locality. Therefore a map is included in each section in Chapter 3 (Materials and Methods) indicating site localities as well as site descriptions.

1.3 Problem statement and Justification

The impact of the Cenozoic deposits of the last 65 Ma on the modern society is not certain. This implies that little is known about the geographical boundaries and localities or the engineering characteristics and economic potential, and implications of these deposits in South Africa. The aim of the project is therefore to compile a document which includes the geographical extent, mineral composition, geotechnical, economic potential as well as archaeological sites. A chronostratigraphic timeline of the terrestrial Cenozoic geological deposits of South Africa is included.

1.4 Aims and Objectives

The main aims were to compose a chronostratigraphic timeline as well as compile a map of the terrestrial Cenozoic deposits of South-Africa.

The following objectives were set to accomplish the above mentioned aims:

1. To fill some knowledge gaps with respect to the palaeoenvironmental conditions, which had an influence on the Cenozoic deposits. The correlation between the palaeo and modern conditions will give a good indication of the climate change which occurred in the last 65 Ma years. This can be directly related to the different geology deposits which are present today and can indirectly improve the tourism industry in South Africa by investigating various sites which contain a large variety of hominid, floral and faunal remains.
2. To investigate the geotechnical characteristics of Cenozoic deposits on selected pedogenic deposits as well as sand and clay deposits over South Africa. This can indirectly improve foundation designs, quality of buildings and structures for the areas underlain by these deposits.

3. To evaluate the economic potential of the Cenozoic deposits such as alluvial diamonds, heavy metals in sand, phosphate, road building materials such as calcrete, ferricrete and gypcrete, and other building material such as sand, and as a source for cement manufacturing as well as diatomaceous earth, agricultural limestone, and ceramic clay deposits.
4. Summarise the tourism potential of the Cenozoic deposits in South Africa.
5. Summarise as well as determine the agricultural potential for selected Cenozoic deposits in South Africa.

Therefore the purpose of the study was to compile a comprehensive framework of literature background on the Cenozoic Period. Within this framework, selected field and analytical data were obtained and integrated with existing knowledge. From this research, correlations will be made between observations, information and aligned with geo-environmental events affecting the Cenozoic Deposits over the last 65 million years. Research results will be used to compile a Cenozoic map and chronostratigraphic timeline.

1.5 Hypothesis

Due to the close interaction of the Cenozoic deposits and humans it will have an major impact on many aspects of present day living such as construction, agriculture, archaeology, tourism and economic potential.

1.6 Layout of this dissertation

Chapter 1 is an introduction to the project including the study area, problem statement, aims and objectives and the hypothesis.

Chapter 2 comprise of a literature review which starts with Chapter 2.1 as a summary of the climatic and tectonic events, which resulted in altering and/or the formation of the geomorphologic inland features of South Africa, in the last 65 Ma. The chapter starts a few years before the Cenozoic in the Cretaceous Era and ends in the Present or Holocene Period. Chapter 2.2 includes literature on selected palaeosol localities e.g. Florisbad and Cornelia sites, including the fossil record and chronostratigraphy of each site. Chapters 2.3.1 – 2.3.6 includes clastic sedimentary deposits associated with the Cenozoic deposits. This includes literature regarding cave sediments, gravel deposits, the Pebble Marker, terrestrial sand deposits, drainage depressions and a periglacial deposit. This mainly contains information on the

distribution, formation and composition of these deposits. Chapter 2.4 includes a literature review on the pedogenic deposits such as calcrete, silcrete, dorbanks, ferricrete, manganocrete, phoscrete, gypcrete and intergrade pedocretes. This mainly contains information about the distribution, formation and characteristics of each.

Chapter 3 includes the materials and analytical methods that were used in this study. This includes physical, geochemical and mineralogical methods.

In Chapter 4 the results are discussed for site specific analyses. A summary of the economic and tourism potential of Cenozoic deposits are included in Chapter 4.1 and 4.2. Chapter 4.3 contains information regarding the geochemical composition and palaeoenvironmental conditions of the palaeosol sites of Florisbad and Cornelia. The information included in Chapter 4.4.1 – 4.4.6 is mainly analytical results of the various clastic sediments of the Cenozoic Era. This includes the geochemical composition and microbial activity of cave sediment, the distribution and geochemical composition of gravel deposits e.g. Windsorton gravel sequence and the distribution and particle size analyses of the Pebble Marker, the geotechnical and agricultural potential of terrestrial sand deposits as well as the geochemical composition are included. The drainage depression sediments are also included and the element composition, geotechnical and agricultural potential are discussed. The periglacial site includes information regarding the particle size analyses and the geochemical composition. Chapter 4.5 comprise of the pedogenic deposits including the site descriptions, geochemical composition and geotechnical characteristics. In Chapter 4.6 the compiled map of the terrestrial Cenozoic deposits as well as the basic chronostratigraphic timeline are included.

In Chapter 5 the conclusions are discussed which states that the Cenozoic Map, see Figure 1, is an underestimation of the distribution of the Cenozoic deposits of South Africa, and that it was possible to construct a basic chronostratigraphic timeline. Future recommendations are also discussed, which includes further research that could be done on the Cenozoic deposits of South Africa. Such as:

- The basic compiled map can be reviewed to determine whether the outcrops are sufficient in respect to size to be allocated to the map.
- Compiling a detailed timeline of the Cenozoic deposits using this research as a baseline study.

The data used in this study is included in the appendices. This includes the full data analyses sheets from laboratory results.

1.7 Provisos

The terms stated below are apparent to the layout of this dissertation as well the information it contains:

1. This dissertation is mainly a compilation study and will focus on the inland deposits, but will include selected coastal sand and pedogenic deposits (which corresponds in some instances with the coastal Cenozoic deposits (Figure 2). All coastal deposits are not included because the stratigraphy of the coastal deposits are highly complex and interrupted due to aggregation and degradation as well as influenced by active ocean currents. The time allocated for this project was not sufficient to do proper research on the coastal deposits.
2. It was not possible to sample all the Cenozoic outcrops and therefore site specific data and field observations were made.
3. Due to the wide extent of this project not all aspects will be covered in equal detail, but an attempt has been made to describe all information adequately.
4. Only selected samples have been analysed with the Scanning Electron microscope (SEM) and the stereo microscope and therefore only a few samples have SEM images.
5. Pedogenic samples were identified in the field before geochemical analyses were conducted, therefore samples may not always comply with the minimum requirement to be classified in a certain section. This is clearly stated where applicable.
6. It must be noted that many referred images are taken from literature sources but referenced accordingly.
7. Differences in geomorphological, archaeological, geological and pedological descriptions and analytical interpretations are present but this project tried to put it together and intergrade the four disciplines.
8. Due to the significant degrees of variation in the climatic data over such a considerable time Period, the interpretation of the data and the chronostratigraphic timeline constructed in this research are based on the most widely accepted understanding of the ages in the literature, and the referencing of these ages to the analytical data obtained in this study. Further study would be required whereby the Epochs within the given Era were each analysed in further detail, and from which more accurate extrapolations could be made with regards to the climatic data.

Chapter 2 – LITERATURE REVIEW

This chapter will firstly discuss the events that occurred in the last 65 Ma, including climatic conditions, tectonic events and geomorphological features. Chapter 2.2 includes a literature review of selected palaeosols in South Africa. In Chapters 2.3.1 - 2.3.6, literature regarding the clastic sediment deposits related to the Cenozoic Era will be included such as cave sediments, gravel deposits, the Pebble Marker, terrestrial sand, drainage depression and periglacial sediment. The pedogenic deposits, such as calcrete, silcrete, dorbanks, ferricrete, manganocrete, phoscrete, gypcrete and intergrade pedocretes, will be discussed in Chapter 2.4.

2.1 Geomorphic and tectonic events of the last 65 Ma

This section includes a sequence of events that occurred in the last 65 million years. Climatic conditions, tectonic events as well as geomorphologic features will be discussed.

It must be noted that extrapolating events to specific Periods in time is a challenge to all scientists and leads to different opinions, hence this is an attempt to „create an image“ of the last 65 million years. A time scale of 10 000 – 100 000 years was associated with the characteristic Period it takes for a surface landform to develop (White, 1988).

Table 3 is a summary of King's (1951) research on the modification of the South African land surface due to erosion, associated with the rejuvenation of river systems, as a result of the westward tilting of the continent.

Table 3: Erosion episodes of the African surface (King, 1951).

Used term	Period and duration	Surface characteristics
African Erosion Surface	End of the Cretaceous (active for 120 Ma, King (1951) Maud, 2012:14).	Erosion of the surface similar to present topography, (McCarthy and Rubidge, 2005:25). Pedocretes associated with these deposits are silcrete or laterite underlain with deeply weathered kaolinite saprolite (Maud, 2012:13).

Table 3 (cont): Erosion episodes of the African surface (King, 1951).

Used term	Period and duration	Surface characteristics
Post-African Surface I	Early Miocene uplift, approximately 19 M ago (15 Ma of erosion took place).	Erosion of soil that covered the African Erosion Surface. Episode of upliftment resulted in erosion of 200 m below the African surface due to rejuvenated drainage systems of the Gariep and Koa Rivers, (Maud, 2012, Partidge <i>et al.</i> , (2006).
Post-Africa Surface II	Initiated 2.6 Ma ago (Major Pliocene uplift) (3 Ma of erosion took place).	Uplift of up to 900m in the east and 100m in the west. Climate changes, glacial activity, Last Glacial Period (18 ka).

During the late Cretaceous Epoch Gondwanaland disintegrated completely and about 90 Ma ago southern Africa was separated from the Falkland plateau. A meteorite impact approximately 65 Ma ago caused a mass species extinction episode. The Tertiary Period experienced warping of the surface having major effects on the drainage patterns (McCarthy and Rubidge, 2005, Van Deventer, 2009).

During the Cretaceous Period the climatic conditions were humid and warm (Maud, 2012, Partridge *et al.*, 2006, McCarthy and Rubidge, 2005) as supported by the plant material fossilised in marsh sediment in the Northern Cape (Partridge, 1998). Most of the surface features formed during the Cretaceous, such as the Limpopo and palaeo rivers such as the Karoo and Kalahari River (McCarthy and Rubidge, 2005). The climate changed to a more arid Period in the later Cretaceous and beginning of the Palaeocene which was characterised by the existence of a shrub type plant species. Maud (2012) stated that uplift of the subcontinent mainly occurred during the Cretaceous Period and regional scale uplift did not occur in the Palaeocene. During the last 3000 Ma before the Cenozoic Era, the Kalahari basin established due to the erosion Period that existed after maximum uplift occurred on the rim of the sub-continent (McCarthy and Rubidge, 2005; Partidge *et al.*, 2006). The Kalahari Group sediments started to deposit during the late Cretaceous and the beginning of the Cenozoic approximately 65 Ma ago (Haddon, 2005). The drier Period that existed in the late Cretaceous and beginning of the Palaeocene was associated with the initiation of calcrete and silcrete formation (Maud, 2012; McCarthy and Rubidge, 2005; Partidge *et al.*, 2006) in the west of South Africa. The distributions of these deposits are extensive and will be discussed in more detail in the results and discussion section. The completion of duricrust formations ended by the Early Palaeocene

in the western part of the country. Since the breakup of Gondwana the Period of erosion continued until the beginning of the Miocene Epoch.

Since the Cretaceous Period two main palaeo-river systems (Figure 3) drained the western interior of South Africa. These rivers, the Kalahari and the Karoo Rivers had a southwest- to western flow direction. The present location of the Orange/Gariep River (will be referred to as the Gariep River further in the text) mouth is the approximate drainage location where the Kalahari River entered the Atlantic Ocean (Kounouv, Viola, de Wit and Andreoli, 2008; McCarthy and Rubidge 2005; Goudie 2005). Kimberlite pipes were exposed due to vast erosion that took place and resulted in diamonds being transported to the coastal areas. The Karoo palaeo-river system was the primary transporter of diamonds from the original source of origin to the western side of the coast as well as south of the Gariep River (Wilson *et al.*, 2007). The alluvial diamonds present in abundance in the offshore marine deposits close to the Gariep River supported the evidence that a palaeodrainage system was located in that area (Kounov *et al.*, 2008). Diamonds trapped in gravels of the palaeodrainage systems along the ancient routes are still mined today. Gravel deposits will be discussed further in Chapter 2.3.2. Alluvial diamond mines still exist today along the Orange, Vaal and Mooi Rivers. Another palaeodrainage system drained the northern Free State called the Kimberley River (Partridge *et al.*, 2006:593).

The palaeo-Gariep River originated from a joint stream between the Karoo River and a tributary of the Kalahari River that was redirected south due to the uplift along the Griqualand-Transvaal Axis (McCarthy and Rubidge, 2005). From Prieska in the Northern Cape the Gariep River is a remnant from the Kalahari System whereas the streams upstream from Prieska as well as the Vaal River are remnants from the Karoo River. The Koa River, being 200 m wide in some places, as well as the Gariep River, which drained the western side of the subcontinent, eroded up to 100 m below the original African surface as a result of increasing flow rate. Partridge (1997) and Maud (2012) stated that by the Mid-Miocene between 18 – 12 Ma ago major rivers such as the Gariep River rejuvenated in the Northern Cape. This was caused by the Early Miocene Uplift and resulted in the occurrence of river erosion that was up to 300m below the existing African Surface. Gravel deposits associated with the Koa River were dated to be Middle Miocene in age (Wilson *et al.*, 2007; Partridge *et al.*, 2006). During this time the Koa River was an active northern flowing river and a tributary of the lower Gariep River. End of the Mid-Miocene, fluvial activity decreased and ceased in the Koa River Basin and was mainly due to further acidification, and tectonic activity of the Griqualand-Transvaal Upliftment Axis. The formation of the Kalahari Basin also had an impact on the disintegration of the palaeo-rivers as well as possible mantle plumes underlying the South African surface (Goudie, 2005).

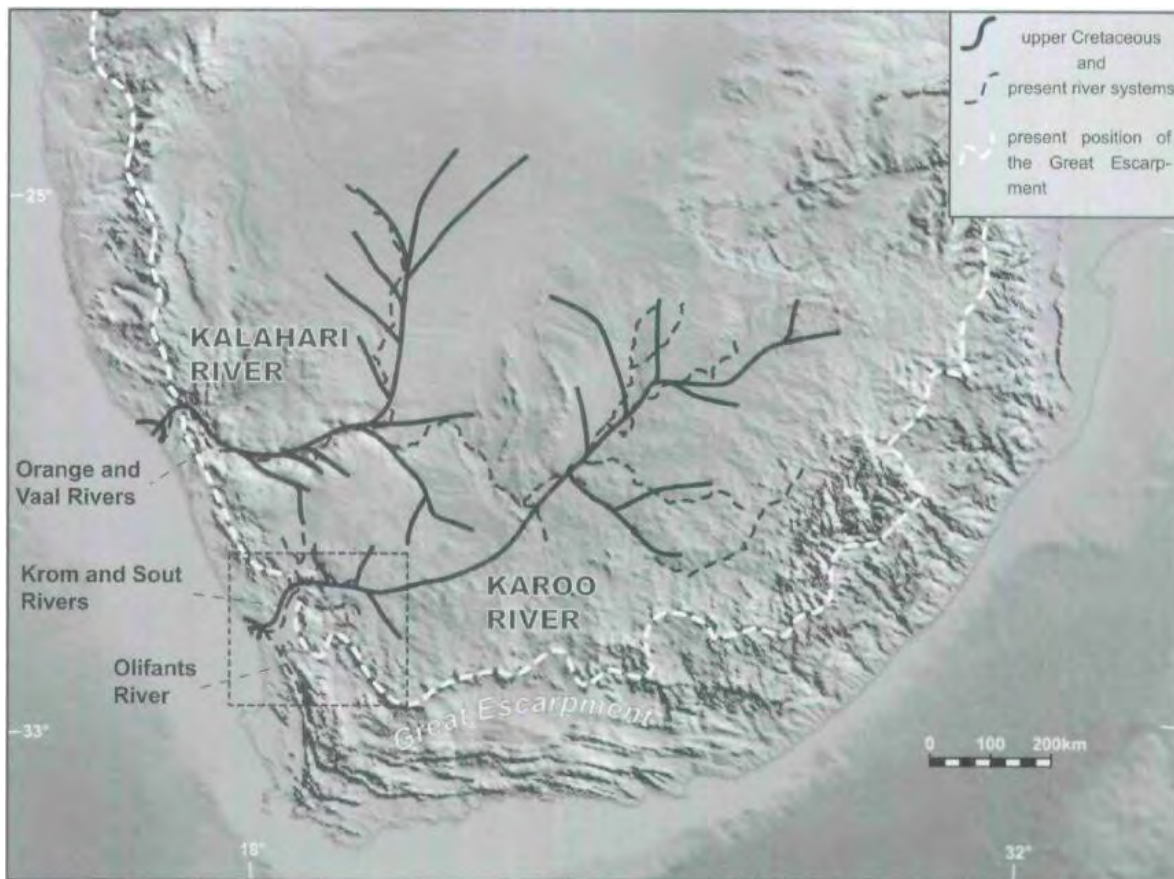


Figure 3: Map indicating the location of the Kalahari and Karoo palaeodrainage systems relative to the present day Gariep, Vaal, Krom, Sout and Olifants Rivers (Kounouv *et al.*, 2008).

The Miocene upliftment approximately 19-20 Ma ago (Partridge *et al.*, 2006; Maud, 2012) resulted in an elevation of approximately 300 m that existed in the eastern part of the subcontinent and resulted in the formation of the Post-African I Surface. The most accurate proof was the drainage systems response to change in topography especially in the western part of southern Africa. Minor interior axes such as the Transvaal-Griqualand Axis could also have uplifted at the same time as the Miocene uplift (Partridge *et al.*, 2006).

During the Pliocene (5-3 Ma) an uplift episode existed that exceeded the Miocene uplift by far. Elevations up to 900 m in the eastern side of the subcontinent existed (Partridge *et al.*, 2006:586), whereas the recorded western and southern sides elevations were 100 m and 200 m. This resulted in further increase in river flow and erosion of westward flowing rivers (Maud, 2012). The Griqualand-Transvaal Upliftment Axis were reactivated during the Pliocene uplift (Maud, 2012:17; Partridge *et al.*, 2006:588), or referred to by Van Deventer (2009), as the Plio-Pleistocene epeirogenic uplift. Subsidence of the Bushveld Basin also occurred (Partridge *et al.*, 2006:588). The reactivation of the Griqualand-Transvaal Axis contributed to the redirection of drainage systems such as the Kalahari and Karoo Rivers.

After the major upliftment occurred climatic conditions changed resulting in glacial and interglacial conditions to exist. Decline in sea levels gave rise to the exposure of the continental shelf and resulted in mainly coastal aeolian deposits to exist namely the Knysna Formation, near Wilderness in the South Coast. The last glacial maximum started about 18 Ka (McCarthy and Rubidge, 2005; Tchakerian, 1994; Maud, 2012) and ended 10 ka where in this time the sea level around South Africa was 130 m lower than the present due to the water captured in ice sheets in the Northern Hemisphere (McCarthy and Rubidge, 2005). The level of the rivers closest to the sea was affected directly and was deeply eroded. These eroded beds were filled with alluvial and/or estuarine sediments during the rise of the sea level. The overall decline in sea level occurred during the Late Pliocene and beginning of the Pleistocene. Periods between stagnant states of the ocean water levels resulted in the establishment of different deposits in between the marine-cut benches. An example of these deposits is the diamondiferous deposits that occur in the West Coast. This diamond bearing terraces is situated on a marine-cut bench at an elevation of 70 m above present sea level and was dated to 4.3 ± 0.68 Ma (Maud, 2012:18).

The increase in cold temperature in the Northern Hemisphere resulted in the increase in arid conditions in the Southern Hemisphere. The age of the Kalahari sand that was mentioned by Harmse and Hatting (2012), correlates to the Mid-Pleistocene, proved by artefacts dated to post-Archeulean Period. The Kalahari sand layer covers older gravel deposits along the Vaal River in the North-West Province. River terrace formations of major rivers formed due to the change in river drainage patterns and are evident in the diamondiferous Vaal River Gravels.

Dune building in the Kalahari Desert only lasted about 8 ka, from 19 ka up to 11 ka (19 ka – 16 ka, Lancaster, 1988) Sections of the Namib Desert still experience erosion at the present (Tchakerian, 1994). The Quaternary experienced arid conditions the same time as the glacial Period in the Northern Hemisphere up to 10 ka ago (McCarthy and Rubidge, 2005, Van Deventer, 2009). A variety of climatic changes, which occurred in the Quaternary Period, influenced individual river flow patterns and catchment areas, each river system reacting uniquely (Tooth *et al.*, 2004).

The Holocene Period or the present is during an interglacial Period associated with mild temperature (McCarthy and Rubidge, 2005).

2.2 Palaeosols

Palaeosols can give insightful information regarding the palaeoclimate in which formation occurred. Research focussed on palaeosols includes palaeontology, palaeobotany,

sedimentology and palynology to name a few. The palaeosols investigated in this study includes Florisbad Spring sequence and Cornelia fossil site.

2.2.1 Florisbad

Florisbad Spring sequence fossil site is situated approximately 45 km from Bloemfontein in the Free State Province (28°46" S, 26°04" E). This site is also referred to as the Florisbad Formation and is characterised by the mammalian fossils from Florisian Land Mammal Age (LMA), occurring in the succession of sand and organic horizons, MSA (Middle Stone Age) human activity horizon and the remains of the *Homo helmei* skull fragment (Van Zinderen Bakker 1995:99; Partridge *et al.*, 2006:597). The Florisbad hominid was dated at 259 Ka by using electron spin resonance (ESR) dating (Grün *et al.*, 1996). The mammalian fossil record overlying the Middle Stone Age succession was dated to 125 ka, (Grün *et al.*, 1996). The palaeoterrain of Florisbad can be simulated by evaluating the fossil database collected from the spring site. A correlation can be made between the species that existed in that Period and the climate conditions. The successions are described by Visser and Joubert (1991), Coetzee and Brink (2003), as well as by Douglas *et al.*, (2010), Coetzee and Brink (2003) and Kuman *et al.*, (1999).

2.2.2 Cornelia-Uitzoek

Cornelia or also known as the Cornelia-Uitzoek site (S 27.159563°, E 28.87868°) is situated close to the town of Cornelia in the eastern Free State in South Africa (Brink *et al.*, 2012) and has an elevation of 1540 mamsl. The Cornelian Land Mammal Age (LMA) refers to the Uitzoek locality in South Africa and has an age of 1.1 – 0.7 Ma, Middle Pleistocene, (Brink *et al.*, 2012; Tooth *et al.*, 2004:89; Szabo, 1979). Excavation occurred at the site in the 1920, 1930 and 1953 but only in the 1990's fieldwork was resumed (Bender and Brink, 1992). The homonine specimen found is the oldest fossil outside of the Malmani dolomite karts landscapes of northern South Africa.

The terrain at Cornelia-Uitzoek site (see Figure 4) comprises of dongas which are shaped in a dendritic formation of v-shaped channels and join as one channel at the main Schoonspruit river stream. Channel incision was the primary force, which resulted in dongas to form where erosion of some unconsolidated alluvial deposits as well as basal shales followed (Tooth *et al.*, 2004). Periods of constant climatic conditions also existed, which resulted in sedimentation that is present today as palaeosols. Cornelia-Uitzoek site is mainly significant for archaeology, but is relevant to sedimentologists as well as quaternary researchers.

The oldest deposits of the Vaal Basin are valley bottom clays which are not preserved in the entire Basin except in fragments such as at Cornelia-Uitzoek site (Butzer *et al.*, 1973). Also see Chapter 2.3.2 Gravel deposits.

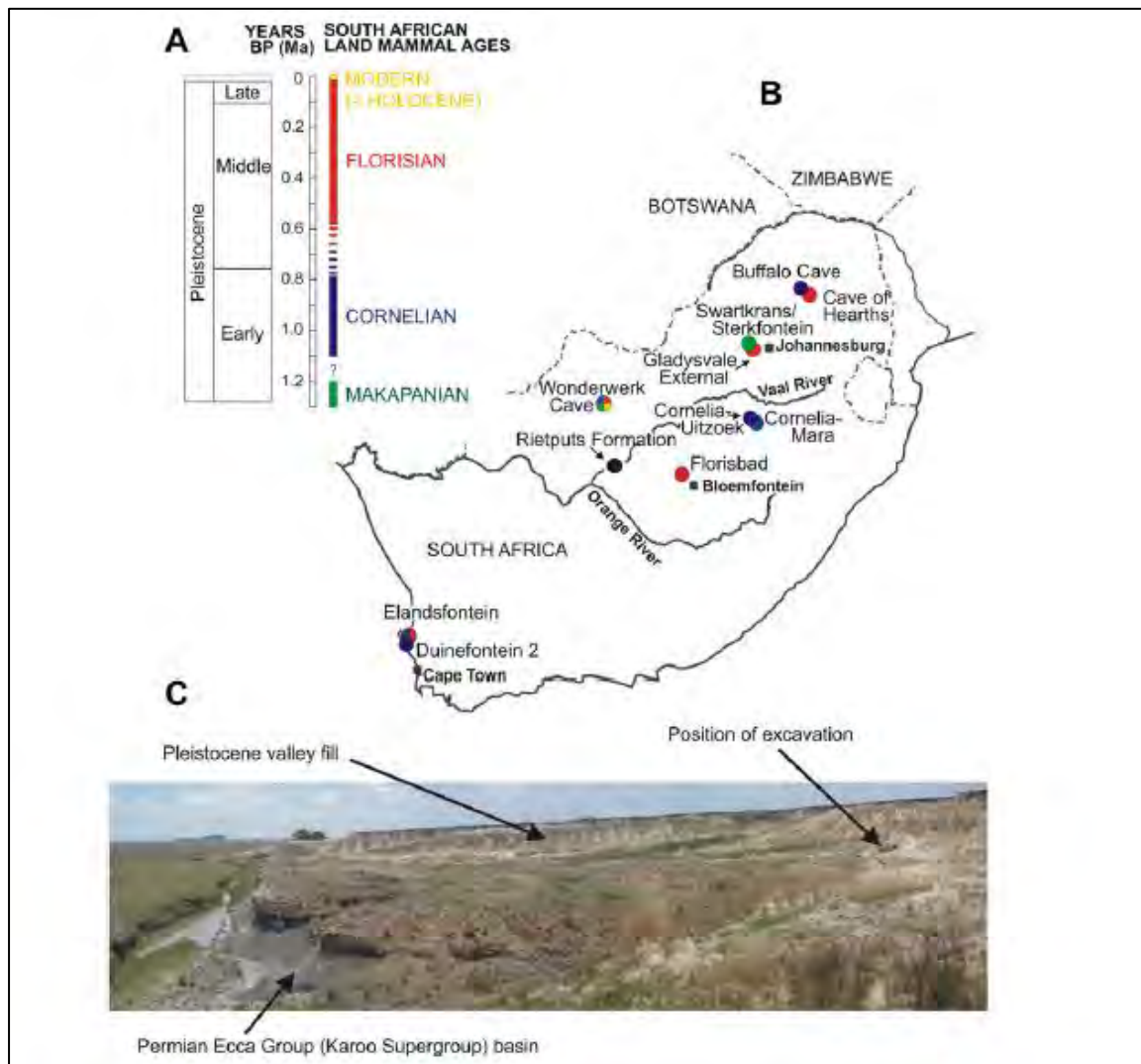


Figure 4: A compilation of images from Brink *et al.*, (2012:528) indicating (A) the position of Cornelia Land Mammal age in the chronostatigraphy, (B) the position of Cornelia in South Africa as well as (C) the view of the Cornelia site indicating the Pleistocene valley fill, the basal Ecca and the position of excavation (used with permission).

2.3 Clastic sediments of the Cenozoic Era (Chapter 2.3.1 – 2.3.6)

In this section the clastic sediments of the Cenozoic Era are discussed. This includes cave sediments, gravel deposits, the Pebble Marker, terrestrial sands, drainage depressions and a periglacial site close to the Groot Marico district.

2.3.1 Cave sediment

Firstly a distinction must be made between karst and caves. Karst is a landform which develops mainly due to the dissolution of limestone bedrock or to less extent also from the dissolution of gypsum, but in rare cases also forms due to the erosion of different geological formations such as quartzite (Oxford Dictionary of Earth Sciences, 2008; White, 1988; Sweeting, 1972). Karst environments include surface features such as karst valleys, towers, pavement, dolines, sinkholes, and polje karst, resulted from the dissolution of bedrock from surface or groundwater (White, 1988). Caves are the underground landforms associated with karst environments which have a natural opening/s on the surface, which a human can access (White, 1988; Oxford Dictionary of Earth Sciences, 2008; Sweeting, 1972).

The main factors influencing cave formation are summarised by Sweeting (1972) as: the characteristics and structure of limestone, the type and amount of water, the geographical position, and physiographical setting and climate variations such as temperature and precipitation.

In South Africa the active karst areas are divided into three regions namely; the limestone of Cenozoic age along the southern coast; the Congo Cave Group of Late Proterozoic age; as well as the Transvaal Supergroup dolostone in the Malmani Supergroup of early Proterozoic age in the northern half of South Africa. The older, palaeokarst regions are situated in the Northern Cape, Mpumalanga, Gauteng and North-West provinces (Martini, 2006).

The karst region of Cenozoic age stretches from Saldanha to East London for approximately 1000 km. In the sandy limestone geology of the Alexandria area in the Eastern Cape, mostly dolines and surface karst dissolution features exist. The only occurrence of caves in this region is close to Bredasdorp in the more prominent limestone deposits.

The Congo Cave Group is situated in an area of approximately 20 km long and 2 km wide consisting of shale and limestone of Precambrium age. The morphological features of the caves are unique for its well-developed flat ceilings, gentle slopes and simplicity. This is due to the surface streams being captured by the subsurface, resulting in the formation of long passages to form. The pureness of the limestone was also a factor which influenced the morphology. The famous Congo Cave which comprises of a 2.5 km dry passage with gentle slopes and a wide diameter indicating that it was carved into the limestone after a surface stream was captured into the subsurface. This cave is aged to the Late Tertiary or Early Pleistocene due to the location being much lower than terraces dated to the middle or late Tertiary at the top.

The Transvaal Supergroup comprises of quartzite, shale, dolomite and chert interlayers as well as manganese and iron oxides. Dolomite outcrops cover wide areas in the eastern and north

western side of the country and mostly has a surface area which is not typical of karst landforms. This may be due to highly resistant rock such as chert as well as the semi-arid climate. The caves located in the Transvaal Basin comprise 80% of the total caves in South Africa, with the highest concentration being spread from Pretoria (Gauteng) in a westerly direction to Stilfontein (North-West).

The sediments present in caves as well as speleothems can provide valuable information regarding the palaeontology, archaeology as well as the palaeoclimatic conditions (Hunter *et al.*, 2006), from the Late Pliocene to the present (Martini, 2006:661; White, 1988:303; Partridge *et al.*, 2006). Sweeting (1972) states that cave sediments are used to compile the wet, cold, dry and warm cycles of the Pleistocene.

Cave sediments are divided into (a) calcareous deposits, in the forms of precipitated limestone, known as stalactites and stalagmites, (b) clays from limestone solutions and cave debris and (c) the non-calcareous deposits such as alluvial sediments, including a range of fine and coarse particles.

Calcareous deposits have calcite (CaCO_3) as the dominant mineral having a rhombohedral crystalline form which is stable at ordinary temperature. Whereas in some caves the mineral aragonite, with the same composition but a different mineral composition as calcite, that of orthorhombic crystalline structure, is not as stable as calcite and also 16% more soluble. This allows aragonite to be dissolved in water which is saturated with calcite. Aragonite can indicate warm environments. Gypsum (CaSO_4) is also a mineral associated with cave deposits, especially if the limestone contains shale layers (Sweeting, 1972).

Calcareous deposit formation is associated with the precipitation of CaCO_3 . This occurs when water drips from the cave roof and precipitates as rings of calcite to form a spherical feature namely stalactites. Curtain-like structures form due to running water entering the cave roof through joints and cracks. Drip test done from stalactites in New South Wales indicated that the highest recorded value for CaCO_3 was 327 ppm as to 95 ppm Ca analysed in the pool of water from the Cave City Cave, California (Sweeting, 1972). Stalagmites, which are formed on the cave floor, contains $\text{Ca}(\text{HCO}_3)_2$ due to evaporation occurring as the drop falls to the ground. Plate-like precipitation forms dominantly in the centre of the stalactite and are described as candle-like structures. Stalagmites may contain values as high as 97% CaCO_3 and 77% limestone.

The growth of stalactites and stalagmites are influenced by many aspects and can reflect climatic changes, such as the amount of water entering a cave as well as the change in temperature. Stalagmite formation is linked to wet Periods.

Other deposits which form in caves are flowstones and rimstone deposits, seepage deposits such as helictite, cave shields or plaettes, cave coral and cave flowers, as well as deposits formed under water such as calcite rafts. For further reading on these deposits see Sweeting (1972).

The non-calcareous deposits are alluvial sediments, including a range of fine and coarse particles. These deposits are collected in the cave via vadose and phreatic water (Sweeting, 1972; Martini, 2006). Cave breccia is associated with wet and frosty climates, (Sweeting, 1972). Clays associated with caves are dominated by the mineral illite, but may contain sepiolite and kaolinite too. The clays are mainly transported into the cave but may also have formed due to the dissolution of impure limestone. Gravels and are also transported into the caves through vadose water or roofs that collapse. Most of these deposits have a CaCO_3 precipitate as an outside coating which preserves the sediments. Ice can also be seen as a non-calcareous deposit in caves but are not present in South Africa.

Lithostratigraphic studies of the Sterkfontein, Swartkrans, Makapansgat and Kromdraai caves were done by investigating the cave debris accumulated in front of or beneath vertical openings which comprised of calcified bone beds, debris cones or cave fill as well as fossil remains. This resulted in the Sterkfontein and Makapansgat Formations, the Swartkrans Formation as well as the Kromdraai Formation (Partridge *et al.*, 2006).

2.3.2 Gravel deposits

Van Riet Lowe (1937) described gravels with the following definition: “It occurs in the nature of a poorly stratified river-wash, made up of boulders and pebbles set in sandy and clayey matrix of reddish brown colour.”

Gravels associated with palaeodrainage systems especially with the palaeo-rivers such as the Karoo, Kimberley and Kalahari have significant importance with respect to the evolution of palaeodrainage systems from the Cretaceous to the Cenozoic Era. More arid climatic conditions and erosion during the Cenozoic Era with respect to the Cretaceous, Butzer (1973) as well as the effect of the tectonic activities of the Griqualand-Transvaal Axis resulted in the formation of less distinct drainage systems to form and the deposition of gravel deposits.

Gravel deposits are associated with many rivers in South Africa and are divided into two categories, namely the younger and the older gravels. The higher the river terraces from the existing river level, the older the gravel deposit (Wilson *et al.*, 2007). High level terraces are also referred to as „older gravels” by (Harmse and Hattingh, 2012).

Gravel deposits can have a high economic potential as it is linked to alluvial diamonds associated with palaeodrainage systems. Diamonds are transported from kimberlite sources (Wilson *et al.*, 2007; Marshall and Norton, 2012). Wilson *et al.* (2007) listed various river systems where alluvial diamonds occurs e.g. Vaal, Gariep, Sak, Koa, Buffels, Spoeg, Horees, Groen and the Olifants River systems. All of the mentioned rivers enter the west coast of South Africa in the Atlantic Ocean. Diamondiferous gravels associated with the Lichtenburg area (North-West Province) are possibly from the palaeo-Harts River flowing southward towards Schweizer-Reneke (Partridge *et al.*, 2006). It is stated that alluvial diamonds found north of the Olifants River mouth and south of the Gariep River on the western coast have been transported via palaeo-rivers such as the Karoo River (Wilson *et al.*, 2007). The Older Gravels in the Gariep river overlying uneven bedrock and those with the most poorly sorted orientation has the most abundant diamond concentrations. This also linked to the “Proto-gravels” and pre- Proto gravels which yielded more diamonds than the “Meso-gravels”. The age and the sedimentary setting are two key factors that influenced the diamond size (Wilson *et al.*, 2007).

2.3.2.1 Windsorton

Windsorton situated in the Northern Cape has distinct alluvial gravel deposits associated with the Vaal River and has a relatively known stratigraphy of Cenozoic age (Marshall and Norton, 2012:34; Butzer, 1973). The basal geology of the middle Vaal River is Venterdorp lavas and occasionally overlain by Karoo shale and Dwyka tilite which are younger. The Cenozoic aged gravels and fine-grained sediment sequences are the youngest and were deposited in palaeodrainage channels from the Vaal River by the post-Karoo Vaal River during different Periods up to the Holocene (Figure 5 and 6).

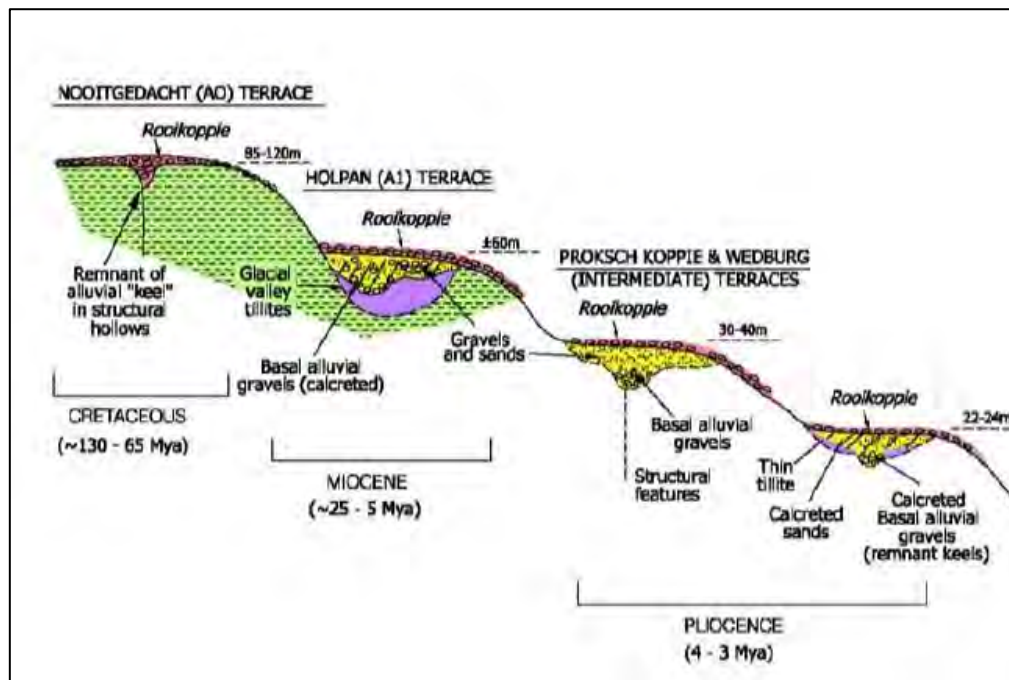


Figure 5: The stratigraphic units of the lower Vaal Basin indicating the different terraces above the present Vaal River channel as well as the younger gravels below and the older gravels at the top (Wilson *et al.*, 2007).

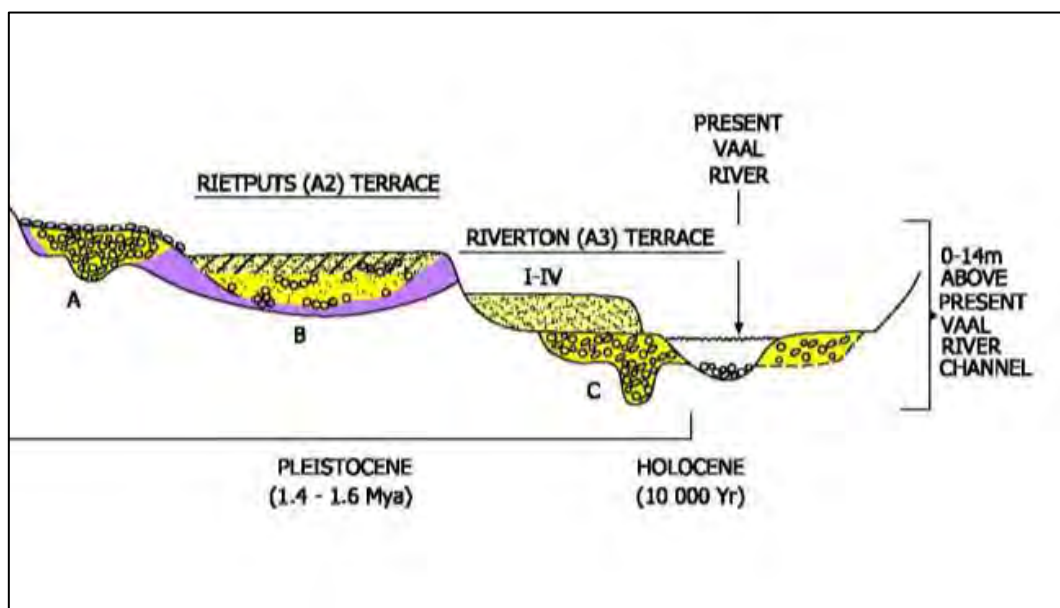


Figure 6: The continued stratigraphic column of the lower Vaal Basin up to the Holocene Period (Wilson *et al.*, 2007).

The stratigraphy of the alluvial gravels as seen in Table 4 can be divided into Older gravels (Nooitgedacht Deposits, Holpan Sequence, Proksch Koppie and Wedburg units) and younger gravels (Rietputs alluvial gravels and Riverton alluvial gravels) (Marshall and Norton, 2012). The older gravel being located in more abundance on the western side of the river and are situated further away. Marshall and Norton (2012) explained the Holpan sequence geochronology

starting with the erosion of the Karoo sediments followed by the River shifting from its flow path over the Holpan platform in an eastern direction and forming the gravel Deposit. A calcretification Period occurred and fluvial processes were reactivated. The younger gravels from the Riverton and Rietsput Deposits are situated opposite and more evenly distributed alongside the river. The lower Vaal River Basin alluvial terraces contained Archeulian artefacts and fossils and have been linked to the Pleistocene Period (Butzer *et al.*, 1973).

Table 4: The stratigraphy of the alluvial gravels of Cenozoic Age (De Wit *et al.*, 2000 and SACS, 1980 by Marshall and Norton, 2012).

MESOZOIC - CAINOZOIC DEPOSITS	Upper Pleistocene	A3 Gravels (Riverton alluvial gravels)
	Middle Pleistocene	A2 Gravels (Rietputs alluvial gravels)
	Pliocene	Intermediate Gravels (Proksch Koppie and Wedburg units)
	Miocene	CALCRETISATION
		A1 Gravels (Holpan Sequence)
	Upper Cretaceous	A0 Gravels (Nooitgedacht Deposits)

The Older gravel that are found in Windsorton area are the Wedburg gravels, which are located approximately 20-24 m above the present river level (Marshall and Norton, 2012) or 21-30 m according to Wilson *et al.* (2007) and the Proksch Koppie, which is 30-45 m above the present Vaal River level (Wilson *et al.*, 2007:48). These Deposits are of Pliocene age and can be situated on both sides of the river. The Rooikoppie Gravels, also associated with the older gravels occurs at Windsorton (Table 5).

The young gravels from the Riverton and Rietputs gravels are of the 12-14 m terrace where the youngest Riverton gravels are located in the 8-9 m and 4-5 m terraces and are the main gravel terrace found in the Windsorton area (Figure 6), (see Chapter 4.4.2.1).

Table 5: The Rooikoppie gravel variations (compiled from Marshall and Norton, 2012 and Wilson *et al.*, 2007)

Eluvial	Colluvial
The eluvial Rooikoppie Deposit consist of a horizon with pothole features, formed in dolomite, and filled with alluvial gravels, diamonds and other surface material and is mostly calcified. This horizon underlies an oxidised soil horizon with coarse pebbles. They are linked to the Holpan deposits of Miocene age (Marshall and Norton, 2012).	Colluvial Rooikoppie Deposits may have a wide distribution and mainly contain uncemented pebbles of quartz, agates and quartzite. This deposit is approximately 10-20 cm thick and not linked to a specific age of formation. The main formation processes are linked to ferricrete or laterite development as well as slope erosion. Ferricrete formation is linked to humid and warm environmental condition. These deposits are reworked fluvial-alluvial, diamond bearing gravels and older gravels (Marshall and Norton, 2012). They are linked to the Cretaceous Nooitgedaght Deposits. The Proksch Koppie and Wedburg Deposits, of Pliocene age, are also very similar to these deposits (Marshall and Norton, 2012).

These gravels deposits are mainly known for the associated alluvial diamonds present and a minimum estimate of the total alluvial diamond collected from Windsorton in the Northern Cape as 130 000 carats in the 60 m terraces of the Rooikoppie Deposits and 72 696 carats in the 0-20 m Rietsputs and Riverton terraces (Wilson *et al.*, 2007).

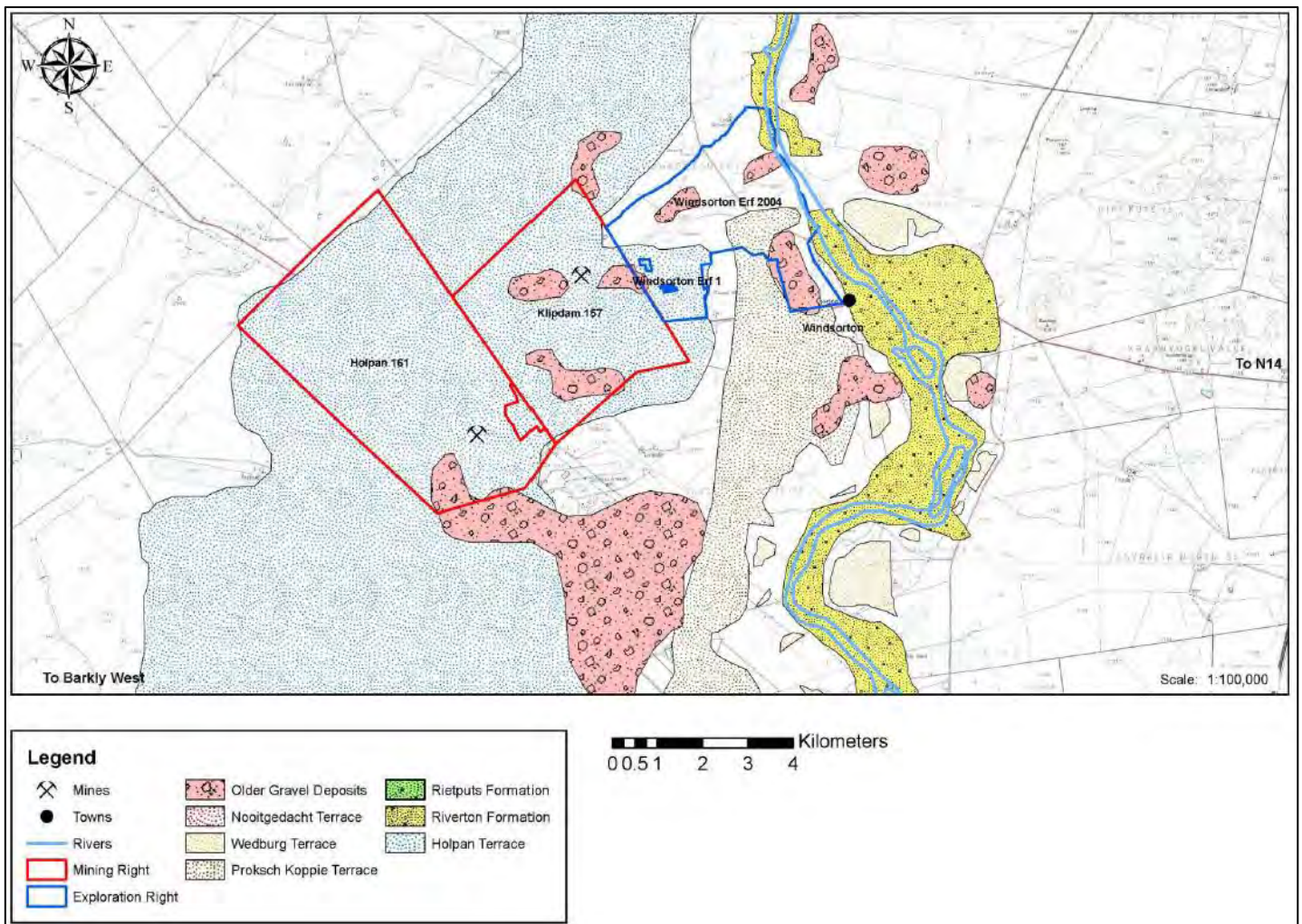


Figure 7: An image of the terraces of the Middle Vaal River of Helgen (1979) done by Rockwell Diamand Inc (Marshall and Norton, 2012).

2.3.3 Pebble Marker

The Pebble Marker is a sedimentary layer which is not uniform with respect to the orientation and composition. Weinert (1980) cited Jennings and Brink (1961) who initially named the Pebble Marker as a unique feature in South African soil profiles. In the proceedings of the Geoterminology Workshop (Brink and Bruin, 2002) the Pebble Marker was also described as a widespread gravel layer occurring in South African soil profiles. Du Plessis *et al.*, (1991) stated that the Pebble Marker was a widely distributed, recent deposit and contained artefacts. It is a common deposit north of the Gariep River into the northern neighbouring countries such as Botswana, Zimbabwe, Malawi and Zambia. The southern boundary is indicated in the compiled map as seen in Figure 17 (Van Deventer, pers comm: 2015).

Brink and Bruin, (2002); Du Plessis *et al*, (1991); Weinert (1980) and Brink (1985) mentioned that the layer occurs between the residual and the overlain transported soils. This layer was observed in a soil profile in Vereeniging in 1949 between the residual and the transported alluvial material. This characteristic position in the soil profile resulted in defining the layer as a gravel layer occurring between the overlain transported material e.g. Kalahari sand and the residual soil. The layer mainly contained sub-angular to rounded rock fragments (Weinert, 1980).

The origin of the Pebble Marker as well as the age differs from localities was stated by Brink and Bruin, 2002). A few means of origin were mentioned, including basal gravel deposits from ancient river terrace resulting in the Pebble Marker; colluvial deposits transported downwards due to gravity and rain wash; and action of termites resulting in a biogenic stone line to form as first described by Brink (1985). The last mentioned forming process involved the termites to transport the small fraction particle from the subsurface to the surface to build their termitaries leaving behind the larger sized particles forming the Pebble Marker. The age of the Pebble Marker is younger than two million years (Brink, 1985) and varies from early Pleistocene to late Tertiary, but can also still form today (Brink and Bruin, 2002).

2.3.4 Terrestrial sand deposits

The terrestrial sand deposits mainly include wind transported deposits, also referred to as aeolian sand deposits. The main aeolian deposits in South Africa are the Namib and the Kalahari sands. In this section the focus will be on the Kalahari rather than the Namib deposits. The coastal sand deposits will not be discussed in this section as these are seen as coastal deposits and are not in the scope of this study.

The main geomorphological features associated with aeolian sand deposits are dunes, which can give significant insight regarding the aeolian activity in the past if the Period associated with dune development, dust emissions as well as rates of sand movement can be investigated. The Kalahari and Namib dunes have been subjected to many studies regarding aeolian geomorphology as well as luminescence dating (Thomas and Wiggs, 2012).

The Namib sand sea stretches from the northern boundary which is the Kuiseb River in Namibia, with the Atlantic ocean being the western boundary, to the southern boundary close to the Gariep River (Thomas and Wiggs, 2012). There is also redistributed Namib sand in the Northern Cape in the Pofadder region. Sand of the Namib sand sea is derived from transported wind, river and sea systems and dunes formed due to intense wind activity which moved sand to the dune field. Dune activity was probably active during the dry Period of the Tertiary or even earlier (Thomas and Wiggs, 2012).

Before the Kalahari sands can be described a valid point as stated by Haddon (2005) must be noted. The Kalahari, meaning the „great thirst“, must be divided under the correct terms for evaluation purposes. The Kalahari sand deposit, which stretches from northern parts of South Africa up to the Congo, is relatively small in relation to the Kalahari Group. The Kalahari Group includes all the Kalahari sediment which was deposited into the Kalahari Basin and covers a much wider area.

Early deposits or the base of the Kalahari Group, see Figure 68 later in the document, deposit was dated by Partridge *et al.*, (2006) and Haddon (2005) as Late Cretaceous Age (<90 Ma). Kalahari sand, thus the unconsolidated sands of the Kalahari Group, covers a wide area up to 2.5 million km² of South Africa and varies in thickness over the surface due to underlain palaeosurface (Haddon, 2005).

Kalahari sand from North Africa has a distribution that extends down to the Vaal River in the North-West Province. Sands covering most of the surface area of western Limpopo, Northern Cape, northern North-West Province and the southern and north-western Free State are distributed aeolian sand (Söhnge and Visser, 1937 used by Harmse and Hattingh, 2012; Hunter *et al.*, 2006).

Redistributed aeolian Kalahari sands were deposited in the mid-Pleistocene Period (Bond, 1948 and Du Toit, 1954 used by Harmse and Hattingh, 2012) in alternating drier and moister conditions. These deposits are mainly situated in the western parts of South Africa and are distributed or derived as far as the Congo, Angola, Zambia, Namibia and Botswana (Harmse and Hattingh, 2012; McCarthy and Rubidge, 2005:273; Thomas and Wiggs, 2012:145). The distribution of the Kalahari sand led to the largest known extent of sand in the modern world (Baillieul, 1975 used by Haddon, 2005:1), also referred to as the „Mega Kalahari“ by Thomas and Shaw (1991) used by Partridge *et al.*, (2006).

2.3.5 Drainage depression

Winegardner (1995) defines pans (drainage depressions) as soil horizons that are strongly compacted, hardened and may have high clay content. Drainage depressions are widely distributed in the drier parts of South Africa with the highest concentration being located in the western Free State and in the north western North-West Province. The underlying shale from the Ecca Group is the main geological unit in which the pans form in this area. The orientation of the pans is mainly related to the palaeodrainage systems in the area. This indicates that the underlying geology, i.e. substratum (Marshall and Harmse, 1992), has an influence on the formation of pans and the palaeodrainage systems determines to a great extend the orientation (Holmes, 2015 and Norman and Whitfield, 2006). Forming processes of pans also include the

removal of sediment due to animal activity for drinking purposes (Marshall and Harmse, 1992) as well as wind removal (Holmes, 2015). The initiation factors include suitable substratum which has a high potential to weather, disrupted drainage due to tectonic or climatic disturbance and geological structures such as dolerite structures in the Free State Province (Marshall and Harmse, 1992).

Pans in the Free State Province were mainly formed as a result of aridification Periods. The Kalahari River which was a dominant palaeoeriver decreased in flow due to the activity of the Transvaal-Griqualand Uplift axes during the Miocene and Pliocene uplifts as well as a decrease in rainfall and/or temperature. Wind erosion formed deflation surfaces which initiated drainage depressions. The orientations of pans in the Northern Cape are linked to palaeodrainage channels of Hartbees, Sak and Koa, which existed from the Cretaceous to the Miocene. During the decrease in rainfall in the Tertiary, pans formed in the channels, i.e. the Van Wyksvlei, Brandvlei and Bosluispan. The clusters of pans in the Chrissies Lake District in Mpumalanga are ascribed to the substratum which can easily weather and to the tectonic activities in the past (Marshall and Harmse, 1992) or consolidation settlement of deposits in the lower underlying formations can occur and subsequently the layers on top will follow the depressions topography and eventually the most top layer reflects the same depression after the last consolidation settlement took place.

Pan sediments can be derived from the Gordonia Formation and can vary in silt, clay and sand composition. Pans, including evaporates, are indicators of groundwater with a high salinity influencing the composition. Pans are mostly of young age but this can vary (Partridge *et al.*, 2006).

Propagation of drainage depressions are needed to ensure the survival of these landforms (Marshall and Harmse, 1992).

Lunette dunes are associated with pans and are mainly situated on the southern or south-eastern margin of the pan due to the dominant wind direction. Lunette referring to the semicircular shape of the dune and comprises of sediment transported from the base of the pan. Lunette dunes can be used to investigate palaeoenvironmental conditions such as changes in wind patterns as well as aridity (Holmes, 2015; Norman and Whitfield, 2006; Haddon, 2005; Erasmus and Harmse, 1992). The dune length is determined by the length of the pan (Erasmus and Harmse, 1992).

Main drainage depressions in South Africa includes the Haksteenpan in the Northern Cape, being one of the largest in South Africa, Verneukpan near Brandvlei in the Northern Cape, Voëlpan, close to Allanridge in the Free State, Baberspan together with Leeupan and many

others in the western part of South Africa. Many salt drainage depressions are also a common feature in South Africa, e.g. the Soutpan close to Bloemfontein in the Free State Province and Commissioner's salt pan in the North-western Cape.

2.3.6 Periglacial deposits

Periglacial is a term first used by Lozinski in 1909 (Flint, 1957 and French, 2011) which referred to loess as well as frozen ground characteristics in the deposits. The definition of periglacial was stated as a deposit being „*peripheral to a glacier*” (Flint, 1957:197), meaning adjacent to glaciers (Boggs, 2011) or belts around formerly glaciated regions (Cotton, 1952). French (2011) stated that periglacial deposits are non-glacial deposits associated with features in cold climatic conditions such as ice formation, water freezing and frost heaving.

The main transportation process responsible for periglacial deposits is solifluction (Boelhouwers and Meiklejohn, 2002; Goudie, 1981; Flint, 1957; Cotton, 1952), which involves the movement of water saturated waste down a slope, normally with a gentle angle. Deposits associated with glacial and periglacial activity is referred to as nonstratified drift, thus grain orientation being non-uniform and grain sizes varying (Flint, 1957; Boggs, 2011; Menzies, 2011). The solifluction deposit differs from till due to the sediment being less worn and almost the same as the original sediment. Big boulders may be included in the profile and transported through frost heaving. Mostly the profile does not exceed a thickness of 3 meters. In western and central Europe, solifluction deposits are found in nonglaciated areas and may have indicated seasonal freezing (Flint, 1957). The formation of periglacial deposits can also be ascribed to intense flood episodes (Goudie, 1981).

Periglacial deposits in southern Africa mainly occur in the regions of high relief mountains of the Western Cape along the great escarpment to the Lesotho Highlands as seen in Figure 8 (Boelhouwers and Meiklejohn, 2002). Many studies have been done on the periglacial deposits of the Drakenberg Mountain (Boelhouwers, 1988, 1991), the Western Cape Mountains (Boelhouwers, 1991, 1993, 1996) and Hex River Mountains (Boelhouwers, 1995).

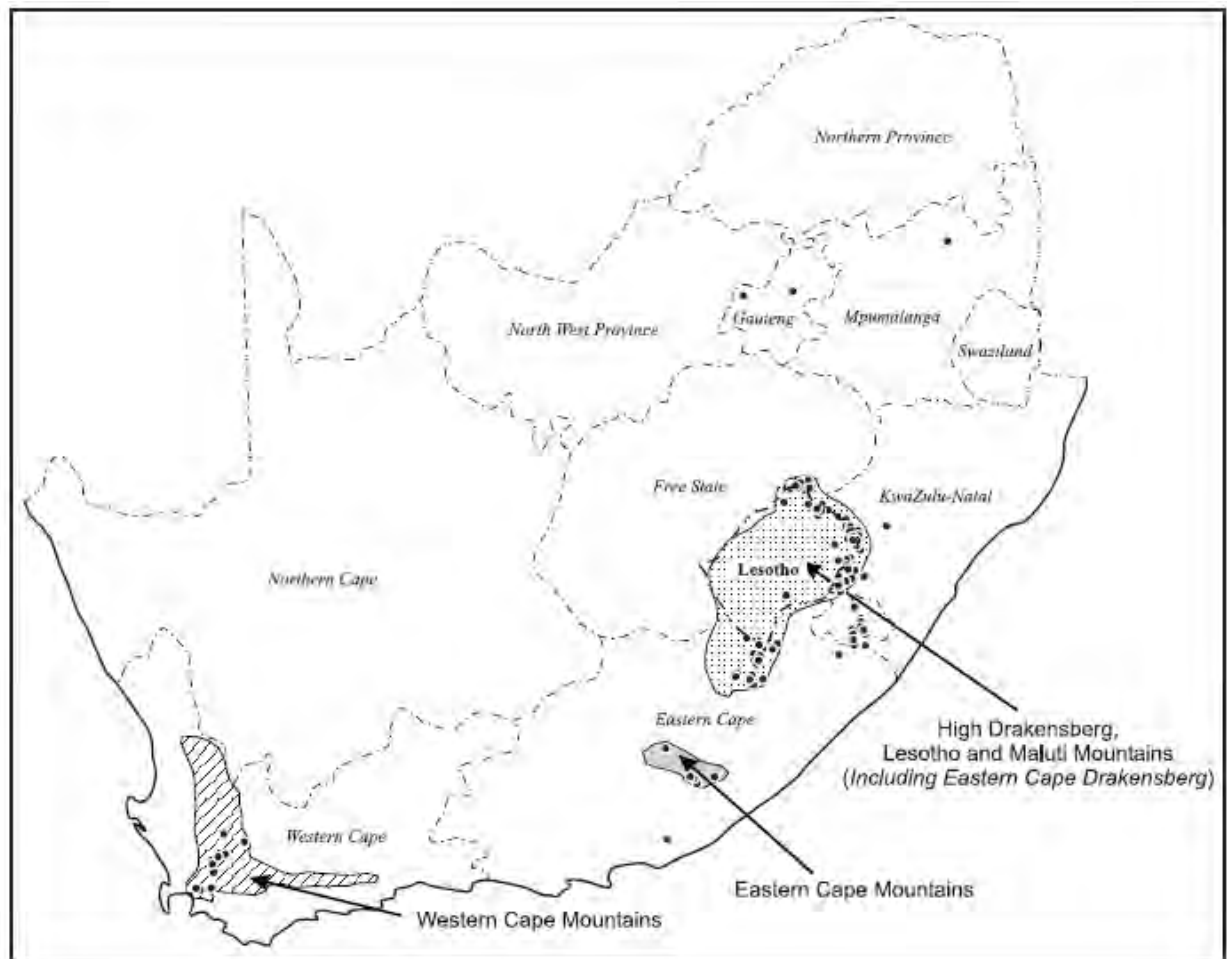


Figure 8: Occurrence of periglacial and glacial landforms situated mainly in high altitude terrains in South Africa (Boelhouwers and Meiklejohn, 2002).

The periglacial deposits are many linked to the Periods of frost in the Quaternary and Pleistocene glaciations (Boelhouwers and Meiklejohn, 2002).

2.4 Pedogenic deposits

Pedogenic material or pedocretes is defined by Weinert (1980) as soils cemented by silica, calcium carbonate or iron oxide to form new material. „Pedo” refers to soil and „crete” refers to the suffix added to define the material; ferricrete is iron hydroxide cemented pedocrete, calcrete is calcium carbonate cemented pedocrete, silcrete is impregnated with silica and phoscrete with phosphate. Stages of pedocretes formation start with the precipitation of material to form soft nodules in the soil horizon leading to a honey comb structure (small cavities present in the mass) and ends as a hard structure or hardpan. The hardpan is a result of the remaining cavities to fill completely with the cement material. In this section there will also be referred to the term „duricrust”, which was defined by Woolnough (1927) and Goudie (1973) and cited by

Nash and Shaw (1998) and state that it is a term used to describe calcrete, ferricrete, silcrete, gypcrete, phoscrete as well as magnesicretes.

The climatic-N value of Weinert (Figure 9) indicates the effect of climate on weathering. Where the N-value is less than 5, decomposition occurs and where the N-value is more than 5, disintegration takes place (Weinert, 1980). The pedogenic material used as road construction material in South Africa is indicated in Table 6, and will be further referred to in this chapter.

Table 6: Pedogenic material used in road construction in South Africa (Weinert, 1982)

Material	Surfacing aggregate	Base	Sub-base	Selected subgrade and fill	Gravel wearing coarse	Concrete aggregate
Calcrete	X	X	X	X	X	X
Ferricrete		X	X	X	X	
Phoscrete		X				
Silcrete		X	X	X	X	

The geotechnical characteristics of pedogenic material are very complex and vary considerably in respect to the host material, the cementing agent and the stage of development; the last mentioned being the most important. The stages of development range from silicified, calcified or ferruginised sand, to powder pedocretes, boulders and hardpan deposits (Netterberg and Caiger, 1983). This results in the foundation conditions to vary and may cause consolidation settlement, and structure damage. Settlement may take place when a soft calcrete is underlying a hard calcrete. In some instances the pedogenic material needs to be removed and increases the cost of excavation. Adequate geotechnical investigations are essential for specific site determinations (Department of Public Works, 2007)

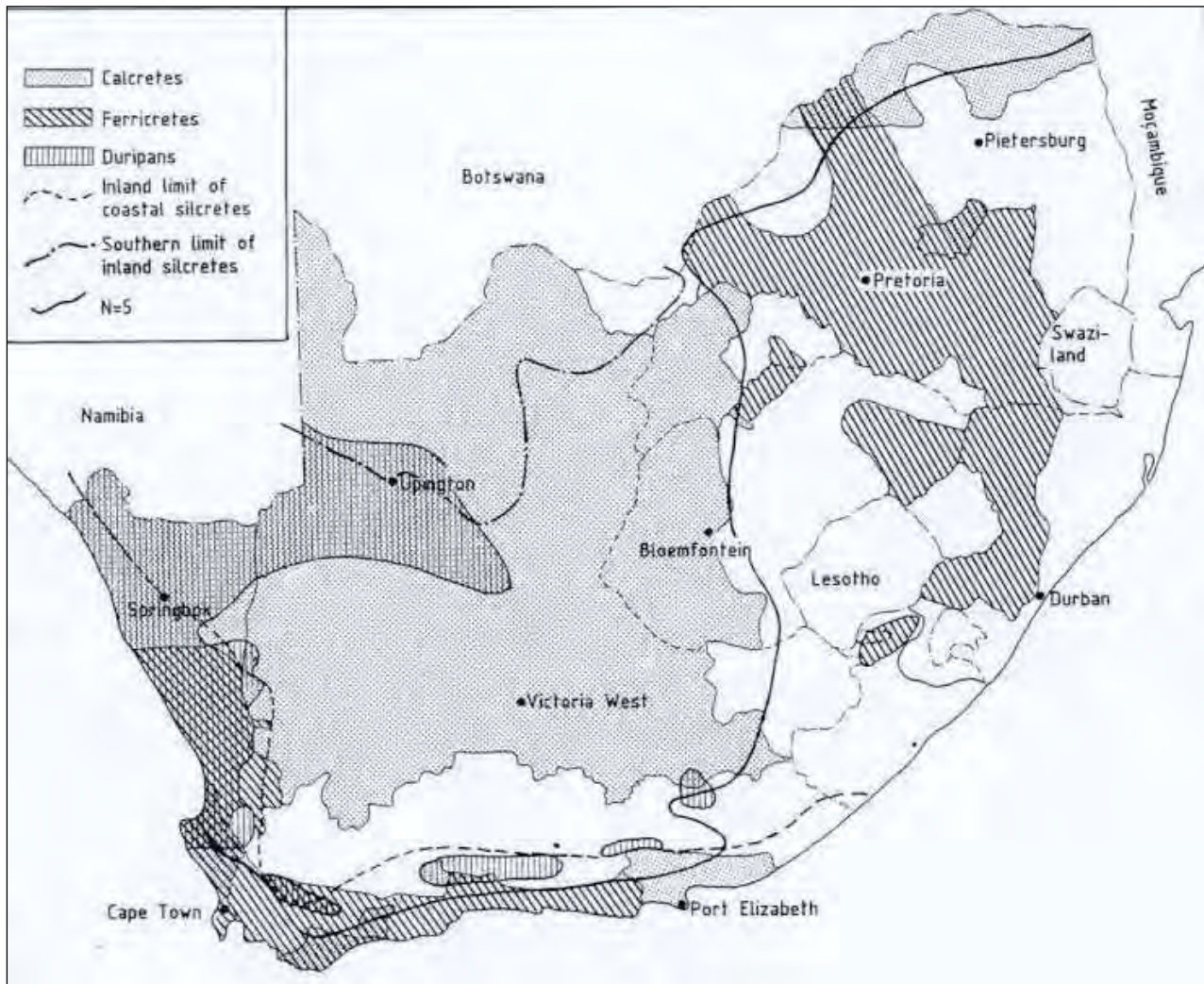


Figure 9: The distribution of pedogenic material by Weinert (1980).

2.4.1 Calcrete

Calcrete was defined by Goudie (1972): „Calcrete can be defined as terrestrial material composed dominantly but not exclusively of calcium carbonate, and involving the cementation of, accumulation in and/or replacement of greater or lesser quantities of soil, rock or weathered material primarily within the vadose zone. It does not, however, embrace cave deposits (speleothems), spring deposits (for which tufa or travertine are accepted terms), marine deposits (such as bedrock), or lacustrine algal stromatoliths.“ Netterberg (1969b) defines calcrete as: „Almost any terrestrial unconsolidated material which has been cemented and/or replaced by dominantly calcium carbonate. The unconsolidated material could be residual soil, alluvium, weathered rock, colluvium, or a soil in the pedological sense, but for the convention, cave deposits are excluded.“

A material can be defined as a calcrete when the material consists of more than 50% CaCO_3 and is hardened (Netterberg and Caiger, 1983). Goudie (1972) summarised the geochemistry of calcretes, also used by Haddon (2005), as summarised in Table 7.

Table 7: The average geochemical values for calcrete for South Africa as well as the world, Goudie (1972).

Average geochemical values for calcretes in South Africa (mainly using geochemical values from samples collected in the Kalahari region)	Geochemistry	Average geochemical values for calcretes over the world
79.13%	CaCO_3	79.28%
43.19 %	CaO	42.62%
11.83%	SiO_2	12.30%
3.66%	MgO	3.05%
8.72%	MgCO_3	-
2.38%	Al_2O_3	2.12%
1.89%	Fe_2O_3	-
1.51%	Fe_2O_3	2.03%

The main mineral in calcium carbonate is microcrystalline calcite as determined by X-ray diffraction (Goudie, 1972). Other minerals present in calcrete includes: Al_2O_3 , Fe_2O_3 , MnO and SiO_2 .

The ages of calcretes in South Africa are divided into five groups by Netterberg (1969b), also used by Haddon (2005:94), being pre-Pliocene, Pliocene (can vary from lower to middle-Pliocene), First Intermediate (Middle Pleistocene, calcified alluvial sand and gravels, contains Acheulian tools), Second Intermediate (Upper Pleistocene, contains Middle Stone Age tools) and Recent (contains Later Stone Age tools). The age of calcrete was defined by Netterberg (1969b:88) as "...the age of the first onset of calcification."

Calcrete may be associated with karst features such as sinkholes as seen close to Bredasdorp in the Cape Province (Weinert, 1980).

Calcretes can be divided into two main categories i.e. pedogenic and non-pedogenic calcretes (Haddon, 2005:95), and are mainly classified according to their formation processes (Nash and McLaren, 2003:4). Pedogenic calcretes form due to the vertical distribution of calcium carbonate in a soil and are influenced by the soil forming factors (Nash and McLaren, 2003), which according to Netterberg (1969a) are mainly parent material and climate. Non-pedogenic calcrete are mostly independent from climate and varies greatly due to the geomorphological setting. The macromorphology is presumably structureless and massive and may contain mollusc shells and diatoms (Nash and McLaren). The pedogenic classification is mainly described by

Netterberg (1983, 1969) as seen in Table 8. The geotechnical implications of calcretes are described together with the types of calcretes, or also referred to as growth stages by Netterberg and Caiger (1983), Netterberg (1969), due to the varying implications of each type. The classification of non-pedogenic calcrete is seen in Table 9.

The soil forms which include diagnostic horizons of soft and hard carbonated horizons can also be linked to the Cenozoic Era. This includes the soil forms e.g. Steendal, Immerpan, Kimberley, Plooyburg, Etosha, Gamoep, Addo and Prieska, (The Soil Classification Working Group, 1991).

Table 8: The pedogenic calcrete types, characteristics and the geotechnical implications of each.

Type of calcrete	Characteristics	Geotechnical implications
Calcified soil, (Netterberg and Caiger, 1983).	Only a thin layer of carbonate covers the sand/gravel particle. If 10-15% CaCO_3 is present the original soil properties have been altered, (Netterberg and Caiger, 1983). Also referred to as calcic soil by Fey (2010), which discussed the general properties, morphology, chemical and physical properties, classification, genesis and use. Calcified soils also have a carbonate (CaCO_3) percentage lower than 50% and is very fine grained (Weinert, 1980).	Calcified soils can normally be dug with a shovel and pick, (Netterberg and Caiger, 1983).
Soft or powder (calcrete silt/sand, Netterberg and Caiger, 1983)	Can consist of up to 70% CaCO_3 and are mainly silt or fine sand sized carbonate particles (Netterberg and Caiger, 1983). Powder calcretes may be formed through similar forming factors as hardpan calcretes, but are probably at different phases of development (Chen <i>et al.</i> , 2002).	Can be compacted but should be avoided for road building purposes, (Netterberg and Caiger, 1983).

Table 8 (cont): The pedogenic calcrete types, characteristics and the geotechnical implications of each.

Type of calcrete	Characteristics	Geotechnical implications
Pedogenic calcrete		
Nodular (can be referred to as calcified gravels and sands in geotechnical terminology, (Netterberg and Caiger, 1983).	Calcretes nodules can vary in size, texture and shape but would probably not exceed 60 mm. A mixture of silt to gravel sized particles covered with carbonate cement are common, (Netterberg and Caiger, 1983). Nodular calcrete deposits can probably indicate early stages of development and may indicate low rainfall that occurred at that point in time as stated in a study done by Netterberg (1969a). Nodular calcrete can indicate conditions drier than 800 mm per annum (Netterberg, 1969a).	Nodular calcretes can be very hard but normally don't have to be ripped but only bulldozed and can be compacted for a good road base material, (Netterberg and Caiger, 1983).
Honeycomb (Netterberg and Caiger, 1983).	Honeycomb calcrete are interconnected features formed by the fusion of calcrete nodules, normally not exceeding 30 mm in diameter, (Netterberg and Caiger, 1983).	Honeycomb calcrete are excellent pavement material when ripped and rolled, (Netterberg and Caiger, 1983).
Hardpan	Nodular calcrete have been cemented together (Netterberg and Caiger, 1983:240; Netterberg, 1969a) and are the final stage of calcrete development. Hardpan calcretes can form in conditions lower than 550 mm per annum. Can contain shells and/or diatoms and mostly lack the soil cover at the top of the profile (Netterberg, 1969a).	Blasting or crushing is required occasionally but hardpans are mostly ripped and used as pavement material, (Netterberg and Caiger, 1983).
Boulder	Boulder calcretes may be seen as weathered hardpan calcretes and are much harder. These deposits are mainly covered with soil and are rounded at the surface (Netterberg, 1969a).	Can be used as filling material but rather not for pavement purposes due to the coarse texture and hard consistency, (Netterberg and Caiger, 1983).

Table 9: The non-pedogenic calcrete types and characteristics.

Non-pedogenic	Characteristics
Non-pedogenic superficial calcrete	Calcium carbonate transported superficially into gullies and forms laminated crusts (Nash and McLaren, 2003).
Non-pedogenic gravitational zone calcrete	Calcium carbonate accumulates in permeable channels due to downward movement (Nash and McLaren, 2003).
Non-pedogenic groundwater calcrete	Lateral movement of calcium carbonate in groundwater. Also referred to as valley calcretes, lake margin or alluvial fan calcretes. Forms above the groundwater table in the capillary zone (Nash and McLaren, 2003).
Detrital and reconstituted calcrete	Breccia or recemented calcretes in situ (Nash and McLaren, 2003).

2.4.2 Silcrete and Dorbanks

Silcrete and dorbanks are included in the same section due to the fact that both deposits are dominated by a silica rich matrix and are distributed in the same areas over South Africa, mainly being in the Northern and Western Cape Provinces.

Silcrete is defined by Weinert (1980) as a material which is impregnated with amorphous silica. The formation of silica starts as a gel which turns into opal and crystallizes into chalcedony and can later form SiO_2 (Weinert, 1980; Nash and Ulliyott,). The source of silica may be from decayed grass, diatomaceous earth or clays comprising of replaced silica (Weinert, 1980). Goudie (1972) included ash and tuff sediment as silica sources. The physical properties of silcrete comprise of a shiny or glossy appearance, mainly greyish-white in colour, but many variations may occur such as red, brown or green (Nash and Ulliyott, 2007), and cannot be scratched with a knife, (Weiner, 1980). A material can be defined as a silcrete when consisting of a minimum of 85% silica, (Nash and Shaw, 1998; Nash and Ulliyott, 2007) and may contain elements such as iron, titanium and aluminium oxides.

Fey (2010) states that all silcretes are palaeodeposits and that no active silcrete horizons are formed in the present. Silcrete occur as caps on higher elevated landscapes or in drainage lines/valleys and were formed in conditions with high pH levels, above 9, or low pH levels below 4. Evaporation in semi-arid to arid conditions may result in a pH above 9 to exist (Nash and Ulliyott, 2007). Goudie (1972) stated that the process of silicification occurs during desert weathering.

Silcretes are mainly found in the drier western part of the country as well as in the Limpopo valley (Partridge, 2006) and the Kalahari (Goudie, 1972; Nash and Ulliyott, 2007). The distribution of silcretes in South Africa extends along the coast line from the southern part of Namibia along the southern coast up to the Eastern Cape (Maud, 2012; Goudie, 1972) and are referred to as the Grahamstown Formation (Partridge, 2006). The thickness of the silcrete deposits varies considerably as do the ages, but Partridge (2006) states that mature duricrusts are of end-Cretaceous to Palaeocene age.

Silcretes can be divided into pedogenic and non-pedogenic variations. Pedogenic silcrete are subdivided into microquartz or opaline dominated cement. Whereas non-pedogenic silcretes are divided into groundwater, drainage-line or pan variations, see Figure 10. The morphology of the pedogenic silcrete are strongly developed and tabular, but can also be less blocky, and the non-pedogenic silcretes can be massive or tubular bodies. The morphology alone cannot be used to identify a silcrete type, the chemistry and micromorphology must also be taken into consideration (Nash and Ulliyott, 2007).

The ages of silcretes are difficult to estimate and the non-pedogenic silcretes were linked to the Paleogene up to the Quaternary (Nash and Ulliyott, 2007).

The clay mineralogy of silicic deposits, including silicic sand and pedocretes, are sepiolite, smectite, palygorskite, kerolite, mica and koalinite (Fey, 2010).

Dorbanks are hard, resistant surface cover layers (Fey, 2010), and as it seems like a palaeo-features capping the old Tertiary landscape, it can rather be seen as an active forming feature in the present climate. The thickness of dorbanks are inconsistent (Fey, 2010) and are mainly found in the drier western part of the country as well as in the Limpopo valley (Partridge, 2006) and the Kalahari (Goudie, 1972; Nash and Ulliyott, 2007). Dorbanks can contain other cements such as iron-oxide and calcium carbonate instead of only silica. Dorbanks differ from silcrete as being seen as a diagnostic soil horizon (The Soil Classification Working Group, 1991).

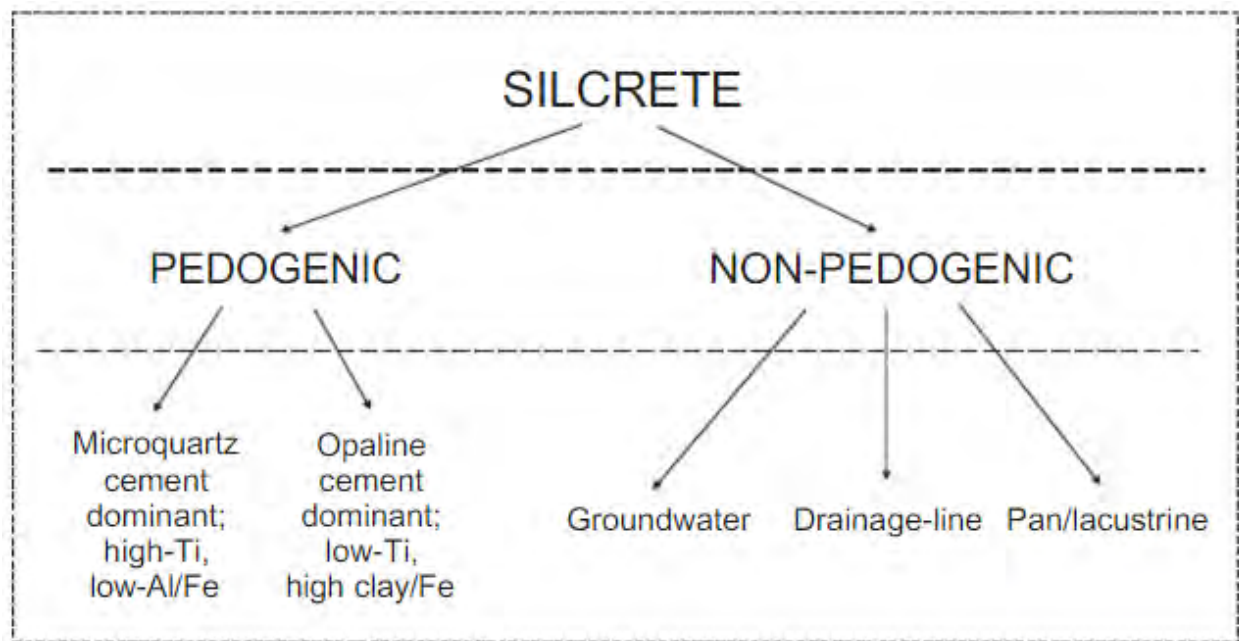


Figure 10: Geomorphological classification of silcretes from Nash and Ulliyott (2007).

2.4.3 Ferricrete and manganocrete

Ferricrete and manganocrete are discussed in this section due to both having similar mineralogical and geochemical compositions Verplanck *et al.*, (2007) also referred to manganocretes as a ferricrete with a black matrix due to the manganese oxide present.

Firstly a distinction must be made between frequently used terms e.g. laterite, plinthite and ferricrete, which are commonly used incorrectly.

Laterite is soil material rich in iron and aluminium oxides which forms due to the weathering of the parent material. Laterite becomes very hard when exposed to air (De Wet, 1991).

Plinthite is a soil material which has iron and manganese oxides and hydroxides present. A plinthite soil horizon is divided into soft and hard, and are distinguished whether it can be cut by a spade or not (De Wet, 1991).

Ferricrete is defined by Weinert (1980) as a material which is impregnated with iron hydroxide. Ferricrete are classified, much the same as calcrete, as ferruginous soil, ferruginised soil, powder ferricrete, nodular, honeycomb, hardpan and boulder ferricrete. The powder and boulder ferricrete are rare and the main occurrence of ferricrete is in the nodular and honeycomb formations (Weinert, 1980).

Manganocrete is a duricrust which comprises of manganese oxides as cementing material, and can also contain iron oxides (Ruxton and Taylor, 1982).

Ferricrete forms mainly in areas where the climatic N-value of Weinert (1980) is below 5. This indicates that in these areas the climate is preferable for ferricrete development. For the formation of ferricrete a fluctuating water table is required of which decomposed mafic minerals are the main sources of ferrous iron. The ferrous iron is then converted to insoluble ferric iron which precipitated at the base of the perched water table to form ferricrete (Weinert, 1980). Ferricrete and manganocrete forms similarly and this entails that dissolved iron and manganese minerals in a reduced state precipitates in an oxidized environment, mainly in down gradient from the source. Manganocrete is not restricted to a climatic zone and can occur in areas independent from the climatic N-value of Weinert. Manganocrete can be distinguished from ferricrete by the vast extent of occurrence. Depending on pH and EC manganese can exist in Mn^{2+} , $Mn^{4+}O_2$, $Mn_2^{3+}O_3$ and $Mn_3^{2+/3+}O_4$, (Verplanck *et al.*, 2007).

In the Highveld region of South Africa, which is the inland plateau with an elevation above 1500m, the main factor for the development of ferruginous crusts was the stagnation of water in the surface depressions filled with aeolian sand (Harmse and Hattingh, 2012). In some areas ferricrete preserved the erosion surfaces (Fey, 2010). In the Kalahari basin ferricrete forms when iron-oxide from an iron rich source precipitates in the soil (Haddon, 2005).

The distribution of ferricretes in South Africa occurs in the southern coastal area, eastern part of the country such as KwaZulu-Natal and in the northern part such as in the Limpopo province. In the Kalahari the distribution of ferricrete is not as prominent as the calcretes but form composite horizons which are present along the Molopo River as well as along river valleys and pans (Haddon, 2005).

The morphological characteristics of ferricrete such as host material and cement may vary between different localities. The cement, which the ferricrete is comprised of, may give significantly more information regarding the conditions in which the ferricrete formatted (De Wet, 1991).

The mineralogy of ferricretes includes minerals such as Fe_2O_3 , SiO_2 , Al_2O_3 , TiO_2 , MnO , V_2O_5 , and a mineralogic composition of quartz, goethite, microcline and kaolinite (De Wet, 1991).

Ferricrete is used as construction material in South Africa (De Wet, 1991:2), but is not as frequent in road construction due to insufficient quantities at sources or the abundance of a better material close by (Weinert, 1980:193). The presence of shallow ferricrete prevents major agricultural activities to establish in an area due to its indurated morphology (De Wet, 1991). See Table 10 for the engineering characteristic used for ferricretes.

Table 10: A ferricrete classification for engineering purposes (modified from De Wet, 1991)

	Ferricrete					
	Soft plinthite			Hard plinthite		
Class:	Mottled	Nodular		Massive	Boulder	
Group:	Mottled soils	Pisolithic Oolitic Pedoturbules	Nodules	Honey-comb	Massive	Boulder
Engineering utilization:	If moderately or slightly plastic and sandy	Depends on matrix material	If plastic, has to be modified, else good, better if coarse	Good. Check plasticity of matrix	Good, provided not too hard	Usually not suitable

The soil forms which include diagnostic horizons of soft and hard plinthic horizons can also be linked to the Cenozoic Era. This includes the soil forms such as Longlands, Wasbank, Westleigh, Dresden, Avalon, Glencoe and Bainsvlei (The Soil Classification Working Group, 1991).

2.4.4 Phoscrete

Phoscrete refers to a material which is impregnated by phosphate, the host material commonly being calcrete. The main source of phosphate is from guano and hence the distribution of phoscrete is mainly restricted to coastal areas. In the western coastal area such as Saldanha Bay in South-Africa phoscrete occurs as phoscrete or phosphorite. Phosphorite is formed from phosphate derived from decayed animals or decomposed rocks (Weinert, 1980). Other forms of phosphate resources are from marine, igneous, metamorphic and biogenic deposits (Van Straaten, 2002).

The sea-level variations at Langebaan fossil site will be discussed below. Langebaan site may also be seen as palaeosol (Chapter 2.2).

The CHEMFOS Ltd mine situated on the farm Varswater, close to Langebaan, mined phosphate on a small scale prior to 1965 until AMCOR joined and the mining activity expanded.

In 1968 the South African Museum started its Langebaanweg Research Project which focuses on fossil and deposit investigation (Hendey, 1982).

Langebaanweg fossil site is situated in the south Western Cape Province and is known for its abundance in Tertiary vertebrate fossils. The Pliocene succession has the most abundant phosphate ore as well as the most fossils. The main factor which influenced sediments to be deposited as various successions was the changing sea-level. It was recognised that the correlation between the global and local sea-level changes in South Africa was closely related. This allows that the deposits at Langebaanweg can be related to other events that occurred in the same geological-time-scale. The sea level transgression (sea level rise) and the regression (sea level fall) were estimated for the time Period from the Oligocene up to the Pleistocene. The Oligocene Epoch (37-24 Ma) experienced a falling of sea level hundred meters below the present until the beginning of the Early Miocene. This resulted in severe erosion occurring along the coast. In the Early Miocene the sea level started to rise to the present sea level about 20 Ma ago. The episode referred to the „Early to Middle Miocene transgression“ lasted up to 13 Ma, where the highest sea level was reached, which was 120 – 140 m above the present day sea level. A Period of „Middle to Late Miocene regression“ existed from 13 Ma to 5.2 Ma, in which the sea level was lower than today. An early Pliocene transgression from 5.2-4.2 Ma existed resulting in a rise in sea level to 90 m and a Period of regression (4.2-2.8 Ma) followed resulting in the decline of the sea level beneath the present. In the Late Pliocene, 2.7-1.7 Ma, the sea level rose up to 20 meters above the present during a transgression Period. The last regression took place 1.7 Ma ago during the end of the Pliocene (Hendey, 1982).

This regression and transgression resulted in stratigraphic units to form the Langebaanweg succession as seen in Figure 11. The Elandsfontein, Varswater, Veldrif, Langebaan, Springfontein and Witzand Formations make up the Sandveld Group, see Figure 12. These formations are linked to the coastal Cenozoic deposits of South Africa, and are therefore not discussed in further detail as it is outside the scope of this research project.

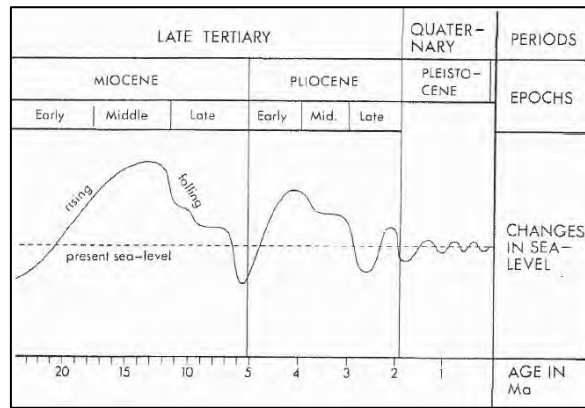


Figure 11: The sea-level change from the Late Tertiary to the Quaternary Period (Hendey, 1982).

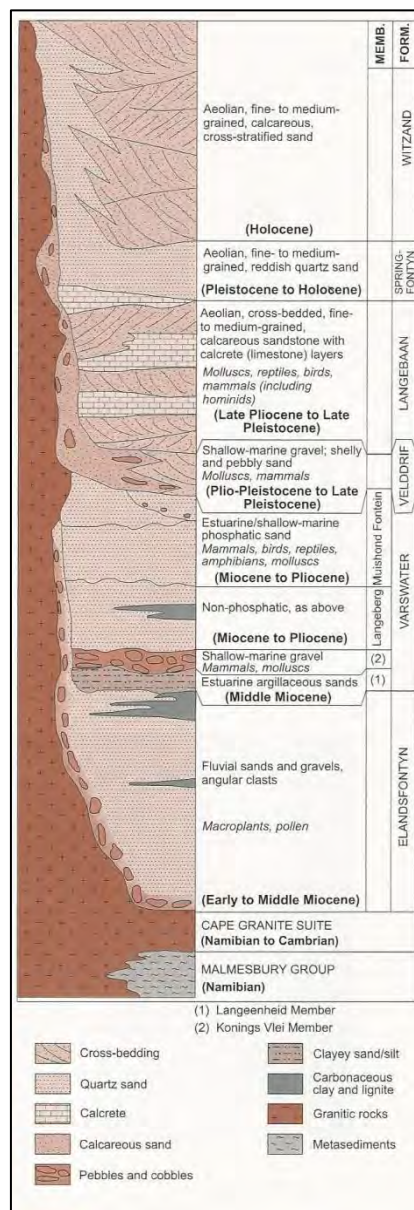


Figure 12: Lithostratigraphy of the Sandveld Group indicating the different stratigraphical units (Roberts *et al.*, 2006).

2.4.5 Gypcrete

Gypcrete is also referred to as gypsum crusts (Nash, 2012; Watson, 1983), and are defined as an accumulation of calcium sulphate dihydrate ($\text{CaSO}_4 \cdot 2\text{H}_2\text{O}$) with a varying thickness in the uppermost 10 m of the surface with a gypsum content from 15% to 100% and can be loose, powdery, crystalline or cemented.

Gypcrete mainly occurs in the drier western regions in South Africa and more specifically in areas where the mean annual rainfall is less than 200 mm/yr and the evaporation is greater than the precipitation (Watson, 1983), this corresponds with the specification for gypsic soils to form (Fey, 2010). Gypcrete may be formed as pedogenic and non-pedogenic material. The pedogenic gypcrete is associated with evaporation of lacustrine environments and may occur on inclined surfaces, colluvial or alluvial sediments or dune sand. Non-pedogenic gypcrete are mainly associated with surface depressions. Gypcrete vary from powder to tabular structured features (Nash, 2012).

The main source of gypsum for pedogenic gypcrete is windblown sand or the reworking of primary gypsum sources resulting in the formation of secondary gypcrete deposits. Sources for sulphur which also forms gypcrete are sea spray or fog, biogenic sulphur, evaporates from marine origin or pyrite weathering (Nash, 2012; Watson, 1983; Fey, 2010). Non-pedogenic gypcrete formation is mainly ascribed to the interaction between surface and groundwater as well as the evaporation of groundwater with a low groundwater table (Nash, 2012).

The distribution of gypcrete in South Africa is mainly along the western coast and Namaqualand and extends up to Angola and the Namib Desert, and also occurs east of Upington (Nash, 2012; Watson, 1983).

Age determinations of gypcrete are a challenge due to the susceptibility of gypcrete to solution under wetter climate conditions. This could indicate that little gypcrete deposits remain or that the crust only formed in the Holocene (Watson, 1983).

2.4.6 Intergrade pedocretes

The term intergrade refers to a soil or soil horizon with the properties of two genetically different soils (Oxford Dictionary of Earth Sciences, 2008) and pedocrete is defined by Weinert (1980) as soils cemented by silica, calcium carbonate or iron oxide to form new material. Therefore an intergrade pedocretes refers to a pedocretes with properties of two or more different soils or pedocretes such as calcrete, silcrete or ferricrete.

Nash (2012) states that intergrade pedocretes are formed in a later stage of cementation by the precipitation of minerals in pores or by alteration caused by the percolation of water. Nash and Shaw (1998) defined intergrade pedocretes of silcrete-calcrete composition as a chemically precipitate near surface or surface crust which is cemented with a mixture of silica and CaCO_3 . In regions of the Kalahari good examples exist of sil-calcretes (silicified calcrete) and cal-silcretes (calcareous silcrete). More variations exist e.g., cal-ferricrete (calcretised ferricrete), ferro-calcrete (iron-cemented calcrete), ferro-silcrete (iron-cemented silcrete) as well as an intergrade pedocrete consisting of calcrete and gypcrete. In certain regions, with very arid climatic conditions, calcrete and gypcrete can occur in the same profile (Goudie, 1983). Another term „silici-calcrete“ refers to calcrete which are replaced with silcrete. Sil-calcretes are abundant in South-Africa (Goudie, 1972:452) as well as Botswana, where the sil-calcrete deposits aged 235-275 ka BP at the rim of the Moshaweng valley in the southeast Botswana (Nash and McLaren, 2003). Ages must be linked to site specific studies and must not be interpolated for different regions. In the western parts of South Africa intergrade pedocretes of gypcrete and calcrete are common (Van Deventer, pers comm, 2015)

CHAPTER 3: MATERIALS AND METHODS

Samples were collected during various field excursions and localities were selected over South Africa. Sampling included a wide range of equipment such as hand and automated hand augers, spade, geological hammer, trowel and a drill. Samples were mainly collected in 5 l plastic bins or sampling bags. Fragile sample such as calcretes nodules were wrapped in Glad Wrap for protection.

Samples were firstly air dried and then crushed and passed through a 2 mm sieve. Stones were not included in the crushing process and some samples were only collected for observational and/or microscope analyses purposes.

3.1 Materials

The following materials are discussed in the materials section as palaeosols, clastic sediments including cave deposits, gravel deposits, Pebble Marker, terrestrial sand deposits, drainage depressions and a periglacial deposit. The pedogenic deposits, such as calcrete, silcrete, dorbanks, ferricrete, manganocrete, phoscrete, gypcrete and intergrade pedocretes are also included. Each deposit with the corresponding coordinates and representative map will be discussed in individual tables.

Palaeosols

In the palaeosols, as seen in Table 11, the Florisbad and Cornelia palaeohorizons are included with the sample number, locality and coordinates. The Florisbad palaeosol site is situated approximately 45 km from Bloemfontein in the Free State province and contains a variety of mammal fossils of Florisian Land Mammal Age. Well preserved test pits, mainly used for archaeological purposes, indicated distinct palaeohorizons. Sediment samples were collected from selected horizons in the Test Pit 3 from the Florisbad site.

Cornelia-Uitzoek palaeosol site is situated in the eastern Free State close to the town Cornelia and comprises of dongas, or v-shaped dendritic channels. Many fossils were excavated at this site and are referred to as the Cornelian Land Mammal Age. Sediment samples were collected from selected palaeosol horizons.

The palaeosol localities are indicated in Figure 13.

Table 11: The selected palaeosol localities including the coordinates and locality map.

Type	Sample number	Locality or description	Coordinates: Latitude (S), Longitude (E) and elevation (mamsl)
Florisbad	B15	Florisbad (First horizon) Aeolian sand.	28° 46' 9.0006"S 26° 4' 16.9998"E 1272 mamsl
	B16	Second horizon: Iron and carbonate dominated horizon.	28° 46' 9.0006"S 26° 4' 16.9998"E 1272 mamsl
	B17	Third horizon: Greenish-brown soil.	28° 46' 9.0006"S 26° 4' 16.9998"E 1272 mamsl
	B18	Fourth horizon: White leached soil.	28° 46' 9.0006"S 26° 4' 16.9998"E 1272 mamsl
	B49	Representative present A-horizon	28° 13' 57.1794"S 24° 41' 57.084"E 1272 mamsl
Cornelia	B34	Bed rock (Ecca)	27° 9' 34.308"S 28° 52' 43.2474"E 1542 mamsl
	B35	Basal gravel	27° 9' 34.308"S 28° 52' 43.2474"E 1542 mamsl
	B36	Yellow clay horizon	27° 9' 34.308"S 28° 52' 43.2474"E 1542 mamsl
	B37	Laminated clay	27° 9' 34.308"S 28° 52' 43.2474"E 1542 mamsl
	B38	Grey clay	27° 9' 34.308"S 28° 52' 43.2474"E 1542 mamsl
	B39	Gravel	27° 9' 34.308"S 28° 52' 43.2474"E 1542 mamsl

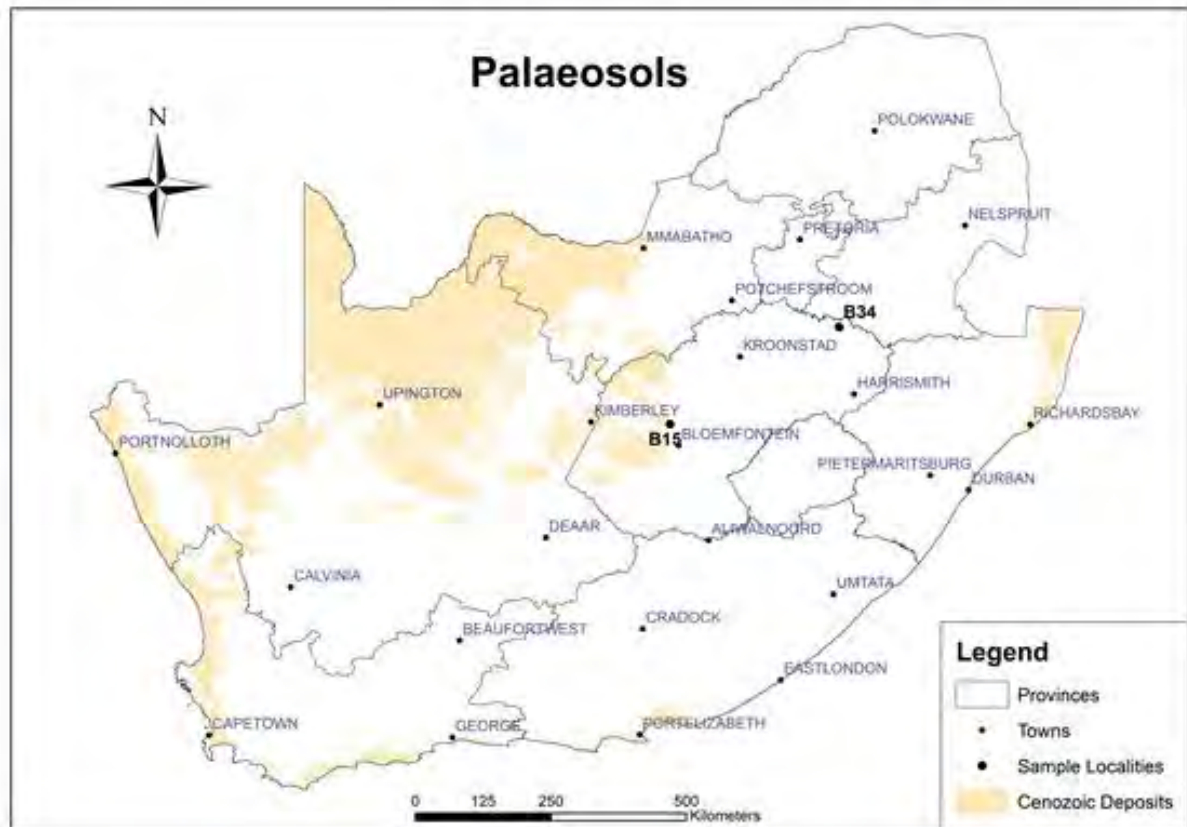


Figure 13: Selected palaeosol localities in South Africa, (ArcMap, 2010).

Caves

Selected caves were visited in the North-West Province, including the Rietpan Cave, close to Swartruggens, Lime Quarry Cave, Jaws and Lepalong caves, all situated close to Carltonville, as seen in Figure 14 and Table 12. Floor sediments were sampled from each cave as well as small pieces of stalactites where present. More examples of cave localities are indicated in Figure 15, and indicate the abundance of caves in the Far West Rand region.

Table 12: The selected cave localities in the North-West province including the coordinates and locality map

Type	Sample number	Locality or description	Coordinates: Latitude (S), Longitude (E) and elevation (mamsl)
Caves	B109A	Rietpan Cave, North-West. A horizon.	25°59'35.699S 26°36'15.80"E 1515 mamsl
	B109B	Rietpan Cave, North-West. B horizon.	25°59'35.699S 26°36'15.80"E 1515 mamsl

Table 12: (cont): The selected cave localities in the North-West province including the coordinates and locality map

Type	Sample number	Locality or description	Coordinates: Latitude (S), Longitude (E) and elevation (mamsl)
	B110A	Lime quarry cave (Goldfields), North-West. A horizon.	26°17'26.015S 27°24'47.772E 1502 mamsl
	B110B	Lime quarry cave (Goldfields), North-West. B horizon.	26°17'26.015S 27°24'47.772E 1502 mamsl
	B111A	„Jaws“ cave, North-West. A horizon.	26° 29' 4.92"S 27°10'54.696E 1489 mamsl
	B111B	„Jaws“ cave, North-West. B horizon.	26° 29' 4.92"S 27°10'54.696E 1489 mamsl
	B112A	Hut Caves (Deelkraal/Lepalong caves), North-West, A horizon	26°28'35.29"S 27°14'13.92"E 1593 mamsl

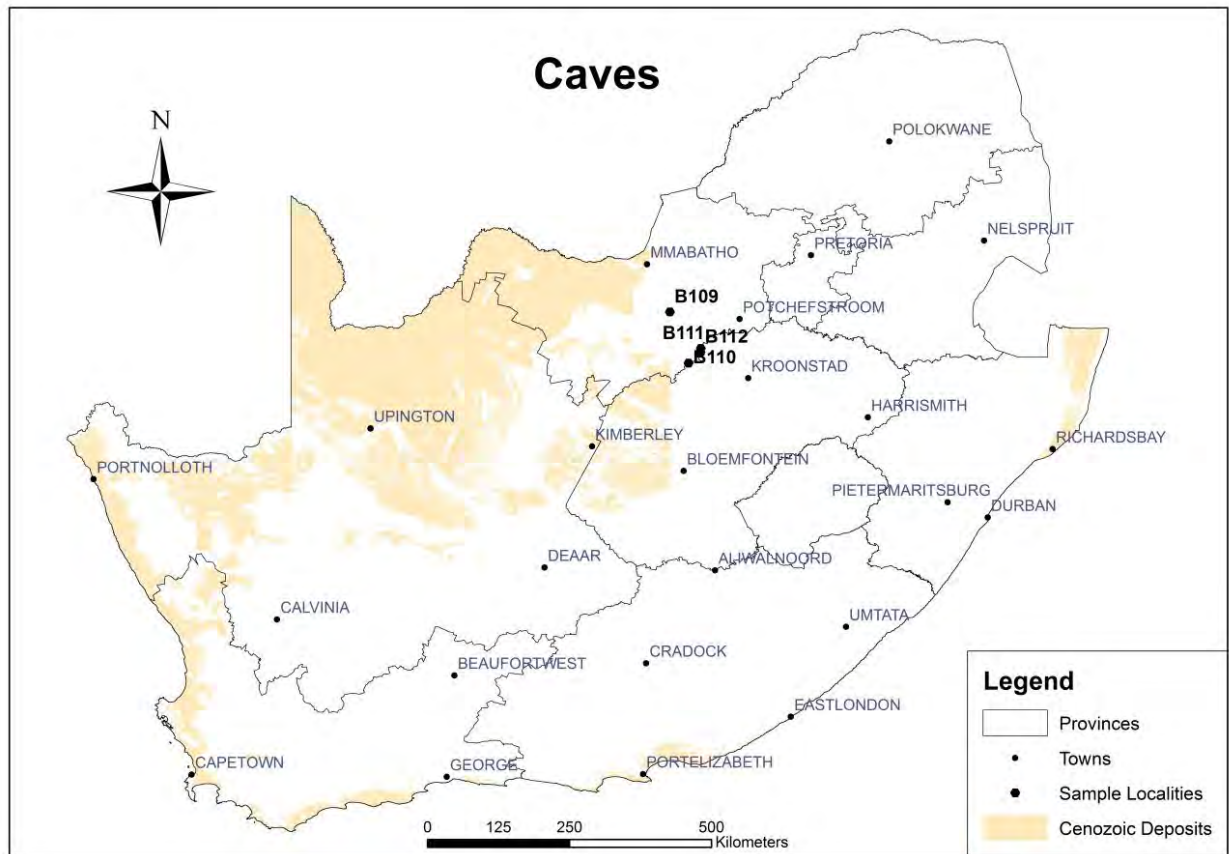


Figure 14: Selected cave localities in the North-West Province, South Africa, (ArcMap, 2010).

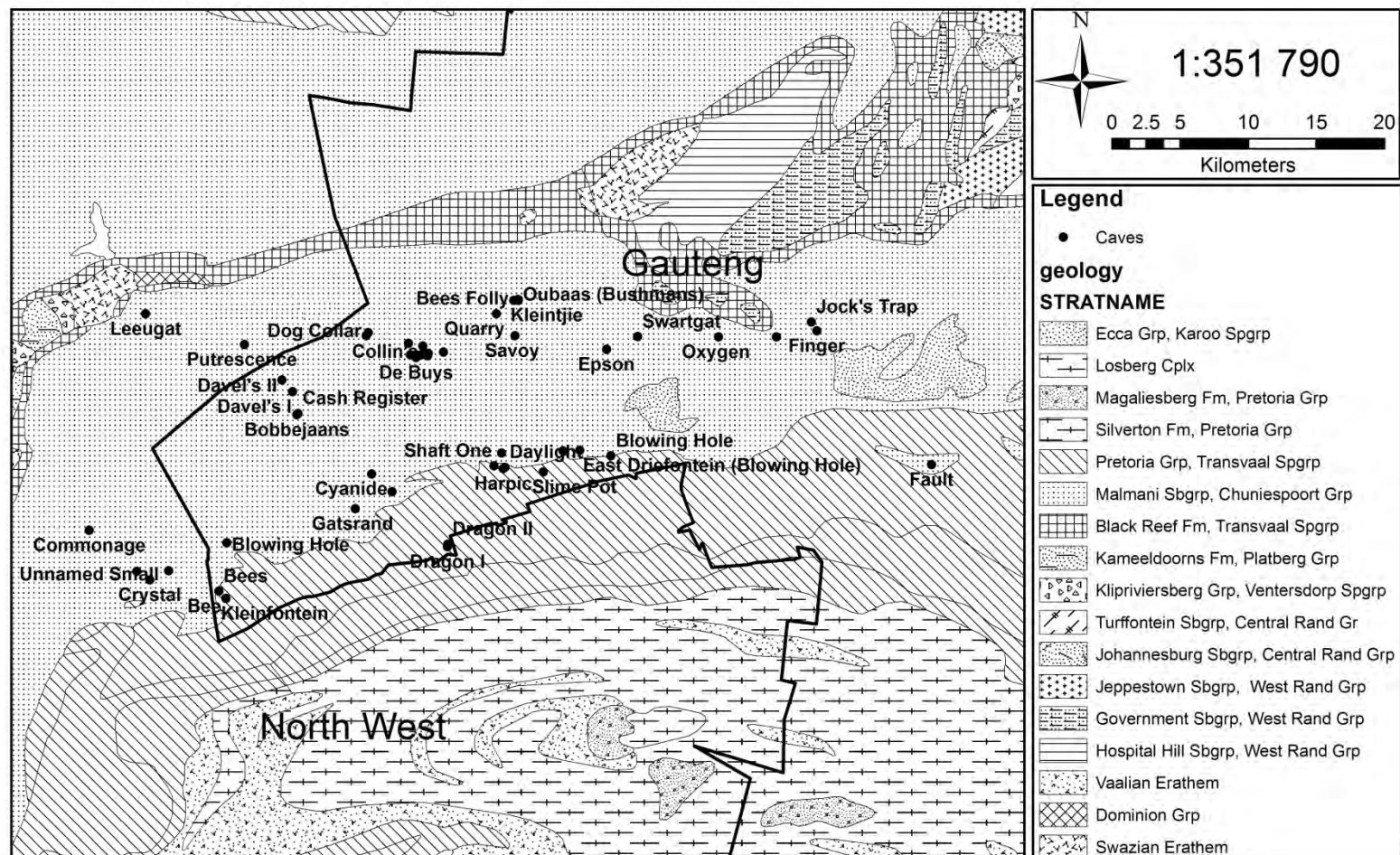


Figure 15: Caves of the Far West Rand in the North-West and Gauteng Provinces Map compiled in ArcMap (2010) by Jaco Koch, information used from Goldfield North-West (with permissions). Grp= Group, Spgrp= Super Group, Cplx= Complex.

Gravel deposits

Gravel deposits have a wide distribution over South Africa and are mainly associated with rivers systems. Various gravel deposits were sampled over South Africa as indicated with a „B“ in Table 13 and in Figure 16, and more examples of gravel deposits were indicated with a „G“ respectively. The diamondiferous gravels are indicated with a „D“ in Table 13.

The main gravel deposit sampled was at Windsorton in the Northern Cape which had distinct alluvial gravel deposits associated with the Vaal River and had a relatively known stratigraphy of Cenozoic age, Marshall and Norton (2012), Butzer (1973). The younger gravels which are represented by samples B19 – B28 were associated with the Riverton and Rietsput Formations and the older gravels found in the area were associated with the Wedburg gravels as well as the Rooikoppie gravels, (Marshall and Norton, 2012). The older gravels were only recorded during field observations.

Table 13: Selected gravel deposits over South Africa indicating the locality and coordinates.

Type	Sample number	Locality or description	Coordinates: Latitude (S), Longitude (E) and elevation (mamsl)
Gravel deposits: Field visits	B	Windsorton gravel deposit associated with the Riverton and Rietsput Formations	
Windsorton-Profile 1	B19	A-horizon: Aeolian sand	28° 20' 03.24"S 24° 43' 01.4"E 1124 mamsl
	B20	B-horizon: Yellow sand horizon with black mottles	
	B21	First alluvial gravel deposit (D)	
	B22	Stratified sand horizon	

Table 13 (cont): Selected gravel deposits over South Africa indicating the locality and coordinates.

Type	Sample number	Locality or description	Coordinates: Latitude (S), Longitude (E) and elevation (mamsl)
	B23	Second alluvial gravel deposit (D)	
	B24	Third alluvial gravel deposit (D)	
Profile 2	B25	Clay with structure	28° 20' 03.24"S 24° 43' 01.4"E 1124 mamsl
	B26	Homogenous clay (without structure)	
	B27	Clay layer	
	B28	Clay layer	
Setlagoli River gravel	B68	Gravel deposit close to the Setlagoli River in the Vergeleë area, North-West Province.	25° 57' 35.28"S 24° 44' 2.0394"E 1121 mamsl
Limpopo River gravels	B86A	Limpopo River gravels close to Stockpoort, Limpopo	23° 26' 3.12"S 27° 21' 5.04"E 815 mamsl
	B86B	Rock associated with the Limpopo River gravels close to Stockpoort, Limpopo	23° 26' 3.12"S 27° 21' 5.04"E 815 mamsl
	B86C	Conglomerate associated with the Limpopo River gravels close to Stockpoort, Limpopo	23° 26' 3.12"S 27° 21' 5.04"E 815 mamsl
	B88	Baltimore Gravel Deposit associated with the Limpopo River basin.	23° 17' 31.92"S 28° 26' 12.1194"E 1003 mamsl

Table 13 (cont): Selected gravel deposits over South Africa indicating the locality and coordinates.

Type	Sample number	Locality or description	Coordinates: Latitude (S), Longitude (E) and elevation (mamsl)
Olifants River Gravel	B97	Olifants River gravels close to Lutzville, Western Cape	31° 33' 0"S 18° 21' 0"E 67 mamsl
More examples of gravel sites	G		
	G1	Gravels are found at Rysmierbult associated with the Mooi River. Boulders are up to 80 cm in diameter. (D)	26° 21' 03.26"S 27° 08' 07.89"E 1457 mamsl
	G2	Terraces of up to 80 m thick occur around Douglas in the Northern Cape. Associated with the Vaal River. (D)	29° 09' 00.24"S 23° 43' 20.41"E 1032 mamsl
	G3	Wonderfonteinspruit a tributary of the Mooi River located at Venterspos in the North-West are associated with gravel terraces cemented with ferricrete.	26° 16' 03.85"S 27°37' 22.61"E 1581 mamsl
	G4	Groot Marico River gravel terraces especially south-east of the Dwars Mountains.	25° 25' 48.16"S 22°55' 48.98"E 1581 mamsl
	G5	Molopo River gravel terraces in the North-West.	25° 35' 08.43"S 26°24' 51.26"E 1006 mamsl
	G6	Limpopo River gravels occur sporadically with the best representation at Groblers Bridge.	22° 59' 59.94"S 27°57' 02.79"E 790 mamsl
	G7	Selati River gravels at Phalaborwa, Limpopo, but are weakly developed.	24°02'17.8"S 31°10'46.87"E 315 mamsl
	G8	Letaba River gravels in the Limpopo Province occur sporadically.	23°57'46.57"S 31°47'46.82"E 225 mamsl
	G9	Crocodile River gravel, close to Crocodile Bridge and Komatipoort in Mpumalanga.	25°21'59.38"S 31°50'10.39"E 197 mamsl
	G10	Komati River gravels mainly occur between Badplaas and Komatipoort, Mpumalanga.	25°54'19.05"S 30°33'03.31"E 1540 mamsl
	G11	Lepalala River gravels, Limpopo. Thick terraces of approximately 5 m occur at Beauty.	23°13'07.69"S 27°54'11.38"E 809 mamsl
	G12	Olifants River gravels are prominent in Oudtshoorn in the Western Cape.	33°24'06.96"S 22°09'30.80"E 774 mamsl
	G13	Eerste River gravels are found in Stellenbosch, Western Cape.	33°58'20.22"S 18°47'29.67"E 34 mamsl

Table 13 (cont): Selected gravel deposits over South Africa indicating the locality and coordinates.

Type	Sample number	Locality or description	Coordinates: Latitude (S), Longitude (E) and elevation (mamsl)
	G14	Hex River Valley in the Western Cape is associated with Hex River gravels occurring sporadically.	33°29'05.63"S 19°35'16.29"E 413 mamsl
	G15	Storms River in the Southern Cape, has sporadically distributed gravels.	33°58'27.48"S 23°53'20.90"E 246 mamsl
	G16	Tugela River gravels mainly occur on the eastern side of the Drakensberg, KwaZulu Natal.	28°56'2.27"S 30°13'42.37"E 1353 mamsl
	G17	Baken, south of the Oranje River in the Northern Cape. Baken gravels are some of the thickest gravel deposits in South-Africa and can be up to 100 m thick. (D)	29° 30' S 18° 55' 0.12"E 968 mamsl
	G18	Gravels associated with the Boesmans River in the Eastern Cape	33°40'08.81"S 26°38'11.62"E 23 mamsl
	G19	Harts River gravels are mainly found on the south-eastern side of the palaeodrainage systems such as the Koa, Kalahari and Karoo- Rivers.	26°37'4.48"S 25°35'32.94"E 1358 mamsl

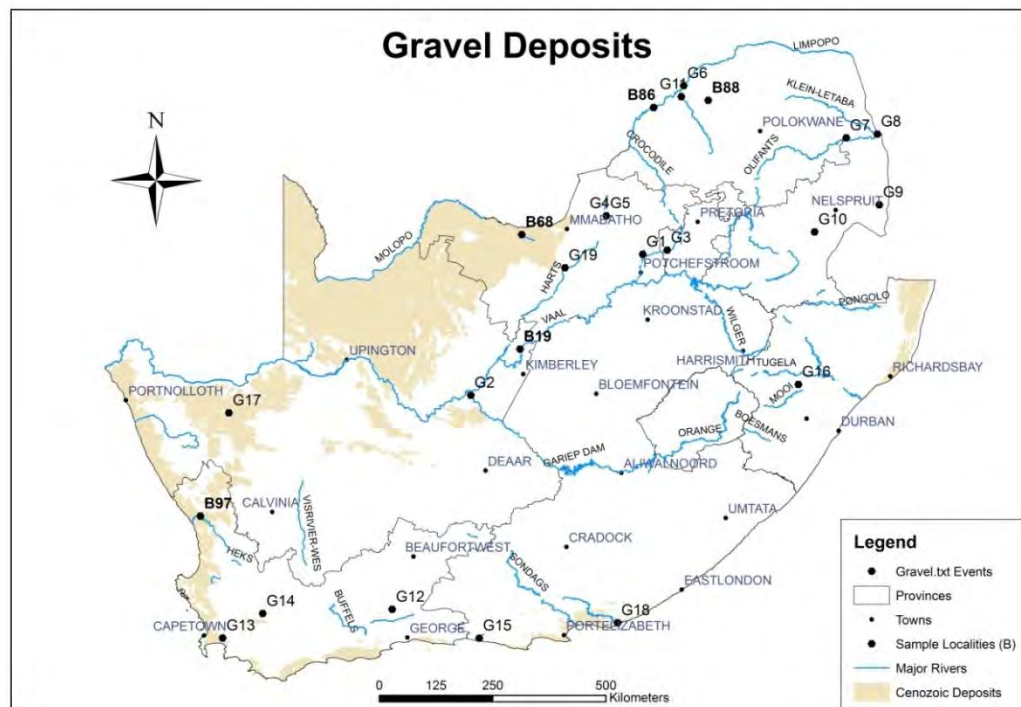


Figure 16: Major gravel deposits of South Africa, „B“ indicating the samples collected form field visits and „G“ indicating more examples of gravel deposits (ArcMap, 2010).

The Pebble Marker

The Pebble Marker was sampled at two selected localities in the North West province as seen in Table 14, the first being close to Schweizer Reneke and the second close to Potchefstroom. The distribution of the Pebble Marker is much more extensive and the southern border is from Upington in the Northern Cape to the eastern Swaziland border, and the distribution extents up to Zambia in the north (Van Deventer, pers comm, 2015). The southern boundary of the Pebble Marker described by Van Deventer (pers comm, 2015) is indicated in Figure 17. The Pebble Marker is similar to the gravel deposits but is much younger and mainly always situated below the Kalahari sand layer.

Table 14: Selected localities of the Pebble Marker as well as the coordinates

Type	Sample number	Locality or description	Coordinates: Latitude (S), Longitude (E) and elevation (mamsl)
Schweizer Reneke	B32	Pebble Marker close to Schweizer Reneke, North-West.	27° 9' 52.776"S 25° 16' 53.112"E 1346 mamsl
New Machavie	B65	Pebble Marker at New Machavie site, North-West	26°47'35.02"S 26°55'22"E 1363 mamsl
	B66 (Repeat of B65)	Pebble Marker at New Machavie site, North-West	26°47'35.02"S 26°55'22"E 1363 mamsl

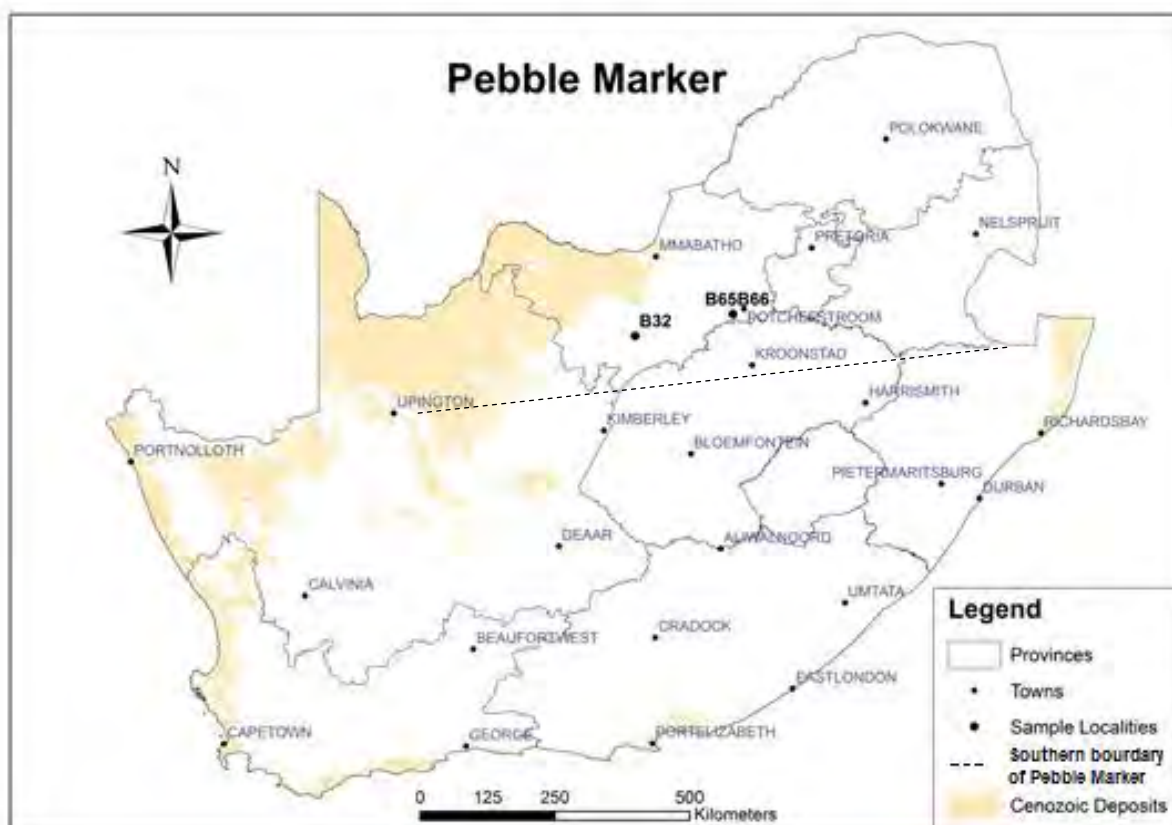


Figure 17: The Pebble Marker sample localities at selected sites in the North-West Province (ArcMap, 2010).

Terrestrial sand deposits

Various Kalahari sand samples were collected over South Africa, as indicated in Figure 18. The samples were mainly collected in the Northern Cape Province, but also in the North-West Province. The localities and coordinates are indicated in Table 15.

Table 15: Selected Kalahari sand deposits including the localities and coordinates

Type	Sample number	Locality or description	Coordinates: Latitude (S), Longitude (E) and elevation (mamsl)
Aeolian sand deposits: Kalahari sand	B30	Kalahari sand, Windsorton, Northern Cape	28° 20' 53.916"S 24° 42' 51.6234"E 1201 mamsl
	B41 (B40: repetitive sample)	Koa sand dunes from Aggeneys in the Northern Cape	29° 11' 59.9994"S 18° 51' 0"E 989 mamsl

Table 15 (cont): Selected Kalahari sand deposits including the localities and coordinates

Type	Sample number	Locality or description	Coordinates: Latitude (S), Longitude (E) and elevation (mamsl)
	B42	Kalahari sand from Groblershoop in the Northern Cape	28° 53' 35.3682"S 21° 58' 56.8092"E 869 mamsl
	B44 (B45: repetitive sample)	„Brulsand" sample form Witsand Nature Reserve in the Northern Cape	28° 33' 20.9412"S 22° 27' 52.5492"E 1225 mamsl
	B53	„Brulsand" sample form Witsand Nature Reserve in the Northern Cape	28° 33' 20.9412"S 22° 27' 52.5492"E 1225 mamsl
	B54	Kalahari sand from Schweizer Reneke in the North-West Province.	27°9'51.411S 25°5' 55.32"E 1357 mamsl
	B77	Kalahari sand from Vergeleë in the North-West province	25°54'17.64"S 24°21'47.8794"E 1107 mamsl

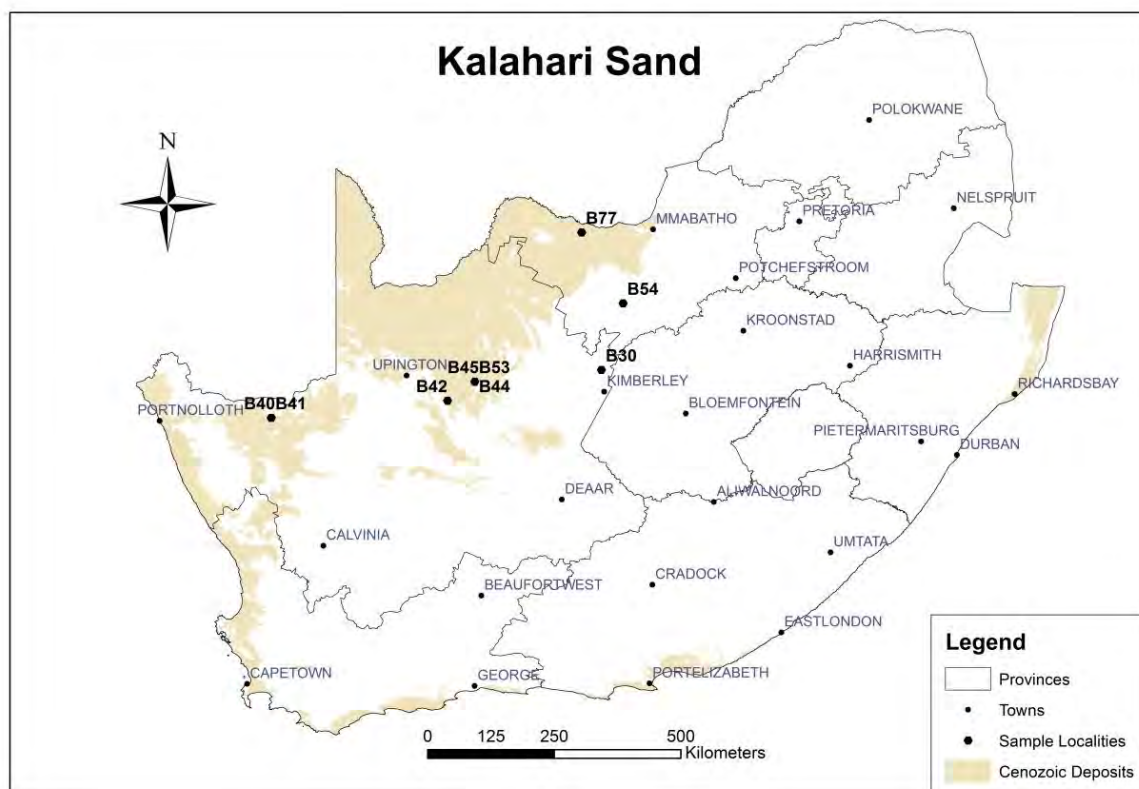


Figure 18: Selected Kalahari sand localities in the North-West and Northern Cape Provinces in South Africa (ArcMap, 2010).

Coastal sand deposits

Selected coastal sand samples were collected from the Northern-Cape Province and indicated in Figure 19. The localities and coordinates are indicated in Table 16.

Table 16: The coastal sand deposits including the localities and coordinates.

Type	Sample number	Locality or description	Coordinates: Latitude (S), Longitude (E) and elevation (mamsl)
Coastal sand	B1	Close to Loeriesfontein, Northern Cape	30°43'49.5978"S 18°49'40.9002"E 628 mamsl
	B2	Close to Leliefontein, Northern Cape	30°20'53.2962"S 17°36'7.2"E 337 mamsl

Table 16 (cont): The coastal sand deposits including the localities and coordinates.

Type	Sample number	Locality or description	Coordinates: Latitude (S), Longitude (E) and elevation (mamsl)
	B4	Close to Koingnaas, Northern Cape	30°11'32.7978"S 17°19'8.1978"E 70 mamsl
	B5, B6	Sample (white dominated colour) between Springbok and the sea, in the Northern Cape	29° 51' 42.8004"S 17° 24' 58.9998"E 285 mamsl
	B7	Sample (Palaeodune), north of Port Nolloth, North-western Cape.	29° 9' 1.6992" S16° 51' 53.1"E 42 mamsl
	B8	Shell layer in coastal sand profile, North of Port Nolloth, North-western Cape.	29° 9' 1.6992" S16° 51' 53.1"E 42 mamsl
	B9	First red sand dunes, 30km away from sea, Northern Cape.	29° 18' 28.5006"S 17° 3' 59.601"E 175 mamsl

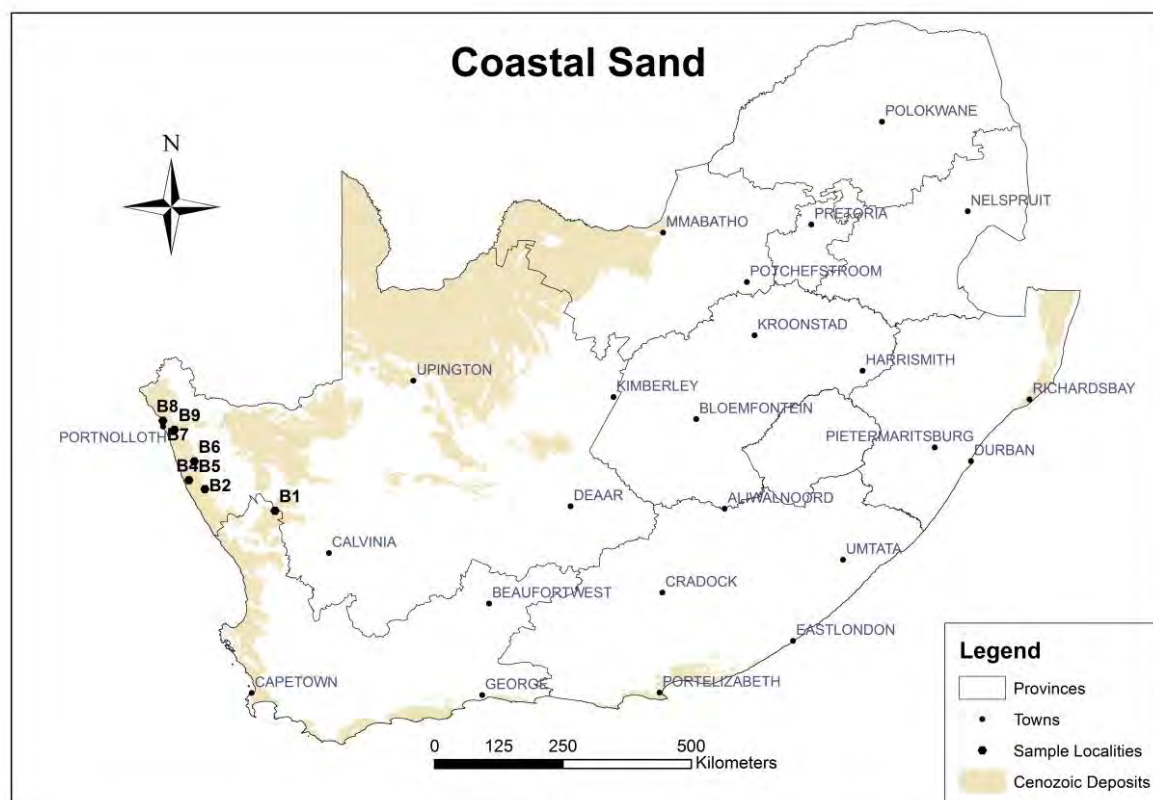


Figure 19: Selected coastal sand localities in the Northern and Western Cape Provinces in South Africa (ArcMap, 2010).

Drainage depressions

Selected drainage depressions were sampled over South Africa as seen in Figure 20 and the localities and coordinates are indicated in Table 17. The samples were mainly collected in the Free State, North-West and Northern Cape provinces. The drainage depression localities were compared to the gleyic map from (Fey, 2010:115). It must be noted that all gleyic material by Fey (2010) is not considered to be drainage depressions or pans.

Table 17: Selected drainage depression localities over South Africa as well as coordinates.

Type	Sample number	Locality or description	Coordinates: Latitude (S), Longitude (E) and elevation (mamsl)
Drainage depressions (pans)	B13	Small pan situated in underlying dolomite close to Stilfontein, North-West.	26° 47' 29.2986"S 26° 47' 54.3012"E 1356 mamsl

Table 17 (cont): Selected drainage depression localities over South Africa as well as coordinates.

Type	Sample number	Locality or description	Coordinates: Latitude (S), Longitude (E) and elevation (mamsl)
	B47	Pan A-horizon, Windsorton, Northern Cape	28° 13' 57.1794"S 24° 41' 57.084"E 1201 mamsl
	B48	Pan A-horizon, Windsorton, Northern Cape	
	B50	Pan A-horizon, Windsorton, Northern Cape	
	B51	Pan B-horizon, Windsorton, Northern Cape	
	B55	Pan C-horizon, Windsorton, Northern Cape	
	B59	Voëlpan in Allanridge, Free State. Samples were collected on the north-western side of the pan.	27° 46' 9.5982"S 26° 38' 49.1994"E 1309 mamsl
	B62	Pan in Viljoenskroon, Free State	27° 12' 49.6008"S 26° 54' 18.6006"E
	B63	Gleyed (hydromorphic) top layer of the pan close to Bloemhof, North West Province	27°44'20.7"S 25°19'25.3"E 1211 mamsl
	B71	Lunette dune on the South eastern side of a pan close to Bloemhof, North-West	27°44'25.7"S 25°20'11.9"E 1216 mamsl

Table 17 (cont): Selected drainage depression localities over South Africa as well as coordinates.

Type	Sample number	Locality or description	Coordinates: Latitude (S), Longitude (E) and elevation (mamsl)
	B64	Grootvloerpan, south of Kenhardt in the Northern Cape.	29°59'52.3"S 20°39'38.9"E 875 mamsl
	B83	Small pan located on Wexford farm in Tosca area, North-West.	25° 52' 15.2394"S 24° 24' 23.76"E 1083 mamsl
	B84	Salt Pan (top crust) in Steenbokpan, Limpopo. Salt was used commercially in the past.	24° 17' 57.1194"S 27° 25' 41.16"E 957 mamsl
	B85	Salt Pan (grey clay) in Steenbokpan, Limpopo.	24° 17' 57.1194"S 27° 25' 41.16"E 957 mamsl
	BX3	Verneukpan near Brandvlei, south of Kenhardt in the Northern Cape, Southern part of the pan mainly pebbles.	30° 00'30.1"S 21°08'40.9"E 864 mamsl
	BX4	Verneukpan near Brandvlei, south of Kenhardt, Northern Cape. Central part of the pan.	30° 00'30.1"S 21°08'40.9"E 864 mamsl
	BX5	Verneukpan near Brandvlei, south of Kenhardt, Northern Cape, basal shale.	30° 00'30.1"S 21°08'40.9"E 864 mamsl

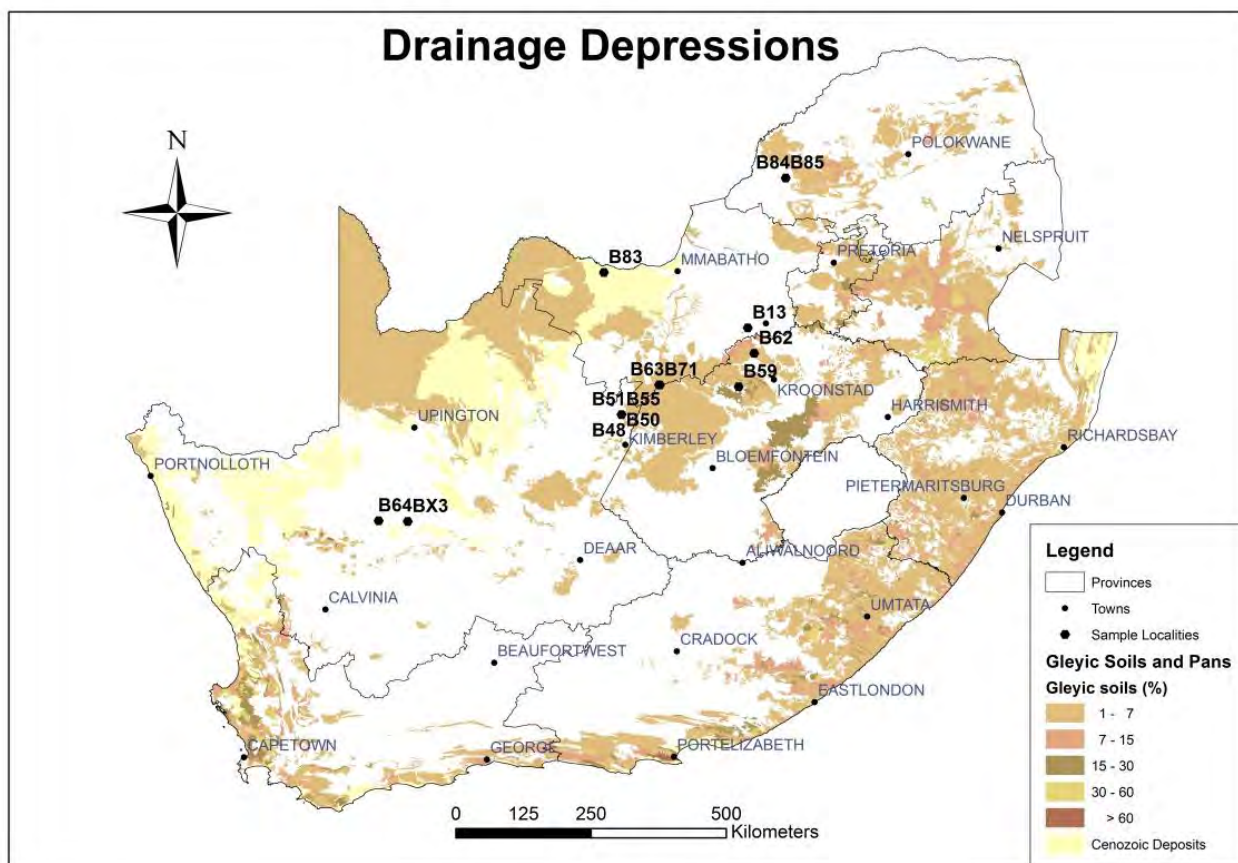


Figure 20: Selected drainage depression localities in the North-West, Free State and Northern Cape Provinces in South Africa (ArcMap, 2010). Gleyic soil and pan information from (Fey, 2010:115).

A periglacial deposit

A unique periglacial site was found close to Groot Marico in the North-West Province as seen in Figure 21. The locality and coordinates are included in Table 18.

Table 18: The periglacial site situated close to Groot Marico as well as the site coordinates.

Type	Sample number	Locality or description	Coordinates: Latitude (S), Longitude (E) and elevation (mamsl)
Periglacial	B102	Concretions at periglacial site, Groot Marico, North-West Province	S25°34'27.3"S E26°23'47.7"E 1084 mamsl
	B104	Periglacial deposit sediment (Sand part of glacial deposit)	25°34'27.3"S 26°23'47.7"E 1085 mamsl
	B2K	Stone tools and pot shards	25°34'27.3"S 26°23'47.7"E 1086 mamsl

Table 18 (cont): The periglacial site situated close to Groot Marico as well as the site coordinates.

Type	Sample number	Locality or description	Coordinates: Latitude (S), Longitude (E) and elevation (mamsl)
	B105	Andalusite rich sand	25°34'27.3"S 26°23'47.7"E 1087 mamsl
	B106	Periglacial deposit sediment (Dongas with rocks)	25°34'27.3"S 26°23'47.7"E 1088 mamsl
	B107	Periglacial deposit sediment (Dongas without rocks)	25°33'01.3"S 26°23'35.7"E 1088 mamsl

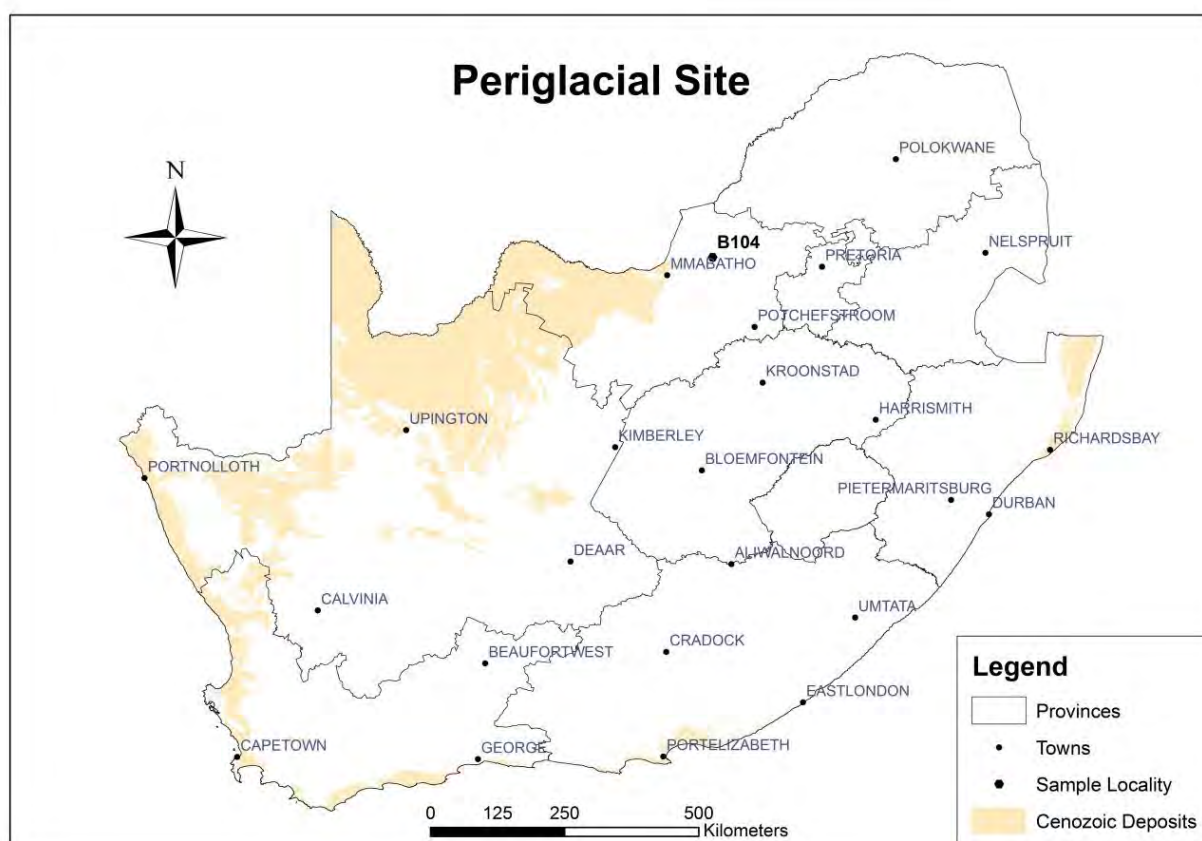


Figure 21: A periglacial site located in the North-West Province close to Groot Marico (ArcMap, 2010).

Pedogenic material: Calcrete

Calcrete were sampled at selected localities over South Africa as seen in Figure 22, and the localities as well as the coordinates are indicated in Table 19. The localities were mainly in the

North-West and Northern Cape Provinces. The calcrete sample localities were compared to the calcic soils from Fey (2010).

Table 19: Selected calcrete localities over South Africa as well as coordinates

Type	Sample number	Locality or description	Coordinates: Latitude (S), Longitude (E) and elevation (mamsl)
Pedogenic material: Calcrete	B29	Calcrete, Windsorton, Northern Cape	28° 20' 53.916"S 24° 42' 51.624"E 1139 mamsl
	B58	Calcrete core sample from the Windsorton area, Northern Cape.	28° 20' 40.38"S 24° 43' 4.08"E 1133 mamsl
	B60	Calcrete, close to Upington in the Northern-Cape.	29°10'14.9"S 21°13'29.6"E
	B70	Soft carbonate situated on elevated calcrete bank, Vergeleë, North-West Province.	25° 52' 13.08"S 24° 24' 41.4"E 1083 mamsl
	B72	Soft carbonate, Vergeleë, North-West Province.	25° 52' 13.08"S 24° 24' 38.1594"E 1084 mamsl
	B81	Calcrete bank: Kalahari - Vergeleë (Calcrete bank used for building material)	25° 50' 32.28"S 24° 20' 14.6394"E 1084 mamsl
	B82	Subfossil: <i>Lymnaea truncatula</i> in calcrete, in the Vergeleë area, North-West Province.	25° 50' 32.28"S 24° 20' 14.6394"E 1084 mamsl
	B90	Hard carbonate, Saldanha Bay, south-western coast	32° 59' 18.3114"S 18° 2' 21.12"E 14 mamsl

Table 19 (cont): Selected calcrete localities over South Africa as well as coordinates

Type	Sample number	Locality or description	Coordinates: Latitude (S), Longitude (E) and elevation (mamsl)
	B103A	Calcrete nodules at periglacial site, Groot Marico, North-West Province	S25°34'27.3"S E26°23'47.7"E 1084 mamsl

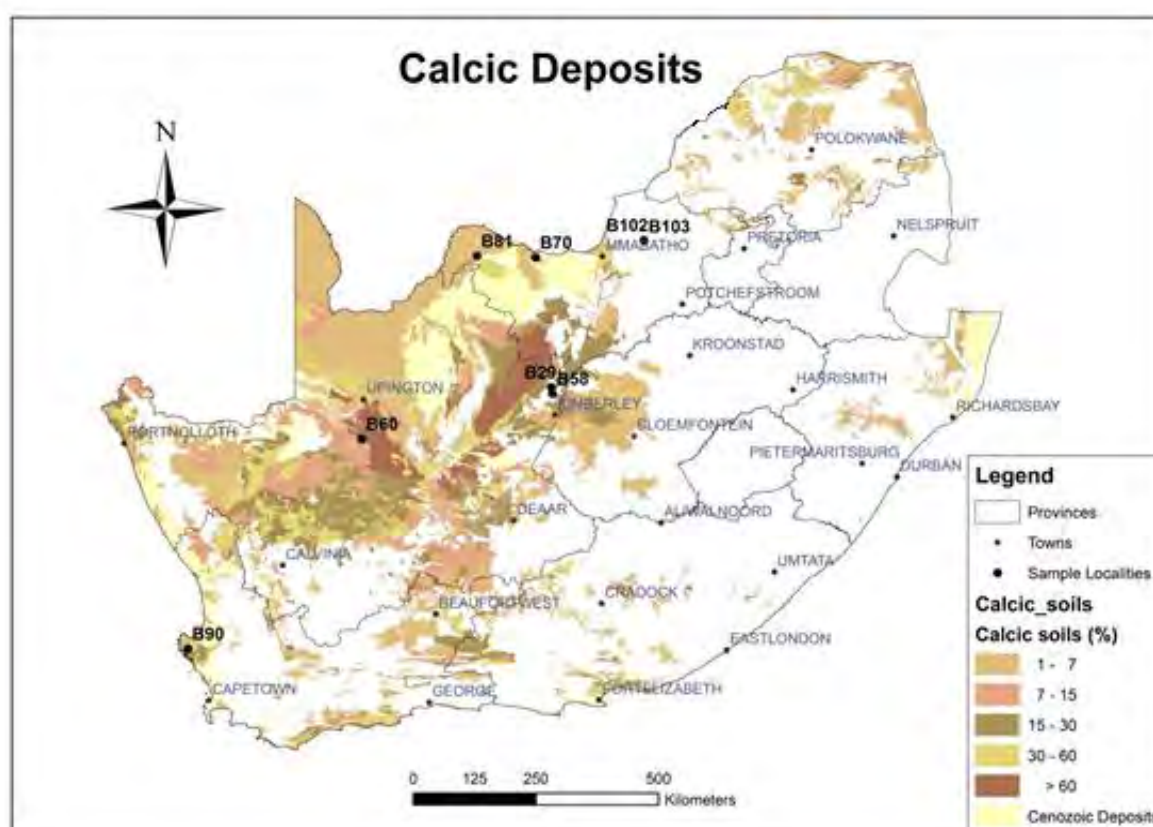


Figure 22: Calcic deposits of South Africa including calcic soils from Fey (2010) and calcrete (ArcMap, 2010).

Silcrete

Silcrete samples were mainly collected in the North-West Province as seen in Figure 23, and the localities and coordinates are indicated in Table 20. The silcrete samples are compared to the silicic soils from Fey (2010).

Table 20: Selected silcrete localities over South Africa as well as coordinates.

Type	Sample number	Locality or description	Coordinates: Latitude (S), Longitude (E) and elevation (mamsl)
Silcrete	B73	Silcrete from the Kalahari in the Vergeleë region, North West.	25° 52' 47.2794"S 24° 25' 47.9994"E 1089 mamsl
	B79	Silcrete from the Kalahari in the Vergeleë region, North West.	25° 46' 31.44"S 23° 58' 31.44"E 1081 mamsl

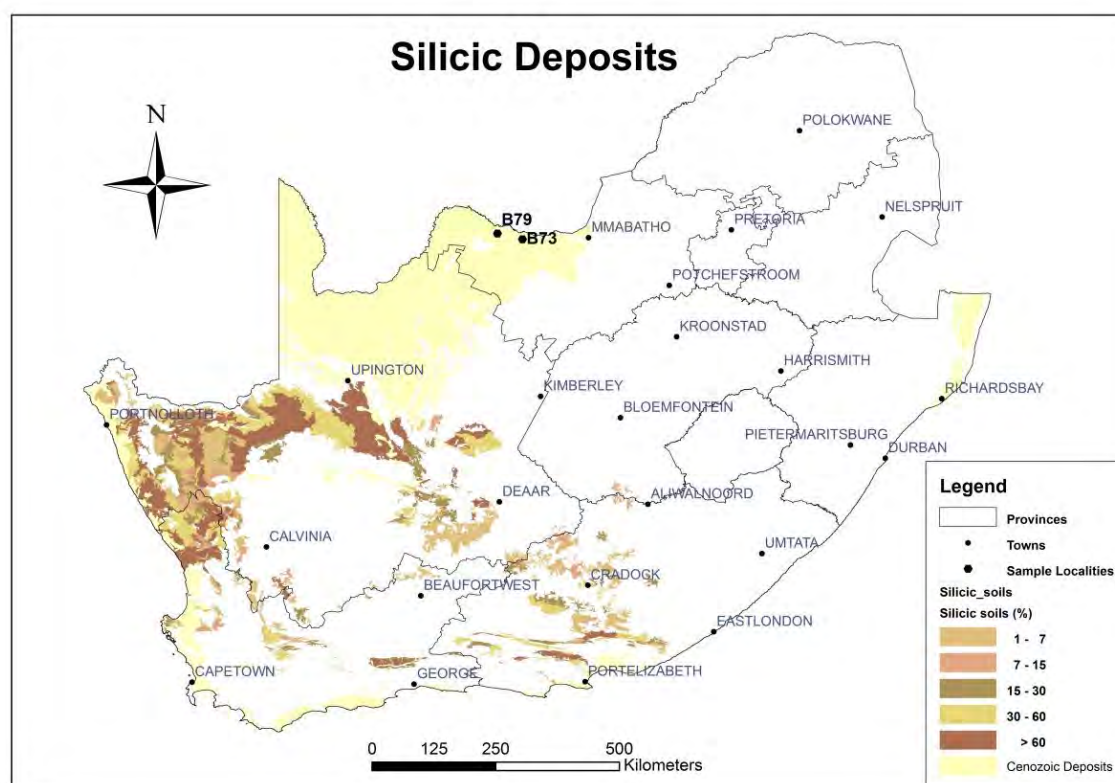


Figure 23: Silicic deposits of South Africa including silicic soils from Fey (2010) and silcrete (ArcMap, 2010).

Dorbanks

Dorbanks samples were mainly collected from the Northern Cape Province as seen in Figure 24 and the localities and coordinates are indicated in Table 21.

Table 21: Selected dorbank localities over South Africa as well as coordinates.

Type	Sample number	Locality or description	Coordinates: Latitude (S), Longitude (E) and elevation (mamsl)
Dorbanks	B43	Dorbank of the Aggeneys area, Northern Cape	29° 11' 59.9994"S 18° 51' 0"E 984 mamsl
	B56	Dorbank of the Pofadder area, Northern Cape	29° 7' 42.999"S 19° 23' 40.9992"E 988 mamsl
	BX2	Close to Verneukpan near Brandvlei, south of Kenhardt, Northern Cape.	30° 00'30.1"S 21°08'40.9"E 864 mamsl

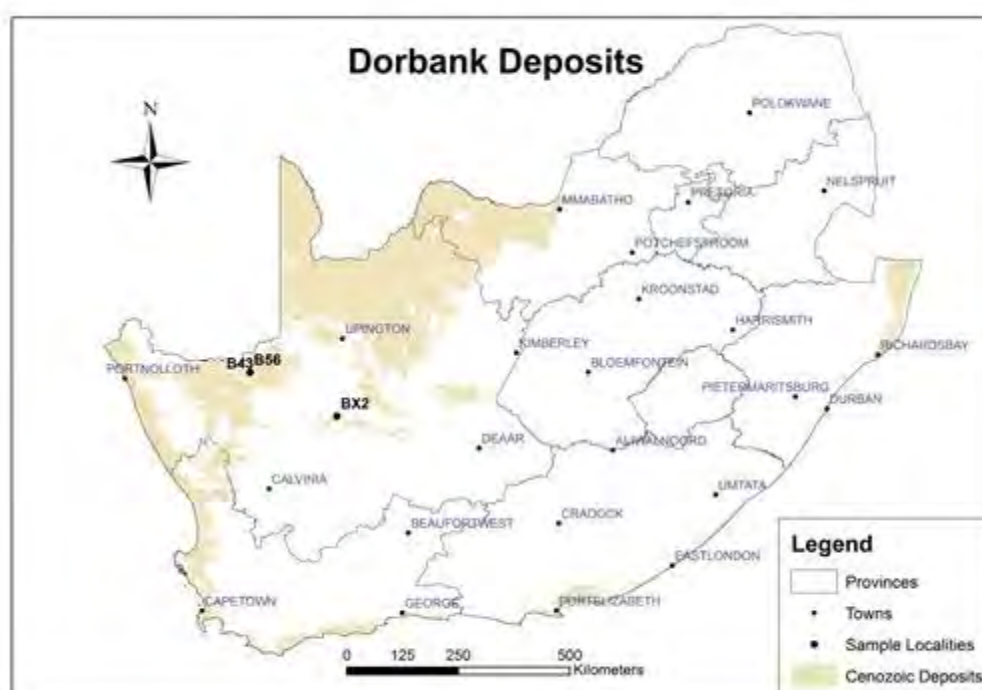


Figure 24: Selected dorbank localities in the Northern Cape Province (ArcMap, 2010).

Ferricrete

Ferricrete samples were mainly collected from the North-West and Northern Cape Province as seen in Figure 25 and the localities and coordinates are indicated in Table 22. The ferricrete sample localities were compared to the oxidic soils from Fey (2010).

Table 22: Selected ferricrete localities over South Africa as well as coordinates.

Type	Sample number	Locality or description	Coordinates: Latitude (S), Longitude (E) and elevation (mamsl)
Ferricrete	B14	Ferricrete from the Stilfontein area, North West.	26° 47' 34.7994"S 26° 54' 57.8988"E 1345 mamsl
	B75	Ferricrete from the Vergeleë area, North West.	25° 52' 48.3594"S 24° 25' 46.92"E 1093 mamsl
	BX1	Close to Verneukpan near Brandvlei, south of Kenhardt, Northern Cape.	30° 00'30.1"S 21°08'40.9"E 864 mamsl

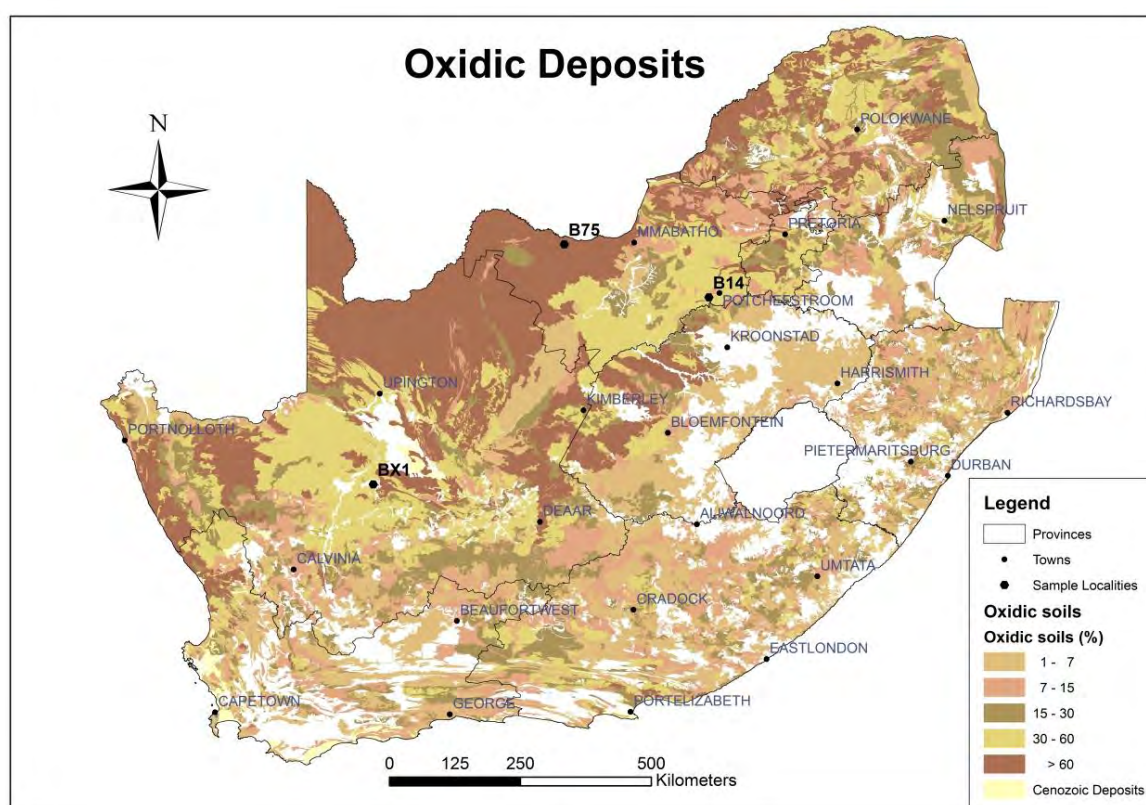


Figure 25: Oxidic deposits of South Africa including oxidic soils from Fey (2010). Ferricrete sample localities are indicated (ArcMap, 2010).

Manganocrete

Manganocrete samples were mainly collected from the North-West Province as seen in Figure 26 and the localities and coordinates are indicated in Table 23.

Table 23: Selected manganocrete localities over South Africa as well as coordinates.

Type	Sample number	Locality or description	Coordinates: Latitude (S), Longitude (E) and elevation (mamsl)
Manganocrete	B11	Manganocrete from the Stilfontein area, North West.	26° 47' 29.601"S 26° 45' 54"E 1390 mamsl
	B12	Manganocrete from the Stilfontein area, North West.	26° 48' 3.8982" S26° 46' 6.9594"E 1376 mamsl

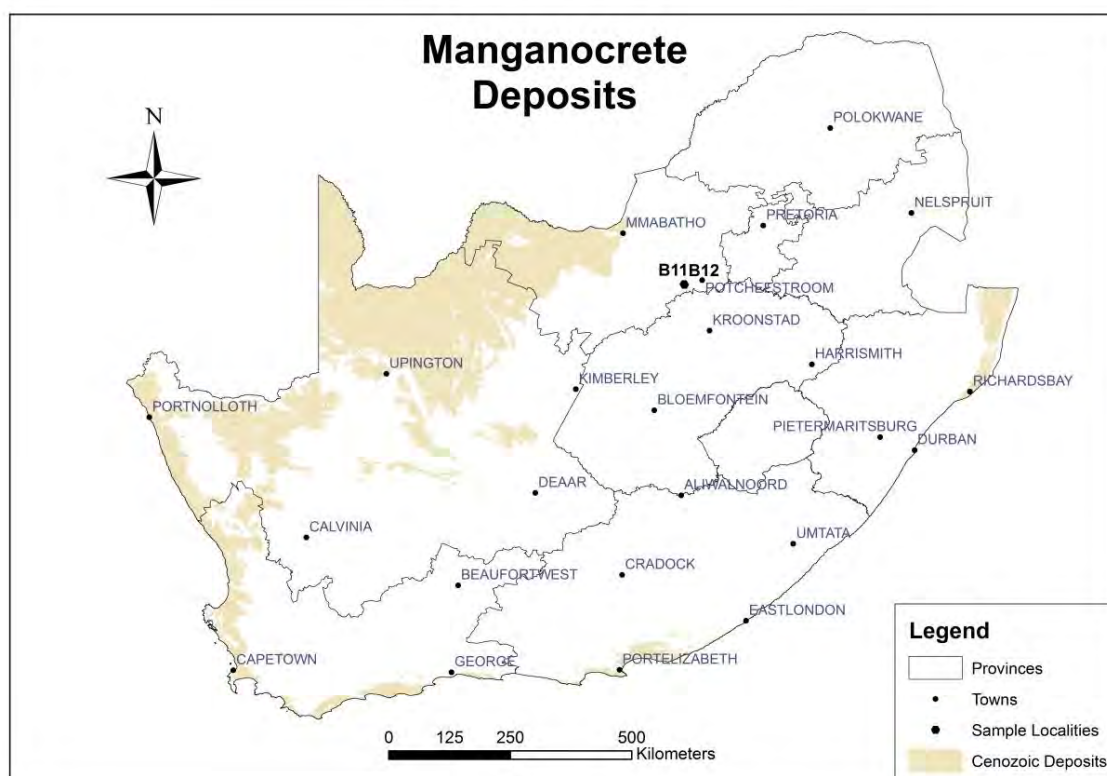


Figure 26: Selected manganocrete sample localities from the Stilfontein area, North-West (ArcMap, 2010).

Phoscrete

A phoscrete sample was collected close to Langebaan in the Western Province as seen in Figure 27 and the locality and coordinate are indicated in Table 24.

Table 24: A selected phoscrete locality close to Langebaan in the Western Cape as well as the coordinates.

Type	Sample number	Locality or description	Coordinates: Latitude (S), Longitude (E) and elevation (mamsl)
Phoscrete	B98	Phoscrete from the Langebaan area, Western Cape	32° 57' 20.4798"S 18° 6' 49.899"E 46 mamsl

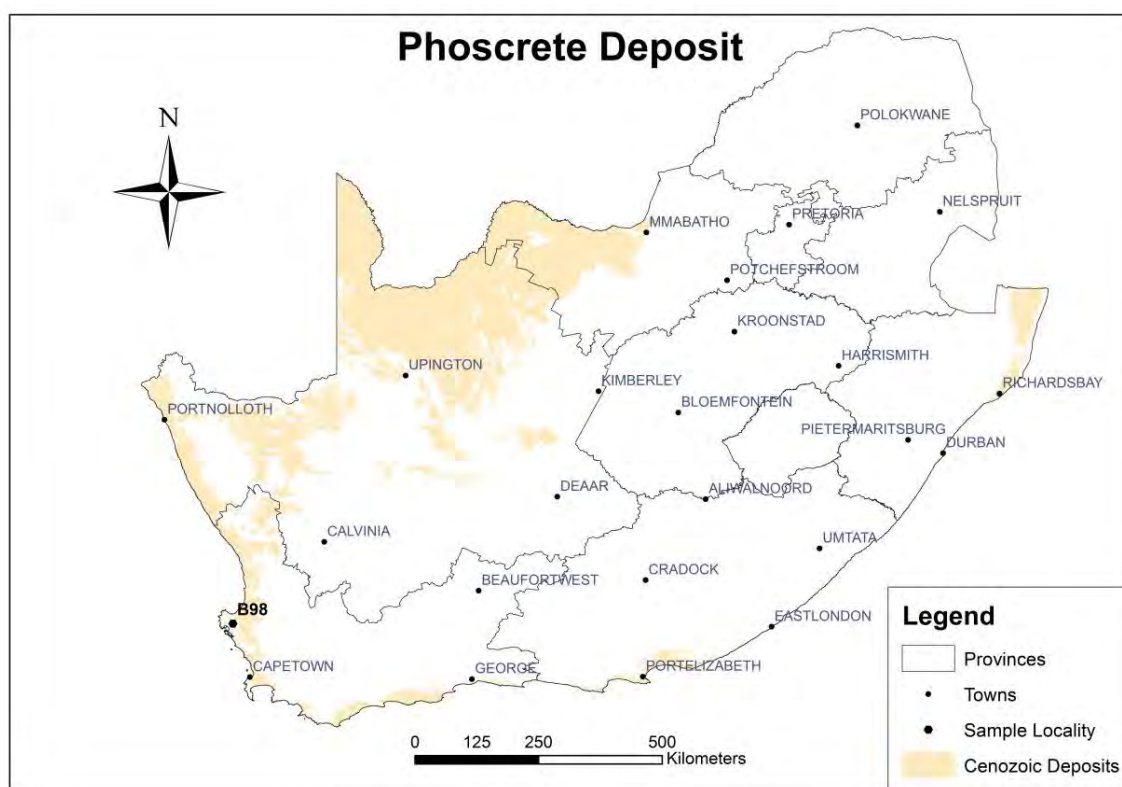


Figure 27: A phoscrete sample locality from the Langebaan area in the Western Cape (ArcMap, 2010).

Gypcrete

Gypcrete samples were mainly collected from the Western Cape Province as seen in Figure 28 and the localities and coordinates are indicated in Table 25.

Table 25: Selected gypcrete localities over South Africa as well as coordinates.

Type	Sample number	Locality or description	Coordinates: Latitude (S), Longitude (E) and elevation (mamsl)
Gypcrete	B89	Agricultural gypsum: AFMINE close to Yzerfontein, Western Cape.	33° 19' 58.7994"S 18° 9' 43.1994"E 24 mamsl
	B91A	Fine gypcrete sampled from hills beside the main road to Porterville, Western Cape.	32° 51' 24.4794"S18° 35' 45.6"E 61 mamsl
	B91B	Gypcrete pieces (peducutanic material), Gypcrete hills beside the main road to Porterville, Western Cape.	32° 51' 24.4794"S18° 35' 45.6"E 61 mamsl
	B92	Hard gypcrete, beside the main road to Porterville, Western Cape.	32° 51' 35.64"S 18° 36' 3.2394"E 51 mamsl
	B93	Hard gypcrete, beside the main road to Lutzville, Western Cape.	32° 51' 35.64"S 18° 36' 3.2394"E 151 mamsl
	B94	Soft gypcrete, beside the main road to Lutzville, Western Cape.	32° 51' 35.64"S 18° 36' 3.2394"E 151 mamsl
	B95	Gypcrete with feldspar present beside the main road to Lutzville, Western Cape.	32° 51' 35.64"S 18° 36' 3.2394"E 151 mamsl
	B96	Gypsum mine (Maskam Mine), Vanrhynsdorp, Western Cape.	31° 33' 21.96"S 18° 20' 44.16"E 136 mamsl

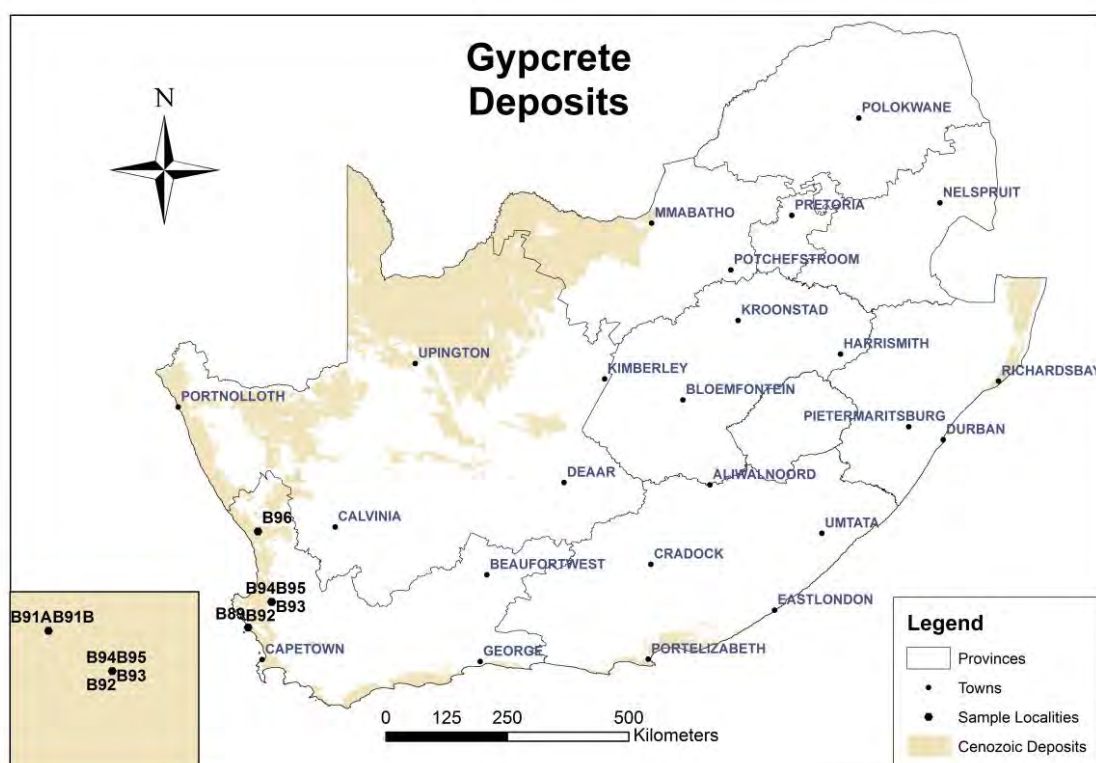


Figure 28: Selected gypcrete sample localities in the Western Cape (ArcMap, 2010).

Intergrade pedocrete

Intergrade pedocrete samples were mainly collected from the Northern Cape and North West Provinces as seen in Figure 29 and the localities and coordinates are indicated in Table 26.

Table 26: Selected intergrade pedocrete localities over South Africa as well as coordinates.

Type	Sample number	Locality or description	Coordinates: Latitude (S), Longitude (E) and elevation (mamsl)
Intergrade pedocretes			
Dorbank, Gypcrete	B3	Garies area, Northern Cape	30° 22' 8.6016" S17° 34' 33.8988"E 174 mamsl
Dorbank, Calcrete, Gypcrete	B10	Aggeneys area, Northern Cape	29° 15' 6.0984"S 18° 54' 17.6004"E 875 mamsl
Calcrete, Ferricrete, Silcrete	B74	Vergeleë area, North-West	25° 52' 48.3594"S 24° 25' 47.28"E 1090 mamsl

Table 26 (cont): Selected intergrade pedocrete localities over South Africa as well as coordinates.

Type	Sample number	Locality or description	Coordinates: Latitude (S), Longitude (E) and elevation (mamsl)
Calcrete, Ferricrete	B108	Steenbokpan area, Limpopo	23°46'29.06"S 27°23'03.86"E 966 mamsl

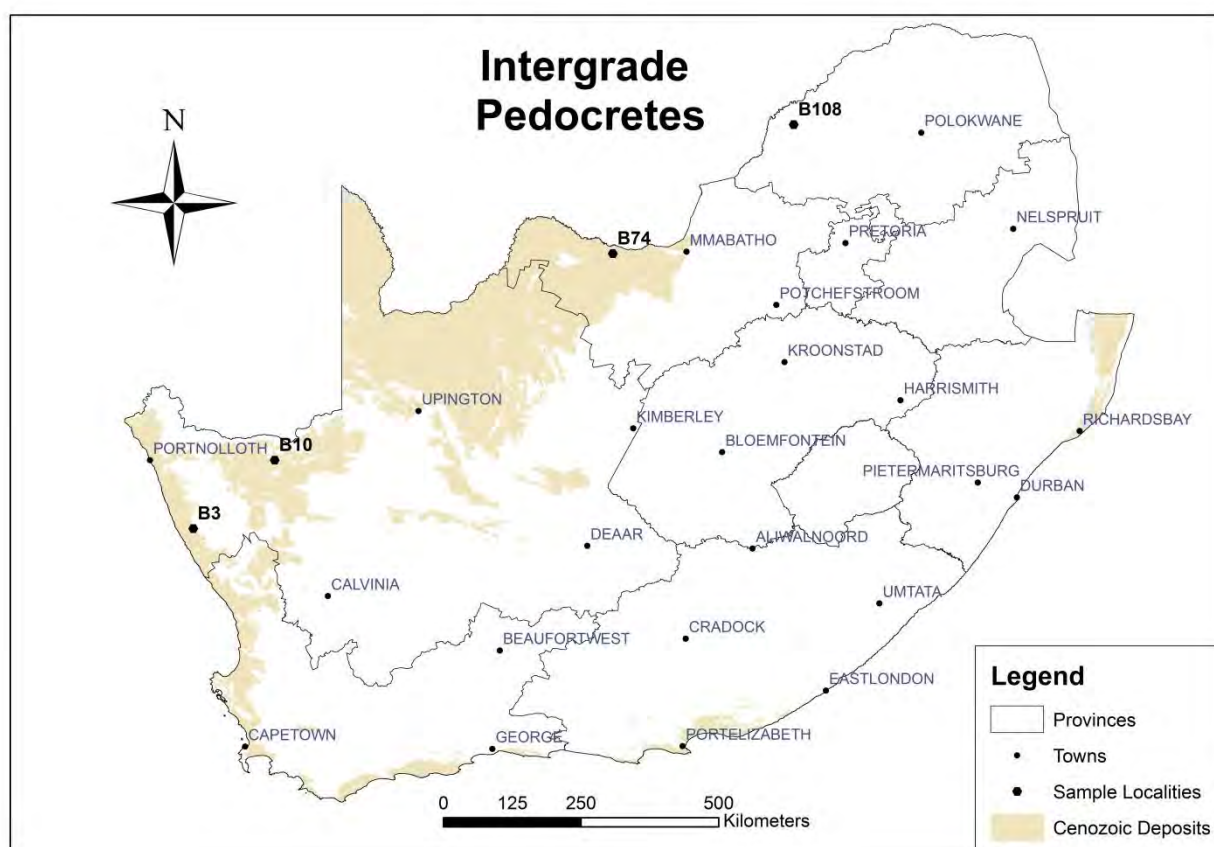


Figure 29: Selected intergrade pedocretes localities in the Northern Cape, North-West and Limpopo Province (ArcMap, 2010).

3.2 Methods

Physical, chemical, mineralogical and analytical methods were used to compile a database for the Cenozoic deposits of South Africa. The analyses were done at various laboratories at the North-West University (Potchefstroom Campus), including the NWU Soil Laboratory, the Water Retention laboratory, the XRD/XRF Laboratory as well as the Scanning Electron Microscope (SEM) laboratory. Sample analyses including particle size distribution, cation exchange capacity and ICP-MS analyses were done by Eco-Analytica Potchefstroom. This section is a summary of the sampling methods, sample preparation as well as the analytical methods used.

Sampling methods

Sampling was site specific due to the vast extent of this project. The exposed surface section of the soil/pedogenic deposit at the sample location was removed before sediments were collected to ensure minimum contamination. Duplicate samples were collected per site and were transported in enclosed containers.

Sample preparation

Samples were air dried or dried in an oven, which did not exceed 40°C, at the NWU Soil Laboratory. The samples were also kept out of direct sunlight to ensure that no compounds were released or fixated. Soils were crushed and passed through a 2mm sieve when dried completely, excluding stones. This was done according to the preparation method described by the Non-Affiliated Soil Analysis Work Committee (1990). This is the standard soil preparation which was used for all the samples collected.

3.2.1 Physical analyses:

The physical analyses included the angle of repose, atterberg limits, particle size distribution, water retention and loss-on-ignition. These analyses were conducted at the NWU Soil Laboratory as well as the NWU Water Retention Laboratory except the particle size distribution which was done by Eco-Analytica Laboratory, Potchefstroom. These analyses were done to compile a database for the physical properties of the Cenozoic deposits of South Africa.

3.2.1.1 Angle of repose (Funnel method)

The funnel method used for Angle of repose is proposed by Lui (2011) and is a standard test used by the American Society of Testing and Materials (Method No. C1444-00), (ASTM, 2001). The angle of repose can be defined as the angle at which soil grains orientate when piled relative to the underlying horizontal surface. The angle of repose is supposed to be the same as the angle of the friction between the internal grains.

A soil sample of 400 g with a maximum particle size of 2 mm is gently passed through a funnel, see Figure 30. The funnel base is set at a fix height from the surface to ensure no incorrect varying results. The conical orientation of the grains is measured with an electrical water levelling instrument in degree relative to the horizontal surface and referred to as the angle of repose.

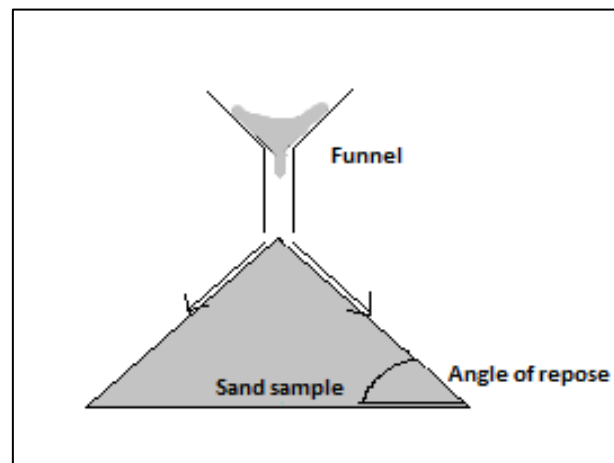


Figure 30: The angle of repose illustrated by indicating the cone-like structure of a sand sample transferred through a funnel.

3.2.1.2 Atterberg limits

The Atterberg Limits estimated the water content of a material to determine aspects such as shrink and swell potential thus the degree of movement in materials. This is characterised by the plasticity of the material. Atterberg limits are mainly used to estimate the plastic limit (PL) and the liquid limit (LL) in materials. The lowest amount of water required to make a soil plastic is referred to as the PL (Bowles, 1986 and Fey, 2010). The amount of water required to make a soil act as a liquid, but still have some shearing strengths, is referred as the LL (Fey, 2010). The Atterberg Limits are dominantly used by geotechnical engineers. The PL can indicate the probability of clay or silt to compress as well as the water holding capacity and cohesiveness of

the material. The LL can be used in the estimation of maximum density of compacted material as well as establishing the settlement in consolidated material (Fanourakis, 1991).

The fall cone penetrometer test was used to determine the LL as seen in Figure 31. The British Standards (1377:1975) soil method was altered because the automatic penetrometer (STYS-4 Digital Liquid Limit device) was used. Soils with varying saturation percentages were penetrated with the penetrometer to determine the depth at which the cone penetrated each soil. Then the water content (w%) was determined by oven drying the sample with a known initial and final mass. The relationship of the w% and the depth were plotted on a graph. The w% which is the LL was used at a depth of 15.7 mm. The standard calculation used was as follows:

$$\text{Penetration (mm)} = \sqrt{\text{mass} \times 5} \quad (\text{Schmidhuber, 2015}).$$

The PL was determined by using the NS 8003-1982 method. The saturated sample was hand rolled on a glass plate till a diameter of 3 mm was reached. The wet sample was oven dried at 60° C for two days. The water content (w%) of the sample was determined by determining the weight loss before and after drying. The determined water content is the PL (Tefera, 2013).

The PI (Plasticity Index) was determined as follows (Fanourakis, 1991):

$$PI = LL - PL \quad \text{Eq. 1}$$



Figure 31: The laboratory equipment to determine plasticity index (Photograph taken by Schmidhuber, 2015, with permission).

The plasticity index from Burmister (1949) was used as reference to determine whether a material had a high or low plasticity, see Table 27.

Table 27: The plasticity index (PI) from Burmister (1949)

PI	Description
0	Non-plastic
1-5	Slightly plastic
5-10	Low plasticity
10-20	Medium plasticity
20-40	High plasticity
>40	Very high plasticity

3.2.1.3 Particle size distribution

The particle size distribution indicates the proportion of varying particle sizes in a soil sample or profile.

Particle sizes larger than 2 mm in diameter is estimated using a 2 mm sieve to determine the percentage samples passing through the 2 mm sieve and the redundant sample being larger than 2 mm. The sediments larger than 2 mm, being pebbles, cobbles or boulders are estimated by measuring a few selected sediments and classifying each. A sample, smaller than 2 mm, is analysed using the sieve as well as pipette method. Seven classes are characterized: coarse sand (2 - 0,5 mm), medium sand (0,5 – 0,25 mm), fine sand (0,25 – 0,106 mm), very fine sand (0.106 – 0,05 mm), coarse silt (0,05 – 0,02 mm), fine silt (0,02 – 0,002 mm) and clay (<0,002 mm). The silt (coarse and fine) and the clay are estimated using the sedimentation or pipette method, (Non-Affiliated Soil Analysis Work Committee, 1990).

3.2.1.4 Water retention

The water retention method is mainly used to determine the water holding capacity of soils to indicate the potential for plant available water. The Model 1600 Pressure Plate Extractor manufactured by Soilmoisture Equipment Corptm is used. The elements of the Pressure Plate Extractor consists of a pressure vessel and lid, clamping bolts, O-ring seals and water releasing plastic tubes (outflow tubes). Water is removed from the soil by applying pressure in the concealed Extractor. This results in a constant pressure difference to be established between the water in the soil, higher pressure, and the water in the porous ceramic plate on which the samples are situated, lower pressure. The positive pressure applied by the air compressor results in a soil water distribution through the porous ceramic plate. This water is forced through the plate due to the pressure in the vessel being higher than the atmospheric pressure until

equilibrium is reached. A set of standard suctions are used respectively e.g. 10, 30, 500, 1000 and 1500 kPa.

Six different samples are placed in custom made PVC (Polyvinyl Chloride) rings on a ceramic plate and overall three repetitions are done per sample. By testing different samples at a time the risk of errors per samples can be avoided. The Extractor can accommodate three ceramic plates at a time allowing 18 samples to be done simultaneously. The samples are transferred to PVC rings on the ceramic plate and left for 3 hours to saturate completely by adding excess water on the plate. The custom made rings have a height of 1 cm. This results in the equilibrium time to be decreased. The original rings being 2 cm in height increased the Period that it took for equilibrium to be reached with four times. Thus the custom made rings are used.

Starting at the lowest pressure value the goal is to reach equilibrium. This is the point at which no water is discharged through the ceramic plate and the outflow tubes anymore, thus an equal force between the pressure in the vessel and the soil matrix potential is reached. The same concept is applied to all the above mentioned suction pressures.

The suction plate extractor is placed on the triangular foot piece on the bottom of the vessel with further plates proceeding to the top and separated by plastic spacers. The outflow tubes are connected and the unused outlets are closed with plugs. The O-ring seals are placed in position, the vessel is closed and clamps on the top are secured. Pressure is applied by switching on the compressor and controlling it by means of a valve and pressure gauge. Set the pressure to the desired value till equilibrium is reached which may take up to 24 hours.

The 1 bar flow suction plate extractor is used when measuring samples at pressures of 100 kPa and less. For pressures between 100 kPa and 1500 kPa the 15 bar suction plate extractor is used.

The weight of water loss is calculated for each pressure indicating the water holding capacity for each sample.

3.2.1.5 Loss-on-ignition (Total organic carbon)

The Loss-on ignition (LOI) method (Donkin, 1991) determines the soil organic carbon and is used to evaluate the nutrient status of soil. This method is simple, quick and accurate.

Samples are air dried and sieved through a 2 mm screen. Each sample consists of 15 g of soil and three repetitions are done per sample. The samples are dried in an oven for two hours at 60°C and then placed directly into the high intensity oven in a muffle furnace at 450°C for 6

hours. The weight loss is measured in grams after ignition and a correction factor is applied (Donkin, 1991). The muffle furnaces used for ignition is seen in Figure 32.

$$\text{OC} = 0.284 \cdot \text{LOI}\% \text{ at } 450^\circ\text{C for 6 hours} \quad \text{Eq. 2}$$

The temperature of 450°C for 6 hours are used as it is the optimum temperature at which organic carbon is ignited, at higher temperature the mineral clay structural water is also released and thus contributes to the carbon value in the sample (Donkin, 1991).



Figure 32: Cups used for ignition of organic carbon in the high intensity oven.

The soil organic matter comprises of the total amount of organic components such as decomposed humus and living organisms, whereas the organic carbon is the index to soil organic matter (Du Preez *et al.*, 2011) or the soil organic carbon is also defined by Stockmann *et al.*, (2013: 81) as the carbon component originated from organic material.

3.2.2 Geochemical analyses:

3.2.2.1 pH – H₂O

The pH is the negative logarithm to the base 10 of the activity of the H⁺ ions. The pH will be lowered when the adsorbed H⁺ ions are displaced by soluble cations that have a higher affinity for adsorption (Non-Affiliated Soil Analysis Work Committee, 1990).

The method is applied on a mass basis which involves a 1 :2,5 soil/water ratio suspensions. The pH meter is calibrated with the standard buffer solution. The pH meter was calibrated every hour to ensure accuracy. The standard buffer solution is commercially available as pH = 4, 7 and 8. A sample of 10 g (≤ 2 mm) dried soil is placed in a glass beaker to which 25 cm³ de-ionised water is added. A glass rod is used to stir the contents for 5 seconds and then stirred after a 50

minute resting Period. Then after 10 minutes rest the samples is tested with the calibrated pH meter (Non-Affiliated Soil Analysis Work Committee, 1990:3).

3.2.2.2 pH – KCl

In the method, 1 mol dm⁻³ KCl is used to make a soil suspension where the activity of the hydrogen ions can be measured. The KCl decreases the potential variation in salt concentration from various sources such as irrigation water and fertilizers. The standard buffer solution was used to calibrate the pH meter. A sample of 10 g (≤ 2 mm) dried soil is placed in a glass beaker to which 25 cm³ KCl solution (1 mol dm⁻³) is added. The KCl solution is made by adding 74.5 g KCl to 1 dm³ de-ionised water. A glass rod is used to stir the contents for 5 seconds and then stirred after a 50 minute resting Period has passed. Then after 10 minutes rest the samples is tested with the calibrated pH meter (Non-Affiliated Soil Analysis Work Committee, 1990)

3.2.2.3 Electrical conductivity (EC) in saturated paste

The electrical conductivity (EC) in a saturated paste indicates the soluble salts in the soil by determining the total dissolved salts in the extract. The salt hazard of brackish soils can be determined by using the EC values of the soil.

The electrical conductivity (EC) was expressed in MilliSiemens per meter (mS/m) (Non-Affiliated Soil Analysis Work Committee, 1990).

3.2.2.4. Cation exchange capacity (CEC) and exchangeable cations

The nutrient status of a soil is determined by the cation exchange capacity and exchangeable cations. The extractions of exchangeable as well as water soluble cations are done by using ammonium acetate solution (1 mol dm⁻³). For soils containing high concentrations of water soluble cations the analyses is done separately.

After saturation of the exchange complex the adsorbed cation can be displaced by a salt solution such as potassium chloride. The CEC of the soil is equal to the ammonia which is separated by steam distillation (Non-Affiliated Soil Analysis Work Committee, 1990).

3.2.2.5 X-ray Fluorescence

The XRF analyses were done by Ms. Belinda Venter at the XRF/XRD Laboratory, North-West University. X-ray fluorescence is a non-destructive method used to determine the concentration of different elements in a sample. It is also referred to as Wavelength-dispersive X-Ray Fluorescence (WDXRF). The samples are transferred to aluminium cups and compressed to a thickness of 6 mm using a Lenton power press, weighing 25 tons. The samples are then

irradiated with a Rh X-ray tube. The PANalytical Axios XRF instrument is used to determine the elements in the sample. The Super Q database with calibrated OMNIAN standards are used to compile a database of the major elements in weight percentage values and lighter trace elements in parts per million.

3.2.2.6 Portable X-ray Fluorescence (PXRF)

The Delta Handheld X-Ray fluorescence analyser was used for element analyses ranging from Mg to U. The Geochem mode was selected for analyses to comply with the samples. The calibration check coupon was used as a reference sample and provided the testing standard by calibrating the instrument to a spectrum with a known standard (Alloy 316 Stainless Steel). Samples were crushed to pass through a 2mm sieve and transferred to small plastic containers. The analyser was placed on the even surface of the prepared sample and analysed. InnovX data software and Windows Embedded CE operation system was used to process the data. Results were expressed in parts per million (ppm), (Innov-X System manual, 2010)

Method for converting ppm to oxide % for pedocretes (See Chapter 4)

The 4 highest element concentrations in parts per million were used for each sample respectively. The samples were converted to weight percentage (wt%) as indicated in Equation 3:

E.g. B29:

Eq. 3

$$\text{wt}\% = \frac{195950}{1000000} \times 100$$

$$= 19.5\%$$

The weight percent for all four elements were calculated and converted to oxides (e.g. CaO) using Microsoft Excel (2010) and conversion factors from Geologynet (www.geologynet.com/programs/convert.xls) as seen in Table 28.

These values were normalised to 100% by using the equation below to determine the total oxide percentage relative to 100%: Eq. 4

$$\text{Wt\%} * \text{conversion factor} = \% \text{oxide}$$

$$19.5\% * 0.715 = 14\% \text{ CaO}$$

$$\frac{\% \text{oxide}}{\text{Total oxides \%}} \times 100$$

$$\frac{14}{22.59} * 100 = 62\% \text{ CaO}$$

Table 28: The conversion of elements to oxides

Highest elements	Calcrete sample (B29): wt%	Conversion factor	Oxide %	Normalise calculations	Oxide % normalised
Ca	19.59%	0.71470	19.56% x 0.71470 = 14%	$\frac{14}{22.59} \times 100$	62.69% CaO
Si	12.87%	0.46744	12.87% x 0.46744 = 6.008%	$\frac{6.008}{22.59} \times 100$	26.89 SiO ₂
Al	2.06%	0.52925	2.06% x 0.52925 = 1.08%	$\frac{1.08}{22.59} \times 100$	4.85% Al ₂ O ₃
Fe	1.8%	0.6994	1.8% x 0.6994 = 1.242%	$\frac{1.242}{22.59} \times 100$	5.55 Fe ₂ O ₃
			Total: 22.34%		Total: 100%

3.2.2.7 Inductively coupled plasma mass spectrometry (ICP-MS)

The samples were analysed using the International standard method (EPA3050b), (Wolf, 2005). In the method acid digestion is used to prepare sediments, sludge and soils for analyses using inductively coupled plasma mass spectrometry (ICP-MS). The ICP-MS method is used to determine chemical concentrations by combining a high-temperature source (ICP) and a mass spectrometer (Wolf, 2005). The ICP-MS results are expressed in parts per million and converted to oxide percentages were applicable, see section 3.2.2.6 for calculations.

3.2.2.8 Dehydrogenase activity

The dehydrogenase activity is an indication of the microbial activity in a soil. The method used is precise and quick and uses a 100 µg iodonitrotetrazolium chloride (INT)-formazan ml⁻¹ assay mixture and 2(*p*-iodophenyl)-3-(*p*-nitrophenyl)-5-phenyl, tetrazolium chloride (iodonitrotetrazolium chloride, INT) as the substrate. Iodonitrotetrazolium formazan (INTF) was reduced and after extraction with N,N-dimethylformamide and ethanol it was measured with a spectrophotometer. A TRIS buffer (1 M) at 40°C and pH 7 was used to achieve optimal INT reduction rate. The intercellular enzyme correlates well with the microbial biomass in this method (Von Mersi and Schinner, 1991).

3.2.2.9 Total S%, N% and P%

The TruSpec Ad-On Module is used to determine the total sulphur in a sample and is independent from the nitrogen, carbon and hydrogen determinations. The analyser measures the concentration of sulphur dioxide gas after different stages in a heat and oxygen combustion system. The values are expressed as percentage or as parts per million or grams (TruSpec, 2004)

The TruSpec CN instrument is used to determine the carbon and nitrogen in a sample. The samples are analysed through three phases; purging, combustion and analyse phase. The data is processed in Windows software and the results are expressed in percentage or parts per million (LECO, 2006).

3.2.3 Mineralogical analyses

3.2.3.1 Stereomicroscopic identification of matrix, particles and inclusions

The Nova Stereomicroscope with trinocular head is used for various identification purposes. This includes matrix-, particle roundness and orientation- and inclusion identification. Selected samples, mostly sand fraction, are investigated and photographs are taken to indicate variations between samples, mostly from different localities or different climatic regions.

3.2.3.2 Scanning Electron Microscope (SEM)

Scanning Electron Microscope analyses were done by the Dr. Anine Jordaan and Dr. Lourens Tiedt at the SEM Laboratory at the North-West University. Selective samples were analysed. A layer of sediment grains were stuck to a doubled sided carbon strip on an aluminium pin. The samples were sputter coated with gold-palladium and viewed at 10 kV with a FEI Quanta 250 FEG (Bruno, Czech Republic) Scanning Electron Microscope (SEM) with integrated software. Qualitative energy-dispersive microanalysis (EDS XRF) is performed at 15kV with the same instrument by using an Oxford X-max 20 SDD detector and INCA software. This allows the focus to be on the surface features of the grains such as roundness, orientation as well as determining the matrix material.

3.2.3.3 X-ray Diffraction (XRD)

The XRD analysis was done by the certified Biograde Laboratories in Pretoria.

X-Ray diffraction is a non-destructive technique used to identify and quantifies different crystalline phases in a sample. The samples were crushed, spilt and milled using a tungsten carbide ring mill at the North-West University Soil Laboratories. The sample was prepared for XRD analyses using the back loading preparation method by the Biograde Laboratory. The material was analysed with a PANalytical Empyrean diffractometer with PIXcel detector. As a result of different crystalline structures detected in a sample, unique diffractograms were generated indicating the different phases of the structures present. The X'Pert Highscore plus software were used to identify the different phases. The Rietveld method was used to determine the relative phase amounts in weight % and the mathematical errors were indicated next to the amount in weight percentage.

CHAPTER 4 - RESULTS AND DISCUSSIONS

Site specific deposits: The economic, agricultural and geotechnical characteristics of the Cenozoic deposits

In this chapter, specific sites will be discussed including site descriptions, lithological stratigraphy, sediment characteristics and the economic and tourism potential, agricultural potential and geotechnical implications regarding the selected Cenozoic deposits.

All samples were specifically selected per locality and representative samples were collected which results in this project being more a compilation study than a statistical study.

Cenozoic deposits are mainly divided into palaeosols, clastic sediments and pedogenic deposits. The palaeosol sites at Florisbad and Cornelia, which are also fossil bearing sites that can aid the tourism industry, are discussed relative to the palaeoenvironmental significance. The clastic sediments comprise of cave sediment, which has high palaeoenvironmental significance, gravel deposits which are also linked to palaeoenvironmental changes as well as being diamond bearing and contributes to the economic potential. The terrestrial sand deposits, including Kalahari and redistributed coastal sand, are discussed and the drainage depressions are also included as clastic sedimentary deposits. The pedogenic deposits include calcrete, silcrete and dorbanks, ferricrete and manganocrete, phoscrete, gypcrete and intergrade pedocretes. These deposits are used for construction and road construction materials.

4.1 Economic potential of the Cenozoic deposits

The economic potential of the selected Cenozoic deposits are summarised as seen in Table 29. This included clastic sedimentary deposits such as sand deposits, clay deposits, gravel deposits and cave sediments. Pedogenic deposits were also included such as ferricretes, phoscrete, calcrete, silcrete and gypcrete. The economic uses varied from fertilizers to road construction materials.

Table 29: Economic potential of Cenozoic deposits (table modified from Van Deventer, 2009)

Deposit	Economic use
Ferricrete	Road construction material (Weinert, 1980).
Phoscrete	Phosphate fertilizer (Van Straaten, 2002; Visser, 1989).
Calcrete and/or calcic soils	Diamonds in calcrete conglomerates (Marshall and Norton, 2012), road building material (Fey, 2010; Haddon, 2005; Netterberg and Caiger, 1983), agriculture limestone (MVSA, 2007; Van Straaten, 2002:25), diatomaceous earth (Visser, 1989), building material (Figure 33).  Figure 33: House built of calcrete in the North-West Province close to Tosca.
Silcrete	Road construction material (Weinert, 1980).
Sands	Road building material / construction (Ngcofe and Cole, 2014).
Coastal sand	Ilmenite mineral, mainly occurs in coastal sand, and is mined close to Richards Bay in KwaZulu-Natal (Visser, 1989).
Salt pans	Sodium and soda (Visser, 1989).
Clay deposits	Various clays are used in industries such as ceramics, paper, rubber, plastic, oil, paint and pesticides (Schmidt, 1976). Palygorskite-rich clay deposits and smectite are two examples of such clays (Partridge <i>et al.</i> , 2006). Palygorshite (attapulgate) has high adsorption and absorption potential and is used as a catalyst, for dewatering and decolouring, parting agent, bonding and thickening agent (Schmidt, 1976; Galan, 1996).

Table 29 (cont): Economic potential of Cenozoic deposits (table modified from Van Deventer, 2009).

Deposit	Economic use
Gravel deposits (Vaal, Gariep, Olifants, Karoo, Kalahari) (Schweizer Reneke, Windsorton)	Diamonds (Wilson <i>et al.</i> , 2007; (Visser, 1989).
Gypcrete and/or gypsum	Building and agricultural use (Fey, 2010; Van Straaten, 2002). Gypsum mines are located close to Vanrhynsdorp and Yzerfontein in the Western Cape (Visser, 1989). Gypsum is also used in ceiling boards and plaster (Ngcofe and Cole, 2014).
Cave deposits	Bat guano (rich in phosphate and nitrate) can be used for agricultural fertilizer (Gnaspini, 2012).

4.2 The Cenozoic deposits supporting the tourism industry

The Cenozoic deposits comprise of various sites supporting the tourism industry such as seen in Table 30. This includes fossil bearing sites such as Florisbad as well as different caves, which can be visited by the public.

Table 30: The Cenozoic deposits or sites supporting the tourism industry.

Deposit/Site	Tourism Industry
Florisbad Spring sequence	Archaeological significance, fossils include the Florisbad skull and various animal fossils. The National Museum, at Bloemfontein exhibits the fossils.
Langebaanweg Fossil Site	Archaeological and tourism significance. West Coast Fossil Park can be visited close to Langebaan in the Western Cape.

Table 30 (cont): The Cenozoic deposits or sites supporting the tourism industry.

Deposit/Site	Tourism Industry
Caves:	Caves pertains archaeological significance as well as aids the tourism industry. Various caves can be visited e.g. Sterkfontein Caves about 40 km northwest of Johannesburg and the Cango Cave, near Oudtshoorn, with abundant speleothems (Martini, 2006) and is easily accessible which increases the potential for a good tourist attraction, to name two.
Witsand Nature Reserve	Witsand Nature Reserve in the Northern Cape is mainly visited for the roaring dunes also referred to as „Brulsand“ of the Kalahari.

4.3 Palaeosols

The fossil record contained in palaeosol sites such as Florisbad and Cornelia, can be used to evaluate the climatic conditions of the different habitats in which the species existed and in turn can be used to estimate the chronology and stratigraphy of the deposits in which they occurred. This is complicated due to the vast extent of the sediments as well as the interrupted fossil record.

4.3.1 Florisbad

The stratigraphy of test pit 3 as conducted by Coetzee and Brink (2003) is used as reference for the stratigraphical information in this research project. The element compositions of the palaeohorizons are indicated in Figure 34 and Table 31. The palaeoenvironmental conditions are discussed as well as the geochemical analytical results on the different horizons, as seen in Table 32.

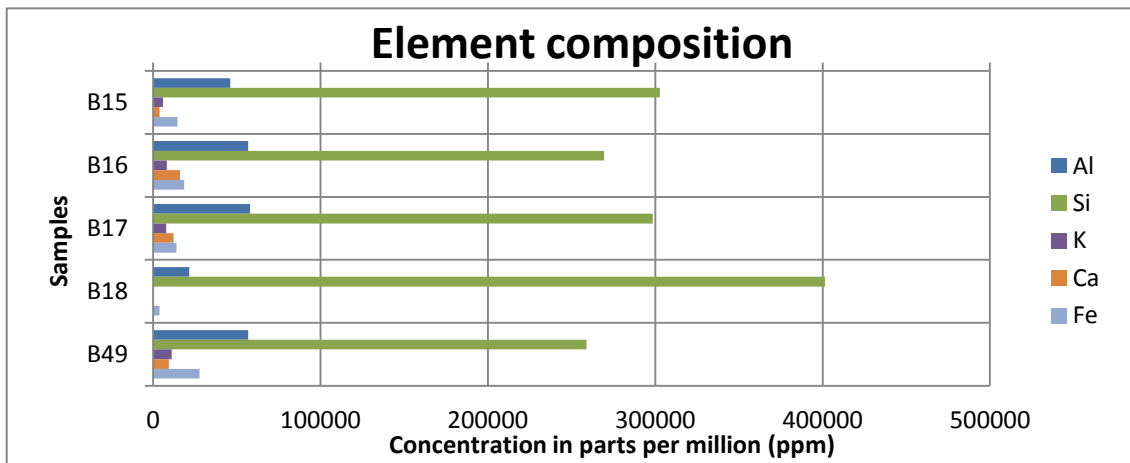


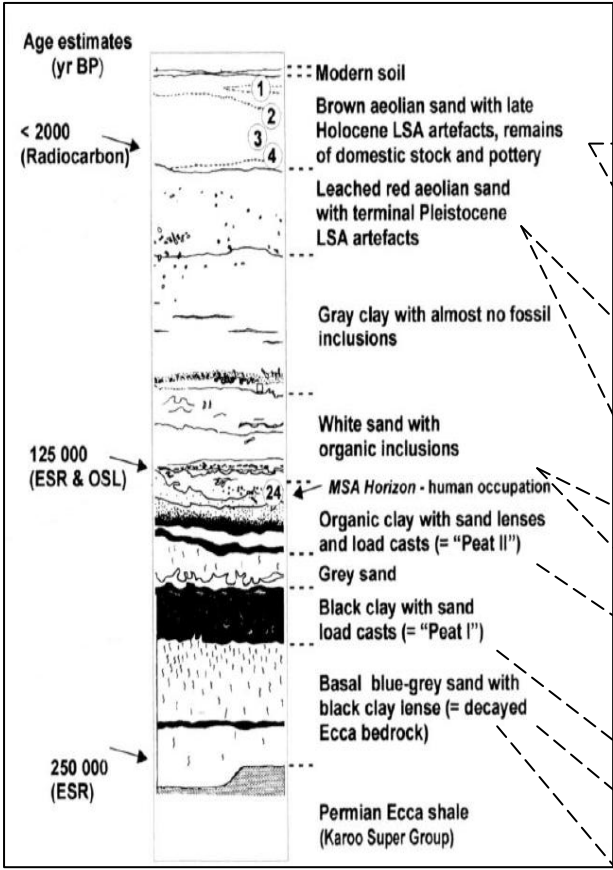
Figure 34: The XRF analyses for the palaeohorizons of the Florisbad palaeosol profile.

Table 31: The XRF analyses indicating the numerical values in parts per million (ppm) of the Florisbad palaeosol horizons.

Sample number	ppm				
	Al	Si	K	Ca	Fe
B15	46113.56	302754.3	5850.51	3736.84	14422.39
B16	56768.81	269384.7	8180.94	16037.13	18420.22
B17	57928.91	298501.9	7739.29	12175.87	13977.61
B18	21602.87	401500.8	0	0	3782.1
B49 (Control reference)	56704.98	258864.8	11110.21	9262.58	27744.22

Test pit 3 was mainly excavated for dating purposes and is representative of the sedimentary horizons at the Florisbad site (Coetzee and Brink, 2003). Coetzee and Brink (2003) also used the optically stimulated luminescence (OSL) and electron spin resonance (ESR) age results from Grün *et al.*, (1996). The dashed lines between Figure 35 and 36 indicate stratigraphic correlation between the profiles. The top horizon (B15) correlated with the „Brown aeolian sand and late Holocene LSA artefacts, remains of domestic stock and pottery“, B16 correlated well with „Leached red aeolian sand with terminal Pleistocene LSA artefacts“, B17 correlates with the „White sand with organic inclusions, B18 includes the „Peat II and Peat I“ and correlates to the „Basal blue-grey sand with black clay lenses“. The stratigraphic profile by Coetzee and Brink (2003:248) indicates more stratigraphic horizons than the five horizons selected in this research project.

Table 32: The Florisbad stratigraphy of test pit 3 with additional field observations, horizon compositions and characteristics.

	Stratigraphy	Profile depth (cm)	Sample	Field observations: Palaeo environments	Horizon composition and characteristics
Figure 35: A stratigraphic column of the third test pit at Florisbad Archaeological site in the Free State province (Coetzee and Brink, 2003, used with permission). (Vertical profile not to scale).	 Figure 36: The Florisbad observed stratigraphy in this research project.	32	B15	Redistributed aeolian sand. Stratification of 15-30 cm thick indicating wind activity.	pH: 8.9 (H ₂ O), 7.3 (KCl) EC: 116 mS/m Texture class: Fine sand
		130	B16	Iron and carbonate concretions present. Carbonate nodules indicates arid conditions and iron concretions indicates fluctuating water conditions. Palaeo root channels.	pH: 9.2 (H ₂ O), 8.1 (KCl) EC: 1701 mS/m Texture class: Fine sand
		175		Carbonated palaeo G horizon. Carbonate consolidation (arid conditions).	Not analysed (insufficient sample)
		220	B17	Greenish brown soil horizon (lacustrine environment)	pH: 7 (H ₂ O, 7.0, 7.7 (KCl)) EC: 4180 mS/m Texture class: Fine sand
		330	B18	Albic E-soil horizon. Most of the oxides are leached out of the horizon (see Figure 34 for XRF results).	pH: 7.6 (H ₂ O, 8.2 (KCl)) EC: 1069 mS/m Texture class: Fine sand
			B49	Recent surface horizon	pH: 8.1 (H ₂ O), 7.7 (KCl) EC: 116 mS/m Texture class: Sandy Loam

The base of the profile consist of Permian Ecca Shale from the Karoo Supergroup followed by grey sand, or referred in the research project as an leached albic E-horizon (B18). A leached E-horizon indicates Periods of water saturated or reduced conditions. The flow of water through the horizon consequently removes the organic material as well as the iron oxides, resulting in the bleached appearance (The Soil Classification Working Group, 1991). This is reflected in the high relative accumulated Si (XRF value) of 401500.8 ppm in the horizon. This indicates that the elements such as Fe, K and Ca were leached out and the Si concentrated. Relative accumulation refers to the concentration of an element due to the leaching of others.

The palaeoenvironmental conditions described by Coetzee and Brink (2003) using various references such as Scott and Nyakale, (2002), Brink (1987) and Van Zinderen-Bakker (1995) indicates that the Peat II horizon (B17) was an indication of a palaeo-lake which resulted in total saturation of the spring (Brink, 1987; Visser and Joubert, 1991; Albrecht and Brink, 2011). The lake system existed from the MSA interglacial Period to the Holocene. The high absolute accumulation of Al value of 57928.91 ppm can be ascribed to the addition of elements to the lake system as well as neomineralization.

The following Middle Stone Age (MSA) horizon indicated human inhabitancy, which may indicate that the site was rich in natural resources. Proceeding to the upper part of the profile, which transforms to more sandy horizons (B16) it can be deduced that the lake system reduced. It is stated that the warmer and wetter conditions during the mid-Holocene Period (6300 ka) would have contributed to the increase in grass cover which was reflected in the increase in pollen (Scott and Nyakale, 2002). The organic lenses in the top Holocene deposits are due to the decay of spring vegetation. This is reflected in the higher organic carbon results of B15, B16 and B17 as seen in Figure 37. The B16 horizon had iron concretions present as seen in the high Fe value of 18420.22 ppm. This indicates that water fluctuating conditions were present. The calcium concretions as seen in the high Ca value of 16037.13 ppm indicated that arid Period were also present, as shown in Figure 34 and Table 31. This indicates fluctuating environmental conditions during the Holocene Period. See Chapter 2.4.1 and Chapter 2.4.3 for calcrete and ferricrete, respectively, which indicates similar climatic conditions, which results in the formation of calcrete as well as ferricrete.

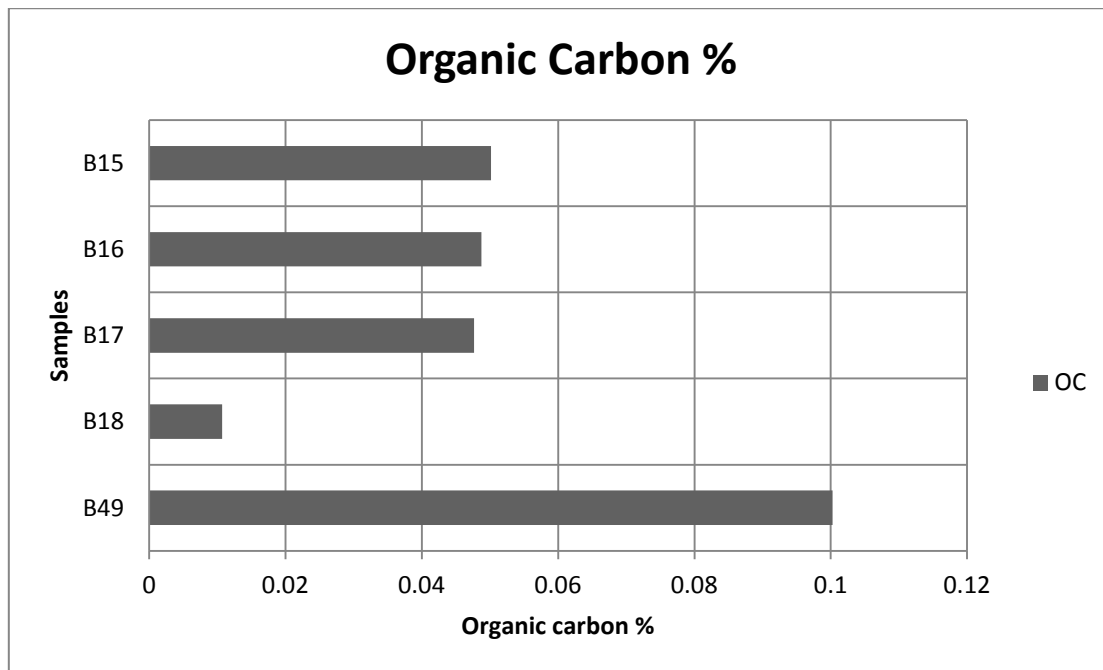


Figure 37: The organic carbon percentage of the Florisbad observed soil horizons.

The sample B49 is the recent surface A-horizon and can be used as a reference sample for present day conditions. Soil organic carbon is mainly used as a parameter for nutrient management in agricultural systems (Patrick *et al.*, 2013). The organic carbon in this instance was measured to indicate if a carbon loss or gain occurred in the present A-horizon. All the soil horizons at Florisbad sequence have low organic carbon percentages, lower than 0.5% organic carbon (Du Preez *et al.*, 2011). It must be taken into account that organic carbon is influenced by many aspects such as soil texture, climate, and topography as well as land use management. The organic carbon percentages as seen in Figure 37 indicate that the present A-horizon has the highest carbon in respect to the palaeohorizons. This can be due to the higher clay percentage with decreased leaching of the horizon. Samples B15, B16 and B17 have similar values whereas B18 has the lowest. This could be due to B18 being a leached E-horizon. This indicates that a carbon gain occurred in the present day A-horizon. The sediment textures of the horizons, see Figure 38, varied from sand (B15, B16 and B18), loamy sand (B17) to sandy loam (B49).

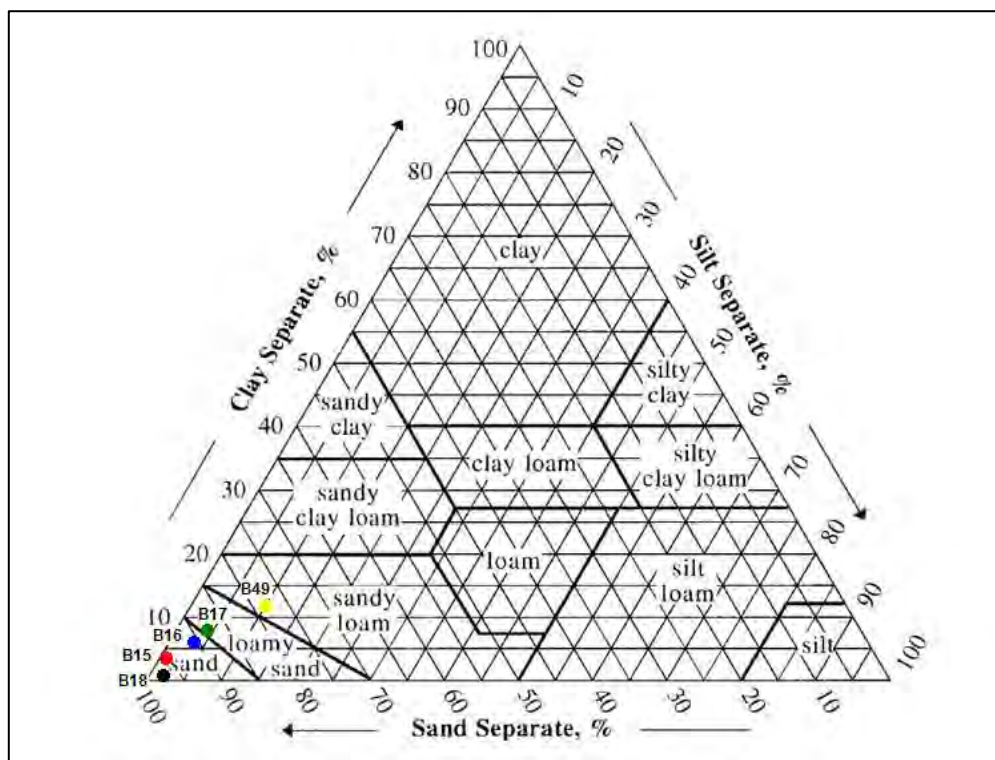


Figure 38: The textural classes of the Florisbad horizons. Calculated from USDA-NRCS (2014).

The XRD analyses, see Table 33, were only conducted on two selected horizons and indicated that quartz is the dominant mineral in both horizons. Plagioclase and microcline are also found in both horizons.

Table 33: The mineral compositions for selected Florisbad palaeoenvironmental horizons.

B16	Mineral	Quartz	Plagioclase	Microcline	Illite	Kaolinite	Gypsum
	Results %	74.08	7.31	6.85	6.01	4.61	1.13
B17	Mineral	Quartz	Microcline	Plagioclase	Dolomite		
	Results %	82.2	9.13	7.88	0.78		

4.3.2 Cornelia-Uitzoek

Table 34: The Cornelia-Uitzoek stratigraphy with additional field observations, horizon compositions and characteristics.

Cornelia	Stratigraphy	Sample	Field observations	Horizon composition and characteristics
Figure 39: The stratigraphy of the Cornelia-Uitzoek profile (Brink <i>et al.</i>, 2012, used with permission).	Figure 40: The top 130 cm of the Cornelia-Uitzoek profile as observed in this research project.	B39	Gravel	pH (H ₂ O): 8 (KCl): 6.6 EC: 329 mS/m Textural class: Clay loam
		B38	Grey clay	pH (H ₂ O): 8.2 (KCl): 6.1 EC: 115 mS/m Textural class: Sandy clay loam
		B37	Laminated clay	pH (H ₂ O): 7.9 (KCl): 6.2 EC: 395 mS/m Textural class: Silty clay loam
		B36	Yellow clay horizon	pH (H ₂ O): 8.2 (KCl): 6.1 EC: 58 mS/m Textural class: Silty clay loam
		B35	Basal gravel	pH (H ₂ O): 7 (KCl): 6 EC: 665 mS/m Textural class: Sandy Loam
		B34	Bed rock (Ecca)	Not analysed

The climatic variations that existed in the Quaternary may have been the cause for palaeohorizons to form. The alternating wetter and drier conditions could be the explanation for the formation of different gravel and clay horizons (Figure 39 and 40) with varying textural classes as seen in Figure 41. The XRF results are relative uniform throughout the profile with no exceptional outliers, see Figure 42 and Table 35. This may indicate that each palaeohorizon can be linked to an event of sediment deposition consisting mainly of gravel and clay.

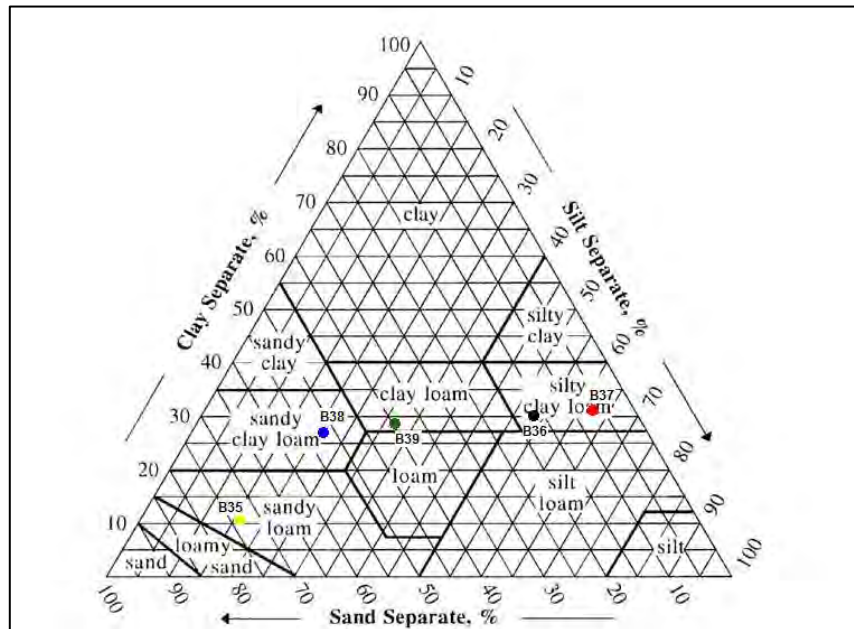


Figure 41: The textural classes of the Cornelia horizons. Calculated from USDA-NRCS (2014).

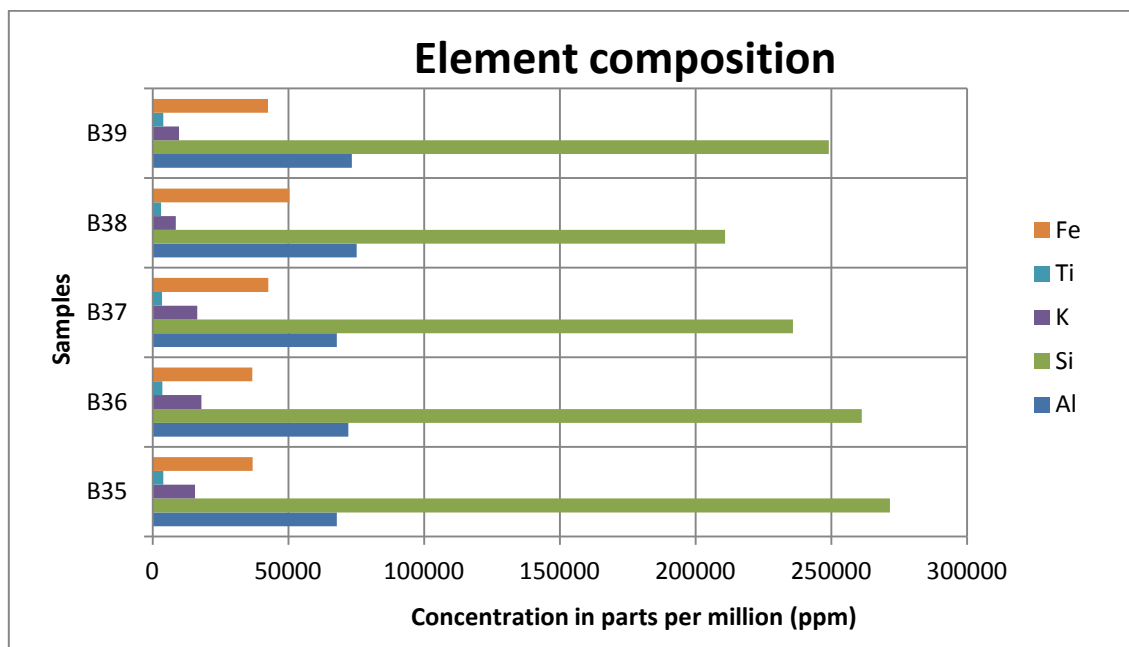


Figure 42: The element compositions as determined by XRF analyses for the Cornelia-Uitzoek palaeosol horizons, mainly indicating high Si values

Table 35: The XRF analyses (as seen in Figure 42) indicating the numerical values in parts per million (ppm) for the Cornelia-Uitzoek palaeosol horizons.

Sample number	Al	Si	K	Ti	Fe
B39	73384.2	249008.5	9708.27	3934.95	42491.58
B38	75121.19	210860.8	8491.06	3144.97	50327.08
B37	67867.08	235877.6	16367.3	3382.15	42588.77
B36	72104.78	261199.6	17990.13	3548.77	36702.65
B35	67790.98	271580.9	15617.79	3888.91	36788.91

The palaeosols localities of Florisbad and Cornelia-Uitzoek, have good tourism potentials as a result of the fossils excavated at the two localities and found at the National Bloemfontein Museum. The localities did not indicate any economic potential.

4.4 Clastic sediments of the Cenozoic Era (Chapter 4.4.1 –4.4.6)

In this section the clastic sediments of the Cenozoic Era are discussed. This includes the cave sediments, gravel deposits, mainly focussing on the Windsorton gravel deposits, the Pebble Marker, terrestrial sands of the Kalahari as well as selected coastal sands, drainage depressions and a unique periglacial deposit.

4.4.1 Caves

Selected caves in the North-West Province e.g. Rietpan Cave, Lime quarry cave, „Jaws“ and the Hut Caves were visited and A and B horizons of the floor sediments were sampled for all the caves except the Hut caves where no B horizon was present. In the scope of this study the Cenozoic Era is of concern and hence the focus will be on the sediments present in caves. The cave sediments are divided into sediment comprising of cave floor sediment and speleothems such as stalactite samples. The locality and site descriptions are discussed in Table 36.

Table 36: The locality and site description of selected caves in the North-West Province.

Sample number	Locality and site description
B109A and B	Rietpan Cave, close to Swartruggens in the North-West Province.  Figure 43: The soil profile of the Rietpan cave indicating layered sediment.  Figure 44: A stalactite and stalagmite in the middle of the Rietpan cave indicated on photo. The Rietpan cave (25° 59'35.6994"S 26° 36'15.8034"E) is situated close to Swartruggens in North-West Province. This cave is situated in the dolomite of the Eccles Formation of the Malmani Subgroup. The estimated age of the cave is Cretaceous and the sediments are younger. The main cave chamber comprises of fine sediment and bats are present. The cave was mined for fertilizers, rich in nitrate and phosphate which originated from the bat guano, and calcite (Keyser and Martini, 1988 and Liebenberg, 2015).
B110A and B	No image The Lime Quarry cave (26° 17'26.0154"S 27°24'47.772"E) situated close to Carletonville in North-West Province is owned by Goldfields Company. This cave was used for mining of the stalactites to produce lime for the building industry (similar than the present day cement) and for agricultural purposes. The cave, with a large central chamber, had no stalactites or stalagmites left. The cave did not have any bats and the sediment was dry.

Table 36 (cont): The locality and site description of selected caves in the North-West Province.

B111A and B	No image The cave namely „Jaws“ (26° 29' 4.92"S 27° 10' 54.696"E), as called by the owner, is situated approximately 30 km from Potchefstroom on the Carletonville road. The cave is one of a series of caves situated in the dolomite of the Malmani subgroup. This cave has dry sediment on the floor and in the narrow passages. No stalactites or stalagmites were present. Bats were present in abundance.
B112	 Figure 45: Remnants of mud huts in an underground cavern, close to Potchefstroom in the North-West Province, referred to as the Hut or Lepalong cave. The cave is situated in the Gatsrand hills approximately 50 km from Potchefstroom on the Carletonville road (26° 28'35.2914"S: 27°14'13.92"E). The cave entrance is level to the surface and is only visible when fairly close. The geology of the cave is unique as being situated in the quartzite between the Pretoria Group sediments and the Eccles Formation of the Malmani Subgroup, which is also seen as the main outcrops on the surface. This seems to be the transitional zone between the Pretoria group sediment and the dolomite and chert from the Malmani subgroup. The cave is damp and clay sediments are present on the floor. A total of about 50 huts are situated in the cave and are divided into hut circles, mounds and enclosed walls made of clay. The cave was used by the BaFukeng (or Baphuti) tribe in the pre-Voortrekker time as a hiding place from Mzilikaza the chief of the Matabele tribe (this was according to natives living in the region). Pottery, ostrich egg shells, animal teeth, an assegai head and two battle axes were found, none which are dated to a specific tribe (Haughton and Wells, 1942). Not bats, stalactites and stalagmites were present due to the overlying quartzitic and shale formation with no carbonates.

4.4.1.1 Cave sediment

The selected elements in the cave sediments are indicated in the ICP-MS analyses graphs - see Figure 46 and 47. The relatively high Ca and Mg can be due to B109, B110 and B111 situated in dolomitic bedrock, $\text{CaMg}(\text{CO}_3)_2$. The Fe is high due to the dolomitic bedrock which is high in hematite (FeO_3). See Appendix C for full ICP-MS results.

The phosphate, nitrate and ammonium present in the cave sediments are mainly ascribed to bat guano (Hess, 1900:129; Saiz-Jumenez, 2013). Bat guano rich in nitrogen are due to insect eating bats whereas phosphate rich guano is from fruit-eating bats (Sikazwe and De Waele, 2004). In a result of high concentration bat guano, microorganism population increases (Gnasplini, 2012), therefore there exists elevated dehydrogenase activity in some caves.

Taylor *et al.* (2002) cited by Jubileus (2008), as well as Quilchano and Maranon (2002), described the dehydrogenase activity as being the total of the microorganism activity present in the soil by measuring the microbial oxidative activities. The dehydrogenase enzymes are present in all microorganisms and are valid to use as microbial activity.

The Rietpan cave (B109) has relatively low phosphate, nitrate and ammonium concentrations, but has higher concentrations in the A-horizon relative to the B-horizon. The A-horizon also has a higher microbial activity which may be due to the bats present in the cave.

The Lime quarry cave (B110) has no phosphate and ammonium present in the cave as well as low concentrations of nitrate. This can be due to no bats present in the cave. The microbial activity is higher in the B-horizon than the A-horizon, which is an uncommon occurrence, but may be due to the horizon being less disturbed than the previously mined A-horizon for agricultural lime.

The high phosphate, nitrate and ammonium concentration of the B111 A-horizon are due to the abundance of bats in the cave resulting in the high dehydrogenase activity as seen in Figure 51. This is an ideal situation where the PO_4 , NO_3 and NH_4 values are high as discussed by Hess (1900). Therefore one can assume that two types of bats are present or occupied the cave at the same stage i.e. insect and fruit eating bats. Insect eating bats contributing in the high NO_3 concentration and fruit eating bats contributing in the high PO_4 concentration.

The Lepalong cave had the lowest concentration of phosphate, nitrate and ammonium as well as very low microbial activity. This may be due to the cave having no bats present as well as the disturbed sediments through human inhabitancy.

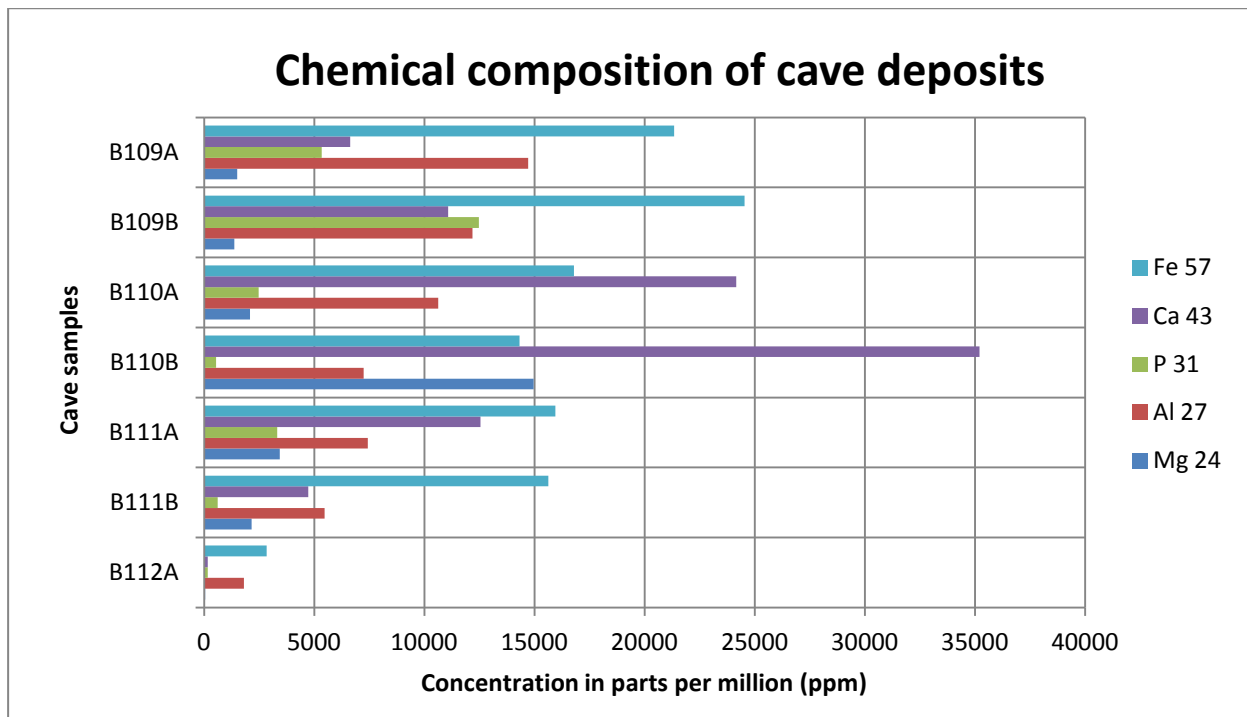


Figure 46: The concentration values of selected elements in the ICP-MS analyses for selected caves in the North-West Province, mainly indicating high Ca and Fe concentrations.

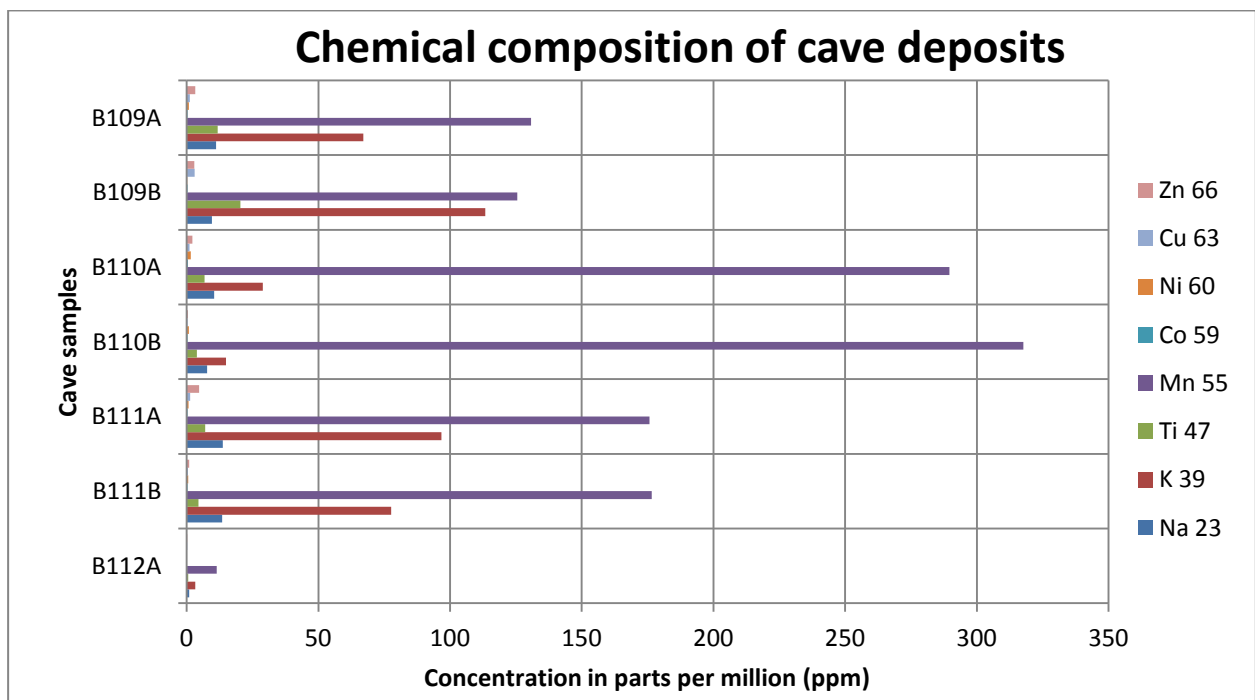


Figure 47: Lower values of the total selected elements in the ICP-MS analyses for selected caves in the North-West Province.

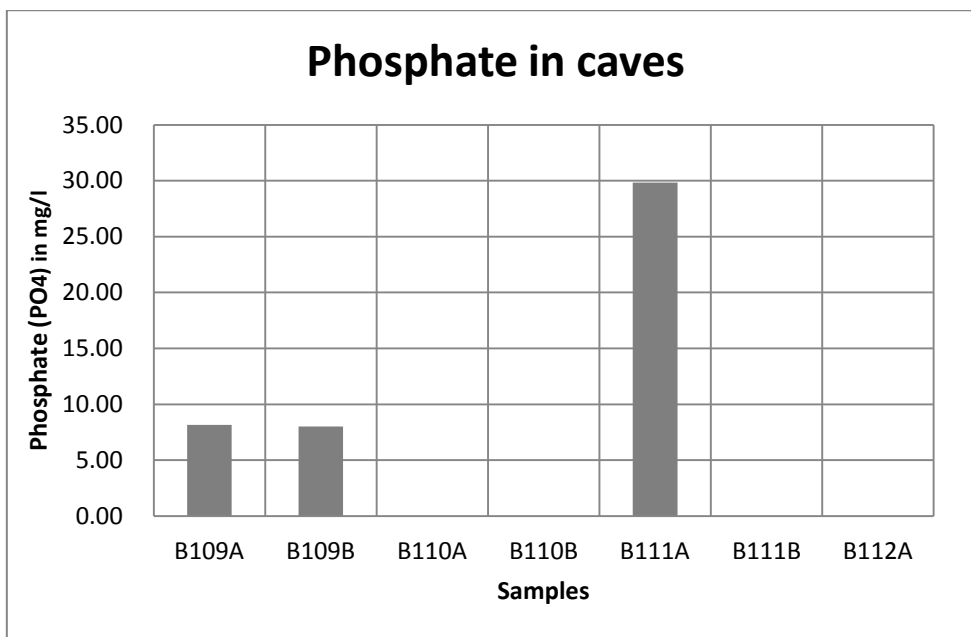


Figure 48: The phosphate (PO₄) levels in the A and B horizons of the cave sediments, B109A, B109B, B110A, B110B, B111A, B11B and B112A, collected at the Rietpan, Lime Quarry, Jaws and Lepalong caves.

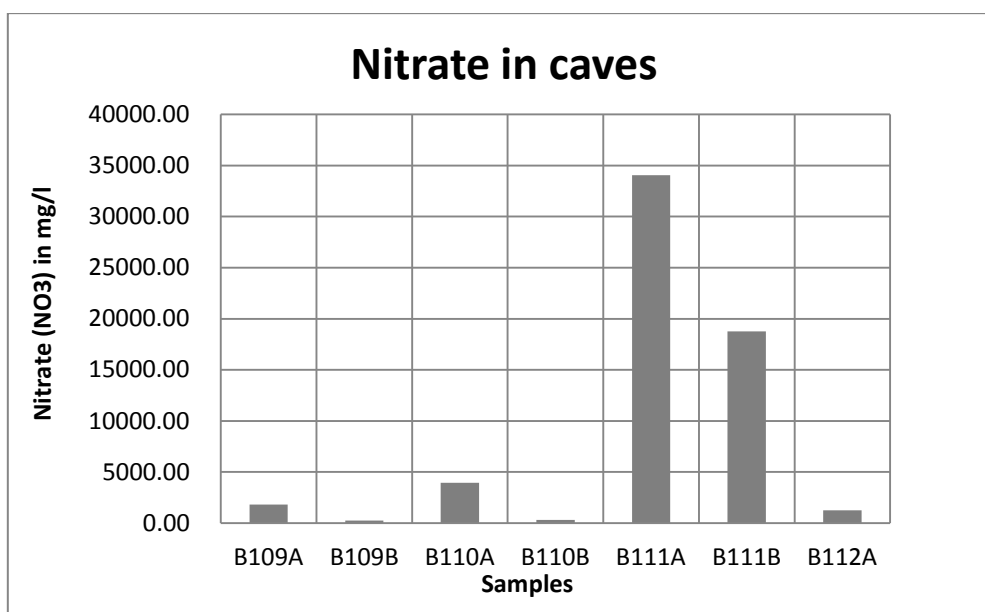


Figure 49: The nitrate (NO₃) levels in the A and B horizons of the cave sediments, B109A, B109B, B110A, B110B, B111A, B11B and B112A, collected at the Rietpan, Lime Quarry, Jaws and Lepalong caves.

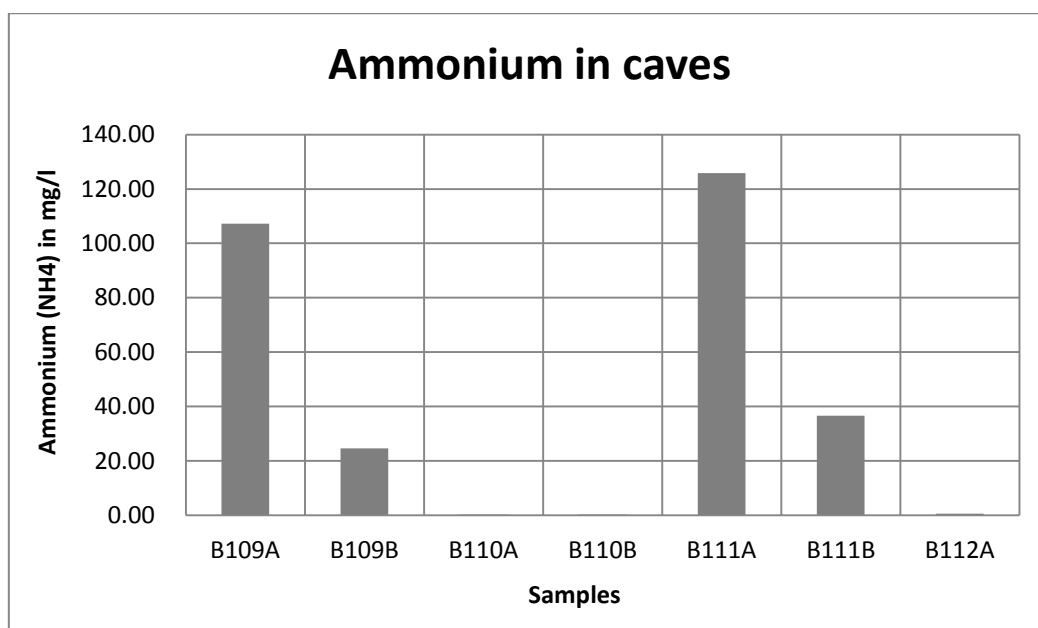


Figure 50: The ammonium (NH₄) levels in the A and B horizons of the cave sediments, B109A, B109B, B110A, B110B, B111A, B11B and B112A, collected at the Rietpan, Lime Quarry, Jaws and Lepalong caves.

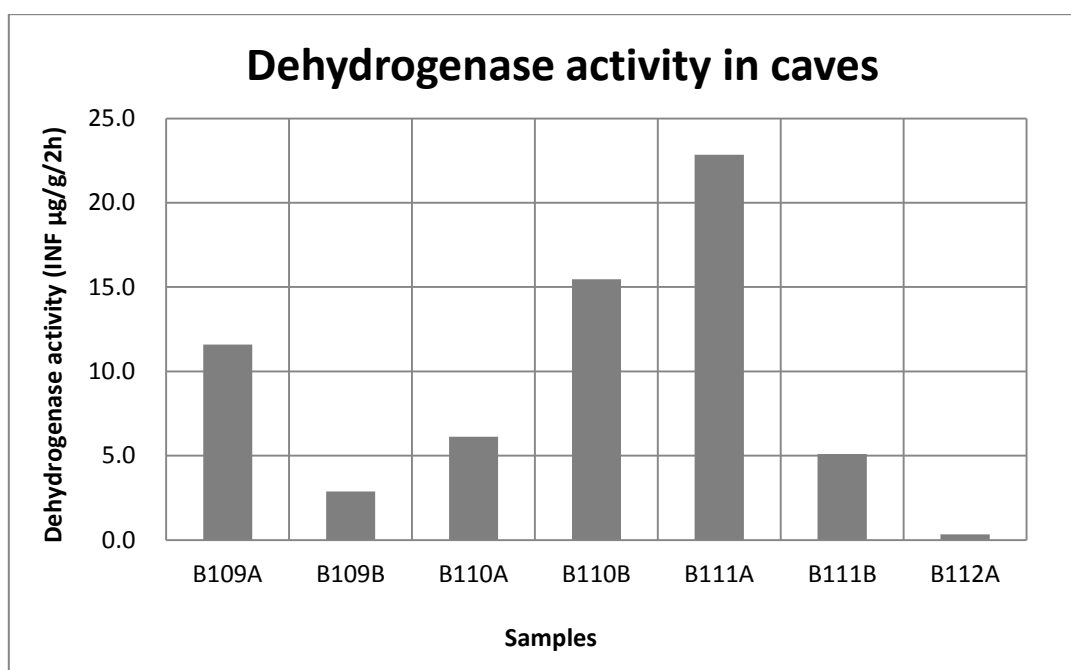


Figure 51: The dehydrogenase activity in the A and B horizons of the cave sediments, B109A, B109B, B110A, B110B, B111A, B11B and B112A, collected at the Rietpan, Lime Quarry, Jaws and Lepalong caves. Sample B111A indicating the highest microbial activity.

The particle size distribution graphs were only conducted for the A-horizons of the different caves. The particle size distribution curves as illustrated in Figure 52 are mainly similar, but slightly differ as B110 has the highest sand percentage and B111A had the highest clay

percentage. All three of the particle size distribution graphs indicated a poorly graded orientation.

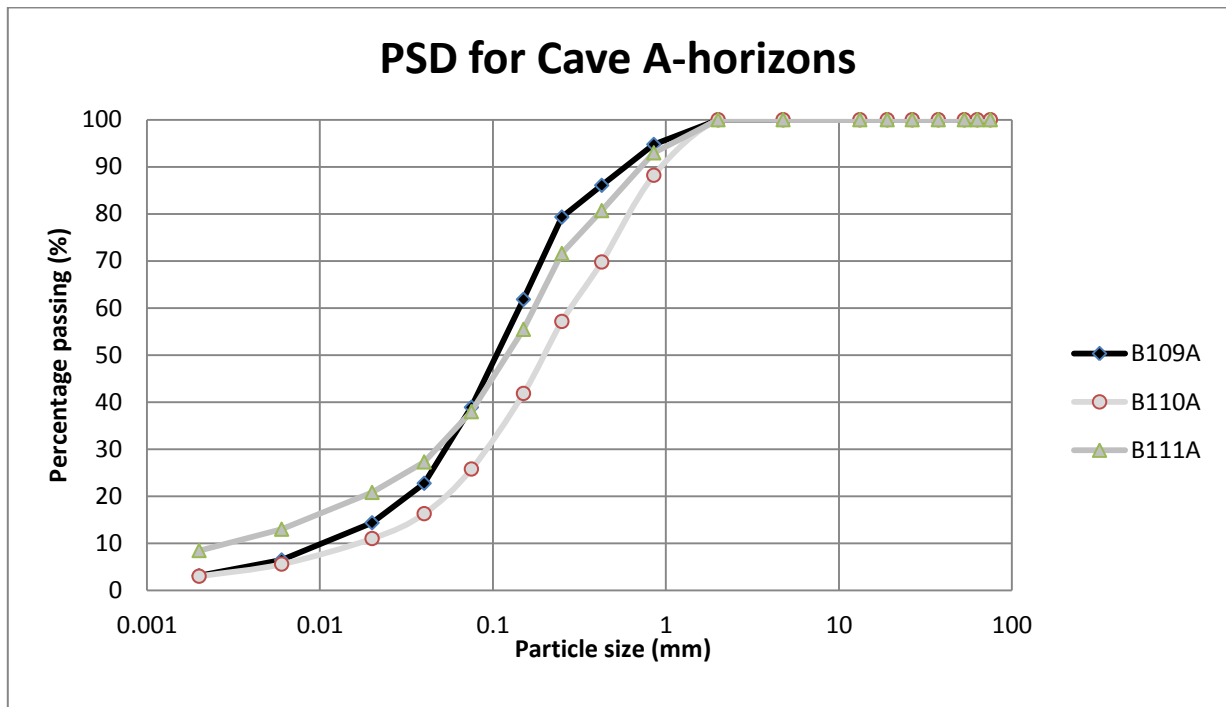


Figure 52: The Particle Size Distribution of all the caves (A-horizons) in dolomitic bedrock (B109, B110 and B111).

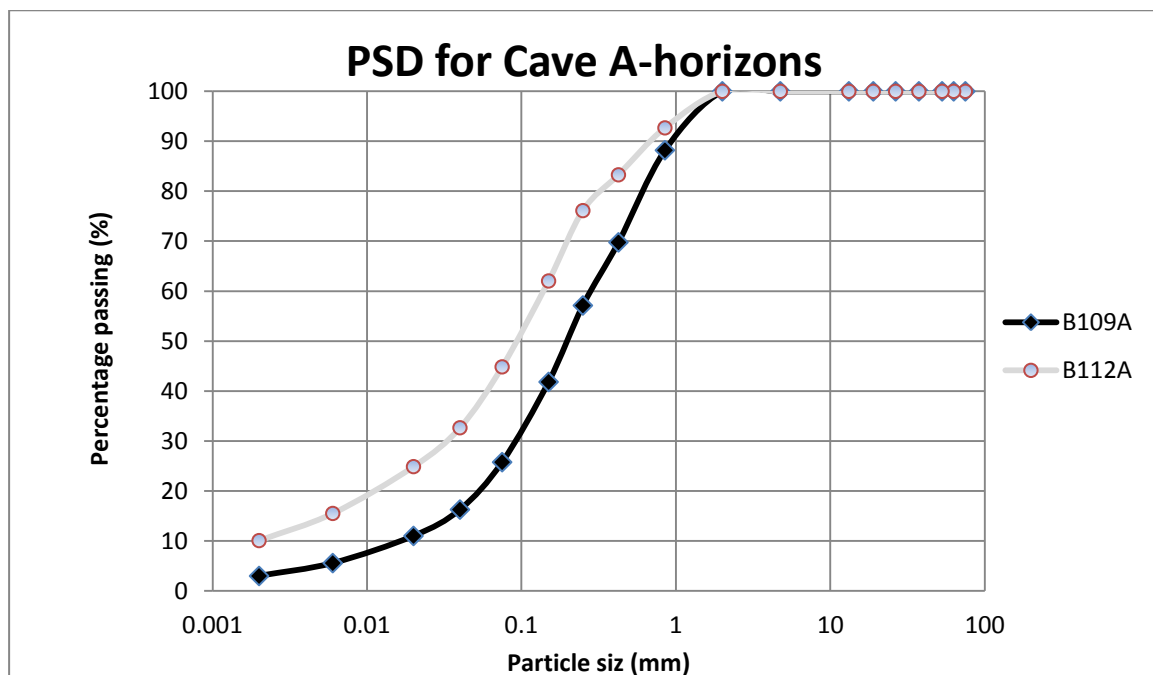


Figure 53: The Particle Size Distribution for the caves with the highest (B112A) and lowest clay (B109A) percentages.

The particle size distribution of the caves as seen in Figure 53 indicates that B112A has the highest clay percentage and the lowest sand percentage and B109A has the lowest clay percentage and the highest sand percentage. Both graphs indicate a well graded grain distribution.

The XRD results, see Table 37, indicate that the caves are mostly abundant in quartz, but also contain clay minerals such as illite (B111 and B112) and kaolinite (B111 and B112). Dolomite is present in B110 and B111 and corresponds to the dolomitic bedrock.

Table 37: The XRD analyses for the cave sediment of samples B109, B110, B111 and B112 indicating the mineral composition of each sample.

B109	Mineral	Quartz	Hematite	Plagioclase	Microcline	
	Results %	96.83	2.66	0.51	trace	
B110	Mineral	Quartz	Hematite	Calcite	Dolomite	
	Results %	93.31	2.94	2.88	0.87	
B111	Mineral	Quartz	Kaolinite	Illite	Dolomite	Gypsum
	Results %	80.89	11.51	7.28	0.32	Trace
B112	Mineral	Quartz	Muscovite	Kaolinite	Illite	Microcline
	Results %	47.22	32.2	11.53	7.54	1.51

4.4.1.2 Stalactites

Three stalactite samples were collected from selected caves e.g. the Lime Quarry cave, „Jaws“ cave and Rietpan cave, in the North-West Province. The geochemical compositions were determined for each as seen in Table 38.

Table 38: The calculated CaO values from XRF data as well as the minerals for three stalactite samples from various caves in the North-West Province.

Samples	CaO %	Minerals (XRD results)	
B110S: A small stalactite from the Lime Quarry cave	65.08	Mineral	Weight %
		Calcite	77.26
		Aragonite	20.32
		Quartz	2.42
S1: A stalactite from a cave close to „Jaws“ cave.	64.79	Mineral	%
		Calcite	91.18
		Aragonite	7.24
		Quartz	1.59

Table 38 (cont): The calculated CaO values from XRF data as well as the minerals for three stalactite samples from various caves in the North-West Province.

S2: A stalactite from the Rietpan Cave	65.61	Mineral	%
		Aragonite	82.51
		Calcite	15.42
		Quartz	1.71
		Dolomite	0.36

The XRF analyses indicated that the stalactite samples from the selected caves in the North-West Province had a high average CaO value of 65.16%. This was mainly due to calcium rich water dripping from the cave roofs Sweeting (1972). The dominant mineral present in both B110S and S1 is calcite, and are normally abundant in stalactites. Sample S2 is however dominated by aragonite and this may indicate that warm environments existed when forming (Sweeting, 1972).

The cave sediments have a high economic potential in regards to bat guano which can be used as fertilisers (Gnaspini, 2012:51). Caves can also be seen to promote the tourism potential of the Cenozoic deposits.

4.4.2 Gravel deposits

Gravel deposits associated with palaeodrainage systems are present in various localities in South Africa. In this study the Windsorton alluvial gravel deposit is discussed as an example of the broad spectrum results which can be deduced from these deposits. The Setlagoli River gravel is also included, but only to indicate the varying geology gathered at one location through the „palaeo Setlagoli River“ or due to fluvial Periods.

The gravel deposits map (Figure 16) indicates the gravel deposits discussed below as well as more examples of gravels deposits located over South Africa, such as Baltimore (Limpopo) associated with the Lepalala River, Stockpoort (Limpopo) associated with the Limpopo River; Mooiriver gravels (North-West) and Schweizer Reneke (North-West) associated with the Vaal River; and the Gariep River gravels (Free State).

4.4.2.1 Windsorton, Northern Cape.

The gravel site (28° 20' 03.24"S 24° 43' 01.4"E), which was excavated for alluvial diamond mining, was used for field observations and collecting samples. The stratigraphy as well as the geochronology can only be compared to literature studies as no artefacts or fossils were found in this succession to be used for date referencing.

The observed profile of the Windsorton gravel site was divided into six horizons in this research project as shown in Table 39. The main focus was on the gravel deposit as indicated in Figure 57, B21, B23 and B24:

The top A-horizon (B19) is aeolian Kalahari sand with a thickness of approximately 1 meter. The horizon has a sandy loam texture with a pH of 7.7 and low EC value of 78 mS/m.

The B-horizon (B20) having an overall yellow soil colour and black mottle inclusions, has a thickness of approximately 2 meters. The horizon has a sandy loam texture and has the highest clay percentage of the soil profile. The pH is 8.7 and the EC value is 77 mS/m.

The first sedimentary alluvial deposit (B21) has a thickness of approximately 1 meter and contains pebble sized particles (4-64 mm) with an unsorted orientation. Some pebbles are calcified. The pebbles are well rounded indicating that the material was water transported at a point in time, the ununiform orientation of the pebbles may indicate that fluvial conditions were the means of transportation of the sand and clay matrix. The pH is 8.6 with a high EC value of 660 mS/m as shown in Figure 57. This can be ascribed to the increase in salts transported through the overlying sandy loam sand horizons with relatively low adsorption potential or pollution from the diamond mining activities.

Stratified sand horizon (B22) with an approximate thickness of 0.5 m had a pH of 8.6 and a low EC value of 28 mS/m. This horizon indicates possible arid palaeo-environmental conditions at that point in time of distributed aeolian sand.

The second gravel deposit (B23) has a thickness of approximately 1 meter and unsorted boulder sized sediments. The pH is 8.6 and the low EC value of 58 mS/m was recorded. From the unsorted orientation of the sediments it can be deduced that this deposit was transported via fluvial episodes. Some pebbles and boulders are calcified.

The third gravel deposit (B24) is similar to B23 and also has unsorted boulder sized sediments and a thickness of 1 meter. The pH is 8.4 and the low EC value of 78 mS/m was determined. Fluvial episode may also be ascribed to the mean of transportation of this gravel horizon.

It can be noted that the second and third horizons, B23 and B24, may be seen as a single gravel deposit due to its similar analytical results. Marshall and Norton (2012:34) refer to similar gravel deposits at Klipdam as being deposited by a large braided river system. The unsorted orientation of the gravel deposit is ascribed to rapid deposition of a river with high velocity. The basal gravel deposit from Holpan was calcified and corresponds with in B23 and B24 horizon which were also calcified.

Table 39: The Windsorton stratigraphy, field observations as well as horizon composition and characteristics.

Younger alluvial deposits.		Meters present above Vaal River
Riverton alluvial gravels	8 - 9	
	4 - 5	
Rietsputs	Thick gravels	

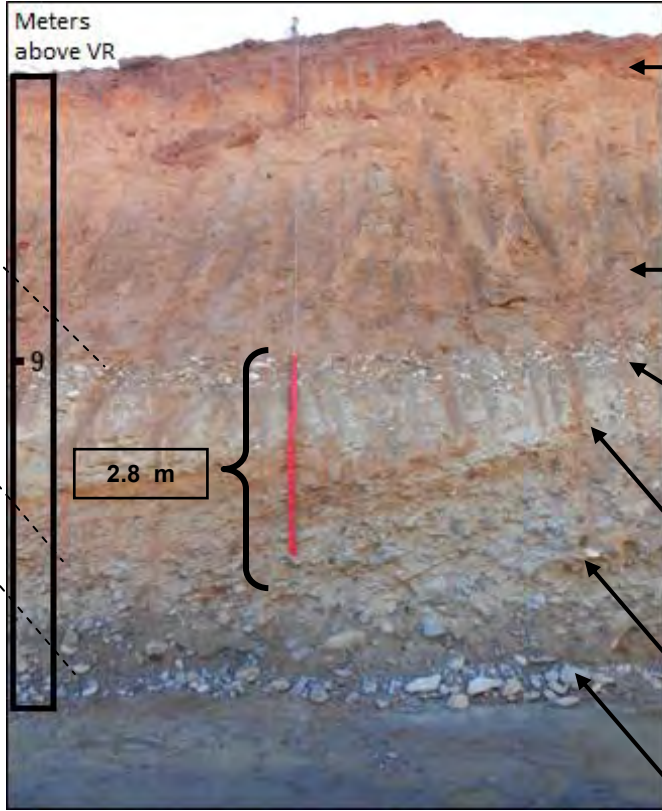
Stratigraphy	Profile depth (m)	Sample	Field observations:	Horizon composition and characteristics
	0-1.4	B19	Kalahari sand	pH: (H2O):7.7, KCl: 6.5 EC: 78 mS/m Texture class: Sandy loam
	1.4-3	B20	Yellow sand horizon with black manganese mottles	pH: (H2O): 8.7, KCl:6.8 EC: 77 mS/m Texture class: Sandy loam
	3-4.4	B21	Alluvial deposit	pH: (H2O):8.6, KCl:7.5 EC: 660 mS/m Texture class: Sandy loam
	4.4-6	B22	Stratified sand horizon	pH: (H2O):8.6,(KCl):7.5 EC: 28 mS/m Texture class: Fine sand
	6-7.2	B23	Alluvial deposit	pH: (H2O):8.6,(KCl):7.5 EC: 58 mS/m Texture class: Fine sand
		B24	Alluvial deposit with boulders	pH: (H2O):8.4 (KCl):7.4 EC:78 mS/m Texture class: Fine sand

Figure 54: The gravel profile from an alluvial diamond excavation at Windsorton in the Northern Cape. The profile is approximately 8 m deep. The scale on the photograph indicates the profile relative to the meters above the present Vaal River (VR)

The pH of all the horizons and gravel deposits are relatively alkaline which may be due to the calcium concretions present in the profile, especially in the gravel deposits. The EC values are low except B21 with a high value of 660 mS/m, see Figure 55.

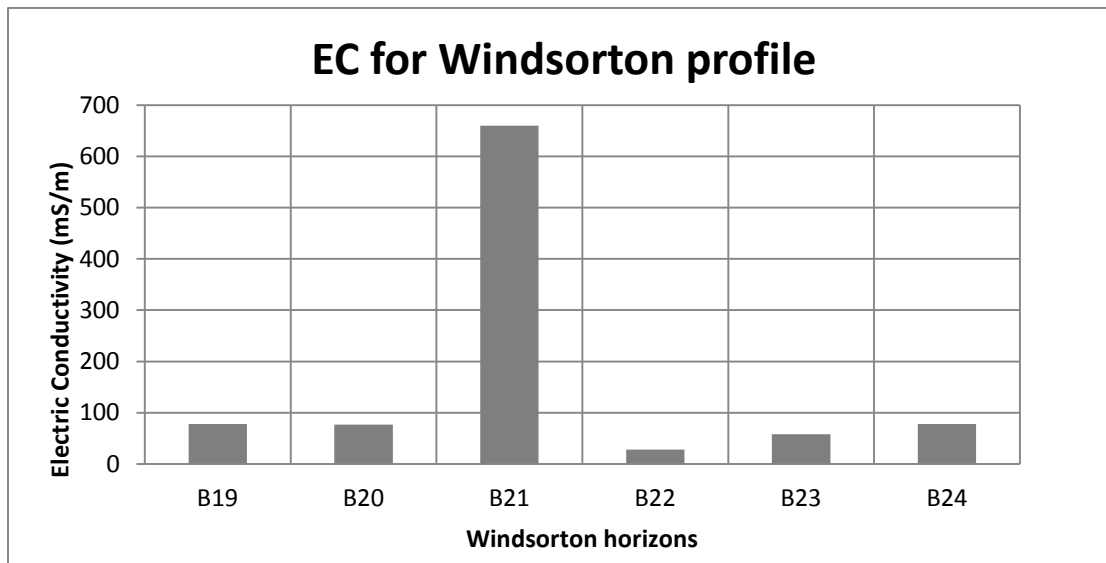


Figure 55: The Electric Conductivity (mS/m) for the Windsorton profile

A cross section as seen in Figure 56 was conducted to determine the elevation of the gravel deposits above the present river elevation. This was done by making the assumption that the present Vaal River has a depth of 3 meters and hence using the base of the river as the present river elevation. The observed profile (Figure 57) had a surface elevation of 1124 m and the river had an elevation of 1113 m (at the base). The top of the observed profile was 11 meters higher than the river resulting in the first gravel deposit to start at 9 meters above the present river base. The observed stratigraphic column was compared with literature and correlated relatively well with the Rietsputs and Riverton I Formation of the +12 to +14 m terrace. The Riverton Formation is located on the lower 8 – 9 and 4 – 5 meters above the present Vaal River level, and the Riverton Formation is situated beneath this deposit and may be a thick horizon (Marshall and Norton, 2012). This implies that the sequence of the Riverton at the top of the profile and Rietsputs Formations at the base correlates with the observed profile. The elevation of the Riverton deposit, mainly comprising of sand, silt and clay sequences and Rietsputs deposits, mainly comprising of gravels, does not correlate well with the literature. This may be due to the variation in thickness of the deposits that were not deposited uniformly in all the regions.

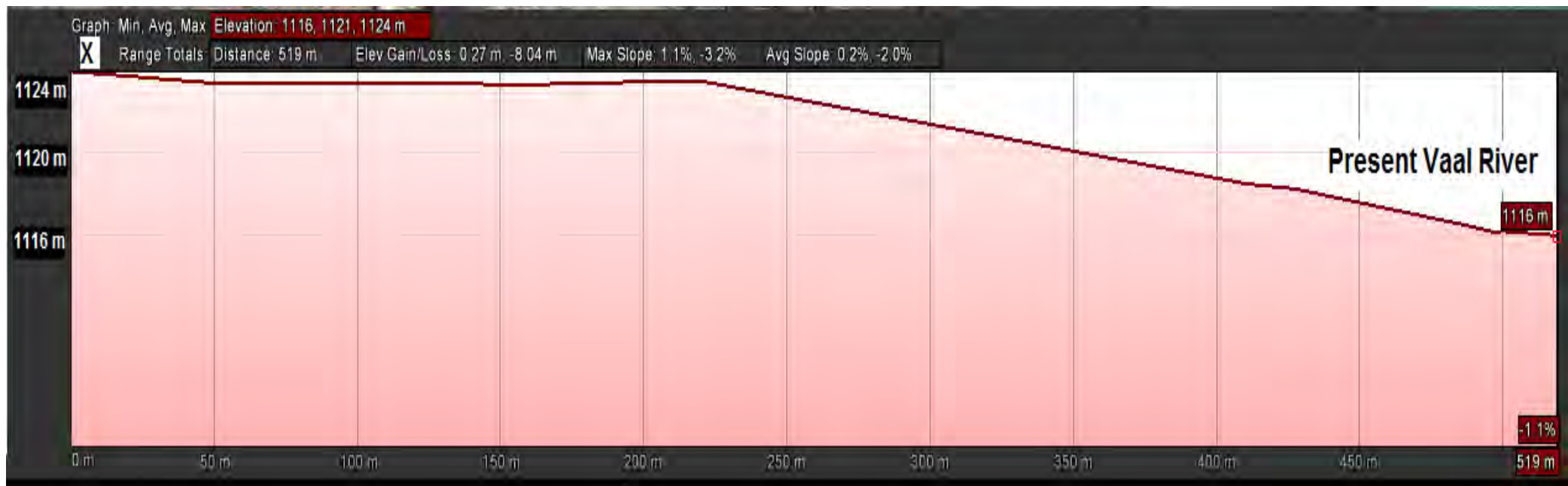


Figure 56: A cross section indicating the elevation from the present Vaal River relative to the gravel profile locality (indicted with an X on the graph). Source: Google Earth (2015)

The textures of the sediments are mainly in the sand and sandy loam textural classes, as seen in Figure 57. The particle sizes of the total weight of sample were estimated as particle sizes larger than 2 mm and smaller than 2 mm as seen in Figure 58. This indicated a relative distribution of the sediments, whether the soil horizon is characterized as a gravel deposit, being larger than 2 mm, or a sand, silt or clay, being smaller than 2 mm.

The horizon, B19, B20 and B22, have the highest percentages particles smaller than 2 mm and grouped together as seen in the particle size distribution diagram (Figure 59). This indicated that B22 has higher percentage of coarse particles in comparison to B19 and B20 and may be due to the position in between the gravels horizons of B21 and B23.

The gravel horizons have the highest percentage of particles larger than 2 mm (Figure 58). The particles of these horizons are smaller than 2 mm and were also compiled in a particle size distribution graph, Figure 60. This indicated that B23 and B24 both had coarser particles relative to B21. This may be due to the fact that B21 is situated under a sand horizon which contributes to the fine sand particles present.

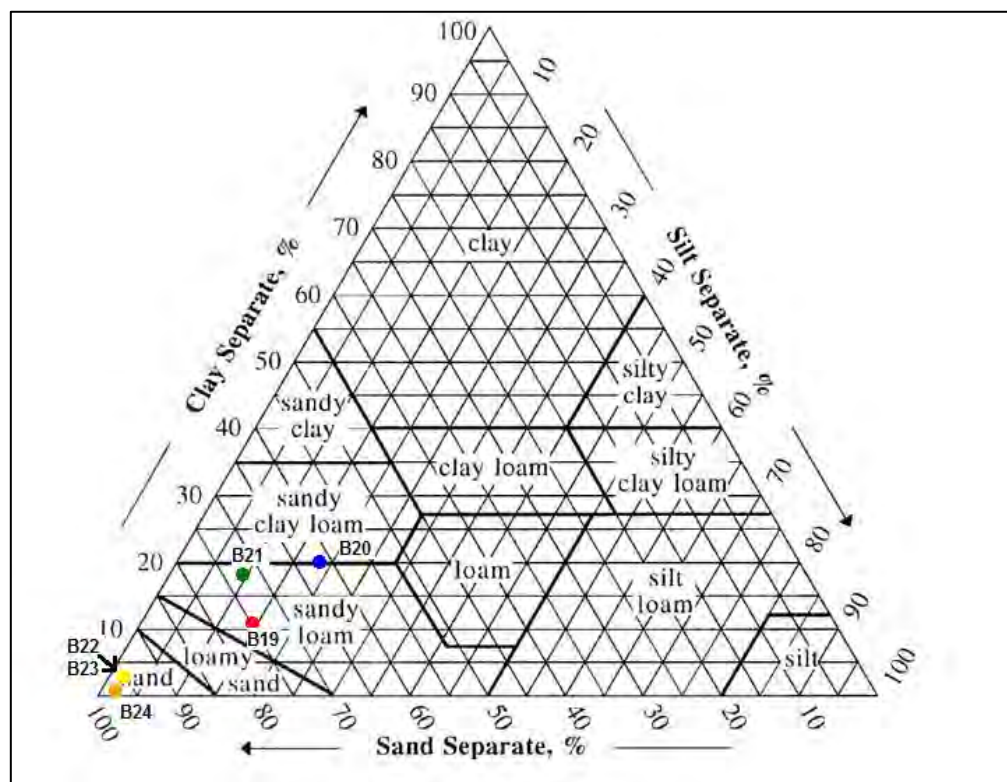


Figure 57: The textural classes of the soil fraction of the Windsorton gravel deposit profile. Calculated from USDA-NRCS (2014).

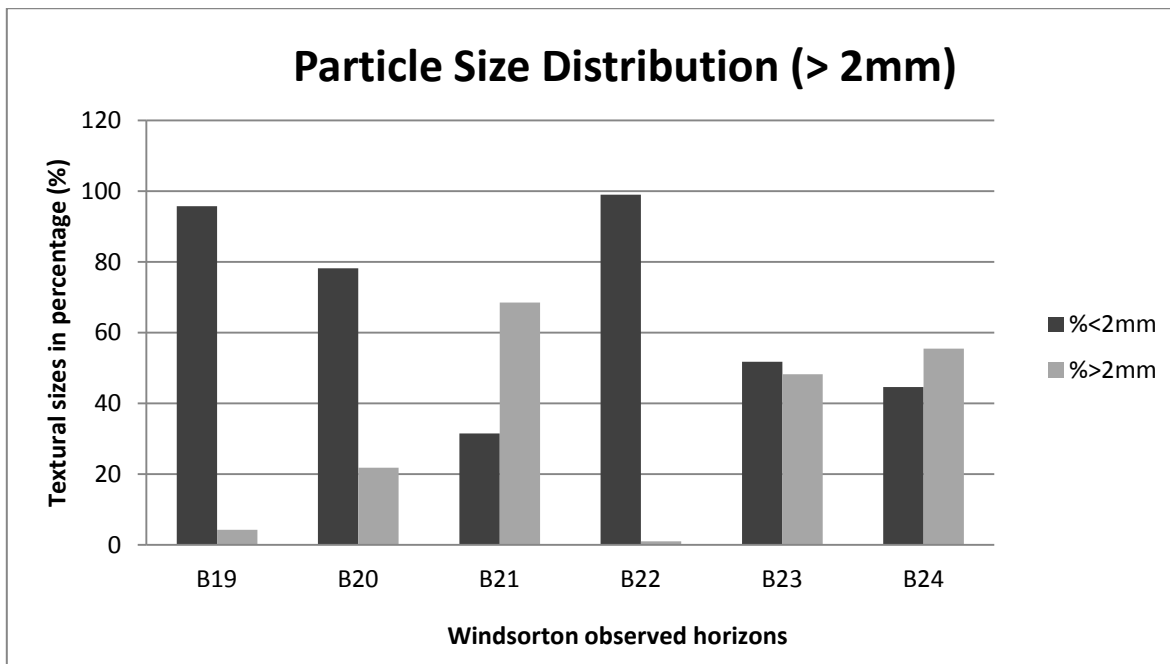


Figure 58: The particle size distribution (> 2mm) of the soil horizon profile of Windsorton gravel deposits in the Northern Cape Province.

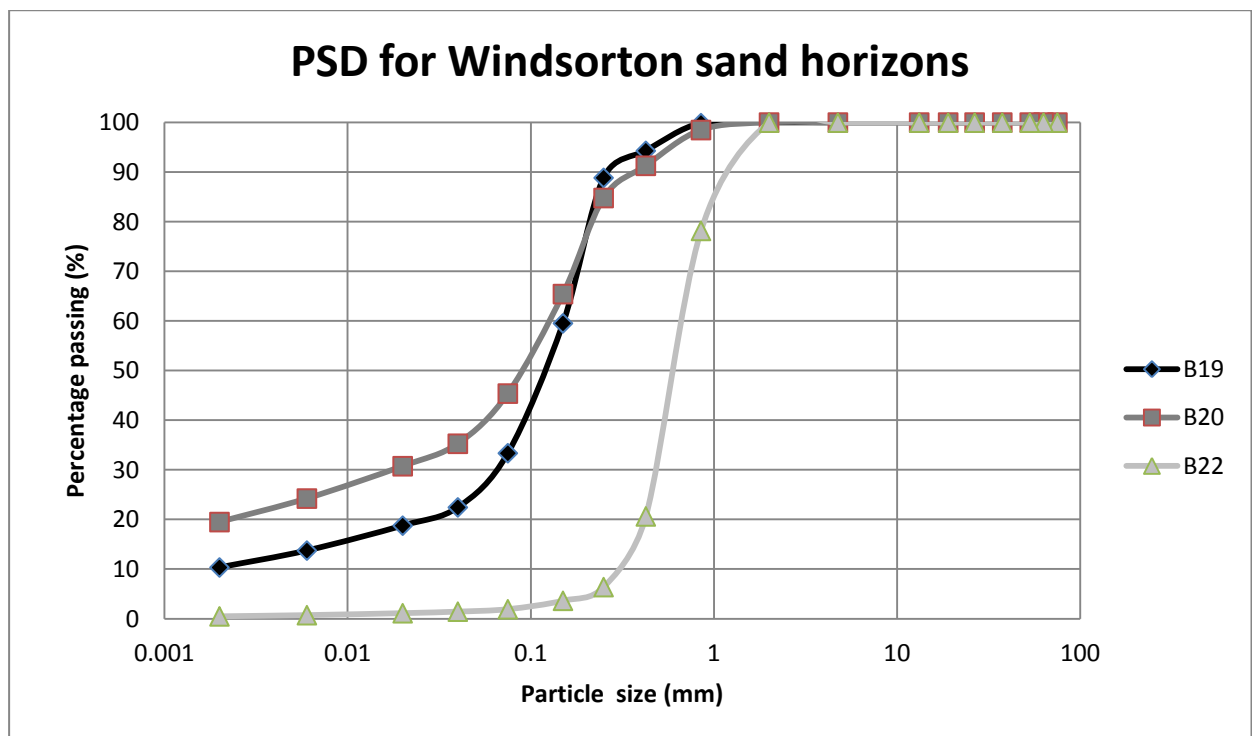


Figure 59: The particle size distribution (< 2mm) of the sand horizons (B19, B20 and B22) of the observed Windsorton profile in the Northern Cape Province.

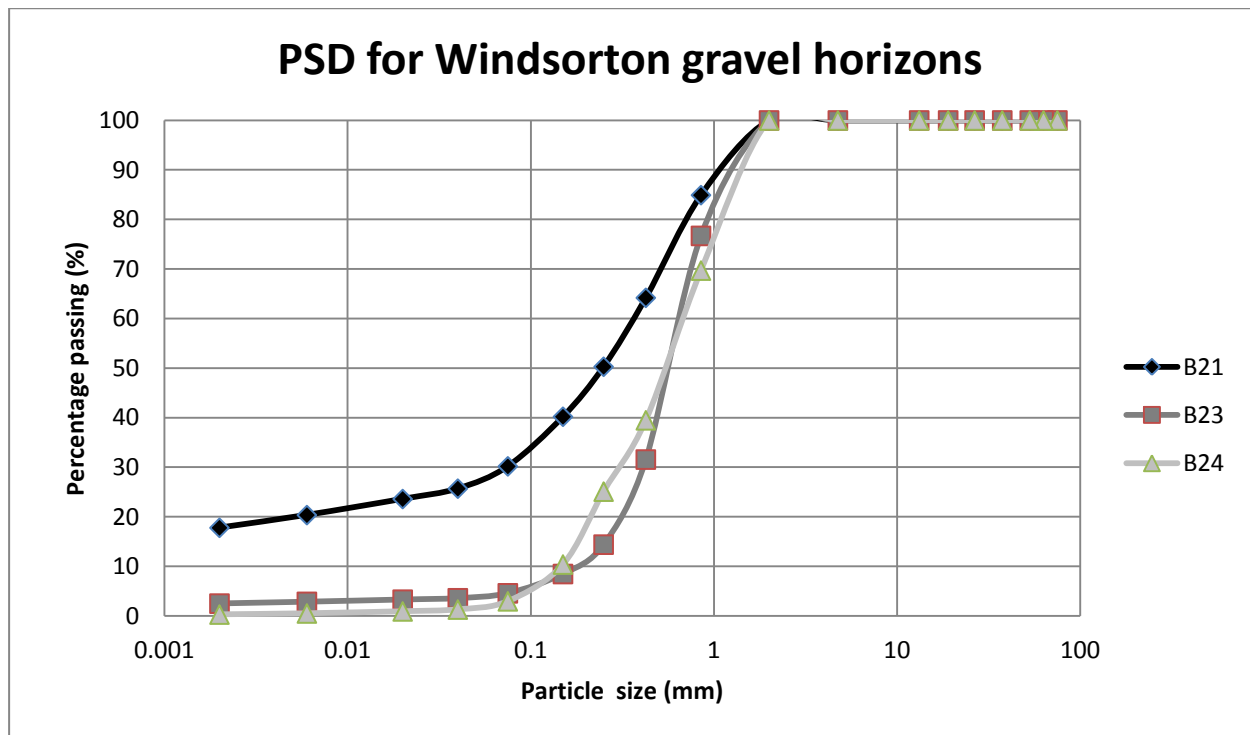


Figure 60: The particle size distribution (< 2mm) of the gravels horizons (B21, B23 and B24) of the observed Windsorton profile in the Northern Cape Province.

This Rooikoppie formation (Figure 61) is a colluvial Rooikoppie gravel deposit as for its vast distribution in the area, uncemented pebbles, red oxidized soil profile as well as the approximate thickness of 20 – 30 cm. This correlates to the characteristics of a colluvial gravel deposits as seen in Chapter 2.3.2.

Gravel deposits such as the Windsorton gravels containing alluvial diamonds can contribute to the Cenozoic deposits economic potential.



Figure 61: The older Rooikoppie gravel occurring in the Windsorton area.

4.4.2.2 Setlagole gravel deposit

The Setlagole River gravel (B68) site (S25°57'35.2", E24°44'2.2") is situated approximately 65 km south east of the town Vergeleë in the North West Province, South Africa. The gravel deposit is situated about 100 m south of the Setlagole River and had an elevation of 1121 mamsl. The main geology of the area is Kalahari sand of the Gordonia Formation. The gravel pebbles are well rounded, with varying compositions including quartz (rose and smoky), jasper, banded ironstone, calcrete and ferricrete as seen in Figure 62. The roundness of the pebbles indicated that water transportation was responsible for transfer. The 2624 Vryburg and 2524 Mafikeng 1:250 000 Geology maps were used to establish the origin of the pebbles located in the Setlagole gravel deposit.

The banded ironstone may have been transported via the tributary Mareetsane River that enters the Setlagole River from an eastern direction. The Mareetsane River flows over banded grey chert, brown jaspilite, amphibolite, lava and chlorite schist outcrops as well as banded ironstone, mica schist, pyrophyllite schist and quartz chlorite schist, dolomite, amphibolite, and rhyolite outcrops. The stream joining the Setlagole River from the south, Mosita se Laagte, may

also have transported pinkish, coarse grained granite to contribute to the presence of quartz in the Setlagole Gravels.



Figure 62: The variations of pebbles located close to the Setlagole River.

This indicates that different lithological units were located in a single locality close to the Setlagole River, which differs from the underlying geology. This may also be ascribed to fluvial episodes which may have occurred.

Further investigation is needed to determine the palaeoenvironmental conditions, fluvial episodes as well as the Period it may have occurred.

4.4.3 Pebble Marker

The Pebble Marker gravel layer was sampled at two localities in the North-West Province, the first being close to Potchefstroom and the second being close to Schweizer Reneke. This layer has a wide distribution over South Africa hence these two Pebble Markers are used as examples of the main characteristics and composition. It must be noted that this can be used as a framework for further studies, but each site specific study must be evaluate individually.

An alternative hypothesis involving the origin of the pebble marker is stated by Van Deventer (2015) that the layer originated from transported sediments via semi-glacial conditions. The very

informal term „slush state“ can aid in understanding the palaeo-environmental condition at that point in time. This represents environmental conditions at which fully glacial conditions were not yet present. The finer particles were removed by wind during drought conditions and the larger fraction of particles remained behind as a lag deposit, and then covered by e.g. Kalahari sand on top. The proposed age of the Pebble Marker, found in the Steenbokpan area in the Northern province, is also rather linked with the late Tertiary Period with an approximate age of 19 000 years (Van Deventer, pers comm, 2015). The age was determined using carbon dating of giraffe bones found in the Pebble Marker. Various stone artefacts of MSA and older were also found in the Pebble Marker in the Limpopo, Crocodile and Marico river valleys from Zeerust to Alldays (Van Deventer, pers comm., 2015). Approximate ages of geomorphologic features such as the Pebble Marker should rather not be extrapolated for all Pebble Markers over South Africa.

The Pebble Marker (Figure 63 a and b) located close to Schweizer Reneke (B32) in the North West Province (S27°9'52.779" E25°16'53.112") includes larger grains of different compositions such as quartz, quartzite and feldspar. This site locality is situated at an open borrow pit which cut through the section and provided an opportunity for closer examination. The underlain geology of this area is 2880 Ma old granite, (Robb and Meyer, 1995) (see geological map 2725A). The soil profile has a base of weathered granite or saprolite followed by the Pebble Marker and has A and B top horizon of Kalahari sand (Hutton soil formation).

The composition of the Pebble Marker seems to differ from the underlying granite bedrock due to the weathered status of the granite. The grains could have been transported from a different location such as the quartz veins present in the Ventersdorp approximately 3 km away from this specific locality. This can indicate that the Pebble Marker is a result of transported sediments. The iron and manganese concretions present also indicate that water fluctuating conditions were present.

The Pebble Marker can also be referred to as a lag deposit. Lag deposit refers to the fine grained matrix being removed by water or mainly wind (Flint, 1957; Cotton, 1952). This indicates that sediment was transported to a different locality where the sand fraction particles were blown away by the wind resulting in larger sediments that were left behind, thus explaining the larger grains present in the Pebble Marker.

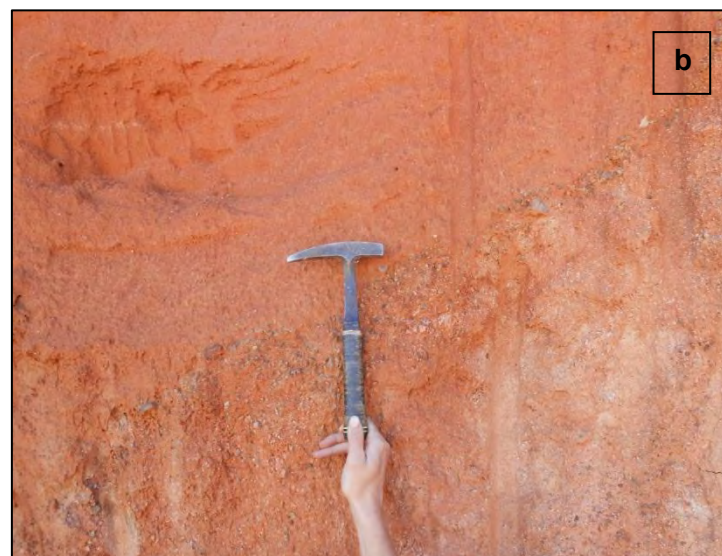
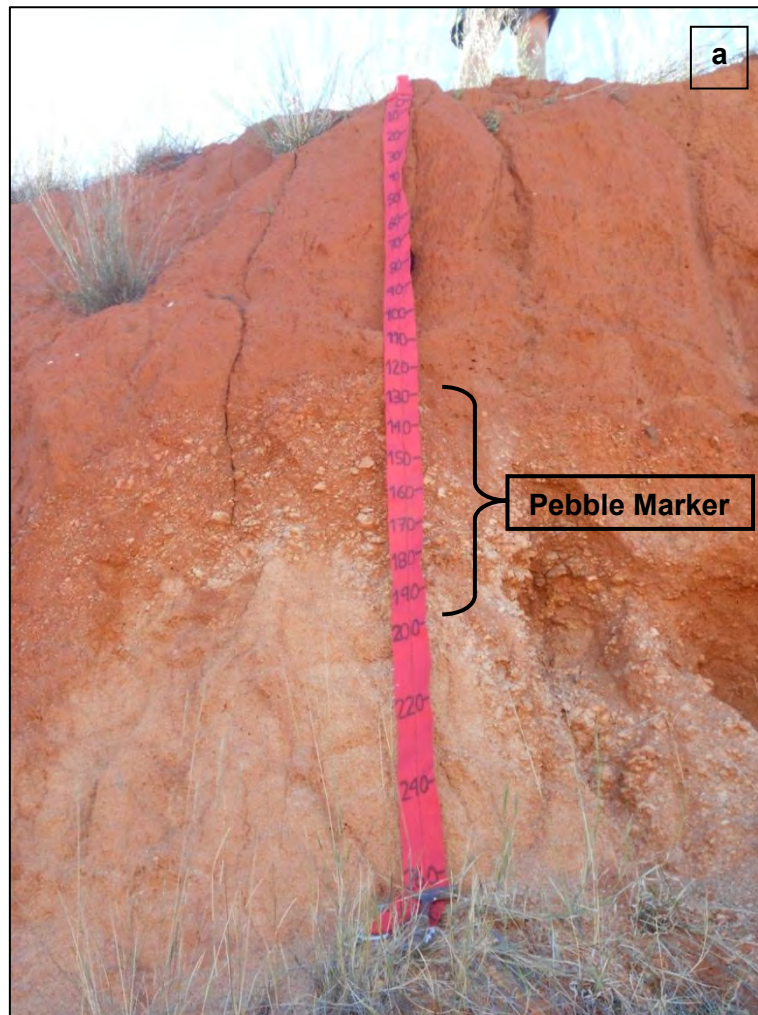


Figure 63 a and b: Pebble Marker located close to Schweizer Reneke, North West province. The geology pick is 25 cm long.

The particle size distribution (>2 mm) as seen in Figure 64, indicates that the pebble marker has an abundance of boulder sized particles (>130 mm) present, and a moderate amount of cobble sized particles (50-130 mm) present. Particles smaller than 50 mm in diameter varies. The particle size distribution graph (<2 mm) indicates a poorly graded composition as seen in Figure 65.

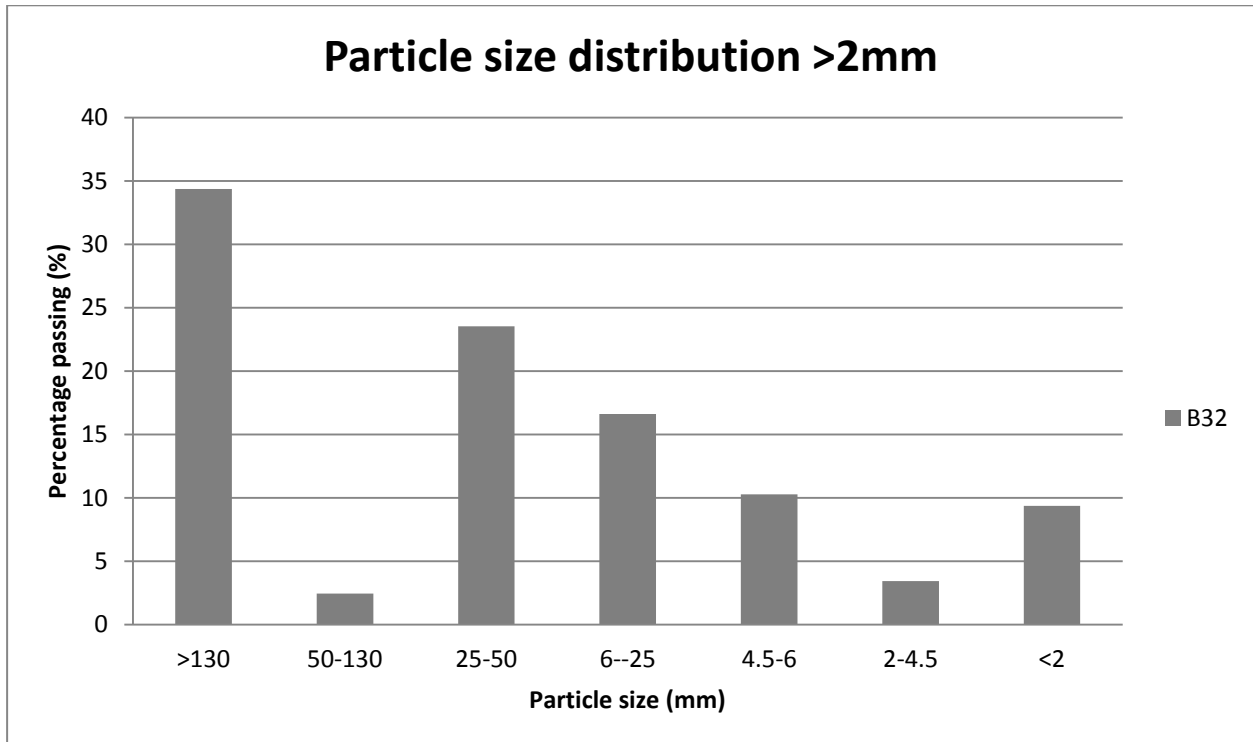


Figure 64: The particle size distribution (>2 mm) of the Pebble Marker located close to Schweizer Reneke, North West province at a borrow pit.

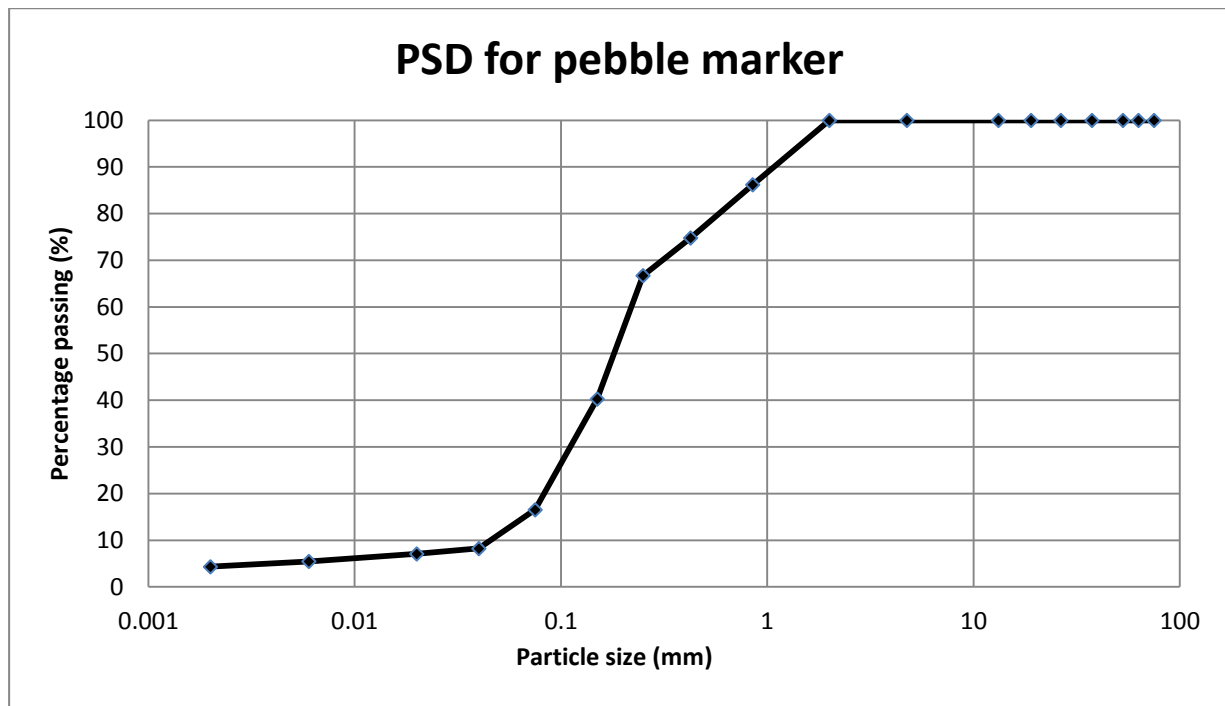


Figure 65: The particle size distribution (<2 mm) of the Pebble Marker located close to Schweizer Reneke, North West province at a borrow pit.

Another example of the Pebble Marker, see Figure 66, is close to the New Machavie agricultural site (26°46'60"N, 26°49'0"E) in the North West province (B65 and B66). The underlying geology is mainly andalusitic lava. The Pebble Marker mainly consists of grain sizes up to 200 mm in diameter, mainly being quartz and chert grains. The chert present in the underlying geology may have been transported over a smaller distance or from weathered dolomite whereas the quartz was transported from longer distances away. The uniformity of the grains orientation indicates that this is not a fluvial deposit and thus supporting the hypothesis that grains were transported in a semi-glacial („slush“) environmental state and that a typical lag deposit was the results after the finer particles have been removed by wind during drought conditions.

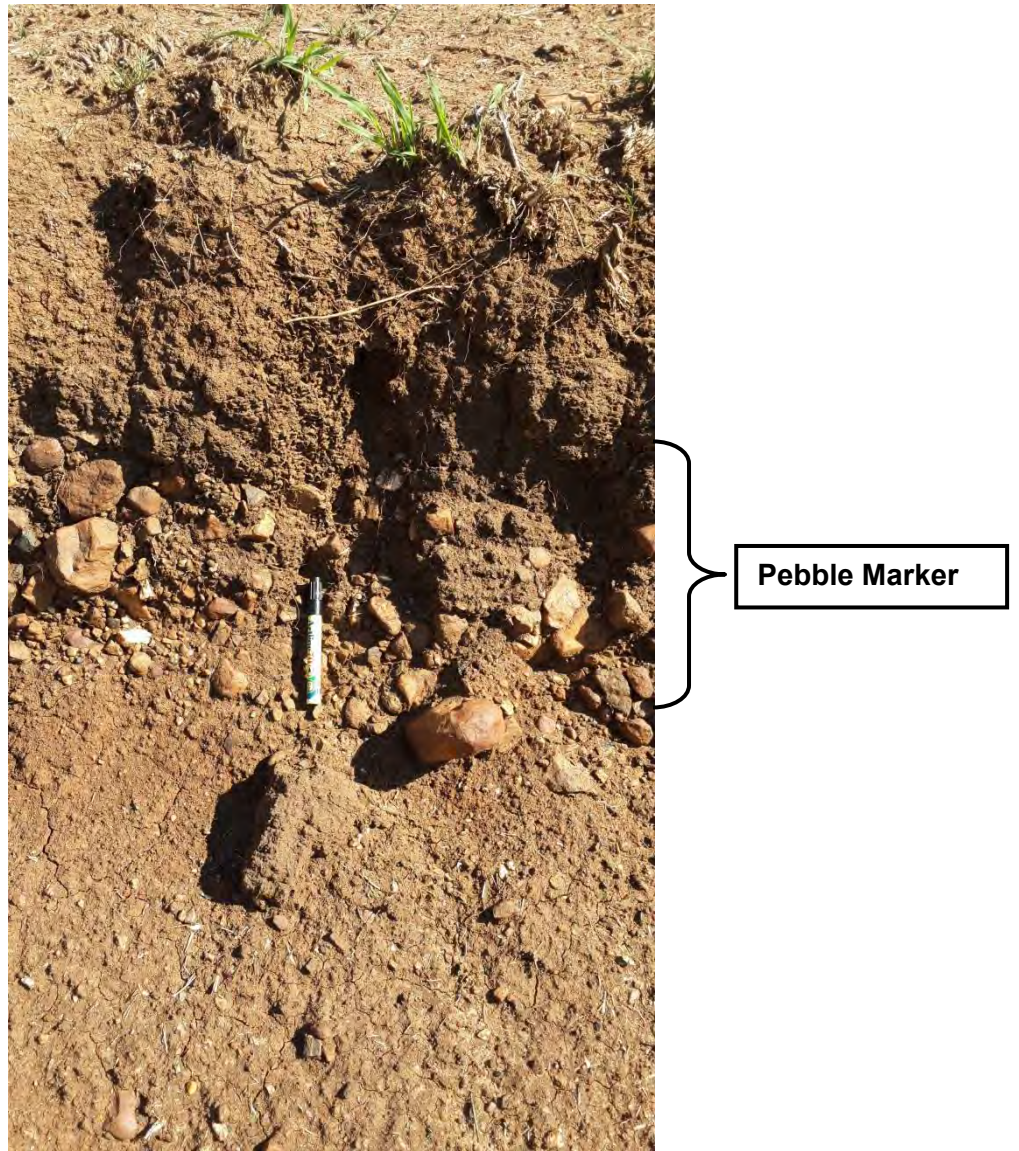


Figure 66: The Pebble Marker of New Machavie in the North-West province.

The particle size distribution (>2 mm) as seen in Figure 67, indicates that the pebble marker has an abundance of boulder sized particles (>130 mm) present.

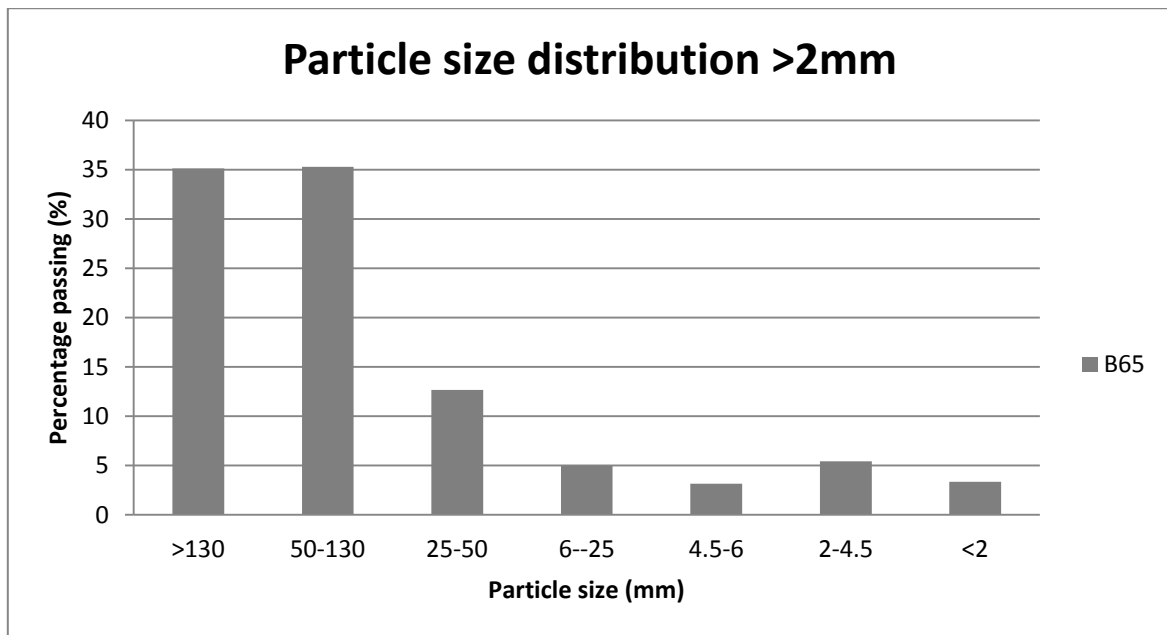


Figure 67: The particle size distribution (>2 mm) of the Pebble Marker located close to New Machavie in the North-West province.

4.4.3.1 Geotechnical characteristics

The Pebble Marker is a very important deposit to take into consideration from a geotechnical perspective. The layer, which improves drainage into the soil (Weinert, 1980), has to be sealed to prevent water from draining through. In the case of constructing a dam the Pebble Marker must be concealed to prevent drainage. The Pebble Marker can give information on the underlying geology (Brink and Bruin, 2002) but due to the fact that the transported Pebble Marker can contain various pebbles from different localities, it is not recommended to be used as the primary indicator to determine the underlying geology and risks.

4.4.4 Terrestrial sand deposits

The sand deposits of this section are divided into Kalahari and redistributed coastal sand deposits. Table 41 and 47 are selected Cenozoic aeolian sand deposits over South Africa. Scanning electron microscope analyses were done on selected samples and therefore only a few SEM images are included as examples. The geotechnical characteristics and element composition are included in Tables 41 and 47.

The main focus of the Kalahari sand deposit section is the windblown sand of the Gordonia Formation, but the Kalahari Group will be discussed below for stratigraphical significance, see Figure 68 and 69.

4.4.4.1 Kalahari Group

As stated by Haddon (2005), a few difficulties arise when trying to define the stratigraphy of the Kalahari Group. This is mainly due to the fact that the formations are not exposed at the surface as a result of the flat topography of the Kalahari areas. Therefore borehole logs and mine exposed areas as well as a few eroded river beds have been used as the base for determining the lithological units. This also has its own obstacles as the units may not correspond well to each other due to small sub-basins being filled with different sediments and resulting in lateral inconsistency. The formations illustrated in Figure 68 and 69 are the general formations of the Kalahari Group.

The general stratigraphy of the Kalahari group was discussed by Thomas (1981) and used by Partridge *et al.*, (2006). The stratigraphy and lithology of the Kalahari Group were recorded by three borehole logs in the Vergeleë region in the North West province (Figure 69) and compared to the section (Figure 68) used by Partridge *et al.*, (2006).

Partridge *et al.*, (2006:591) and Haddon (2005:87) state that the Kalahari Group is divided into the Wessels, Budin, Eden, Mokalanen, Obobogorop, Gordonia and Lonely Formations. Wessels Formation, being the oldest and Lonely Formation (not included in Figure 69) being the youngest formation. Haddon (2005:87) mainly discussed the basal gravels (Wessels Formation), clay (Budin Formation), sandstone (Eden Formation) and unconsolidated sand (Gordonia Formation) formations. Figure 68 indicates that the base of the succession was Pre-Kalahari rocks and Figure 69, in the Vergeleë region, dolomite is the basal geology.

The Wessels Formation consists of clayey gravel which has a wide geographical extent and mainly occurs where the Kalahari is at its thickest, up to 120 m along the southern edge of the basin, but this is not a rule (Partridge *et al.*, 2006 and Haddon 2005). In Figure 69 the gravel associated with the Wessels Formation seems to be absent but the clay component is present as well as calcium carbonate concretions. The concretions may be derived from Ca enriched soil water.

The Budin Formation, has a wide distribution and mostly associated with pre-Kalahari trenches. This formation consists of red-brown, or pink to red, calcareous clays and may have pebbles located at the base. Silcrete or calcrete layers can be present in some locations and the silt and sand content can also vary. This formation is associated with palaeo-shallow lakes with a high salinity and covers the Kalahari floor if the Wessels Formation is absent (Partridge *et al.*, 2006:591 and Haddon, 2005:87). In some localities the clay deposits may have formed due to weathering of the underlying geology (Farr *et al.*, 1981; Bootsman, 1998 used by Haddon,

2005). Figure 69 contains red clay layers with pebbles and correlated well with the description of the Budin Formation in Figure 68, except containing calcareous clays.

The Eden Formation consists of sandstone of various colours such as red, brown or yellow and includes thin pebble layers. The sandstones are poorly consolidated and become more disaggregated and less calcified to the top of the profile. Biotubes filled with sand are characteristic of Eden Formation where the beds are even weaker consolidated (Partridge *et al.*, 2006). Haddon (2005) states that many of the sandstones are silcretised or calcretised. The braided palaeostreams were probably responsible for deposition of this formation. Figure 69 corresponds to the Eden Formation as the field observation indicated that lithology was silcrete. See Table 56 for silcrete analytical results.

The Mokalanen Formation consists of calcretes. This formation can be linked to the transition from the Pliocene to the Quaternary and the palaeoclimate being warmer and more arid than underlain fluvial formation. This could be linked to the global aridification that took place 2.8-2.6 Ma ago. The base of the formation consists of sandy limestone and the top conglomerates with a calcareous matrix. The sandy limestone has undergone silcretisation at various localities. Figure 69 does not correspond well with this formation.

The Obobogroup Formation consists of pebbles and boulders derived from the erosion of the Dwyka tillite. Figure 69 does not correspond well with this formation.

The Gordonia Formation at the top of the Kalahari Group (Figure 68) consists of aeolian sand, mainly rounded quartz grains. The grains are mainly red, having a hematite coating, but can be white due to the haematite being removed through fluvial activity. The formation can be as thick as 30 m and mainly rests on calcrete but also on pre-Kalahari bedrock. The origin is stated to be from local sources. Linear dunes are a characteristic feature of the Gordonia Formation and are linked to Early Pleistocene of Late Pliocene Age. Figure 69 corresponds well with this formation.

The Lonely Formation, not included in Figure 68, consists of diatomaceous limestone. The limestone has a low density and is fossiliferous. This formation has been deposited in shallow lakes of freshwater (Partridge *et al.*, 2006).

4.4.4.2 Kalahari sand

Kalahari sand samples were collected at various localities over South Africa as indicated in the compiled map (Figure 18). The locality, site description, geotechnical characteristics and element composition are discussed for each sample collected as mentioned in Table 41. The scanning electron microscope results are discussed for selected samples as well as the agriculture potential.

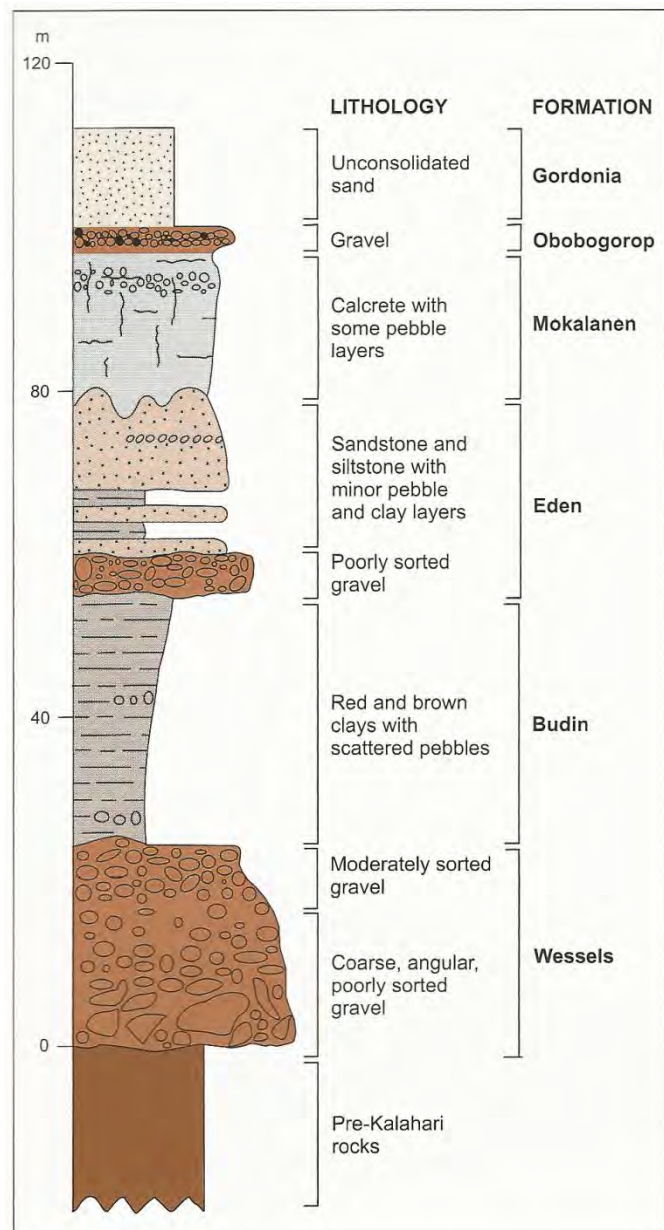


Figure 68: The Kalahari Group section described by Thomas (1981) and used by Partridge *et al.*, (2006).

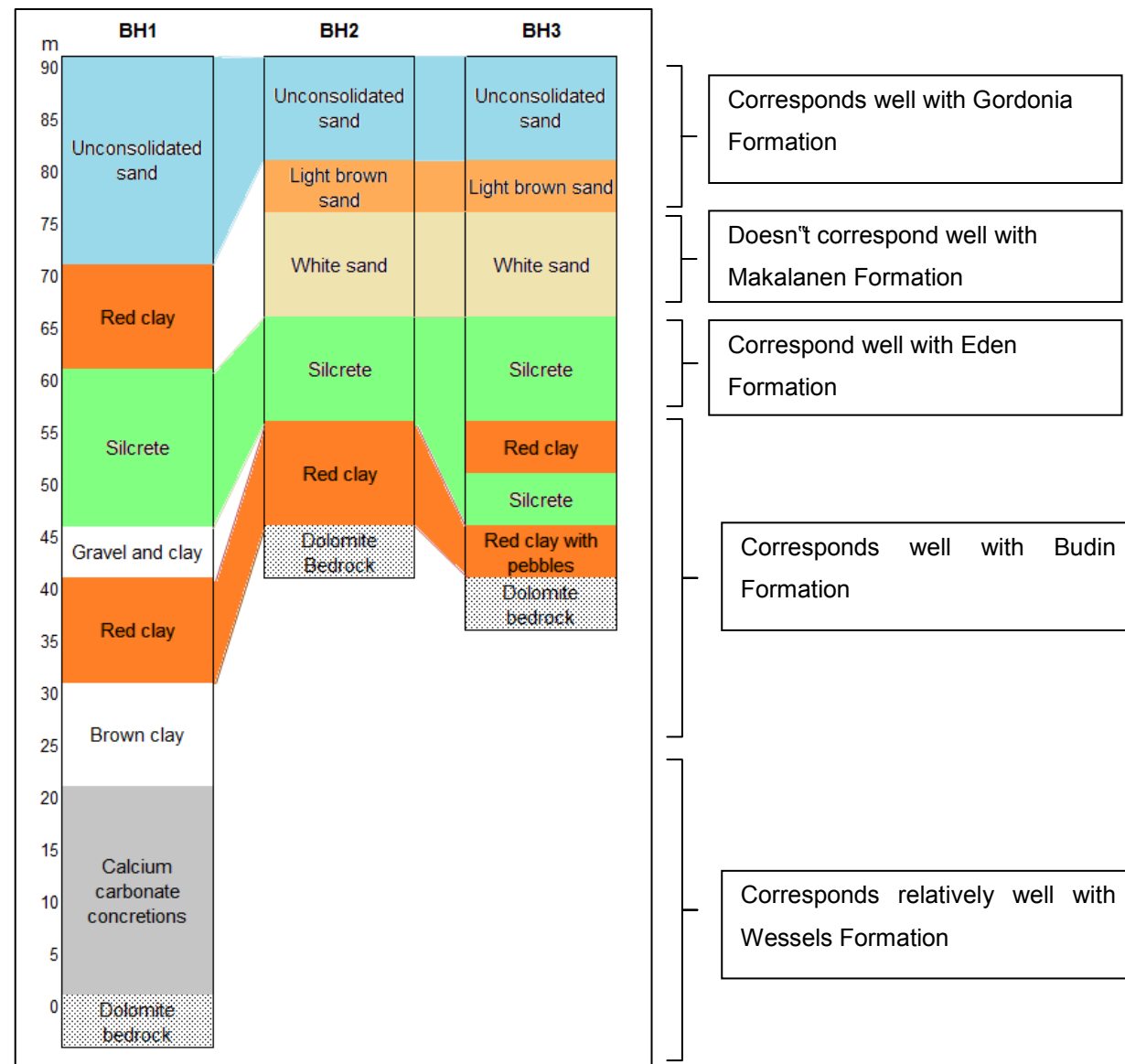


Figure 69: The Kalahari Group section as recorded, in this research, from three borehole logs in the Vergeleë region, Kalahari.

Table 41: Selected aeolian Kalahari sand deposits of South Africa including site descriptions, geotechnical implications and composition.

Sample number	Locality, site description and stratigraphy	Scanning Electron Microscope analyses	Geotechnical and other characteristics	Element composition (Portable XRF results) (Only the 8 highest elements are indicated, see Appendix B for full analytical results)																
B30	Kalahari sand, Windsorton, Northern Cape Kalahari sand A-horizon is 1-2 m thick on a yellow sand horizon followed by gravel layers to the base of the profile.	Not analysed	pH: 8.7(H ₂ O), 7.7 (KCl) EC= 25 mS/m. Angle of repose:30° Linear shrinkage: 2.12% OC (Organic carbon)=0.62% Texture class: Loamy fine sand	Results in ppm PXRF <table><tr><td>Si</td><td>Al</td><td>Ca</td><td>Fe</td></tr><tr><td>228168</td><td>51931</td><td>41486</td><td>35679</td></tr><tr><td>K</td><td>Ti</td><td>P</td><td>Mn</td></tr><tr><td>7085</td><td>3445</td><td>838</td><td>759</td></tr></table>	Si	Al	Ca	Fe	228168	51931	41486	35679	K	Ti	P	Mn	7085	3445	838	759
Si	Al	Ca	Fe																	
228168	51931	41486	35679																	
K	Ti	P	Mn																	
7085	3445	838	759																	
B40	Koa sand dunes from Aggeneys in the Northern Cape		pH =8 (H ₂ O), 6.4 (KCl) EC=15 mS/m. Angle of repose:30.6° Linear shrinkage: 0% OC=0.13% Textural class: Fine sand	Results in ppm PXRF <table><tr><td>Si</td><td>Al</td><td>K</td><td>Fe</td></tr><tr><td>280510</td><td>74394</td><td>23296</td><td>12205</td></tr><tr><td>Ti</td><td>S</td><td>Mn</td><td>Rb</td></tr><tr><td>1684</td><td>709</td><td>305</td><td>223</td></tr></table>	Si	Al	K	Fe	280510	74394	23296	12205	Ti	S	Mn	Rb	1684	709	305	223
Si	Al	K	Fe																	
280510	74394	23296	12205																	
Ti	S	Mn	Rb																	
1684	709	305	223																	

Table 41 (cont): Selected aeolian Kalahari sand deposits of South Africa including site descriptions, geotechnical implications and composition.

Sample number	Locality, site description and stratigraphy	Scanning Electron Microscope analyses	Geotechnical and other characteristics	Element composition (Portable XRF results)			
B42	Kalahari sand from Groblershoop in the Northern Cape		pH =7.9(H ₂ O), 6.5 (KCl) EC=9 mS/m. Angle of repose: 28.8° Linear shrinkage: 0% OC=1.33% Textural class: Fine sand	(Only the 8 highest elements are indicated, see Appendix B for full analytical results)			
				Results in ppm PXRF			
				Si	Al	Fe	K
				346215	52168	12180	2319
				Ti	S	Zr	Mn
				1624	424	128	115

Table 41 (cont): Selected aeolian Kalahari sand deposits of South Africa including site descriptions, geotechnical implications and composition.

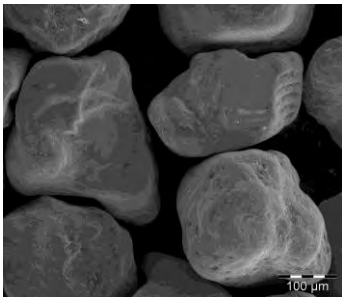
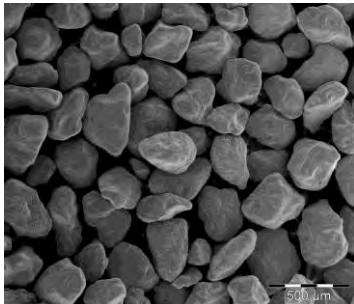
Sample number	Locality, site description and stratigraphy	Scanning Electron Microscope analyses	Geotechnical and other characteristics	Element composition (Portable XRF results)													
B44 B53	„Brulsand“ sample from Witsand Nature Reserve in the Northern Cape	 Figure 70: Sand particles viewed under a Scanning Electron Microscope (SEM) (500 μm)	pH =7.7 (H ₂ O), 5,5 (KCl) EC=3 mS/m. Angle of repose:28.5° Linear shrinkage: 0% OC=0.21% Texture class: Fine sand	(Only the 8 highest elements are indicated, see Appendix B for full analytical results)													
		 Figure 71: Sand particles viewed under a Scanning Electron Microscope (SEM) (100 μm)		Results in ppm PXRF <table><tr><td>Si</td><td>Al</td><td>Fe</td><td>S</td></tr><tr><td>394405</td><td>20994</td><td>2107</td><td>564</td></tr><tr><td>Ti</td><td>Zr</td><td>Mo</td><td>Rb</td></tr><tr><td>460</td><td>78</td><td>6</td><td>4</td></tr></table>	Si	Al	Fe	S	394405	20994	2107	564	Ti	Zr	Mo	Rb	460
Si	Al	Fe	S														
394405	20994	2107	564														
Ti	Zr	Mo	Rb														
460	78	6	4														

Table 41 (cont): Selected aeolian Kalahari sand deposits of South Africa including site descriptions, geotechnical implications and composition.

Sample number	Locality, site description and stratigraphy	Scanning Electron Microscope analyses	Geotechnical and other characteristics	Element composition (Portable XRF results) (Only the 8 highest elements are indicated, see Appendix B for full analytical results)		
B45	Witsand from Witsand Nature Reserve, Northern Cape. Sample collected from white dunes. 	Not analysed	pH =6.7 (H ₂ O), 5 (KCl) EC=3 mS/m. Angle of repose:28.9° Linear shrinkage: 0% OC=0.20% Texture class: Fine sand	Results in ppm PXRF		
	Si			Al	Fe	Ti
	415323			24232	1510	583
	S			Zr	Rb	Sr
	418			30	3	1
Figure 72: Sample being collected from Witsand Nature reserve						

Table 41 (cont): Selected aeolian Kalahari sand deposits of South Africa including site descriptions, geotechnical implications and composition.

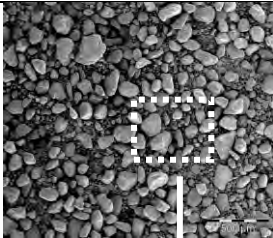
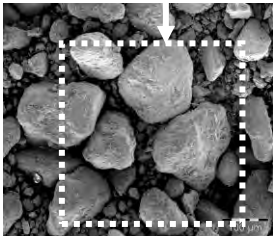
Sample number	Locality, site description and stratigraphy	Scanning Electron Microscope analyses	Geotechnical and other characteristics	Element composition (Portable XRF results) (Only the 8 highest elements are indicated, see Appendix B for full analytical results)													
B54	Kalahari sand from Borrow-pit Schweizer Reneke in the North-West Province.	 a	pH =6.5 (H ₂ O), 5.4 (KCl) EC=69 mS/m. Angle of repose:30° See Figure 77 below for water retention Linear shrinkage: 0% OC=0.21% Texture class: Fine sand	Results in ppm PXRF													
		 b		<table><tr><td>Si</td><td>Al</td><td>Fe</td><td>K</td></tr><tr><td>287240</td><td>69456</td><td>20410</td><td>11556</td></tr><tr><td>Ti</td><td>S</td><td>Zr</td><td>Mn</td></tr><tr><td>3515</td><td>606</td><td>243</td><td>223</td></tr></table>	Si	Al	Fe	K	287240	69456	20410	11556	Ti	S	Zr	Mn	3515
Si	Al	Fe	K														
287240	69456	20410	11556														
Ti	S	Zr	Mn														
3515	606	243	223														

Table 41 (cont): Selected aeolian Kalahari sand deposits of South Africa including site descriptions, geotechnical implications and composition.

Sample number	Locality, site description and stratigraphy	Scanning Electron Microscope analyses	Geotechnical and other characteristics	Element composition (Portable XRF results) (Only the 8 highest elements are indicated, see Appendix B for full analytical results)				
B77	Kalahari sand from Vergeleë in the North-West province	Not analysed	pH =8.3 (H ₂ O), 7 (KCl) EC=11 mS/m.	Results in ppm PXRF				
			Angle of repose:29°	<table><tr><td>Si</td><td>Al</td><td>Fe</td><td>Ti</td></tr></table>	Si	Al	Fe	Ti
			Si	Al	Fe	Ti		
			Linear shrinkage: 0%	<table><tr><td>325268</td><td>38583</td><td>8887</td><td>1517</td></tr></table>	325268	38583	8887	1517
			325268	38583	8887	1517		
OC=0.37%	<table><tr><td>S</td><td>Zr</td><td>Mn</td><td>Rb</td></tr></table>	S	Zr	Mn	Rb			
S	Zr	Mn	Rb					
Texture class: Fine sand	<table><tr><td>770</td><td>111</td><td>62</td><td>14</td></tr></table>	770	111	62	14			
770	111	62	14					
			See Table 43 below for Atterberg limits					

Scanning Electron Microscope analyses

Selected samples (B44 and B54) were analysed under a SEM. This allowed the surface features of the particles to be examined. The rounded shape and the surface textures of the soil particle as well as the overall uniform size of the deposit indicate wind transportation (Boggs: 2011:60), as shown in Figure 70 and 71, 73 a, b, c,

Geotechnical characteristics

The pH of the sand samples varies between 6.5 (B54) and 8.7 (B30). The EC values vary between 3 mS/m (B45, B53) and 69 mS/m, see Figure 74.

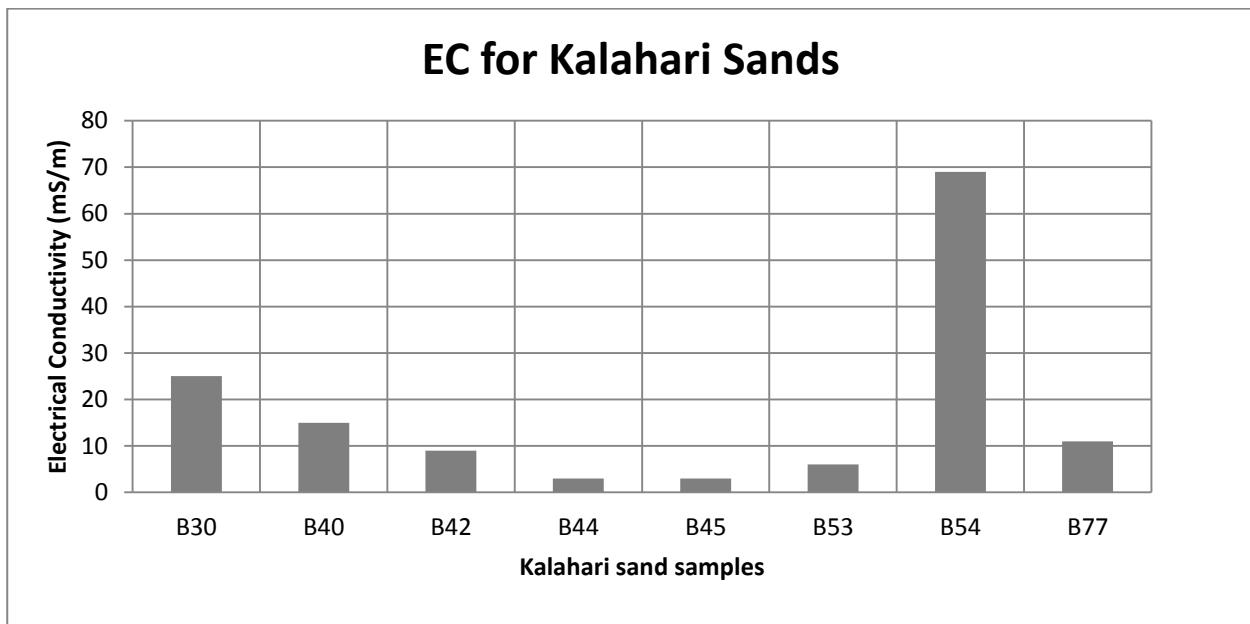


Figure 74: The electrical conductivity of the Kalahari sand deposits

Angle of repose is used to evaluate the slope stability of different soil types. Slope failure can be a time consuming process or occur rapidly mainly due to temperature fluctuation such as heating or cooling. The collapsibility of soils also depends on water content; small amount of water increases the cohesion, where large volumes decreases the friction and increases pore spaces resulting in slope failure. The sand samples collected have low slope stability and will be influenced by temperature fluctuations as well as water content variations. The samples B30, B44, B53, B45, B54 and B77 have angles in the range between 25-30°. The sample B40 is in the 30-38° range, which indicates that the sand deposit has a potential to be collapsible when exceeding this angle, see Table 42. Chanson (2004:165) states that the typical angle of repose for sand sediments are between 26° - 34° and corresponds to most of the samples collected.

Table 42: Flow behaviour determined from the angle of repose measured in degree for all the Kalahari sand samples.

Samples	Angle of repose
B30, B44, B53, B45, B54, B77, B41, B42,	25-30°
B40	30-38°

All sand samples have a linear shrinkage percentage of 0%, which indicates that the deposits do not have potential to shrink or swell with varying conditions such as temperature fluctuations or water variations. The Organic Carbon contents of the samples vary from 0.13% (B40) to 0.62% (B30). The high OC value of B30 is higher than the threshold value of 0.5% OC, and can be due to the higher clay content as indicated in the textural class, see Figure 75, being loamy fine sand, as well as this sample having the highest CEC, as shown in Figure 78.

The Particle Size Distribution values were used to determine the texture classes of the sand samples by using the Soil Texture Calculator from the NRCS- USDA (United States Department of Agriculture, 2014) as seen in Figure 75. All of the samples are classified as sand except B30 which is classified as a loamy sand.

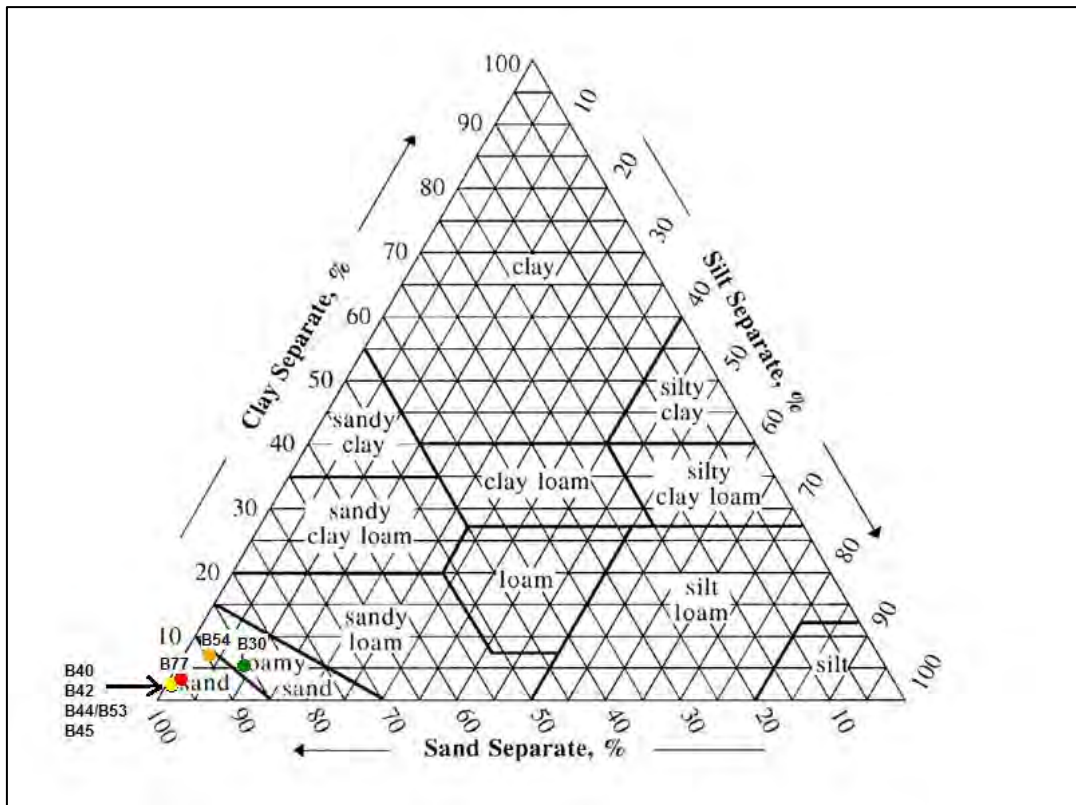


Figure 75: The textural classes of the Kalahari sand samples (Calculated from USDA-NRCS, 2014).

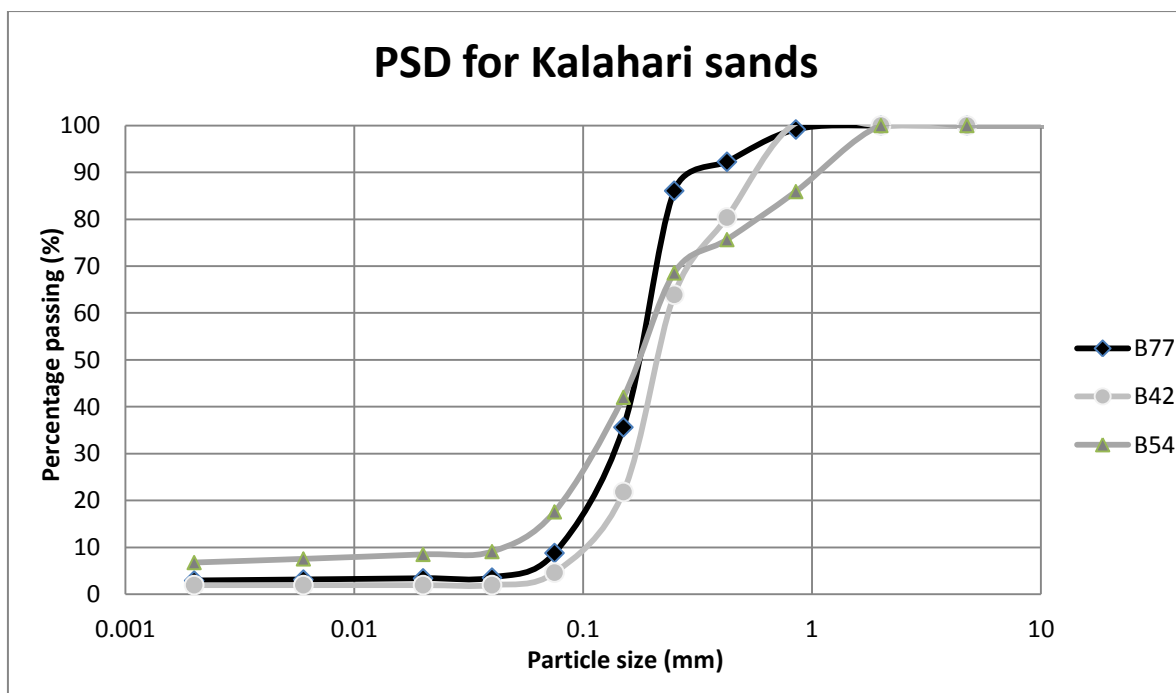


Figure 76: Particle size distribution for Kalahari sand samples, B77, B42 and B54

The Kalahari sand sample (B77) is located in the most central part of the Kalahari Desert relative to the other samples collected (Figure 18). This indicates that this sample could be seen as a good example of which the other samples could be compared to if necessary. Therefore only B42 and B54 were compared to this sample, see Figure 76. The particle size distribution of the collected Kalahari sand samples are all fine sand and it is clear that the sand is poorly graded, and well sorted, referring to uniform size. See Appendix D for full PSD analyses.

The Atterberg Limits (plastic and liquid limit as well as the plasticity index) was determined for B77 as an example for the Kalahari deposits (Table 43). This sample is classified as „slightly plastic“ using the classification system of Burmister (1949), see Atterberg Limits Method in Chapter 3.2.1.2. The plasticity Index compared relatively well to Table 44 taken from Brink (1985), who determined the Atterberg Limits for aeolian sand samples from the Welkom Area in the Free State Province.

Table 43: The Atterberg Limits (plastic and liquid limit as well as the plasticity index) for the Kalahari sand sample (B77)

Sample	Liquid limit (LL)	Plastic limit (PL)	Plasticity index (PI)
B77	52.1	49.07	3.03

Table 44: The Atterberg Limits for aeolian sands from the Welkom area, Free State Province (Brink, 1985)

	Liquid limit (LL)	Plasticity index
Mean	7.4	3.7
Number of tests	7	7

Agriculture potential

The agriculture potential or rather the cash crop production potential of a soil indicates the soils ability to be suitable for crops (MVSA, 2007). Aspects such as the plant available water (PAW) determined by using water retention curves, the EC and pH values must be evaluated to determine whether a crop is suitable for production. The criteria or threshold values at which the agricultural potential will be evaluated are indicated in Table 45.

Table 45: The threshold values used to determine the agricultural potential.

Agricultural factor	Threshold value
pH (H ₂ O)	Between 5 – 8.5 (MVSA, 2007)
EC (mS/m)	<360 mS/m (Van Deventer and Ferreira, 2013).
Plant Available Water also referred to as production crop water requirements.	High production: 450-650 mm/m (FAO, 2015).
Cation Exchange Capacity	Very low <6, low 6-12, moderate 12-25, high 25-40, very high >40 cmol(+)/kg (Hazelton and Murphy, 2007).
Organic carbon (%)	0.5 % organic carbon in South African soils (Du Preez <i>et al.</i> , 2011).

The water retention of B54, Kalahari sand from Schweizer Reneke in the North-West Province is determined as an example of the water retention for a Kalahari sand deposit (Figure 77). The dry bulk density of 1.6 g/cm³ was used according to Hillel (2004). The total saturation at 10 kPa decreases from 4.95% to 3.44% at wilting point (1500 kPa). This indicates that the water in the sand sample is leached out and would not be available for plants. The PAW is determined using Table 46. The textural class of the sample (Figure 75) is classified as sand and this indicates that the PAW is 5%. This was converted to mm/m using an excel sheet from Astrid Hatting (2015, pers. comm). An assumption was made that the profile was uniform in grain size and 1 m thick, see Appendix F. The threshold value of 450-650 mm/m for sorghum was used as sorghum is a drought resistant crop. This indicated that the profile of a meter thick contained 80 mm of water. This is very low and is not sufficient for crop production.

Table 46: Classified texture classes with the corresponding characteristic water values at no salinity, adjusted density and gravel at 2.5% organic matter (Saxton and Rawls, 2006).

Texture class†	Sand	Clay	Wilt pt.	Field cap	Saturation	Plant avail.	Saturated conductivity	Matric density
	— % w —		1500 kPa	33 kPa	0 kPa		mm h ⁻¹	g cm ⁻³
			% v					
Sa	88	5	5	10	46	5	108.1	1.43
LSa	80	5	5	12	46	7	96.7	1.43
SaL	65	10	8	18	45	10	50.3	1.46
L	40	20	14	28	46	14	15.5	1.43
SiL	20	15	11	31	48	20	16.1	1.38
Si	10	5	6	30	48	25	22.0	1.38
SaCL	60	25	17	27	43	10	11.3	1.50
CL	30	35	22	36	48	14	4.3	1.39
SiCL	10	35	22	38	51	17	5.7	1.30
SiC	10	45	27	41	52	14	3.7	1.26
SaC	50	40	25	36	44	11	1.4	1.47
C	25	50	30	42	50	12	1.1	1.33

† Sa, sand; L, loam; Si, silt; C, clay.

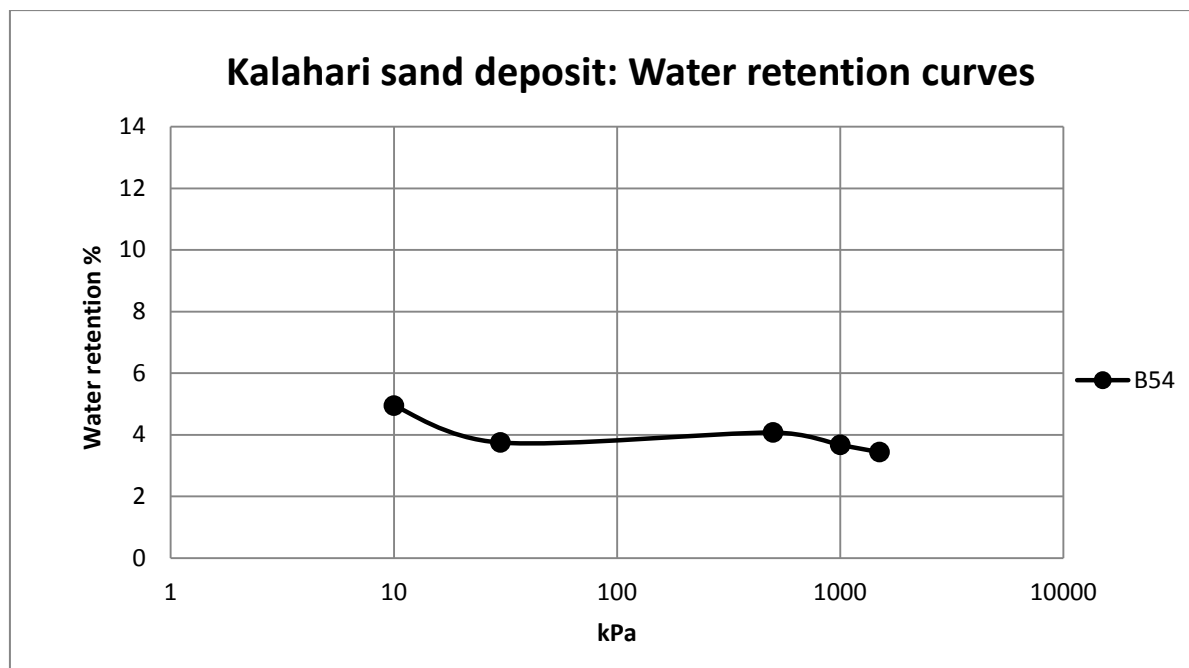


Figure 77: Water retention curves for a selected Kalahari sand sample from Sweizer Reneke in the North-West Province, South Africa.

The cation exchange capacity (CEC) varies from very low for B42, B44, B45 and B53, low for B40, B54 and B77 and moderate for B30, see Figure 78. This indicates that the soil does not have a good ability to provide nutrients to the plants (Brown and Lemon, 2015).

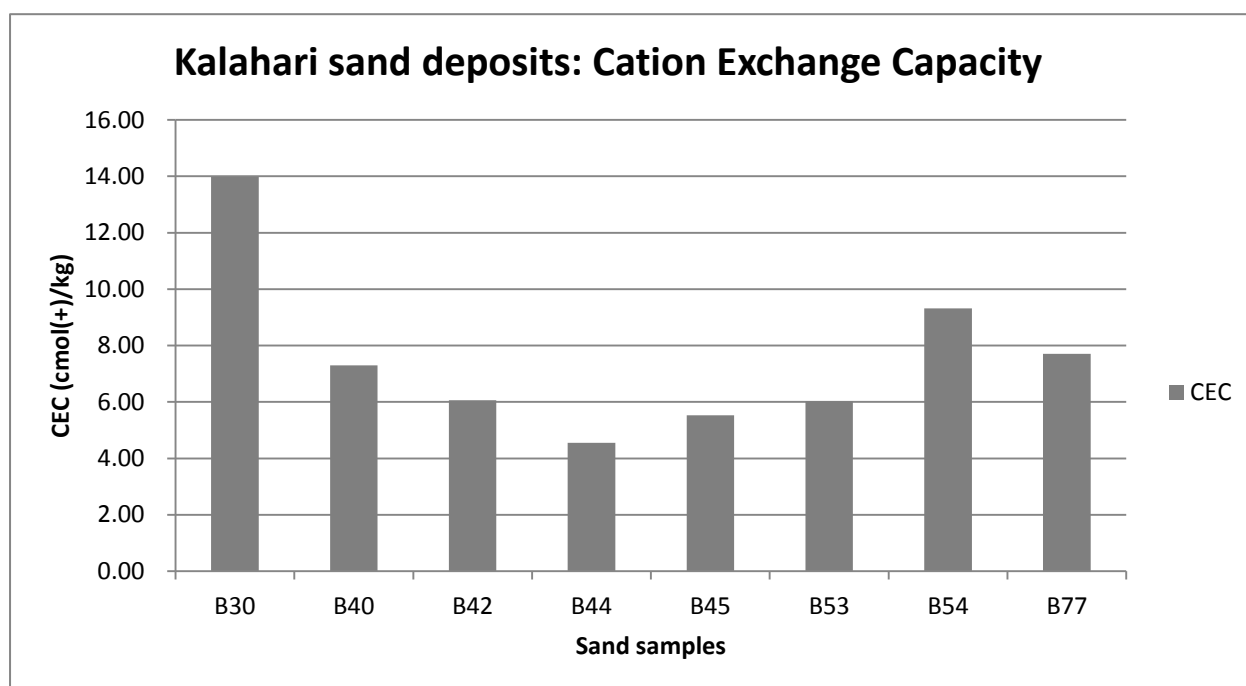


Figure 78: The Cation Exchange Capacity of the Kalahari sand deposits

It can be summarised that the Kalahari sand deposits have the potential to collapse when used to build on due to the sandy texture and void spaces (Brink, 1985:24). The agricultural potential is moderate due to low water retention and CEC, but can be used if good management practises are applied. The Kalahari sand deposits have a moderate tourism potential, as Witsand Nature Reserve in the Northern Cape is a good tourism attraction.

4.4.5 Redistributed coastal sands

The coastal sand section is only included in this research project because these are mainly redistributed coastal sand and can be used for comparison purposes relative to the terrestrial Kalahari sand. The samples were collected at various localities over South Africa as indicated in Figure 19. The locality, site description, geotechnical characteristics and element composition are discussed in Table 47. The SEM results are discussed for selected samples as well as the agriculture potential.

SEM analyses

The selected sample (B4) was observed with a SEM microscope, see Figures 79 and 80. This allowed the surface features of the particles to be examined. The conchoidal patterns on the particle surfaces mainly correspond to beach or near shore environments (Boggs, 2011). Some particles seem to be more rounded. This may indicate that the particles have been wind transported after water transportation took place.

Geotechnical characteristics

The pH of the sand samples varies between 7.3 (B4) and 9.4 (B9). The EC values vary between 8 mS/m (B5) to 93 mS/m (B2) as seen in Figure 81.

The sand samples collected have low slope stability, see Table 48, and will be influenced by temperature fluctuations as well as water content variations. The samples B5 and B9 are in the 25-30° category and samples B1, B2, B4, B6 and B7 are in the 30-38° category and have the potential to collapse when disturbed.

Table 47: Selected Cenozoic coastal sand deposits of South Africa including site descriptions, geotechnical implications and geochemical composition.

Sample number	Locality, site description and stratigraphy	SEM and origin	Geotechnical and other characteristics	Element composition (Portable XRF) (Only the 8 highest elements are indicated, see Appendix B for full analytical results)																
B1	Redistributed coastal sand between Loeriesfontein and Kliprand, Northern Cape. The coastal sand horizon overlays a red soil horizon on a dorbank.	Not analysed	pH =8.5 (H2O), 7 (KCl) EC= 23 mS/m Angle of repose:31° See Figure 84 below for water retention Linear shrinkage: 0% OC=0.40% Texture class: Sand	Results are in ppm PXRF <table><tr><td>Si</td><td>Al</td><td>K</td><td>Fe</td></tr><tr><td>286333</td><td>80365</td><td>32555</td><td>28038</td></tr><tr><td>Ti</td><td>Ca</td><td>P</td><td>V</td></tr><tr><td>4583</td><td>2549</td><td>1065</td><td>410</td></tr></table>	Si	Al	K	Fe	286333	80365	32555	28038	Ti	Ca	P	V	4583	2549	1065	410
Si	Al	K	Fe																	
286333	80365	32555	28038																	
Ti	Ca	P	V																	
4583	2549	1065	410																	
B2	Coastal sand close to Leliefontein, Northern Cape	Not analysed	pH =7.7 (H ₂ O), 7.1 (KCl) EC=93 mS/m. Angle of repose:34° Linear shrinkage: 0% OC=0.63% Texture class: Sand	Results in ppm PXRF <table><tr><td>Si</td><td>Al</td><td>Fe</td><td>K</td></tr><tr><td>246643</td><td>69832</td><td>20455</td><td>27442</td></tr><tr><td>Ti</td><td>S</td><td>Rb</td><td>Zr</td></tr><tr><td>2955</td><td>1037</td><td>273</td><td>233</td></tr></table>	Si	Al	Fe	K	246643	69832	20455	27442	Ti	S	Rb	Zr	2955	1037	273	233
Si	Al	Fe	K																	
246643	69832	20455	27442																	
Ti	S	Rb	Zr																	
2955	1037	273	233																	

Table 47 (cont): Selected Cenozoic coastal sand deposits of South Africa including site descriptions, geotechnical implications and geochemical composition.

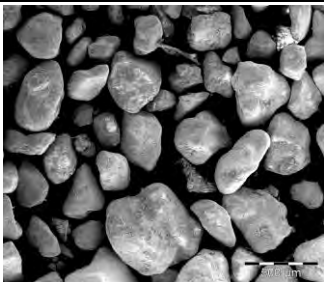
Sample number	Locality, site description and stratigraphy	SEM and origin	Geotechnical and other characteristics	Element composition (Portable XRF results)													
B4	Coastal sand sample from the site north east of Koingnaas in the Northern Cape.		pH =7.3 (H ₂ O), 6.8 (KCl) EC=34 mS/m. Angle of repose:33.2° Linear shrinkage: 0% OC=0.53% Texture class: Sand	(Only the 8 highest elements are indicated, see Appendix B for full analytical results)													
		Figure 79: Sand particles viewed under a SEM (500µm).  Figure 80: A single sand particle viewed under a SEM (100 µm).		Results in ppm PXRF <table><tr><td>Si</td><td>Al</td><td>Fe</td><td>K</td></tr><tr><td>332015</td><td>56161</td><td>10071</td><td>9642</td></tr><tr><td>Ti</td><td>S</td><td>P</td><td>Zr</td></tr><tr><td>1533</td><td>957</td><td>710</td><td>170</td></tr></table>	Si	Al	Fe	K	332015	56161	10071	9642	Ti	S	P	Zr	1533
Si	Al	Fe	K														
332015	56161	10071	9642														
Ti	S	P	Zr														
1533	957	710	170														

Table 47 (cont): Selected Cenozoic coastal sand deposits of South Africa including site descriptions, geotechnical implications and geochemical composition.

Sample number	Locality, site description and stratigraphy	SEM and origin	Geotechnical and other characteristics	Element composition (Portable XRF results)
				(Only the 8 highest elements are indicated, see Appendix B for full analytical results)
B5	Coastal sand sample (white dominant colour) from a dune between Springbok and the coast, in the Northern Cape	Not analysed	pH =7.6 (H ₂ O), 6.7 (KCl) EC=8 mS/m. Angle of repose:28.6° Linear shrinkage: 0% OC=0.21% Texture class: Sand	Results in ppm
				PXRF
B6	Coastal sand sample (white dominant colour) from a dune between Springbok and the sea, in the Northern Cape. (Same locality as B5)	Not analysed	pH =7.3 (H ₂ O), 6.5 (KCl) EC=34 mS/m. Angle of repose:32.3° Linear shrinkage: 0% OC=0.25% Texture class: Sand	Results in ppm
				PXRF

Table 47 (cont): Selected Cenozoic coastal sand deposits of South Africa including site descriptions, geotechnical implications and geochemical composition.

Sample number	Locality, site description and stratigraphy	SEM and origin	Geotechnical and other characteristics	Element composition (Portable XRF results) (Only the 8 highest elements are indicated, see Appendix B for full analytical results)																
B7	Coastal sand sample from a dune, North of Port Nolloth, North-western Cape. The base of the profile was a silcrete/calcrete layer followed by a silcrete conglomerate layer and then by a calcrete horizon with the sand horizon on top.	Not analysed	pH =9.3(H ₂ O), 8.7 (KCl) EC=20 mS/m. Angle of repose:31.9° See Figure 84 below for water retention Linear shrinkage: 0% OC=0.20% Texture class: Sand	Results in ppm PXRF <table><tr><td>Si</td><td>Ca</td><td>Al</td><td>Mg</td></tr><tr><td>288171</td><td>35596</td><td>24091</td><td>22186</td></tr><tr><td>K</td><td>Fe</td><td>Ti</td><td>S</td></tr><tr><td>9473</td><td>5623</td><td>936</td><td>865</td></tr></table>	Si	Ca	Al	Mg	288171	35596	24091	22186	K	Fe	Ti	S	9473	5623	936	865
Si	Ca	Al	Mg																	
288171	35596	24091	22186																	
K	Fe	Ti	S																	
9473	5623	936	865																	
B9	Most western red sand dunes, approximately 30 km away from sea, Northern Cape.	Not analysed	pH =9.4(H ₂ O), 8.4 (KCl) EC=64mS/m. Angle of repose:29.8° Linear shrinkage: 0% OC=0.19% Texture class: Sand	Results in ppm PXRF <table><tr><td>Si</td><td>Al</td><td>Fe</td><td>K</td></tr><tr><td>311522</td><td>49403</td><td>17670</td><td>15583</td></tr><tr><td>Mg</td><td>Ti</td><td>P</td><td>S</td></tr><tr><td>14475</td><td>2829</td><td>857</td><td>536</td></tr></table>	Si	Al	Fe	K	311522	49403	17670	15583	Mg	Ti	P	S	14475	2829	857	536
Si	Al	Fe	K																	
311522	49403	17670	15583																	
Mg	Ti	P	S																	
14475	2829	857	536																	

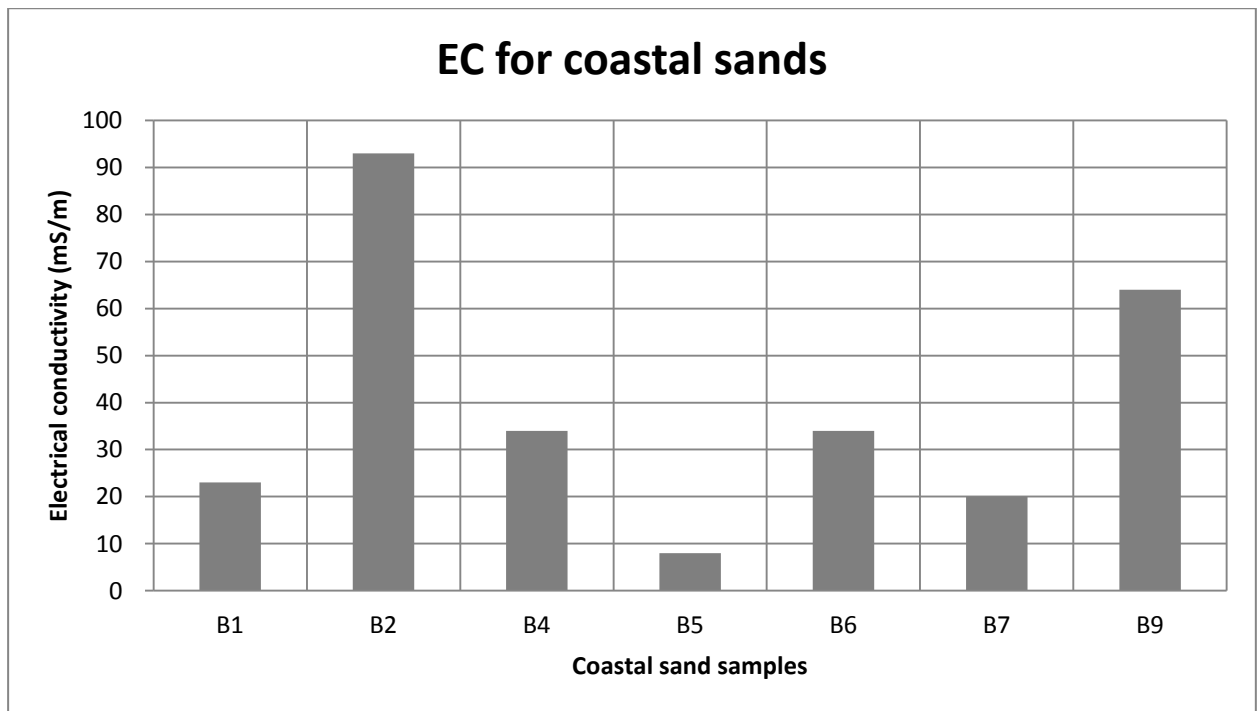


Figure 81: The electrical conductivity of the redistributed coastal sand.

Table 48: The angle of repose for the coastal sand deposits of South Africa.

Samples	Angle of repose
B5, B9	25-30°
B1,B2, B4, B6,B7	30-38°

All sand samples have a linear shrinkage percentage of 0%, which indicates that the deposits do not have potential to shrink or swell with varying conditions such as temperature fluctuations or water variations. The organic carbon content of the samples varies from 0.19% (B9) to 0.64% (B2). The high OC value of B30 is higher than the threshold value of 0.5% OC.

The particle size distribution values were used to determine the texture classes of the sand samples by using the Soil Texture Calculator from the NRCS- USDA (United States Department of Agriculture, 2014) as seen in Figure 82. All the samples are classified as sand textural class. In Figure 82 the graph indicates that all the samples are in the sand texture class, only B4, B9, B1 and B2 are presented in the graph as they overlap B5, B6 and B7.

The particle size distribution of the coastal sand samples indicates that the sand is poorly graded and well sorted, as seen in Figure 83.

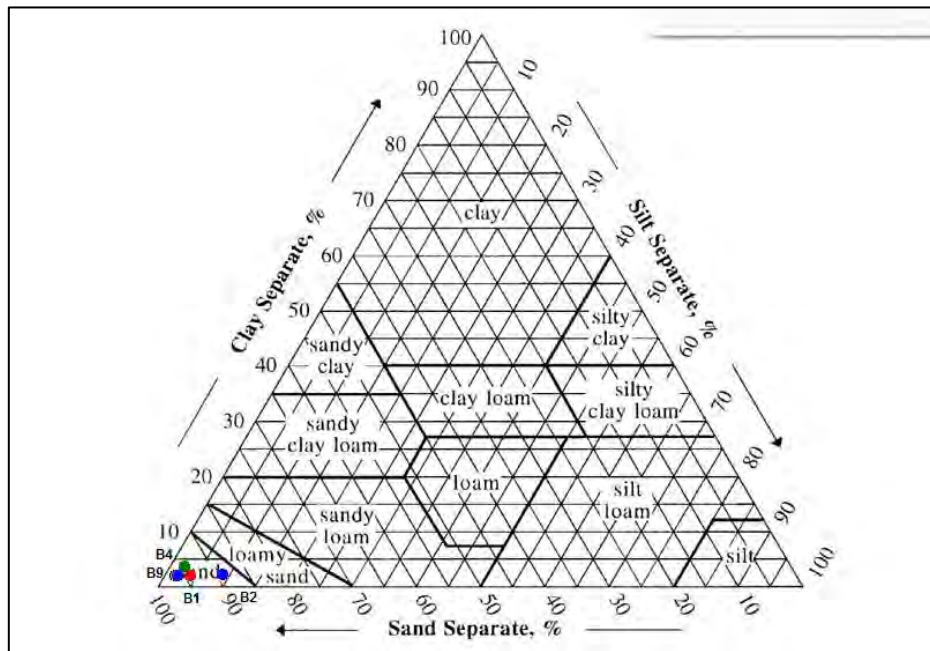


Figure 82: The textural classes of the coastal sand samples (Calculated from USDA-NRCS, 2014).

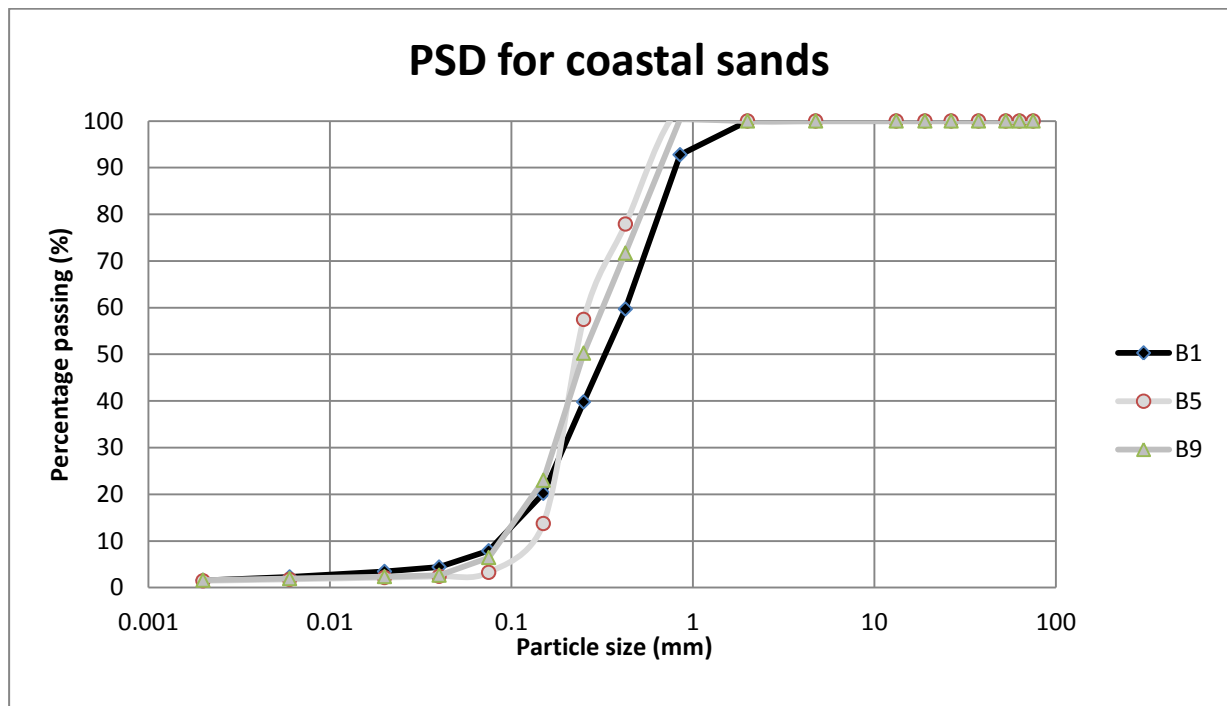


Figure 83: Particle size distribution for redistributed coastal sand samples, B1, B5 and B9.

Agriculture potential

The water retention of two selected sand samples were determined i.e. B1 and B7. Water retention percentage of B1 decreased from 6.76% to 2.87% and B7 gradually decreased from

7.4% to 3.23%. The water in all the sand samples was leached out and was not available to plants for absorption. A dry bulk density of 1.6 g/cm^3 was used (Hillel, 2004:13). The PAW is determined using Table 46. The textural class of the samples (Figure 82) is sand. This indicates that the samples have 5% PAW at 1500 kPa pressure. This value expressed in % was converted to mm/m using an excel sheet form Astrid Hatting (pers. Comm., 2015). The assumptions were made that the profile was uniform in grain size and 1 m thick, see Appendix F. The threshold value of 450-650 mm/m for sorghum was used as sorghum is a drought resistant crop. This indicated that the profile of a meter thick contained 80 mm of water. This is very low and is not sufficient for crop production. Water retention curves for two selected coastal sand samples in South Africa are indicated in Figure 84. See Figure 19 indicating the localities of these samples.

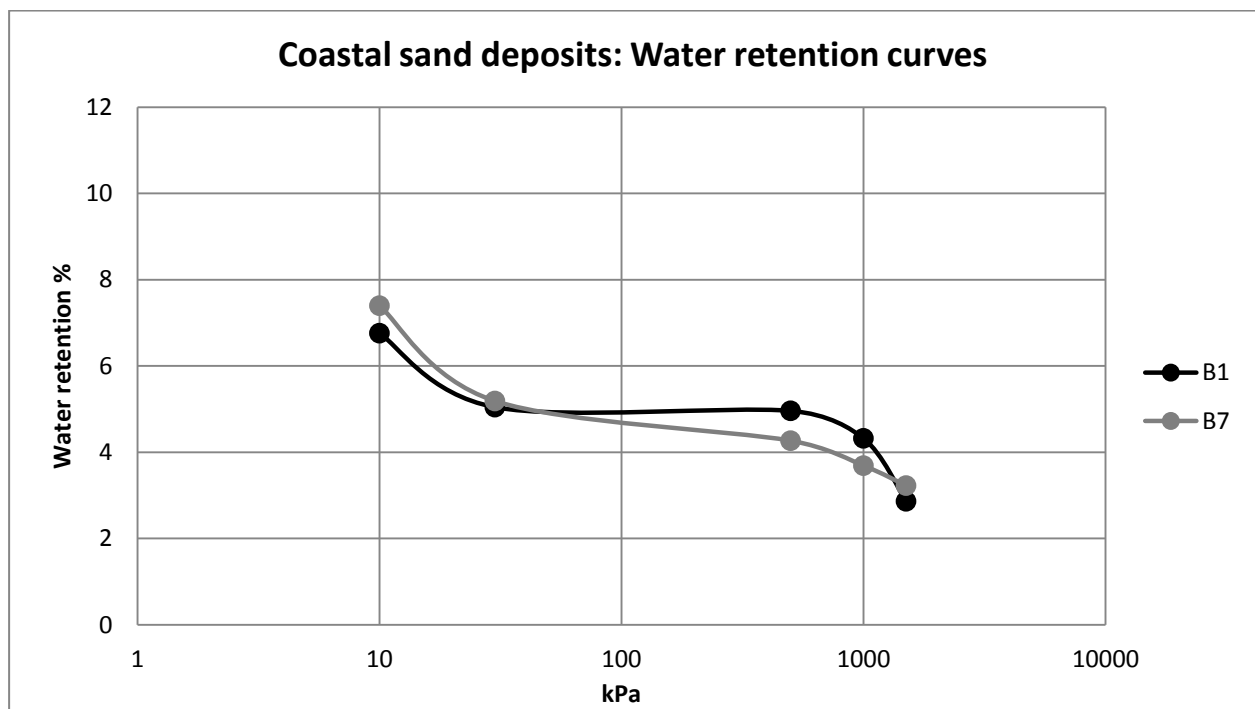


Figure 84: Water retention curves for two selected coastal sand samples from South Africa.

It can be summarised that the coastal sand deposits have the potential to collapse when used as a foundation to build on. These deposits have a low water retention potential and CEC, which results in a low agricultural potential. The results of the coastal and Kalahari sand deposits are therefore relatively similar.

4.4.5 Drainage depressions

Selected drainage depressions were sampled in South Africa from Allanridge and Viljoenskroon in the Free State, Bloemhof, Stilfontein and Tosca in the North-West, Windsorton and Verneukpan, close to Kenhardt, in the Northern Cape and Steenbokpan saltpan in Limpopo province. All sample localities are indicated in Figure 20. The site descriptions and physical and geochemical characteristics are discussed in Table 49.

Drainage depressions in the Northern Cape are associated with Kalahari sand, Ecca shale and Kimberlite, which weather easily and form pans. This may be the case in Windsorton (B47, B48, B50, B51 and B55) and Verneukpan, close to Kenhardt, in the Northern Cape. Dolomitic bedrock, such as for the pan located close to Stilfontein in the North-West (B13), can subsidise and form pans (Marshall and Harmse, 1992). This may not be the only reason for the formation of the pan in Stilfontein, but may have formed due to the weathering of the underlying dolomite bedrock or the weathering of a shale lens found in this area. Verneukpan (CX) is situated in a palaeodrainage of the Gariep -Vaal system of the Northern Cape.

Geotechnical characteristics

The pH of the sand samples varies between 4.8 (B48) and 10.2 (B84). The EC values vary between 9 mS/m (B83) and 8230 mS/m (B84), see Figure 89. The EC high values of B59 (Voëlpan) and B62 (Viljoenskroon pan), B64 (Voëlpan), B84 (Steenbokpan salt pan crust) and B85 (Steenbokpan salt pan) indicates an increased amount of salts present. Sample B59 (Voëlpan) had a high EC value due to a gold mine waste dump situated on the edge of the drainage depression; B62 (Viljoenskroon pan) had a high EC value due to pollution from a peanut butter factory on the edge of the drainage depressions. Sample B64 (Voëlpan) also has a high EC which may also indicate a pollution source. The high EC values of B84 and B85 are ascribed to the Steenbokpan pan being mined for salt in the past.

The linear shrinkage percentage of the drainage depressions is high due to the clay present and it is assumed that smectite or other clay minerals dominate. The linear shrinkage varies from 4.61% (B13) up to 15.92% for B63. This indicates that the deposits have potential to shrink or swell with varying conditions such as temperature fluctuations or water variations. The organic carbon content of the samples varies from 0.55% OC (B59) to 3.88% OC (B63). This indicates that all the samples exceed the threshold value of 0.5% Organic Carbon.

Table 49: Selected drainage depression deposits of South Africa including site descriptions, geotechnical implications and composition.

Sample number	Locality and site description	Geotechnical and other characteristics	Element composition (Only the 8 highest elements are indicated, see Appendix B for full analytical results)																
B13	Small pan situated close to Stilfontein in the North West. The pan is relatively small and located on dolomitic bedrock.  Figure 85: Small pan close to Stilfontein, North-West.	pH =8.4 (H₂O), 7.6 (KCl) EC=123 mS/m Angle of repose: 32° Linear shrinkage: 4.16% OC=2.62% Texture class: Sandy Loam	Results are in ppm PXRF <table> <tr> <td>Si</td><td>Al</td><td>Fe</td><td>Mg</td></tr> <tr> <td>159663</td><td>44959</td><td>43785</td><td>22762</td></tr> <tr> <td>Ca</td><td>K</td><td>Mn</td><td>Ti</td></tr> <tr> <td>8607</td><td>6246</td><td>5149</td><td>3062</td></tr> </table>	Si	Al	Fe	Mg	159663	44959	43785	22762	Ca	K	Mn	Ti	8607	6246	5149	3062
Si	Al	Fe	Mg																
159663	44959	43785	22762																
Ca	K	Mn	Ti																
8607	6246	5149	3062																
B47	Pan, Windsorton, Northern Cape  Figure 86: Pan close to Windsorton in the Northern Cape.	pH =7.9 (H₂O), 7 (KCl) EC=272 mS/m Angle of repose: 32° Linear shrinkage: 5.77% OC=1.05% Texture class: Sandy Loam	Results are in ppm PXRF <table> <tr> <td>Si</td><td>Mg</td><td>Fe</td><td>Ca</td></tr> <tr> <td>248908</td><td>57159</td><td>35693</td><td>9451</td></tr> <tr> <td>K</td><td>Ti</td><td>S</td><td>Mn</td></tr> <tr> <td>7285</td><td>3877</td><td>1709</td><td>818</td></tr> </table>	Si	Mg	Fe	Ca	248908	57159	35693	9451	K	Ti	S	Mn	7285	3877	1709	818
Si	Mg	Fe	Ca																
248908	57159	35693	9451																
K	Ti	S	Mn																
7285	3877	1709	818																

Table 49 (cont): Selected drainage depression deposits of South Africa including site descriptions, geotechnical implications and composition.

Sample number	Locality and site description	Geotechnical and other characteristics	Element composition (Only the 8 highest elements are indicated, see Appendix B for full analytical results)																
B48	Pan A-horizon, Windsorton, Northern Cape	pH =4.8 (H₂O),3.9 (KCl) EC=55 mS/m Angle of repose: 34.8° Linear shrinkage: 5.5% OC=1.24% Texture class: Sandy Clay Loam	Results are in ppm PXRF <table> <tr> <td>Si</td><td>Al</td><td>Fe</td><td>K</td></tr> <tr> <td>200866</td><td>64792</td><td>62765</td><td>7225</td></tr> <tr> <td>Ti</td><td>P</td><td>S</td><td>Ca</td></tr> <tr> <td>5102</td><td>1657</td><td>961</td><td>406</td></tr> </table>	Si	Al	Fe	K	200866	64792	62765	7225	Ti	P	S	Ca	5102	1657	961	406
Si	Al	Fe	K																
200866	64792	62765	7225																
Ti	P	S	Ca																
5102	1657	961	406																
B50	Pan A-horizon, Windsorton, Northern Cape	pH =6.6 (H₂O),5.3 (KCl) EC=23 mS/m Angle of repose: 30.6° Linear shrinkage: 9.85% OC=1.37% Texture class: Sandy Clay	Results are in ppm PXRF <table> <tr> <td>Si</td><td>Fe</td><td>Al</td><td>K</td></tr> <tr> <td>187885</td><td>71016</td><td>70867</td><td>8378</td></tr> <tr> <td>Ti</td><td>Ca</td><td>Mn</td><td>S</td></tr> <tr> <td>5380</td><td>1615</td><td>1165</td><td>528</td></tr> </table>	Si	Fe	Al	K	187885	71016	70867	8378	Ti	Ca	Mn	S	5380	1615	1165	528
Si	Fe	Al	K																
187885	71016	70867	8378																
Ti	Ca	Mn	S																
5380	1615	1165	528																

Table 49 (cont): Selected drainage depression deposits of South Africa including site descriptions, geotechnical implications and composition.

Sample number	Locality and site description	Geotechnical and other characteristics	Element composition (Only the 8 highest elements are indicated, see Appendix B for full analytical results)																
B51	Pan B-horizon, Windsorton, Northern Cape	pH =8 (H₂O),6.5 (KCl) EC=49 mS/m Angle of repose: 31.5° Linear shrinkage: 7.91% OC=1.36% Texture class: Sandy Loam	Results are in ppm PXRF <table border="1"> <tr> <td>Si</td><td>Fe</td><td>Al</td><td>Mg</td></tr> <tr> <td>183081</td><td>94164</td><td>63400</td><td>12730</td></tr> <tr> <td>Ca</td><td>K</td><td>Ti</td><td>Mn</td></tr> <tr> <td>11205</td><td>7984</td><td>4280</td><td>1783</td></tr> </table>	Si	Fe	Al	Mg	183081	94164	63400	12730	Ca	K	Ti	Mn	11205	7984	4280	1783
Si	Fe	Al	Mg																
183081	94164	63400	12730																
Ca	K	Ti	Mn																
11205	7984	4280	1783																
B55	Pan C-horizon, Windsorton, Northern Cape	pH =7.5 (H₂O),6.1 (KCl) EC=89 mS/m Angle of repose: 36.1° Linear shrinkage: 6.3% OC=1.51% Texture class: Sandy Clay Loam	Not sufficient sample for portable XRF analyses																
B59	Voëlpan in Allanridge, Free State. Samples were collected on the north-western side of the pan.	pH =8.3 (H₂O), 7.7 (KCl) EC=3252.2 mS/m Angle of repose: 33° Linear shrinkage: 10.66% OC=0.55% Texture class: Loamy Fine Sand	Results in ppm <table border="1"> <tr> <td>Si</td><td>Al</td><td>S</td><td>Fe</td></tr> <tr> <td>333832</td><td>53819</td><td>11596</td><td>11163</td></tr> <tr> <td>Ca</td><td>K</td><td>Ti</td><td>Mn</td></tr> <tr> <td>5821</td><td>2232</td><td>1660</td><td>151</td></tr> </table>	Si	Al	S	Fe	333832	53819	11596	11163	Ca	K	Ti	Mn	5821	2232	1660	151
Si	Al	S	Fe																
333832	53819	11596	11163																
Ca	K	Ti	Mn																
5821	2232	1660	151																

Table 49 (cont): Selected drainage depression deposits of South Africa including site descriptions, geotechnical implications and composition.

Sample number	Locality and site description	Geotechnical and other characteristics	Element composition (Only the 8 highest elements are indicated, see Appendix B for full analytical results)																
B62	Pan in Viljoenskroon, Free State	pH =8.7 (H₂O), 8 (KCl) EC=6950 mS/m Angle of repose: 35.3° Linear shrinkage: 10.66% OC=3.76% Texture class: Sandy Clay Loam	Results are in ppm PXRF <table> <tr> <td>Si</td><td>Ca</td><td>Al</td><td>Fe</td></tr> <tr> <td>141416</td><td>58970</td><td>42392</td><td>36725</td></tr> <tr> <td>Mg</td><td>Cl</td><td>K</td><td>S</td></tr> <tr> <td>23401</td><td>16675</td><td>9986</td><td>5007</td></tr> </table>	Si	Ca	Al	Fe	141416	58970	42392	36725	Mg	Cl	K	S	23401	16675	9986	5007
Si	Ca	Al	Fe																
141416	58970	42392	36725																
Mg	Cl	K	S																
23401	16675	9986	5007																
B63	Gleyed (hydromorphic) top layer of the pan close to Bloemhof, North West Province. The pan was very dry and had cracks as well as biostructures present.	pH =7.7 (H₂O), 6.6 (KCl) EC=100 mS/m Angle of repose: 37.7° Linear shrinkage: 15.92% OC=3.88% Texture class: Clay Loam	Results are in ppm PXRF <table> <tr> <td>Si</td><td>Fe</td><td>Al</td><td>Ca</td></tr> <tr> <td>176748</td><td>79656</td><td>60811</td><td>7525</td></tr> <tr> <td>Ti</td><td>K</td><td>Mn</td><td>S</td></tr> <tr> <td>5704</td><td>2307</td><td>2298</td><td>1034</td></tr> </table>	Si	Fe	Al	Ca	176748	79656	60811	7525	Ti	K	Mn	S	5704	2307	2298	1034
Si	Fe	Al	Ca																
176748	79656	60811	7525																
Ti	K	Mn	S																
5704	2307	2298	1034																

Table 49 (cont): Selected drainage depression deposits of South Africa including site descriptions, geotechnical implications and composition.

Sample number	Locality and site description	Geotechnical and other characteristics	Element composition (Only the 8 highest elements are indicated, see Appendix B for full analytical results)																
B71	Lunette dune on the south eastern side of a pan close to Bloemhof, North-West (Pan sample number: B63). Calcrete is also mined on the base of the pan for agricultural lime.	pH =8.4 (H₂O), 8.1(KCl) EC= 30 mS/m. Angle of repose:42.6° See Figure 93 below for water retention Linear shrinkage: 7.33% OC=2.56% Texture class: Sandy Loam See Table 50 below for Atterberg Limits.	Results are in ppm PXRF <table border="1"> <tr> <td>Ca</td><td>Si</td><td>Mg</td><td>Cl</td></tr> <tr> <td>208171</td><td>119035</td><td>66579</td><td>41195</td></tr> <tr> <td>Fe</td><td>Al</td><td>S</td><td>K</td></tr> <tr> <td>16585</td><td>11128</td><td>2570</td><td>1781</td></tr> </table> The high Ca value can be ascribed to the calcrete mined in the pan. The lunette dune is marginal to the pan.	Ca	Si	Mg	Cl	208171	119035	66579	41195	Fe	Al	S	K	16585	11128	2570	1781
Ca	Si	Mg	Cl																
208171	119035	66579	41195																
Fe	Al	S	K																
16585	11128	2570	1781																
B64	Grootvloerpan, south of Kenhardt in the Northern Cape. The sample was collected in the upper 40 cm of the profile.	pH =7.8 (H₂O), 6.5 (KCl) EC=5330 mS/m Angle of repose: 35.5° See Figure 93 below for water retention Linear shrinkage: 10.41% OC=1.65% Texture class: Clay	Results in ppm PXRF <table border="1"> <tr> <td>Si</td><td>Al</td><td>Fe</td><td>K</td></tr> <tr> <td>213684</td><td>85802</td><td>81794</td><td>22871</td></tr> <tr> <td>Mg</td><td>Ca</td><td>Ti</td><td>Cr</td></tr> <tr> <td>15477</td><td>8943</td><td>2703</td><td>2127</td></tr> </table>	Si	Al	Fe	K	213684	85802	81794	22871	Mg	Ca	Ti	Cr	15477	8943	2703	2127
Si	Al	Fe	K																
213684	85802	81794	22871																
Mg	Ca	Ti	Cr																
15477	8943	2703	2127																

Table 49 (cont): Selected drainage depression deposits of South Africa including site descriptions, geotechnical implications and composition.

Sample number	Locality and site description	Geotechnical and other characteristics	Element composition (Only the 8 highest elements are indicated, see Appendix B for full analytical results)																
B83	Small pan located on Wexford farm in the Northwest close to Tosca.  Figure 87: Pan close to Tosca in the Northern Province.	pH =8.3 (H₂O),4.2 (KCl) EC=9 mS/m Angle of repose: 35.2° Linear shrinkage: 4.7% OC=1.69% Texture class: Sandy Clay Loam	Results in ppm PXRF <table border="1"> <tr> <td>Si</td><td>Al</td><td>Fe</td><td>K</td></tr> <tr> <td>226038</td><td>61255</td><td>38407</td><td>4750</td></tr> <tr> <td>Ti</td><td>S</td><td>Mn</td><td>V</td></tr> <tr> <td>3076</td><td>663</td><td>263</td><td>194</td></tr> </table>	Si	Al	Fe	K	226038	61255	38407	4750	Ti	S	Mn	V	3076	663	263	194
Si	Al	Fe	K																
226038	61255	38407	4750																
Ti	S	Mn	V																
3076	663	263	194																
B84	Salt Pan (top crust) in Steenbokpan, Limpopo. Salt was used commercially in the past.  Figure 88: Surface cracks of a dry salt pan close to Steenbokpan, Limpopo Province.	pH =10.2 (H₂O), 9.6 (KCl) EC=8230 mS/m Angle of repose: 40.1° Linear shrinkage: 5.8% OC=2.27% Texture class: Loam	Results in ppm PXRF <table border="1"> <tr> <td>Si</td><td>Ca</td><td>Mg</td><td>Al</td></tr> <tr> <td>157811</td><td>55680</td><td>52848</td><td>22986</td></tr> <tr> <td>Fe</td><td>K</td><td>Cl</td><td>Ti</td></tr> <tr> <td>16783</td><td>10836</td><td>5063</td><td>1763</td></tr> </table>	Si	Ca	Mg	Al	157811	55680	52848	22986	Fe	K	Cl	Ti	16783	10836	5063	1763
Si	Ca	Mg	Al																
157811	55680	52848	22986																
Fe	K	Cl	Ti																
16783	10836	5063	1763																

Table 49 (cont): Selected drainage depression deposits of South Africa including site descriptions, geotechnical implications and composition.

Sample number	Locality and site description	Geotechnical and other characteristics	Element composition (Only the 8 highest elements are indicated, see Appendix B for full analytical results)																
B85	Salt Pan (Grey clay) in Steenbokpan, Limpopo.	pH =10.2 (H₂O),9.3 (KCl) EC=2940 mS/m Angle of repose: 37.9° Linear shrinkage: 8.68% OC=1.41% Texture class: Clay Loam	Results in ppm PXRF <table> <tr> <td>Si</td><td>Ca</td><td>Mg</td><td>Al</td></tr> <tr> <td>179052</td><td>64255</td><td>61189</td><td>38977</td></tr> <tr> <td>Fe</td><td>K</td><td>Ti</td><td>Sr</td></tr> <tr> <td>23810</td><td>12771</td><td>2312</td><td>666</td></tr> </table>	Si	Ca	Mg	Al	179052	64255	61189	38977	Fe	K	Ti	Sr	23810	12771	2312	666
Si	Ca	Mg	Al																
179052	64255	61189	38977																
Fe	K	Ti	Sr																
23810	12771	2312	666																
BX3	Verneukpan near Brandvlei, south of Kenhardt in the Northern Cape. Southern part of pan mainly pebbles.	Insufficient sample for geotechnical analyses. Only mineralogical analyses were done, see XRD results (Table 56).																	

This may be due to the high clay content of the sample as reflected in the textural classes seen in Figure 90. The adsorption potential of clays is much higher than sand and therefore the organic carbon content of clay particles are much higher than that of sand.

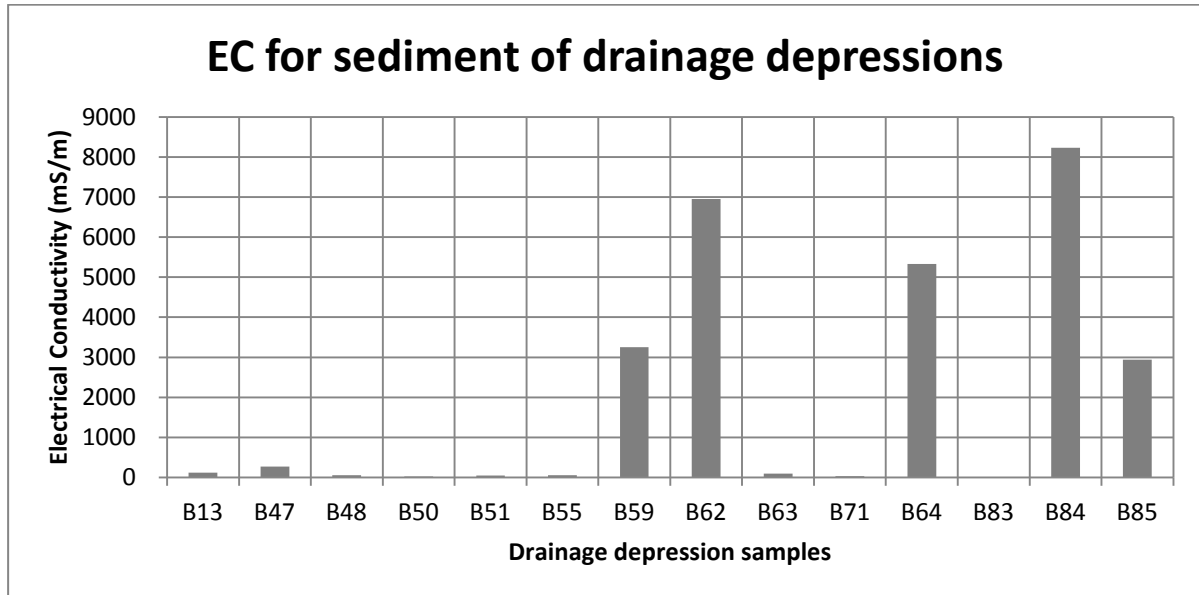


Figure 89: The electrical conductivity of the selected drainage depressions.

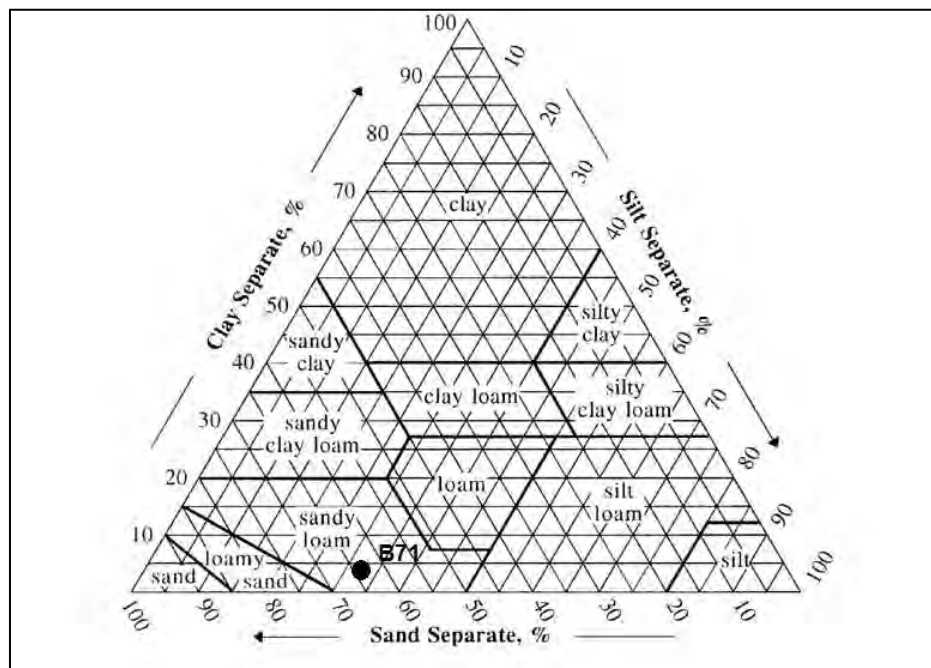


Figure 90: The textural classes of the lunette dune sample form the Bloemhof pan, North-West Province (Calculated from USDA-NRCS, 2014).

The particle size distribution values were used to determine the texture classes of the sand samples by using the Soil Texture Calculator from the NRCS- USDA (United States Department of Agriculture, 2014) as seen in Figure 91. The textural classes vary from sandy loam to silty clay.

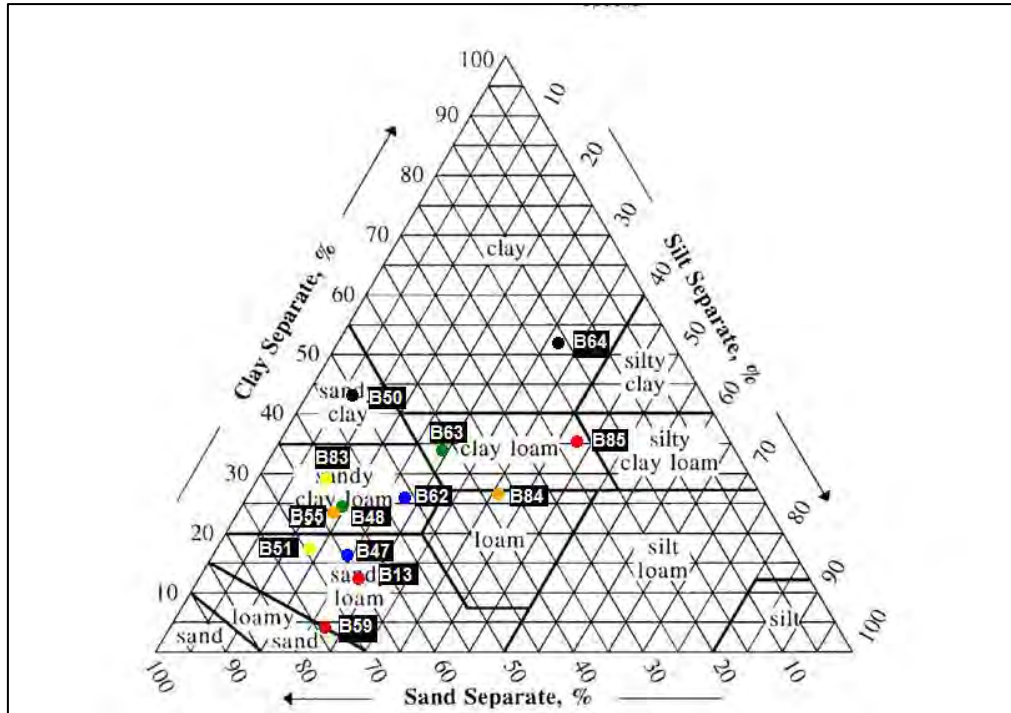


Figure 91: The textural classes of the selected drainage depression samples. Calculated from USDA-NRCS (2014).

Three samples were selected to indicate the particle size distribution variations in different drainage depressions. The particle size distributions of three selected samples are indicated in Figure 92. Sample B48 had a sand clay loam texture and was well graded, whereas B63 has a clay loam texture and was poorly graded and B64 had a clay texture and was also poorly graded.

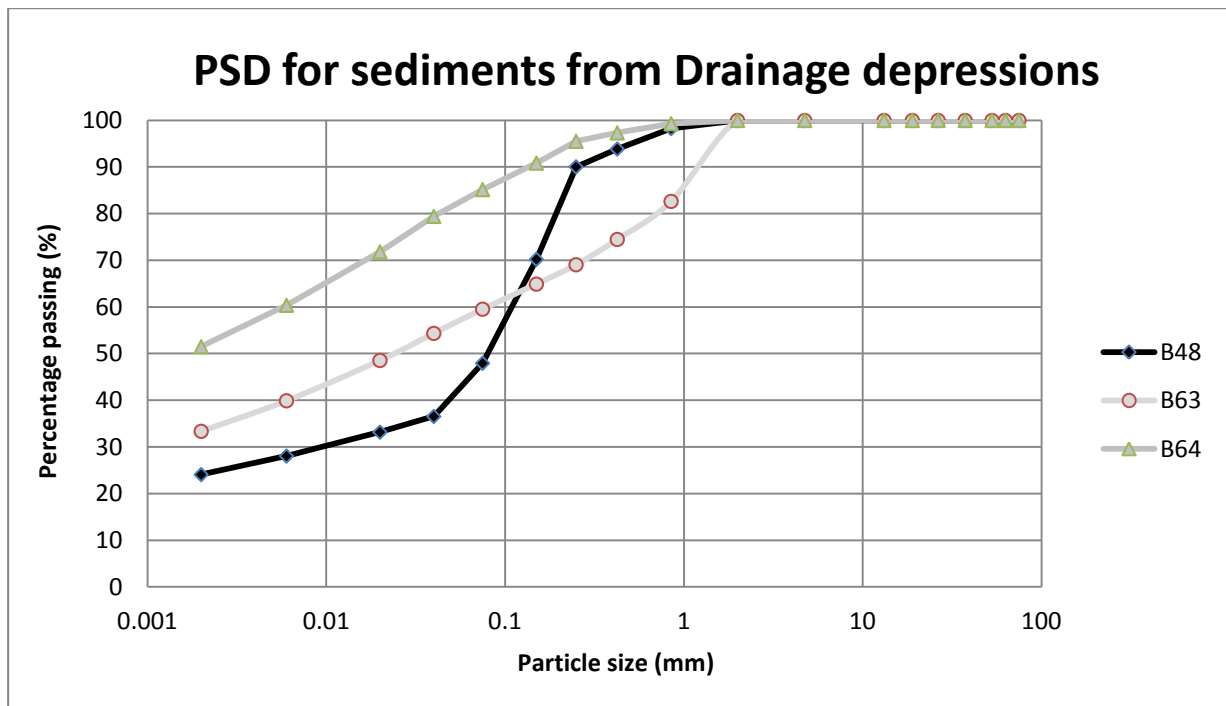


Figure 92: The particle size distribution for selected drainage depressions, B48, B63 and B64.

The Atterberg Limits (plastic and liquid limit as well as the plasticity index) was determined for B77 as an example for a lunette dune sand sample (Table 50). This samples is classified as „slightly plastic“ using the classification system of Burmister (1949), see Atterberg Limits Method in Chapter 3.2.1.2. More examples of the plasticity index for drainage depression sediments are also indicated in Table 51. Sample B59 is seen as having a low plasticity whereas B63, B64 and B83 are described as having a medium plasticity (Burmister, 1949).

Table 50: The Atterberg Limits (plastic and liquid limit as well as the plasticity index) for a lunette dune, sand sample (B77).

Sample	Liquid limit	Plastic limit	Plasticity index
B77	20.59	18.83	1.76

Table 51: The plastic and liquid limits, plasticity index and linear shrinkage for selected drainage depressions (Brummer, 2015)

Sample	Liquid limit (%)	Plastic limit (%)	Plasticity index	Linear shrinkage (%)
B59	25.2	17.91	7.29	1.46
B63	46	23.42	22.58	10.57
B64	37.5	19.46	18.04	9.31
B83	30	16.5	13.5	2.44

The variation of the linear shrinkage as well as the plasticity index may be ascribed to the different textures of the samples, as seen in Figure 91, but also to the amount of clay present (Brummer, 2015), as seen in Table 53. The Atterberg limits for an estuarine dark clay from the Mgeni Valley in Durban (as seen in Table 52 from Brink (1985), correlated well with the Atterberg values in Tables 50 and 51.

Table 52: The Atterberg limits for estuarine dark clay from the Mgeni Valley, Durban (Brink, 1985).

	Range
Clay (<2µm)	20-55
Liquid limit	40-70
Plasticity index	15-30

The mineralogical analyses of selected drainage depression samples are indicated in Table 53. Sample B13 is dominated by quartz, and the dominant clay minerals are kaolinite and illite. Sample B50 is dominated by quartz, with smectite, illite and kaolinite clay minerals present. Sample B59 has high percentages chlorite, halite, gypsum and halite present and are ascribed to the mine waste dump on the edge of the drainage depression. Sample B62 is dominated by quartz and calcite due to the calcrete concretions found in the drainage sediment, and has halite, illite and kaolinite as clay minerals. Sample B63 has relatively high illite and kaolinite contents. Sample B83 is dominated by quartz and the clay minerals are illite and kaolinite. Sample B85 has high smectite and sepiolite concentrations, sepiolite having a high economic potential (Galan,1996). The minerals corresponded well to clay minerals found in the Etosha pan containing illite, smectite, kaolinite, sepiolite, polygorskite and quartz, Venter *et al.*, (1992:41).

Agriculture potential

The dry bulk density value of 1.3 g/cm³ was used for clay material Hillel (2004). Bentonite clay was used as a reference sample with 12% plant available water, determined from Table 46, and a higher water retention capacity relative to B63 and B64. Samples B63 had the lowest water retention percentage value and B64 had a slightly higher percentage value, as seen in Figure 93. This indicates that the water will not be available to the plant as the water will be retained by the clay particles. Bentonite had 156 mm/m water available for plants.

Table 53: The XRD results for selected drainage depression sediments. See Figure 20 for location of samples.

B13	Mineral	Illite	Kaolinite	Microcline	Plagioclase	Quartz			
	Weigth %	8.9	16.81	9.4	3.3	61.6			
B50	Mineral	Illite	Kaolinite	Microcline	Plagioclase	Quartz	Smectite		
	Weigth %	18.95	18.14	11.35	14.08	33.57	3.91		
B59	Mineral	Chlorite	Gypsum	Halite	Illite	Muscovite	Pyrophyllite	Quartz	
	Weigth %	4.02	5.67	1.92	4.8	12.49	9.32	61.77	
B62	Mineral	Calcite	Dolomite	Halite	Illite	Kaolinite	Microcline	Plagioclase	Quartz
	Weigth %	11.11	13.9	3.2	15.43	12.36	7.34	5.29	31.38
B63	Mineral	Illite	Kaolinite	Microcline	Plagioclase	Quartz			
	Weigth %	9.23	21.16	12.23	14.08	43.3			
B83	Mineral	Illite	Kaolinite	Microcline	Plagioclase	Quartz			
	Weigth %	11.57	12.64	4.28	5.34	66.17			
B85	Mineral	Calcite	Illite	Kaolinite	Quartz	Smectite	Sepiolite		
	Weigth %	21.49	5.43	8.93	16.3	27.27	20.27		
BX3	Mineral	Quartz	Muscovite	Illite	Kaolinite	Plagioclase	Microcline		
	Weigth %	63.99	8.58	7.36	7.28	7.26	5.53		

Sample B63 had 182 mm/m water available for plants whereas B64 had 156 mm/m available, see Appendix F for calculations. This indicates that the drainage depressions with high clay values does have higher plant available water relative to the sand deposits but will not be suitable for agricultural purposes, due the high water retention potential of clay.

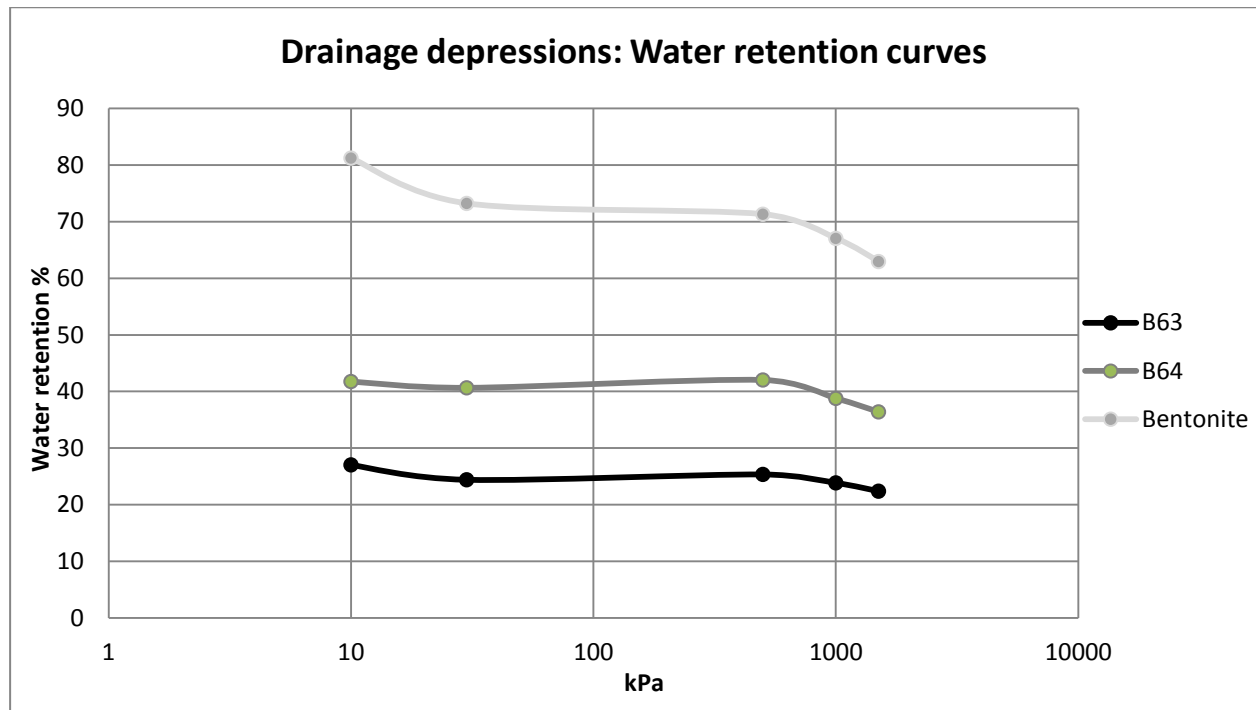


Figure 93: The water retention for selected pan samples (B63 and B64) as well as a reference sample (Bentonite).

It can be summarised that the geotechnical implications of the drainage depressions are mainly dependant on the shrink and swell potential and are not suitable to be used as a base for foundations. The agricultural potential is low due to the high water retention capacity. Selected drainage depressions may also contribute to the economic potential of the Cenozoic deposits such as the salt pans mined in the past for table salt (Venter *et al.*, 1992) and sepiolite being used in many industries for decolouring, parting agent, bonding and thickening agents (Schmidt, 1976 and Galan, 1996).

4.4.6 Periglacial deposit

A periglacial site, see Figure 21, was identified close to Groot Marico in the North-West province. The site was unique as it was never mentioned in literature before. The locality was also unique as the main periglacial localities discussed are situated in the high relief Mountains of the Western Cape along the great escarpment to the Lesotho Highlands (Boelhouwers and

Meiklejohn, 2002). This site included a deposit which comprised of sediment with an unsorted orientation, including boulders, in between two fine grained layers. Samples were collected from the periglacial deposit and element compositions were determined as seen in Table 54.

The first site (S26°41'38.0", E27°05'24.2") is a rock stream or stone stream (Cotton, 1952:29 or Flint, 1957:199), with various parallel striations present on individual rocks. No image is included. The term „rock or stone stream“ indicates solifluction deposit where the boulders were transported and the fine-grained matrix was washed away, also referred to as a lag deposit. Lag deposit refers to the fine grained matrix being removed by water or mainly wind (Flint, 1957 and Cotton 1952).

The site close to Groot Marico in the North-West Province (S26°34'27.3", E26°23'47.7") with an elevation of 1084 mamsl consists of an exposed periglacial deposit. The eroded dongas are as deep as 2 m where the periglacial deposit is exposed on the top part of the donga close to the original surface (Figure 94). The periglacial deposit as seen in Figure 95 indicates the unsorted texture of the grains. The lithology of the clasts is mainly derived from the underlying lithology of the Transvaal Supergroup. The composition of the sediments is mainly dolomite, banded ironstone, quartz and lava particles. The deposit also contains carbonate nodules where the source of calcium could have derived from the underlying dolomite. The calcrete nodules are mostly located on the top of the surface with the concretions varying in shape. The concretions varies from small (<1 cm) up to large (30 cm) irregular and tabular shaped concretions. The shapes include prismatic concretions (Figure 96), angular to subangular and granular (Boggs, 2011). The shapes of the concretions vary due to different nucleation points such as small rock fragment or organic material such as tree branches where the original calcium carbonate started to precipitate and accumulation proceeded.

PXRF results are highly variable due to the contribution of the various rock types in the matrix and pebble layers. The rock types from the Transvaal Supergroup like banded iron stone, dolomite, chert, quartzite and lavas are common. Andalusite sand (B105) is also present and is very common in this area and it was also mined close to Groot Marico. Andalusite is a contact metamorphic mineral formed in the contact aureole between the Pretoria Group shales and the Bushveld Complex. The shales have abundant Al-silicate clay minerals which has been metamorphosed to Al_2SiO_5 due to the heat of the intrusion (Norman and Whitefield, 2006:190). The periglacial deposit mainly consists of SiO_2 , Al_2O_3 , Fe_2O_3 and K_2O , from the highest to the lowest concentration respectively. The full geochemical and mineralogical analysis not discussed due to the variety of minerals that were transported from different geological formations and regions..

The carbonate concretions (B103A) found scattered on the surface of the periglacial site at Groot Marico (Figure 96) had 35.92% CaCO_3 which is not enough to be classified as a calcrete comprising of approximately 42.62% CaO (see Chapter 2.4.1). This can be seen as a carbonate concretion with high concentrations Al and Fe.

4.4.6.1 Periglacial deposit site



Figure 94: Periglacial site close to Groot Marico, North West indicating the erosion dongas as well as the periglacial deposit.



Figure 95: Periglacial deposit located on the top part of the donga close to the original surface see Figure 94 near Groot Marico.



Figure 96: Tabular calcrete concretions found on the surface of the periglacial site.

Table 54: The locality, site description, stratigraphy and compositions of the periglacial site close to Groot Marico in the North-West Province.

Sample number	Locality, site description and stratigraphy	Element composition																			
		Portable XRF results and additional ICP-MS and XRD results for selected samples (indicated) Only the 8 highest elements are indicated, see Appendix B (PXRF) and C (ICP-MS) for full analytical results. ICP-MS results excludes Si																			
B103A	Carbonate concretion at periglacial site, Groot Marico, North-West Province. Hard nodules are found on the surface and vary from round to angular. Diabase, quartzite and banded ironstone pebbles are also present.	Results in ppm																			
		PXRF																			
		<table><tr><td>Si</td><td>Ca</td><td>Al</td><td>Fe</td></tr><tr><td>149223</td><td>108468</td><td>61427</td><td>52676</td></tr><tr><td>Mg</td><td>K</td><td>Ti</td><td>Mn</td></tr><tr><td>18429</td><td>5329</td><td>3727</td><td>627</td></tr></table>		Si	Ca	Al	Fe	149223	108468	61427	52676	Mg	K	Ti	Mn	18429	5329	3727	627		
		Si	Ca	Al	Fe																
		149223	108468	61427	52676																
Mg	K	Ti	Mn																		
18429	5329	3727	627																		
XRD																					
<table><tr><td>Mineral</td><td>%</td></tr><tr><td>Calcite</td><td>43.92</td></tr><tr><td>Quartz-</td><td>16.58</td></tr><tr><td>Kaolinite-</td><td>11.38</td></tr><tr><td>Dolomite-</td><td>11.08</td></tr><tr><td>Muscovite</td><td>6.2</td></tr><tr><td>Microcline</td><td>5.66</td></tr><tr><td>Andalusite</td><td>2.52</td></tr><tr><td>Plagioclase</td><td>2.08</td></tr><tr><td>Illite</td><td>0.58</td></tr></table>		Mineral	%	Calcite	43.92	Quartz-	16.58	Kaolinite-	11.38	Dolomite-	11.08	Muscovite	6.2	Microcline	5.66	Andalusite	2.52	Plagioclase	2.08	Illite	0.58
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		Recalculated PXRF results																			
		<table><tr><td>Geochemistry</td><td>%</td></tr><tr><td>SiO₂</td><td>32.27%</td></tr><tr><td>CaO</td><td>35.92%</td></tr><tr><td>Al₂O₃</td><td>14.96%</td></tr><tr><td>Fe₂O₃</td><td>16.83%</td></tr></table>		Geochemistry	%	SiO ₂	32.27%	CaO	35.92%	Al ₂ O ₃	14.96%	Fe ₂ O ₃	16.83%								
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Table 54 (cont): The locality, site description, stratigraphy and geochemical compositions of the periglacial site close to Groot Marico in the North-West Province.

Sample number	Locality, site description and stratigraphy	Element composition																															
		Portable XRF results and additional ICP-MS and XRD results for selected samples (indicated) Only the 8 highest elements are indicated, view Appendix B (PXRF) and C (ICP-MS) for full analyses results. ICP-MS results excludes Si																															
B104	Periglacial deposit sediment (sand fraction of periglacial deposit)	PXRF				Recalculated PXRF results																											
		<table><tr><td>Si</td><td>Al</td><td>Fe</td><td>K</td></tr><tr><td>239218</td><td>93814</td><td>62815</td><td>7924</td></tr><tr><td>Ti</td><td>S</td><td>Mn</td><td>Cr</td></tr><tr><td>4716</td><td>713</td><td>607</td><td>263</td></tr></table>				Si	Al	Fe	K	239218	93814	62815	7924	Ti	S	Mn	Cr	4716	713	607	263	<table><tr><td>Geochemistry</td><td>%</td></tr><tr><td>SiO₂</td><td>52.95%</td></tr><tr><td>Al₂O₃</td><td>23.38%</td></tr><tr><td>Fe₂O₃</td><td>20.54%</td></tr><tr><td>K₂O</td><td>3.11%</td></tr></table>		Geochemistry	%	SiO ₂	52.95%	Al ₂ O ₃	23.38%	Fe ₂ O ₃	20.54%	K ₂ O	3.11%
		Si	Al	Fe	K																												
		239218	93814	62815	7924																												
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<table><tr><td>Mineral</td><td>%</td></tr><tr><td>Quartz</td><td>49.18</td></tr><tr><td>Muscovite</td><td>18.58</td></tr><tr><td>Kaolinite</td><td>14.76</td></tr><tr><td>Illite</td><td>8.48</td></tr><tr><td>Microcline</td><td>4.87</td></tr><tr><td>Plagioclase</td><td>3.58</td></tr><tr><td>Andalusite</td><td>0.55</td></tr></table>				Mineral	%	Quartz	49.18	Muscovite	18.58	Kaolinite	14.76	Illite	8.48	Microcline	4.87	Plagioclase	3.58	Andalusite	0.55														
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Microcline	4.87																																
Plagioclase	3.58																																
Andalusite	0.55																																
B2K	Stone tools and pot shards																																

Table 54 (cont): The locality, site description, stratigraphy and geochemical compositions of the periglacial site close to Groot Marico in the North-West Province.

Sample number	Locality, site description and stratigraphy	Element composition																			
		Portable XRF results and additional ICP-MS and XRD results for selected samples (indicated) Only the 8 highest elements are indicated, view Appendix B (PXRF) and C (ICP-MS) for full analyses results. ICP-MS results excludes Si																			
B105	Andalusite-rich sand	PXRF																			
		<table><tr><td>Si</td><td>Al</td><td>Fe</td><td>Mn</td></tr><tr><td>194502</td><td>141836</td><td>69089</td><td>5906</td></tr><tr><td>K</td><td>Mn</td><td>Ti</td><td>V</td></tr><tr><td>3568</td><td>5906</td><td>3089</td><td>699</td></tr></table>		Si	Al	Fe	Mn	194502	141836	69089	5906	K	Mn	Ti	V	3568	5906	3089	699		
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		3568	5906	3089	699																
		XRD																			
		<table><tr><td>Mineral</td><td>%</td></tr><tr><td>Andalusite</td><td>36.73</td></tr><tr><td>Quartz</td><td>34.19</td></tr><tr><td>Muscovite</td><td>10.28</td></tr><tr><td>Kaolinite</td><td>6.96</td></tr><tr><td>Chlorite</td><td>5.37</td></tr><tr><td>Illite</td><td>5.11</td></tr><tr><td>Hornblende</td><td>0.73</td></tr><tr><td>Microcline</td><td>0.61</td></tr></table>		Mineral	%	Andalusite	36.73	Quartz	34.19	Muscovite	10.28	Kaolinite	6.96	Chlorite	5.37	Illite	5.11	Hornblende	0.73	Microcline	0.61
		Mineral	%																		
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Recalculated PXRF results																					
<table><tr><td>Geochemistry</td><td>%</td></tr><tr><td>SiO₂</td><td>41.78%</td></tr><tr><td>Al₂O₃</td><td>34.32%</td></tr><tr><td>Fe₂O₃</td><td>21.93%</td></tr><tr><td>Mn₃O₄</td><td>1.95%</td></tr></table>		Geochemistry	%	SiO ₂	41.78%	Al ₂ O ₃	34.32%	Fe ₂ O ₃	21.93%	Mn ₃ O ₄	1.95%										
Geochemistry	%																				
SiO ₂	41.78%																				
Al ₂ O ₃	34.32%																				
Fe ₂ O ₃	21.93%																				
Mn ₃ O ₄	1.95%																				

Table 54 (cont): The locality, site description, stratigraphy and geochemical compositions of the periglacial site close to Groot Marico in the North-West Province.

Sample number	Locality, site description and stratigraphy	Element composition			
		Portable XRF results and additional ICP-MS and XRD results for selected samples (indicated). Only the 8 highest elements are indicated, view Appendix B (PXRF) and C (ICP-MS) for full analyses results. ICP-MS results excludes Si			
B106	Periglacial deposit sediment (Dongas with rocks)	PXRF		Recalculated PXRF results	
		Si	Al	Fe	K
		177613	102627	83663	9284
		Ti	Ca	Mn	Cr
		4007	2202	639	325
				Geochemistry	%
				SiO ₂	40.98%
				Al ₂ O ₃	26.67%
				Fe ₂ O ₃	28.52%
				K ₂ O	3.8%
		XRD			
				Mineral	%
				Quartz	29.55
				Kaolinite	15.92
				Andalusite	15.87
				Muscovite	13.29
				Chlorite	9.23
				Illite	6.85
				Goethite	4.85
				Microcline	3.43
				Hornblende	0.85
				Plagioclase	0.16

Table 54 (cont): The locality, site description, stratigraphy and geochemical compositions of the periglacial site close to Groot Marico in the North-West Province.

Sample number	Locality, site description and stratigraphy	Element composition																											
		Portable XRF results and additional ICP-MS and XRD results for selected samples (indicated). Only the 8 highest elements are indicated, view Appendix B (PXRF) and C (ICP-MS) for full analyses results. ICP-MS results excludes Si																											
B107	Periglacial deposit sediment (Dongas without rocks).	PXRF	Recalculated PXRF results																										
		<table><tr><td>Si</td><td>Al</td><td>Fe</td><td>K</td></tr><tr><td>226714</td><td>79625</td><td>70995</td><td>13857</td></tr><tr><td>Ti</td><td>Mn</td><td>V</td><td>S</td></tr><tr><td>4128</td><td>749</td><td>359</td><td>294</td></tr></table>	Si	Al	Fe	K	226714	79625	70995	13857	Ti	Mn	V	S	4128	749	359	294	<table><tr><td>Geochemistry</td><td>%</td></tr><tr><td>SiO₂</td><td>50.84%</td></tr><tr><td>Al₂O₃</td><td>20.11%</td></tr><tr><td>Fe₂O₃</td><td>23.52%</td></tr><tr><td>K₂O</td><td>5.5%</td></tr></table>	Geochemistry	%	SiO ₂	50.84%	Al ₂ O ₃	20.11%	Fe ₂ O ₃	23.52%	K ₂ O	5.5%
		Si	Al	Fe	K																								
		226714	79625	70995	13857																								
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K ₂ O	5.5%																												
XRD																													

The particle size distribution of the periglacial deposit with rocks (B106), see Figure 98, is abundant in cobble sized particles form 50 -130 mm in diameter (Boggs, 2011:46). The particle size distribution curve of the soil fraction (Figure 99) indicates that the particles are mainly sand. The sand part of the periglacial deposits (B104) is dominated by fine sand. The periglacial deposit, B107, without rocks has a high clay and silt percentage. The particle size distribution curves for different soil types by Hillel (2004), is used for evaluating the curves.



Figure 97: Individual tabular carbonate concretion found on the surface of the periglacial site near Groot Marico.

Stone tools and pot shards (Figure 100 and 101) were found at the periglacial site and dated by Dr. Thembi Russel at the University of the Witwatersrand. The stone stools are Archeulean which dates back to between 1.7 million to 300 000 years when the stone tool manufacturing industry existed for early humans. The pot shards are from pottery of the Sotho-Tswana tribe and are known as the Mokolo traditions and dates to 500 years ago (Hall, 1998). Pot shards are found on top of the periglacial deposits and in the stream beds. The stone tools are found in the deposits and also on the erosion surface and in the streambeds. This occurrence is a confirmation that the stone tools originated before the periglacial period and were transported and deposited together with the other rocks in the periglacial deposit.

The stone tools may be linked to the periglacial deposit as these deposits are linked to the Pleistocene glaciation age (see Chapter 2.3.6). The pottery may be an indication of a Sotho-Tswana tribe living in the vicinity of the periglacial site dongas at a later stage.

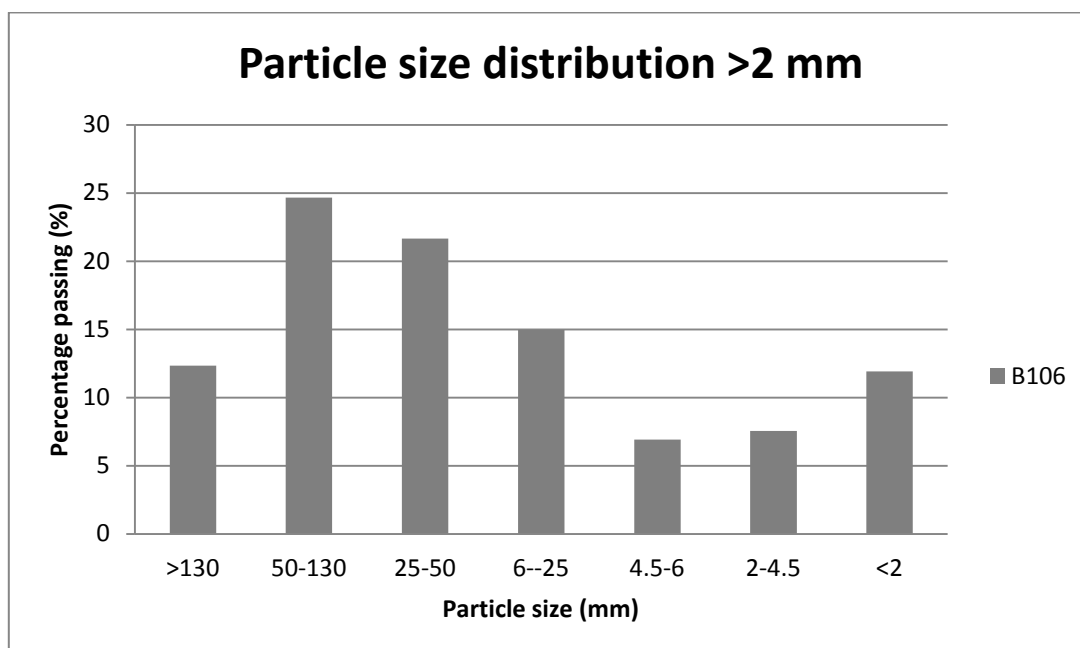


Figure 98: The particle size distribution (> 2 mm) of the periglacial sediment (B106)

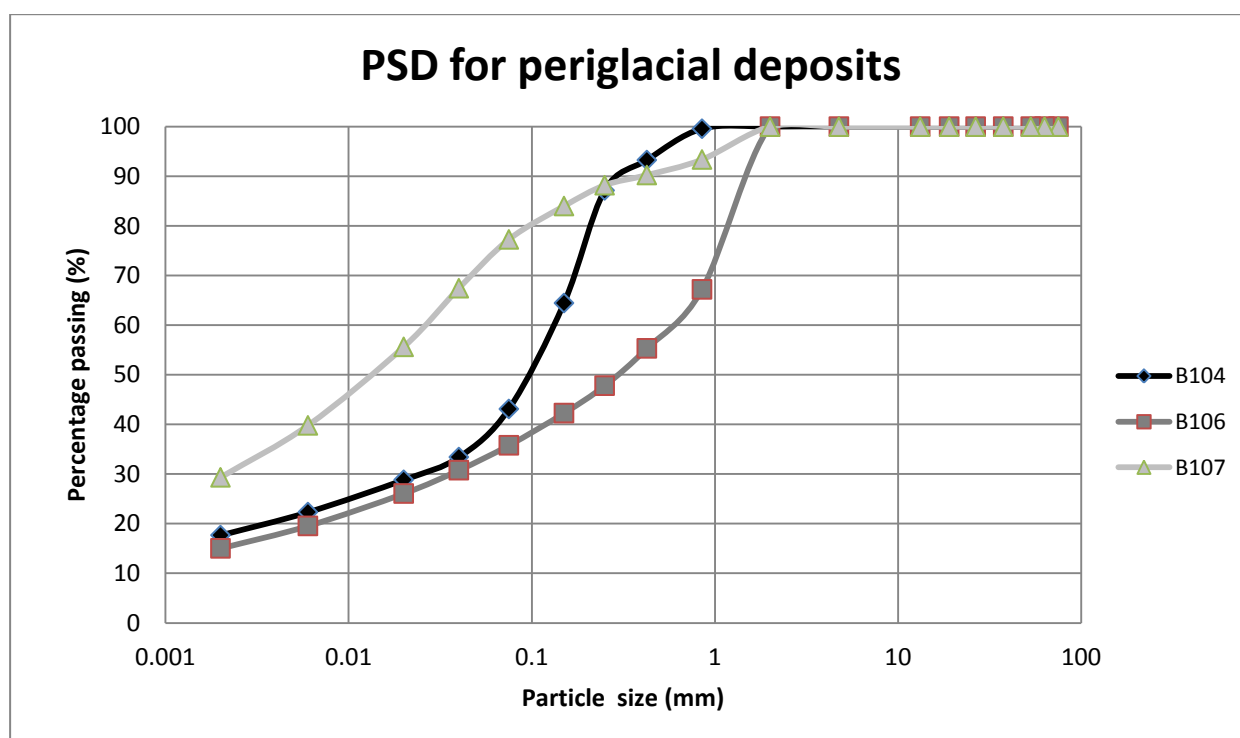


Figure 99: The particle size distribution curves for the soil fraction of the periglacial deposits (B104, B106 and B107), near Groot Marico.



Figure 100: A MSA stone tool found at the periglacial site close to Groot Marico, North-West Province.



Figure 101: A pot shard found at the periglacial site close to Groot Marico, North-West Province.

4.5 Pedogenic deposits

In this section the pedogenic deposits such as the calcrete, silcrete and dorbanks, ferricrete and manganocrete, phoscrete, gypcrete and intergrade pedocretes will be discussed. This includes the distributions, characteristics of each deposit, geotechnical (where applicable) and geochemical composition.

4.5.1 Calcrete

Calcrete samples were collected in various localities over South Africa as indicated in the compiled map, Figure 22. The locality, site description, stratigraphy, geotechnical characteristics, geochemical composition will be discussed for each calcrete sample collected in Table 55 with Figures 102 to 107.

The calcrete samples, indicated in the map of calcic deposits in South Africa (Figure 22), correlated well with the climatic Weinert N-value >5, dominated by calcrete and silcrete (Figure 9). The samples also correlated well with the calcic deposits (mainly calcic soils) of Fey (2010) (Figure 22).

The sub-fossil of the species *Lymnaea truncatula*

The sub-fossil (*Lymnaea truncatula*), found in non-pedogenic calcrete sample B82 (25°50'32.28"S, 24°20'14.6394"E) indicated the palaeo climatic conditions that existed in the Kalahari region in Vergeleë, North-West province (Figure 102). The sample was collected 16.22 km south east of Vergeleë and 131.69 km north west of Vryburg at an elevation of 1087 mamsl. The sub-fossil was identified by Professor Kenné de Kock of the Zoology Department of the North-West University, South Africa. *Lymnaea truncatula* preferred habitat conditions such as swamp or spring water bodies e.g. perennial, still standing water which is clear and has a low salinity status and temperature ranging from 15-20°C. Regions with rainfall intervals of 600-900mm and altitudes of 1000-2000 m are preferred for this species (de Kock *et al.*, 2003). This indicates that the calcretes were formed after the water body was evaporated due to the increase in temperature and/or decrease in rainfall. Connolly (1939) identified this species in „recent limestone“ as he referred to it, in Hope Vlei, near Vryburg and Tlapings Laagte Well, west of Vryburg. The palaeoenvironmental conditions should not be extrapolated to the entire Kalahari region but only to localities where this species are found, due to the variability in microenvironmental conditions or microhabitats that existed.



Figure 102: The sub-fossil of the species *Lymnaea truncatula* found in calcrete in the Vergeleë region, North-West province. (Stereo Micrograph)

Table 55: Characteristics of calcretes in South Africa including stratigraphy, geotechnical implications and geochemical composition.

Sample number	Locality, site description and stratigraphy	Geotechnical characteristics	Element composition																										
			Portable XRF results and additional ICP-MS and XRD results for selected samples (indicated). Only the 8 highest elements are indicated, view Appendix B (PXRF) and C (ICP-MS) for full analytical results. ICP-MS results excludes Si																										
B29	Calcrete profile located in Windsorton, Northern Cape with various layers of calcrete including pebbles in some layers (Figure 102)  Figure 103: Pebbles incorporated in the calcrete.	Can be ripped. Good road building material (Weinert, 1980). Nodular calcretes can be very hard but normally do not have to be ripped but only bulldozed and can be compacted for a good road base material (Netterberg and Caiger, 1983).	Results are in ppm PXRF <table><tr><th>Ca</th><th>Si</th><th>Al</th><th>Fe</th></tr><tr><td>195950</td><td>128675</td><td>20656</td><td>18065</td></tr><tr><th>Ti</th><th>S</th><th>K</th><th>Mn</th></tr><tr><td>2779</td><td>534</td><td>523</td><td>280</td></tr></table> Recalculated PXRF results <table><tr><th>Geochemistry</th><th>%</th></tr><tr><td>CaO</td><td>62.69%</td></tr><tr><td>SiO₂</td><td>26.89%</td></tr><tr><td>Al₂O₃</td><td>4.85%</td></tr><tr><td>Fe₂O₃</td><td>5.55%</td></tr></table>	Ca	Si	Al	Fe	195950	128675	20656	18065	Ti	S	K	Mn	2779	534	523	280	Geochemistry	%	CaO	62.69%	SiO ₂	26.89%	Al ₂ O ₃	4.85%	Fe ₂ O ₃	5.55%
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Table 55 (cont): Characteristics of calcretes in South Africa including stratigraphy, geotechnical implications and geochemical composition.

Sample number	Locality, site description and stratigraphy	Geotechnical characteristics	Element composition																										
			Portable XRF results and additional ICP-MS and XRD results for selected samples (indicated). Only the 8 highest elements are indicated, view Appendix B (PXRF) and C (ICP-MS) for full analytical results. ICP-MS results excludes Si																										
B58	Hardpan calcrete core sample from Windsorton area in the Northern Cape. Calcrete outcrops.	Crushing is required and used as building material (Weinert, 1980). Blasting or crushing is required occasionally but hardpans are mostly ripped and used as pavement material (Netterberg and Caiger, 1983).	Sample was not used for mineral analyses only used for microscope purposes  Figure 104: Hardpan calcrete outcrop																										
B60	Calcrete sample collected close to Upington in the Northern Cape.	Crushing is required and used as pavement or building material (Weinert, 1980). Blasting or crushing is required occasionally but hardpans are mostly ripped and used as pavement materia, (Netterberg and Caiger, 1983).	Results in ppm PXRF <table border="1"><tr><td>Ca</td><td>Si</td><td>Mg</td><td>Fe</td></tr><tr><td>238578</td><td>109760</td><td>31892</td><td>22088</td></tr><tr><td>K</td><td>Ti</td><td>P</td><td>S</td></tr><tr><td>6190</td><td>2234</td><td>1526</td><td>777</td></tr></table> Recalculated PXRF results <table border="1"><tr><td>Chemistry</td><td>%</td></tr><tr><td>CaO</td><td>66.55%</td></tr><tr><td>SiO₂</td><td>19.99%</td></tr><tr><td>MgO</td><td>7.5%</td></tr><tr><td>Fe₂O₃</td><td>5.94%</td></tr></table>	Ca	Si	Mg	Fe	238578	109760	31892	22088	K	Ti	P	S	6190	2234	1526	777	Chemistry	%	CaO	66.55%	SiO ₂	19.99%	MgO	7.5%	Fe ₂ O ₃	5.94%
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Table 55 (cont): Characteristics of calcretes in South Africa including stratigraphy, geotechnical implications and geochemical composition.

Sample number	Locality, site description and stratigraphy	Geotechnical characteristics	Element composition																																																				
			Portable XRF results and additional ICP-MS and XRD results for selected samples (indicated). Only the 8 highest elements are indicated, view Appendix B (PXRF) and C (ICP-MS) for full analytical results) ICP-MS results excludes Si																																																				
B70	Soft carbonate situated on elevated calcrete bank, Vergeleë, North-West Province.  Figure 105: Soft carbonate on the edge of calcrete bank	Can be compacted, but should be avoided for road building purposes (Weinert, 1980 and Netterberg and Caiger, 1983).	Results are in ppm PXRF <table><tr><th>Si</th><th>Ca</th><th>Mg</th><th>Al</th></tr><tr><td>164743</td><td>126409</td><td>21028</td><td>16724</td></tr><tr><th>Fe</th><th>Ti</th><th>K</th><th>S</th></tr><tr><td>13474</td><td>1391</td><td>847</td><td>550</td></tr></table> <table><tr><th>Geochemistry</th><th>%</th></tr><tr><td>CaO</td><td>47.87%</td></tr><tr><td>SiO₂</td><td>40.75%</td></tr><tr><td>MgO</td><td>6.71%</td></tr><tr><td>Al₂O₃</td><td>4.66%</td></tr></table> Results are in ppm ICP-MS <table><tr><th>Ca</th><th>Mg</th><th>Al</th><th>Fe</th></tr><tr><td>164600</td><td>17352</td><td>9785</td><td>7415</td></tr><tr><th>I</th><th>K</th><th>Na</th><th>P</th></tr><tr><td>4715</td><td>1996</td><td>530.25</td><td>476</td></tr></table> <table><tr><th>Geochemistry</th><th>%</th></tr><tr><td>CaO</td><td>85.02</td></tr><tr><td>MgO</td><td>7.55%</td></tr><tr><td>Al₂O₃</td><td>3.71%</td></tr><tr><td>Fe₂O₃</td><td>3.69%</td></tr></table>	Si	Ca	Mg	Al	164743	126409	21028	16724	Fe	Ti	K	S	13474	1391	847	550	Geochemistry	%	CaO	47.87%	SiO ₂	40.75%	MgO	6.71%	Al ₂ O ₃	4.66%	Ca	Mg	Al	Fe	164600	17352	9785	7415	I	K	Na	P	4715	1996	530.25	476	Geochemistry	%	CaO	85.02	MgO	7.55%	Al ₂ O ₃	3.71%	Fe ₂ O ₃	3.69%
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Table 55 (cont): Characteristics of calcretes in South Africa including stratigraphy, geotechnical implications and geochemical composition.

Sample number	Locality, site description and stratigraphy	Geotechnical characteristics	Element composition																										
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B70 (cont)			XRD <table><tr><th>Mineral</th><th>%</th></tr><tr><td>Calcite</td><td>54.22</td></tr><tr><td>Quartz</td><td>22.93</td></tr><tr><td>Kaolinite</td><td>10.55</td></tr><tr><td>Illite</td><td>4.87</td></tr><tr><td>Microcline</td><td>4.5</td></tr><tr><td>Plagioclase</td><td>2.53</td></tr><tr><td>Dolomite</td><td>0.4</td></tr></table>	Mineral	%	Calcite	54.22	Quartz	22.93	Kaolinite	10.55	Illite	4.87	Microcline	4.5	Plagioclase	2.53	Dolomite	0.4										
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B72	Soft carbonate under a hard carbonate layer, Vergeleë, North-West Province.  Figure 106: Soft carbonate under hard calcrete layer	Can be compacted, but should be avoided for road building purposes (Weinert, 1980 and Netterberg and Caiger, 1983).	Results are in ppm PXRF <table><tr><th>Si</th><th>Ca</th><th>Al</th><th>Mg</th></tr><tr><td>235490</td><td>66190</td><td>23822</td><td>14966</td></tr><tr><th>Fe</th><th>Ti</th><th>K</th><th>S</th></tr><tr><td>11072</td><td>1597</td><td>1112</td><td>699</td></tr></table> Recalculated PXRF results <table><tr><th>Geochemistry</th><th>%</th></tr><tr><td>SiO₂</td><td>61.48%</td></tr><tr><td>CaO</td><td>26.46%</td></tr><tr><td>Al₂O₃</td><td>7%</td></tr><tr><td>MgO</td><td>5%</td></tr></table>	Si	Ca	Al	Mg	235490	66190	23822	14966	Fe	Ti	K	S	11072	1597	1112	699	Geochemistry	%	SiO ₂	61.48%	CaO	26.46%	Al ₂ O ₃	7%	MgO	5%
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Table 55 (cont): Characteristics of calcretes in South Africa including stratigraphy, geotechnical implications and geochemical composition.

Sample number	Locality, site description and stratigraphy	Geotechnical characteristics	Element composition																																
			Portable XRF results and additional ICP-MS and XRD results for selected samples (indicated). Only the 8 highest elements are indicated, view Appendix B (PXRF) and C (ICP-MS) for full analytical results. ICP-MS results excludes Si																																
B81	Hardpan calcrete bank situated close to the Setlagoli river fluvial plain, Kalahari - Vergeleë  Figure 107: Hardpan calcrete	Crushing is required and used as pavement or building material (Weinert, 1980). Blasting or crushing is required occasionally but hardpans are mostly ripped and used as pavement material, (Netterberg and Caiger, 1983).	Results in ppm PXRF <table><tr><td>Ca</td><td>Si</td><td>Al</td><td>Fe</td></tr><tr><td>275096</td><td>118628</td><td>3985</td><td>3264</td></tr><tr><td>S</td><td>Ti</td><td>Mn</td><td>V</td></tr><tr><td>1189</td><td>975</td><td>638</td><td>564</td></tr></table> Recalculated PXRF results <table><tr><td>Geochemistry</td><td>%</td></tr><tr><td>CaO</td><td>76.70%</td></tr><tr><td>SiO₂</td><td>21.6%</td></tr><tr><td>Al₂O₃</td><td>0.81%</td></tr><tr><td>Fe₂O₃</td><td>0.87%</td></tr></table> XRD <table><tr><td>Mineral</td><td>%</td></tr><tr><td>Calcite</td><td>94.47</td></tr><tr><td>Quartz</td><td>5.53</td></tr></table>	Ca	Si	Al	Fe	275096	118628	3985	3264	S	Ti	Mn	V	1189	975	638	564	Geochemistry	%	CaO	76.70%	SiO ₂	21.6%	Al ₂ O ₃	0.81%	Fe ₂ O ₃	0.87%	Mineral	%	Calcite	94.47	Quartz	5.53
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Table 55 (cont): Characteristics of calcretes in South Africa including stratigraphy, geotechnical implications and geochemical composition.

Sample number	Locality, site description and stratigraphy	Geotechnical characteristics	Element composition																											
			Portable XRF results and additional ICP-MS and XRD results for selected samples (indicated). Only the 8 highest elements are indicated, view Appendix B (PXRF) and C (ICP-MS) for full analytical results. ICP-MS results excludes Si																											
B82	Subfossil: <i>Lymnaea truncatula</i> found in calcrete situated in a low lying area in the Vergeleë region in the Kalahari.	n/a	Results in ppm PXRF <table><tr><td>Ca</td><td>Si</td><td>Al</td><td>Fe</td></tr><tr><td>321909</td><td>79372</td><td>2492</td><td>2226</td></tr><tr><td>S</td><td>Ti</td><td>Sr</td><td>Mn</td></tr><tr><td>965</td><td>816</td><td>636</td><td>435</td></tr></table>	Ca	Si	Al	Fe	321909	79372	2492	2226	S	Ti	Sr	Mn	965	816	636	435	Recalculated PXRF results <table><tr><td>Geochemistry</td><td>%</td></tr><tr><td>CaO</td><td>85.22%</td></tr><tr><td>SiO₂</td><td>13.72%</td></tr><tr><td>Al₂O₃</td><td>0.48%</td></tr><tr><td>Fe₂O₃</td><td>056%</td></tr></table>	Geochemistry	%	CaO	85.22%	SiO ₂	13.72%	Al ₂ O ₃	0.48%	Fe ₂ O ₃	056%
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Table 55 (cont): Characteristics of calcretes in South Africa including stratigraphy, geotechnical implications and geochemical composition.

Sample number	Locality, site description and stratigraphy	Geotechnical characteristics	Element composition																										
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B90	Hard carbonate, Saldanha Bay, south-western coast	Crushing is required and used as pavement or building material (Weinert, 1980). Blasting or crushing is required occasionally but hardpans are mostly ripped and used as pavement material (Netterberg and Caiger, 1983).	Results in ppm PXRF <table><tr><td>Si</td><td>Ca</td><td>Al</td><td>Mg</td></tr><tr><td>266965</td><td>138910</td><td>37026</td><td>24477</td></tr><tr><td>Fe</td><td>K</td><td>Ti</td><td>S</td></tr><tr><td>4644</td><td>3188</td><td>2546</td><td>1027</td></tr></table> Recalculated PXRF results <table><tr><td>Geochemistry</td><td>%</td></tr><tr><td>SiO₂</td><td>48.28%</td></tr><tr><td>CaO</td><td>38.46%</td></tr><tr><td>Al₂O₃</td><td>7.5%</td></tr><tr><td>MgO</td><td>5.7%</td></tr></table>	Si	Ca	Al	Mg	266965	138910	37026	24477	Fe	K	Ti	S	4644	3188	2546	1027	Geochemistry	%	SiO ₂	48.28%	CaO	38.46%	Al ₂ O ₃	7.5%	MgO	5.7%
Si	Ca	Al	Mg																										
266965	138910	37026	24477																										
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Sample number	Locality, site description and stratigraphy	Geotechnical characteristics	Element composition																										
			Portable XRF results and additional ICP-MS and XRD results for selected samples (indicated). Only the 8 highest elements are indicated, view Appendix B (PXRF) and C (ICP-MS) for full analytical results. ICP-MS results excludes Si																										
B103A	Carbonate concretion at periglacial site, Groot Marico, North-West Province. Hard nodules are found on the surface and vary from round to angular. Diabase, quartzite and banded ironstone pebbles are also present.	Crushing is required and used as pavement or building material (Weinert ,1980). Nodular calcretes can be very hard but normally don't have to be ripped but only bulldozed and can be compacted for a good road base material (Netterberg and Caiger, 1983).	Results in ppm PXRF <table><tr><td>Si</td><td>Ca</td><td>Al</td><td>Fe</td></tr><tr><td>149223</td><td>108468</td><td>61427</td><td>52676</td></tr><tr><td>Mg</td><td>K</td><td>Ti</td><td>Mn</td></tr><tr><td>18429</td><td>5329</td><td>3727</td><td>627</td></tr></table> Recalculated PXRF results <table><tr><td>Geochemistry</td><td>%</td></tr><tr><td>SiO₂</td><td>32.27%</td></tr><tr><td>CaO</td><td>35.92%</td></tr><tr><td>Al₂O₃</td><td>14.96%</td></tr><tr><td>Fe₂O₃</td><td>16.83%</td></tr></table>	Si	Ca	Al	Fe	149223	108468	61427	52676	Mg	K	Ti	Mn	18429	5329	3727	627	Geochemistry	%	SiO ₂	32.27%	CaO	35.92%	Al ₂ O ₃	14.96%	Fe ₂ O ₃	16.83%
Si	Ca	Al	Fe																										
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Al ₂ O ₃	14.96%																												
Fe ₂ O ₃	16.83%																												

The portable XRF results for the highest eight values are seen in Table 55, see appendix B for full analytical results. As stated by Goudie (1972) 42.62% CaO is required for a material to be classified as a calcrete. As the 42.62% CaO is used as a minimum required percentage in this study, samples B29, B60, B70, B81 and B82 can be identified as calcretes. B72, B90 and B103A did not have the minimum CaO%, and may rather be seen as a calcified soil (Weinert, 1980). Sample B103A may have a low CaO percentage due to the locality where the sample was collected (see Chapter 4.4.6: Periglacial deposit). The XRF results were used for interpretation purposes because only one sample was analysed using ICP-MS. The ICP-MS results for B70 correlate moderately well with the XRF results, accept that Si was not analysed with ICP-MS. The SiO_2 in the samples were high due to it being the second most important constitute in calcrete (Goudie, 1972). The hard calcrete samples, B29, B58, B60, B81, B90 and B103 can be associated will the soil forms containing hard carbonate horizons such as Asham, Plooyburg, Gamoep, Prieska and Coega soil forms, and the soft calcrete sample, B70 and B72, can be associated with the soil forms containing a soft carbonate horizon such as Mololpo, Kimberley, Etosha, Addo and Brandvlei (Soil Classification Working Group. 1991 and Fey, 2010)

The XRD analyses were done on samples B70 and B81 and indicate that quartz and calcite are the dominant minerals present. The mineralogical analyses done using a stereomicroscope, indicated quartz minerals in a carbonate matrix as seen on the photomicrography in Figure 108.

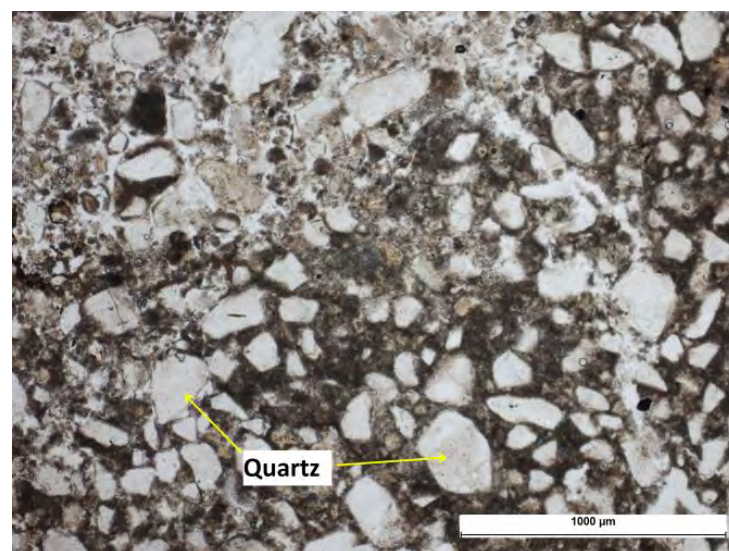


Figure 108: Photomicrograph of calcrete sample (B81) (50X magnification, plane polarised light) indicating the mineral composition. Quartz grains are indicated in a carbonate matrix.

The geotechnical implications of calcretes are mainly dependent on the stage of development as well as the host texture and matrix material (Brink, 1985 and Weinert and Caiger, 1983), therefore site specific investigations are required to determine the accurate implications. It can

be noted that soft carbonates can be compacted, but should be avoided for road building material due to its high solubility during wet conditions, nodular calcretes can be bulldozed and used as a good road base material and hardpan calcretes can require blasting, crushing or ripping to be used as pavement material (Netterberg and Caiger, 1983). Research done in Israel indicated that calcrete outcrops increased the runoff to the cropland and increases the available water, which increased the agricultural potential (Ackermann *et al.*, 2008). This is not relevant to all calcretes which many have a moderate to low agricultural potential.

4.5.2 Silcrete and Dorbanks

Silcrete and dorbank samples were collected in various localities over South Africa as indicated in the compiled maps, see Figure 23 for silcretes and Figure 24 for dorbanks. The locality, site description, stratigraphy, geotechnical characteristics and geochemical composition will be discussed for each sample in Table 56 and Figures 109 to 111.

The silcrete samples, indicated in the silicic map (Figure 23), correlated well with the climatic Weinert N-value >5, dominated by calcrete and silcrete, Figure 9. The samples did not correlate well with the silicic soil deposits (mainly silicic sand) of Fey (2010) (Figure 23). This can be due to silcrete being seen as a palaeo-feature and does not correspond to the younger silicic soils from Fey (2010). The dorbanks, as seen in Figure 24, which are also associated with the silicic deposits, correlated well with Fey (2010).

The dorbank samples, B43, B56 and BX2, can be associated with the soil forms containing dorbank horizons such as Garies, Oudtshoorn and Trawal soil forms (Soil Classification Working Group, 1991 and Fey, 2010).

The portable XRF results for the highest eight values are seen in Table 56 (see appendix B for full analytical results). The oxide percentages were not calculated for the ICP-MS results due to ICP-MS not including Si in the analyses, and as Si is the main element in silcretes. The geochemical composition of a silcrete was stated by Nash and Shaw (1998:14) and Nash and Ulliyott (2007:95) to comprise of at least 85% SiO₂. Sample B79 does not comply with this minimum requirement and may rather be seen as an intergrade pedocrete due to the higher CaO and MgO percentages. The dorbank samples, B43 and B56, both have SiO₂ values of 63.55% and 57.18%, and Fe₂O₃ values of 10.79% and 15.73%, respectively. Both dorbank samples were dominated by high SiO₂, Fe₂O₃ and Al₂O₃ percentages. The silica cement in dorbanks can have additional elements such as calcium carbonates and iron oxides, where iron oxide is responsible for the red colour (Fey, 2010), as seen in Figure 110 and 111 and Table 56.

Table 56: Characteristics of silcretes and dorbank deposits in South Africa including stratigraphy, geotechnical implications and geochemical composition.

Sample number	Locality, site description and stratigraphy	Geotechnical characteristics	Element composition																												
			Portable XRF results and additional ICP-MS and XRD results for selected samples (indicated). Only the 8 highest elements are indicated, view Appendix B (PXRF) and C (ICP-MS) for full analytical results. ICP-MS results excludes Si																												
B73	Silcrete from the Kalahari in the Vergeleë region, North West. Sample was collected from a silcrete outcrop/vein.  Figure 109: Silcrete vein close to Vergeleë in the North-West Province.	Can be used as road construction material (Weinert, 1980).	Results are in ppm ICP-MS <table><tr><td>Fe</td><td>Al</td><td>Mg</td><td>Ca</td></tr><tr><td>12195</td><td>9245</td><td>4025</td><td>1805</td></tr><tr><td>K</td><td>P</td><td>I</td><td>Na</td></tr><tr><td>1392</td><td>432</td><td>407</td><td>393</td></tr></table> Total oxide percentages were not calculated due to Si not being analysed by ICP-MS. XRD <table><tr><td>Mineral</td><td>%</td></tr><tr><td>Quartz</td><td>52.12</td></tr><tr><td>Kaolinite</td><td>18.09</td></tr><tr><td>Illite</td><td>11.8</td></tr><tr><td>Smectite</td><td>9.13</td></tr><tr><td>Plagioclase</td><td>8.87</td></tr></table>	Fe	Al	Mg	Ca	12195	9245	4025	1805	K	P	I	Na	1392	432	407	393	Mineral	%	Quartz	52.12	Kaolinite	18.09	Illite	11.8	Smectite	9.13	Plagioclase	8.87
Fe	Al	Mg	Ca																												
12195	9245	4025	1805																												
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1392	432	407	393																												
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Table 56 (cont): Characteristics of silcretes and dorbank deposits in South Africa including stratigraphy, geotechnical implications and geochemical composition.

Sample number	Locality, site description and stratigraphy	Geotechnical characteristics	Element composition																										
			Portable XRF results and additional ICP-MS and XRD results for selected samples (indicated). Only the 8 highest elements are indicated, view Appendix B (PXRF) and C (ICP-MS) for full analytical results. ICP-MS results excludes Si																										
B79	Silcrete from the Kalahari in the Vergeleë region, North West. A sample was collected from a depth of 39 meters below the surface within a drilled borehole core. The silcrete layer was overlain by a red clay and sand horizon; see Chapter 4.4.4, borehole 1, for the lithostratigraphical sequence.	Can be used as road construction material (Weinert, 1980).	Results in ppm PXRF <table><tr><td>Si</td><td>Mg</td><td>Ca</td><td>Al</td></tr><tr><td>195290</td><td>64426</td><td>55691</td><td>42612</td></tr><tr><td>Fe</td><td>Ti</td><td>S</td><td>Cr</td></tr><tr><td>35479</td><td>2057</td><td>1103</td><td>625</td></tr></table> Recalculated PXRF results <table><tr><td>Geochemistry</td><td>%</td></tr><tr><td>SiO₂</td><td>47.43%</td></tr><tr><td>MgO</td><td>20.20%</td></tr><tr><td>CaO</td><td>20.70%</td></tr><tr><td>Al₂O₃</td><td>11.65%</td></tr></table>	Si	Mg	Ca	Al	195290	64426	55691	42612	Fe	Ti	S	Cr	35479	2057	1103	625	Geochemistry	%	SiO ₂	47.43%	MgO	20.20%	CaO	20.70%	Al ₂ O ₃	11.65%
Si	Mg	Ca	Al																										
195290	64426	55691	42612																										
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Al ₂ O ₃	11.65%																												

Table 56 (cont): Characteristics of silcretes and dorbank deposits in South Africa including stratigraphy, geotechnical implications and geochemical composition.

Sample number	Locality, site description and stratigraphy	Geotechnical characteristics	Element composition																															
			Portable XRF results and additional ICP-MS and XRD results for selected samples (indicated). Only the 8 highest elements are indicated, view Appendix B (PXRF) and C (ICP-MS) for full analytical results. ICP-MS results excludes Si																															
B43	Dorbank for the Aggeneys area, Northern Cape.  Figure 110: Dorbank outcrops on the footslope colluvium near Aggeneys, Northern Cape.	Can be used as road construction material (Weinert, 1980).	Results in ppm																															
			PXRF				Recalculated PXRF results																											
			<table><tr><td>Si</td><td>Al</td><td>Fe</td><td>Mg</td></tr><tr><td>238653</td><td>57277</td><td>27433</td><td>24634</td></tr><tr><td>K</td><td>Ti</td><td>S</td><td>Mn</td></tr><tr><td>14667</td><td>1618</td><td>962</td><td>244</td></tr></table>				Si	Al	Fe	Mg	238653	57277	27433	24634	K	Ti	S	Mn	14667	1618	962	244	<table><tr><td>Geochemistry</td><td>%</td></tr><tr><td>SiO₂</td><td>63.55%</td></tr><tr><td>Al₂O₃</td><td>17.18%</td></tr><tr><td>Fe₂O₃</td><td>10.79%</td></tr><tr><td>MgO</td><td>8.46%</td></tr></table>		Geochemistry	%	SiO ₂	63.55%	Al ₂ O ₃	17.18%	Fe ₂ O ₃	10.79%	MgO	8.46%
			Si	Al	Fe	Mg																												
			238653	57277	27433	24634																												
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Table 56 (cont): Characteristics of silcretes and dorbank deposits in South Africa including stratigraphy, geotechnical implications and geochemical composition.

Sample number	Locality, site description and stratigraphy	Geotechnical characteristics	Element composition																																										
			Portable XRF results and additional ICP-MS and XRD results for selected samples (indicated). Only the 8 highest elements are indicated, view Appendix B (PXRF) and C (ICP-MS) for full analytical results. ICP-MS results excludes Si																																										
B56	Dorbank for the Pofadder area, Northern Cape.  Figure 111: Dorbank close to Pofadder in the Northern Cape.	Can be used as road construction material (Weinert, 1980).	Results in ppm PXRF<table><tr><th>Si</th><th>Al</th><th>Fe</th><th>K</th></tr><tr><td>204944</td><td>55457</td><td>38160</td><td>19470</td></tr><tr><th>Ti</th><th>Ca</th><th>S</th><th>P</th></tr><tr><td>4308</td><td>1720</td><td>1177</td><td>757</td></tr></table> ICP-MS<table><tr><th>Fe</th><th>Al</th><th>K</th><th>Mg</th></tr><tr><td>17358</td><td>8525</td><td>2505</td><td>2349</td></tr><tr><th>Ca</th><th>P</th><th>Ti</th><th>Na</th></tr><tr><td>709</td><td>572</td><td>349</td><td>346</td></tr></table> XRD<table><tr><th>Geochemistry</th><th>%</th></tr><tr><td>SiO₂</td><td>57.18%</td></tr><tr><td>Al₂O₃</td><td>17.42%</td></tr><tr><td>Fe₂O₃</td><td>15.73%</td></tr><tr><td>K₂O</td><td>9.65%</td></tr></table> Total oxide percentages were not calculated due to Si not being analysed by ICP-MS.	Si	Al	Fe	K	204944	55457	38160	19470	Ti	Ca	S	P	4308	1720	1177	757	Fe	Al	K	Mg	17358	8525	2505	2349	Ca	P	Ti	Na	709	572	349	346	Geochemistry	%	SiO ₂	57.18%	Al ₂ O ₃	17.42%	Fe ₂ O ₃	15.73%	K ₂ O	9.65%
Si	Al	Fe	K																																										
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Table 56 (cont): Characteristics of silcretes and dorbank deposits in South Africa including stratigraphy, geotechnical implications and geochemical composition.

Sample number	Locality, site description and stratigraphy	Geotechnical characteristics	Element composition																
			Portable XRF results and additional ICP-MS and XRD results for selected samples (indicated). Only the 8 highest elements are indicated, view Appendix B (PXRF) and C (ICP-MS) for full analytical results). ICP-MS results excludes Si																
BX2	Dorbank sample collected close to Verneukpan near Brandvlei, south of Kenhardt, Northern Cape.	Can be used as road construction material (Weinert ,1980).	XRD <table><tr><th>Mineral</th><th>%</th></tr><tr><td>Calcite</td><td>38.98</td></tr><tr><td>Quartz</td><td>34.1</td></tr><tr><td>Kaolinite</td><td>11.23</td></tr><tr><td>Illite</td><td>5.4</td></tr><tr><td>Microcline</td><td>4.46</td></tr><tr><td>Dolomite</td><td>3.64</td></tr><tr><td>Plagioclase</td><td>2.19</td></tr></table>	Mineral	%	Calcite	38.98	Quartz	34.1	Kaolinite	11.23	Illite	5.4	Microcline	4.46	Dolomite	3.64	Plagioclase	2.19
Mineral	%																		
Calcite	38.98																		
Quartz	34.1																		
Kaolinite	11.23																		
Illite	5.4																		
Microcline	4.46																		
Dolomite	3.64																		
Plagioclase	2.19																		

A ternary diagram was constructed using Triplot software (2005), by assigning three main geochemical components e.g. SiO_2 , Fe_2O_3 and TiO_2 , (Figure 112). The results were compared with a ternary diagram from Goudie (1983) which included 68 silcrete samples. The diagrams correlated well, but the samples in Figure 112 are dominated by SiO_2 , whereas the results of Goudie (1983) have more variability. TiO_2 was included in the diagram as TiO_2 are mostly associated with silcrete formation (Goudie, 1982).

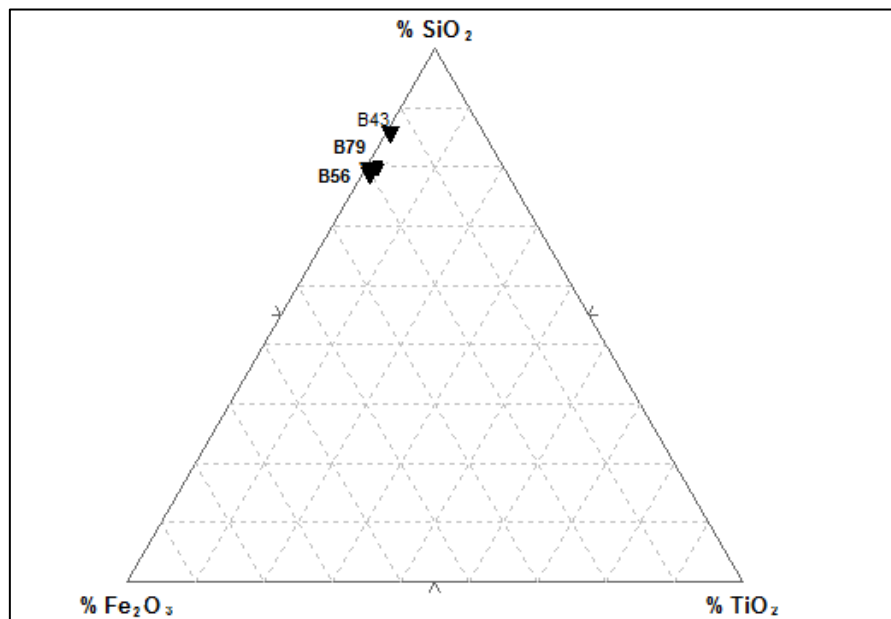


Figure 112: Ternary plots of SiO_2 , TiO_2 and Fe_2O_3 for three silcrete samples from South Africa. (Triplot software, 2015).

The XRD analysis was done on samples B73 and BX2 and indicates that the dominant minerals are quartz, calcite and kaolinite. The minerals were also identified using a stereomicroscope showing quartz in an iron-rich clay matrix as seen on the photomicrograph in Figure 113. The micrograph corresponds to an example of a pedogenic silcrete from South Australia indicated in Figure 114. A micrograph of a dorbank sample (B43) is shown in Figure 115, and indicates an iron-rich matrix with quartz, calcite, microcline and weathered feldspar minerals present.

The geotechnical implications of silcretes and dorbanks are mainly dependent on the stage of development as well as the host texture and matrix material (Netterberg and Caiger, 1983), therefore site specific investigations are required to determine the accurate implications. Silcretes are much harder than calcrete, whereas dorbanks are softer and can be seen as silicified soil in regards to geotechnical implications (Brink, 1985). Dorbanks can be removed or

broken up when situated in the rootzone, before crops can be planted under irrigation (Soil Classification Working Group. 1991).

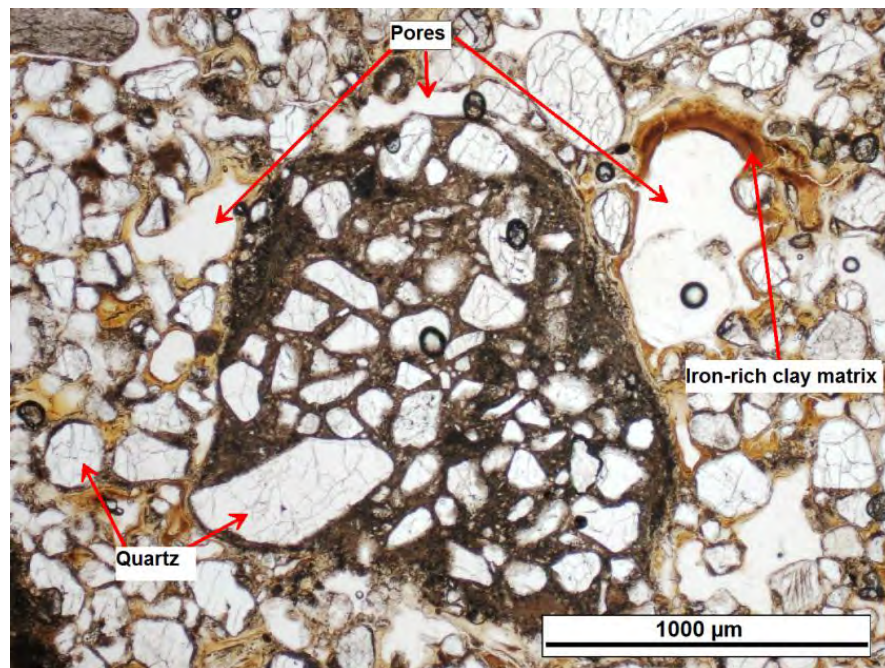


Figure 113: Photomicrograph of silcrete sample B73 (50X magnification, plane polarised light) Quartz grains are indicated in a carbonate matrix.

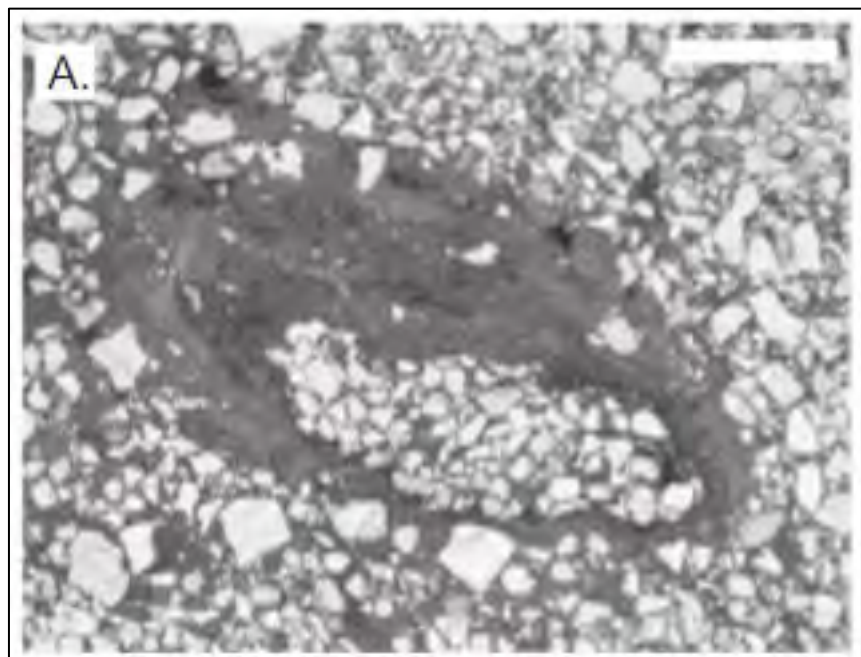


Figure 114: „Thin-section view of a grain-supported to floating fabric glaebular pedogenic silcrete from Stuart Creek, South Australia, consisting of quartz grains surrounded by a microquartz and opal matrix (plain polarised light; scale bar 2 mm; micro-graph courtesy of John Webb)” from Nash and Ulliyott (2007).

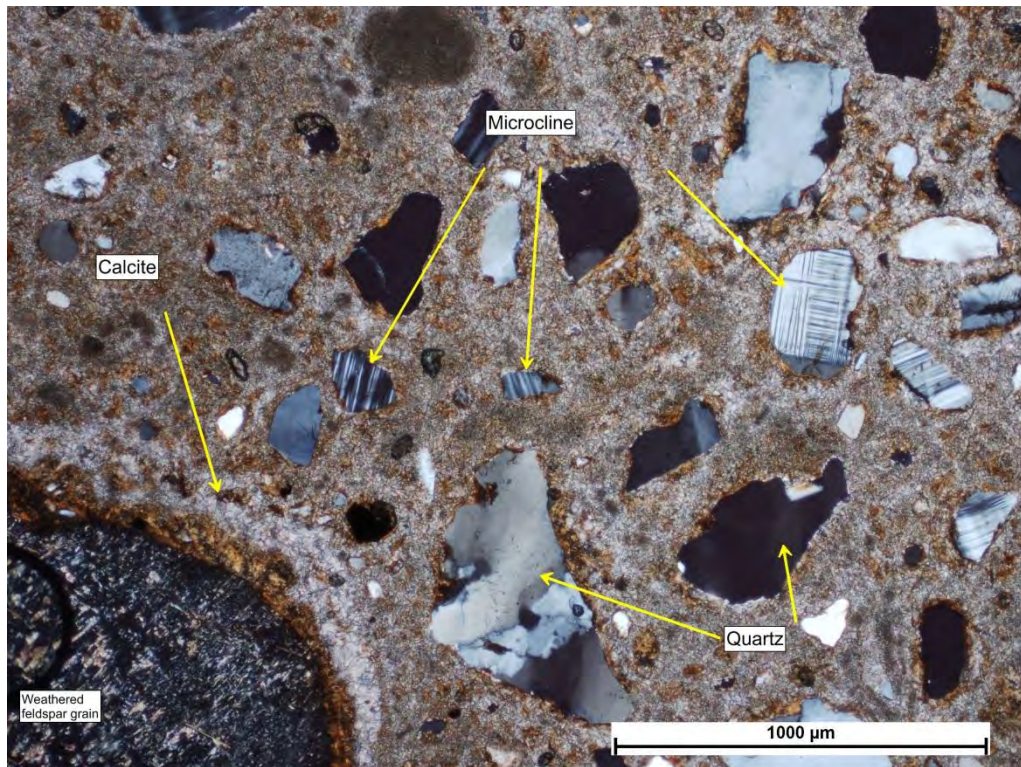


Figure 115: Photomicrograph of dorbank sample B43 (50X magnification, plane polarised light). Quartz, microcline, calcite and weathered feldspar grains are indicated in a matrix.

4.5.3 Ferricrete and Manganocrete

Ferricrete and manganocrete samples were collected in various localities over South Africa as indicated in the compiled maps. The oxidic deposits map includes the ferricretes (Figure 25) and the manganocrete deposits are seen in Figure 26. The locality, site description, stratigraphy, geotechnical characteristics and geochemical composition are discussed for each sample collected in Table 57 and Figures 116 and 117 below.

The locality of ferricrete samples, indicated in the oxidic deposits map (Figure 25), correlated well with the climatic Weinert N-value <5 (Figure 9). The samples also correlated well with the high percentage oxidic soil regions of Fey (2010) (Figure 25). The manganocrete samples indicated in the manganocrete map (Figure 26) are situated at the same sample locality as the ferricrete deposits. The distribution of ferricretes is mainly dominant in the eastern side of South Africa and more examples are found on the 2528 Pretoria and 2628 East Rand Land Type Maps such as the Glencoe and Wasbank soil forms (Land Type Survey Staff, 1987).

The portable XRF results for the highest eight values for the ferricrete and manganocrete (Table 57). See Appendix B for complete analytical results.

Table 57: Characteristics of ferricretes and manganocretes in South Africa including stratigraphy, geotechnical implications and composition.

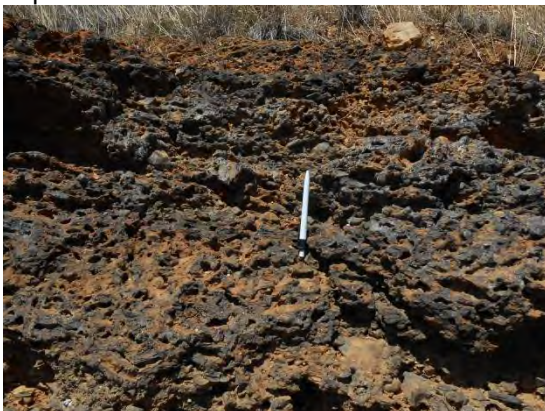
Sample number	Locality, site description and stratigraphy	Geotechnical characteristics	Element composition																										
			Portable XRF results and additional ICP-MS and XRD results for selected samples (indicated). Only the 8 highest elements are indicated, view Appendix B (PXRF) and C (ICP-MS) for full analyses results. ICP-MS results excludes Si																										
B14	Ferricrete from the Stilfontein area, North West Province. Sample was collected from the bank of a lower relief drainage depression.  Figure 116: Ferricrete from an area close to Stilfontein, North-West Province.	Can be used as road construction material (Weinert, 1980).	Results are in ppm PXRF <table border="1"><thead><tr><th>Si</th><th>Fe</th><th>Al</th><th>Mn</th></tr></thead><tbody><tr><td>195290</td><td>170899</td><td>82223</td><td>11754</td></tr><tr><th>K</th><th>Ti</th><th>V</th><th>S</th></tr><tr><td>4310</td><td>4224</td><td>1004</td><td>349</td></tr></tbody></table> Recalculated PXRF analyses<table border="1"><thead><tr><th>Geochemistry</th><th>%</th></tr></thead><tbody><tr><td>SiO₂</td><td>34.96%</td></tr><tr><td>Fe₂O₃</td><td>45.20%</td></tr><tr><td>Al₂O₃</td><td>16.58%</td></tr><tr><td>Mn₃O₄</td><td>3.24%</td></tr></tbody></table>	Si	Fe	Al	Mn	195290	170899	82223	11754	K	Ti	V	S	4310	4224	1004	349	Geochemistry	%	SiO ₂	34.96%	Fe ₂ O ₃	45.20%	Al ₂ O ₃	16.58%	Mn ₃ O ₄	3.24%
Si	Fe	Al	Mn																										
195290	170899	82223	11754																										
K	Ti	V	S																										
4310	4224	1004	349																										
Geochemistry	%																												
SiO ₂	34.96%																												
Fe ₂ O ₃	45.20%																												
Al ₂ O ₃	16.58%																												
Mn ₃ O ₄	3.24%																												

Table 57 (cont): Characteristics of ferricretes and manganocretes in South Africa including stratigraphy, geotechnical implications and composition.

Sample number	Locality, site description and stratigraphy	Geotechnical characteristics	Element composition																																				
			Portable XRF results and additional ICP-MS and XRD results for selected samples (indicated). Only the 8 highest elements are indicated, view Appendix B (PXRF) and C (ICP-MS) for full analyses results. ICP-MS results excludes Si																																				
B14 (cont)			Results are in ppm ICP-MS <table><tr><td>Fe</td><td>Al</td><td>Mn</td><td>I</td></tr><tr><td>150225</td><td>19430</td><td>3585</td><td>976</td></tr><tr><td>P</td><td>K</td><td>Ba</td><td>Cr</td></tr><tr><td>851</td><td>838</td><td>729</td><td>412</td></tr></table> XRD <table><tr><td>Mineral</td><td>%</td></tr><tr><td>Quartz</td><td>38.05</td></tr><tr><td>Goethite</td><td>38.05</td></tr><tr><td>Kaolinite</td><td>8.78</td></tr><tr><td>Illite</td><td>4.07</td></tr></table> Recalculated ICP-MS analyses<table><tr><td>Geochemistry</td><td>%</td></tr><tr><td>Fe₂O₃</td><td>89%</td></tr><tr><td>Al₂O₃</td><td>8.77%</td></tr><tr><td>Mn₃O₄</td><td>2.2%</td></tr><tr><td>I₂O</td><td>0.77%</td></tr></table>	Fe	Al	Mn	I	150225	19430	3585	976	P	K	Ba	Cr	851	838	729	412	Mineral	%	Quartz	38.05	Goethite	38.05	Kaolinite	8.78	Illite	4.07	Geochemistry	%	Fe ₂ O ₃	89%	Al ₂ O ₃	8.77%	Mn ₃ O ₄	2.2%	I ₂ O	0.77%
Fe	Al	Mn	I																																				
150225	19430	3585	976																																				
P	K	Ba	Cr																																				
851	838	729	412																																				
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Table 57 (cont): Characteristics of ferricretes and manganocretes in South Africa including stratigraphy, geotechnical implications and composition.

Sample number	Locality, site description and stratigraphy	Geotechnical characteristics	Element composition																																			
			Portable XRF results and additional ICP-MS and XRD results for selected samples (indicated). Only the 8 highest elements are indicated, view Appendix B (PXRF) and C (ICP-MS) for full analyses results. ICP-MS results excludes Si																																			
B75	Ferricrete from the Vergeleë area, North West.	Can be used as road construction material (Weinert, 1980).	Results are in ppm																																			
			PXRF				Recalculated PXRF analyses																															
			<table><tr><td>Si</td><td>Al</td><td>Fe</td><td>Ti</td></tr><tr><td>292350</td><td>70149</td><td>23567</td><td>2554</td></tr><tr><td>K</td><td>S</td><td>Zr</td><td>Mn</td></tr><tr><td>2521</td><td>613</td><td>179</td><td>168</td></tr></table>				Si	Al	Fe	Ti	292350	70149	23567	2554	K	S	Zr	Mn	2521	613	179	168	<table><tr><td>Geochemistry</td><td>%</td></tr><tr><td>SiO₂</td><td>71.39%</td></tr><tr><td>Al₂O₃</td><td>19.29%</td></tr><tr><td>Fe₂O₃</td><td>8.5%</td></tr><tr><td>TiO₂</td><td>0.8%</td></tr></table>						Geochemistry	%	SiO ₂	71.39%	Al ₂ O ₃	19.29%	Fe ₂ O ₃	8.5%	TiO ₂	0.8%
Si	Al	Fe	Ti																																			
292350	70149	23567	2554																																			
K	S	Zr	Mn																																			
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SiO ₂	71.39%																																					
Al ₂ O ₃	19.29%																																					
Fe ₂ O ₃	8.5%																																					
TiO ₂	0.8%																																					

Table 57 (cont): Characteristics of ferricretes and manganocretes in South Africa including stratigraphy, geotechnical implications and composition.

Sample number	Locality, site description and stratigraphy	Geotechnical characteristics	Element composition																																																				
			Portable XRF results and additional ICP-MS and XRD results for selected samples (indicated). Only the 8 highest elements are indicated, view Appendix B (PXRF) and C (ICP-MS) for full analyses results. ICP-MS results excludes Si																																																				
B11 and B12 (repetition)	Manganocrete sample collected close to Stilfontein in the North-West Province (repetition of B11).  Figure 117: A manganocrete boulder from the Stilfontein area, North-West Province.	Can be used as road construction material (Weinert, 1980).	Results are in ppm PXRF <table border="1"><thead><tr><th>Fe</th><th>Si</th><th>Al</th><th>Mn</th></tr></thead><tbody><tr><td>175268</td><td>126877</td><td>81270</td><td>61032</td></tr><tr><th>K</th><th>Ti</th><th>V</th><th>S</th></tr><tr><td>5279</td><td>3853</td><td>908</td><td>448</td></tr></tbody></table> ICP-MS <table border="1"><thead><tr><th>Fe</th><th>Mn</th><th>Al</th><th>Ba</th></tr></thead><tbody><tr><td>118775</td><td>63325</td><td>22698</td><td>3490</td></tr><tr><th>K</th><th>I</th><th>Ca</th><th>Mg</th></tr><tr><td>2107</td><td>950</td><td>878</td><td>448</td></tr></tbody></table> Recalculated PXRF analyses <table border="1"><thead><tr><th>Geochemistry</th><th>%</th></tr></thead><tbody><tr><td>Fe₂O₃</td><td>45.31%</td></tr><tr><td>SiO₂</td><td>22.20%</td></tr><tr><td>Al₂O₃</td><td>16.01%</td></tr><tr><td>Mn₃O₄</td><td>16.46%</td></tr></tbody></table> Recalculated ICP-MS analyses <table border="1"><thead><tr><th>Geochemistry</th><th>%</th></tr></thead><tbody><tr><td>Fe₂O₃</td><td>57.46%</td></tr><tr><td>Mn₃O₄</td><td>31.97%</td></tr><tr><td>Al₂O₃</td><td>8.3%</td></tr><tr><td>BaO</td><td>2.19%</td></tr></tbody></table>	Fe	Si	Al	Mn	175268	126877	81270	61032	K	Ti	V	S	5279	3853	908	448	Fe	Mn	Al	Ba	118775	63325	22698	3490	K	I	Ca	Mg	2107	950	878	448	Geochemistry	%	Fe ₂ O ₃	45.31%	SiO ₂	22.20%	Al ₂ O ₃	16.01%	Mn ₃ O ₄	16.46%	Geochemistry	%	Fe ₂ O ₃	57.46%	Mn ₃ O ₄	31.97%	Al ₂ O ₃	8.3%	BaO	2.19%
Fe	Si	Al	Mn																																																				
175268	126877	81270	61032																																																				
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BaO	2.19%																																																						

Only samples B14 and B11 were analysed by ICP-MS. The geochemical composition of Fe_2O_3 for the ferricrete samples varied from 8.5% for B75 up to 42.20% for B14. The Fe_2O_3 percentage for B14 determined by ICP-MS is 89% and is much higher than the determined PXRF value. Other geochemical components included SiO_2 , Al_2O_3 and Mn_3O_4 . The PXRF analyses and the ICP-MS analyses correlated well with the manganocrete sample (B11). The Fe_2O_3 percentages varied from 45.31% (XRF) and 57.46% (ICP-MS) and the Mn_3O_4 varied from 16.46% (XRF) and 31.97% (ICP-MS). The XRD analysis was done on the ferricrete sample B14 and indicated that the dominant minerals were goethite, illite, kaolinite and quartz.

The ferricrete samples can be associated with the soil forms containing hard plinthic B horizons such as Wasbank, Dresden and Glencoe (Soil Classification Working Group, 1991).

A photomicrograph of a ferricrete sample (B14) indicated quartz in an iron-rich clay matrix, see Figure 118. Manganocrete was not analysed with a stereomicroscope due to the difficulty of preparation.

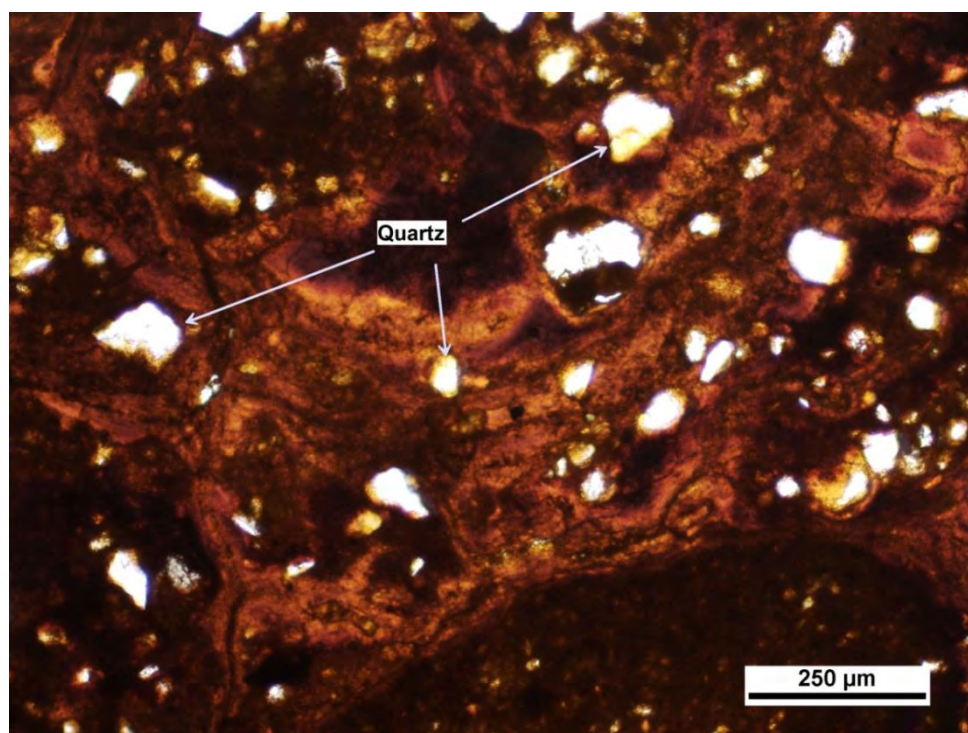


Figure 118: Photomicrograph of a ferricrete sample (B14) (200X magnification, plane polarised light). Quartz grains are indicated in the matrix.

Various types and sizes of other rock fragments and pebbles are frequently present in some ferricrete and manganocrete. In some cases it is difficult to decide whether it is a ferricrete or manganocrete conglomerate or conglomerate in a ferricrete or manganocrete matrix, as seen in Figure 119.

Ferricretes may cause consolidation settlement if underlying ferricrete is soft or nodular (Department of Public Works, 2007). The geotechnical implications of ferricrete and manganocretes must therefore be determined site specifically to be accurate. Ferricretes can be used as good road construction material (Weinert, 1980). The agricultural potential in shallow ferricrete deposits are mainly low due to its indurated morphology (De Wet, 1991), and therefore the agricultural potential of ferricretes are mainly dependant on the thickness of the overlying soil horizon. This implies that e.g. the Glencoe soil form, Orthic A on a yellow-brown apedal B on hard plinthic B horizon, may be suitable for agricultural potential (Soil Classification Working Group. 1991).



Figure 119: A ferricrete/manganocrete outcrop from an area close to Stilfontein in the North-West Province.

4.5.4 Phoscrete

A phoscrete sample was collected close to Langebaan in the Western Cape, South Africa (Figure 27). The locality, site description, geotechnical characteristics and element composition are discussed in Table 58.

Phoscrete may be used for road construction material, but is not common. The elemental composition determined by ICP-MS analyses indicated that P_2O_5 was 20.97% and CaO was 77.6%. The main minerals present in the phoscrete samples were quartz and apatite. The geochemical composition of phoscrete varies a lot due to the carbonate, quartz and phosphate source (Hendey and Dingle, 2005).

Phoscrete has been used as base material for road construction in the Saldanha Bay area Weinert (1980).

Table 58: Characteristics of a phoscrete in South Africa including site description, geotechnical implications and geochemical composition.

Sample number	Locality and site description and	Geotechnical characteristics	Element composition																																						
			Portable XRF results and additional ICP-MS and XRD results for selected samples (indicated). Only the 8 highest elements are indicated, see Appendix B (PXRF) and C (ICP-MS) for full analytical results. ICP-MS results excludes Si																																						
B98	Phoscrete from the Langebaan area, Western Cape.	Not used frequently for road construction material, but have been used as base material in Saldanabay (Weinert, 1980).	Results are in ppm ICP-MS <table><tr><td>Ca</td><td>P</td><td>I</td><td>Al</td></tr><tr><td>169400</td><td>75075</td><td>6535</td><td>4210</td></tr><tr><td>Fe</td><td>Na</td><td>Mg</td><td>K</td></tr><tr><td>3000</td><td>2252</td><td>1941</td><td>1165</td></tr></table> Recalculated ICP-MS analyses<table><tr><td>Geochemistry</td><td>%</td></tr><tr><td>CaO</td><td>77.6%</td></tr><tr><td>P₂O₅</td><td>20.97%</td></tr><tr><td>I₂O₅</td><td>4.4%</td></tr><tr><td>Al₂O₃</td><td>1.4%</td></tr></table> XRD<table><tr><td>Mineral</td><td>%</td></tr><tr><td>Quartz</td><td>48.59</td></tr><tr><td>Apatite</td><td>40.66</td></tr><tr><td>Microcline</td><td>8</td></tr><tr><td>Plagioclase</td><td>2.51</td></tr><tr><td>Illite</td><td>0.3</td></tr></table>	Ca	P	I	Al	169400	75075	6535	4210	Fe	Na	Mg	K	3000	2252	1941	1165	Geochemistry	%	CaO	77.6%	P ₂ O ₅	20.97%	I ₂ O ₅	4.4%	Al ₂ O ₃	1.4%	Mineral	%	Quartz	48.59	Apatite	40.66	Microcline	8	Plagioclase	2.51	Illite	0.3
Ca	P	I	Al																																						
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4.5.5 Gypcrete

Gypcrete samples were collected mainly in the Western Cape, South Africa, see map (Figure 28). The locality, site description, stratigraphy, geotechnical characteristics and element composition are discussed in Table 59 below

The samples collected were mainly gypcrete deposits as well as gypsum from gypsum mines in the Western Cape Province. The geochemistry of the samples varied from 43.11% (B94) to 91.13% (B96) CaSO_4 . Due to the varying gypsum content of gypcrete formations stated by Goudie (1983) a minimum value of 15% gypsum will be used to classify a gypcrete. Therefore all the samples can be classified as gypcrete. Gypcrete may be used for agricultural as well as road building material. Samples B89, B91B and B95 were not analysed due to insufficient amount of sample and ICP-MS results could not be used to calculate the CaSO_4 percentage as S was not included in the analyses. Sample B91A did not contain a sufficient amount of Ca to be classified as a gypcrete, and would rather be classified as a silcrete due to the high percent Si. Gypcrete can be used for agricultural and building purposes (Fey, 2010). A photomicrograph of an indurated gypcrete crust was prepared as seen in Figure 120, and indicates spindle-shaped gypsum grains in a clay and gypsum matrix and correlates well with research done by All-Bassam and Dawood (2009) on gypcrete in the central Iraq.

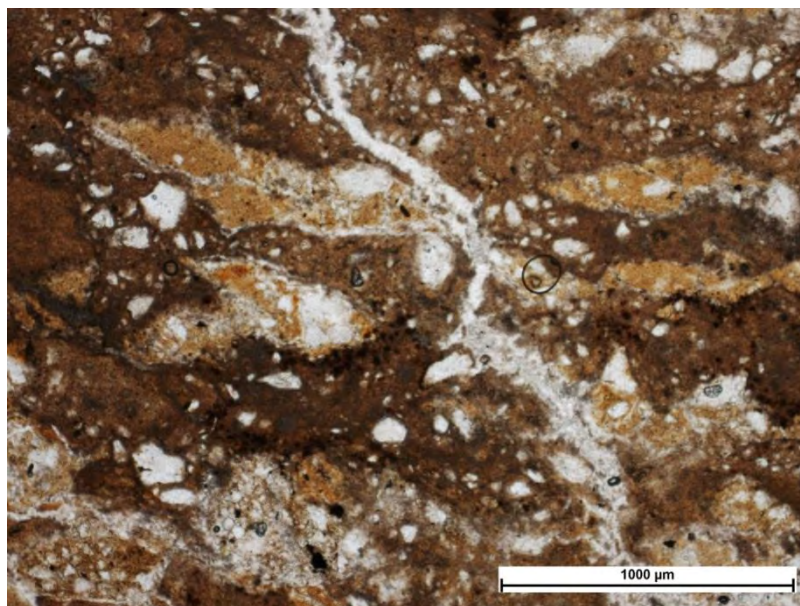


Figure 120: Photomicrograph of gypcrete sample (B92) (50X magnification, plane polarised light).

The geotechnical implications of gypcrete are mainly dependent on the stage of development as well as the host texture and matrix material (Brink, 1985 and Weinert and Caiger, 1983), therefore site specific investigations are required to determine the accurate implications.

Table 59: Characteristics of gypcrete in South Africa, including stratigraphy, geotechnical implications and geochemical composition.

Sample number	Locality, site description and stratigraphy	Geotechnical characteristics	Element composition																																
			Portable XRF results and additional ICP-MS and XRD results for selected samples (indicated). Only the 8 highest elements are indicated, see Appendix B (PXRF) and C (ICP-MS) for full analytical results). ICP-MS results excludes Si																																
B89	Agricultural gypsum: AFMINE close to Yzerfontein, Western Cape.	Gypcrete can be used as agricultural and building purposes (Fey, 2010).	Sample not analysed																																
B91A	Fine gypcrete sampled from hills beside the main road to Porterville, Western Cape.	Gypcrete can be used as agricultural and building purposes (Fey, 2010).	Results in ppm PXRF <table><tr><td>Si</td><td>Al</td><td>Fe</td><td>K</td></tr><tr><td>252918</td><td>111879</td><td>32730</td><td>16340</td></tr><tr><td>Ti</td><td>S</td><td>V</td><td>Zr</td></tr><tr><td>3993</td><td>2713</td><td>538</td><td>369</td></tr></table> Ca was below detectable limit; therefore CaSO₄ could not be determined. XRD <table><tr><th>Mineral</th><th>%</th></tr><tr><td>Quartz</td><td>38.02</td></tr><tr><td>Kaolinite</td><td>20.21</td></tr><tr><td>Muscovite</td><td>15.81</td></tr><tr><td>Gypsum</td><td>11.37</td></tr><tr><td>Illite</td><td>6.37</td></tr><tr><td>Microcline</td><td>5.34</td></tr><tr><td>Plagioclase</td><td>2.86</td></tr></table>	Si	Al	Fe	K	252918	111879	32730	16340	Ti	S	V	Zr	3993	2713	538	369	Mineral	%	Quartz	38.02	Kaolinite	20.21	Muscovite	15.81	Gypsum	11.37	Illite	6.37	Microcline	5.34	Plagioclase	2.86
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Table 59 (cont): Characteristics of gypcrete in South Africa, including stratigraphy, geotechnical implications and geochemical composition.

Sample number	Locality, site description and stratigraphy	Geotechnical characteristics	Element composition																										
			Portable XRF results and additional ICP-MS and XRD results for selected samples (indicated). Only the 8 highest elements are indicated, see Appendix B (PXRF) and C (ICP-MS) for full analytical results. ICP-MS results excludes Si																										
B91B	Gypcrete pieces (peducutanic material), Gypcrete hills beside the main road to Porterville, Western Cape.		Sample not analysed																										
B92	Hard gypcrete, beside the main road to Porterville, Western Cape.	Gypcrete can be used as agricultural and building purposes, Fey (2010).	Results in ppm PXRF <table><tr><td>Ca</td><td>Si</td><td>Al</td><td>Mg</td></tr><tr><td>196371</td><td>99319</td><td>37455</td><td>16421</td></tr><tr><td>K</td><td>Fe</td><td>S</td><td>Ti</td></tr><tr><td>6912</td><td>4936</td><td>3091</td><td>1630</td></tr></table> Recalculated PXRF analyses<table><tr><th>Geochemistry</th><th>%</th></tr><tr><td>CaSO₄</td><td>83.21%</td></tr><tr><td>SiO₂</td><td>10.24%</td></tr><tr><td>Al₂O₃</td><td>4.3%</td></tr><tr><td>MgO</td><td>2.1%</td></tr></table>	Ca	Si	Al	Mg	196371	99319	37455	16421	K	Fe	S	Ti	6912	4936	3091	1630	Geochemistry	%	CaSO ₄	83.21%	SiO ₂	10.24%	Al ₂ O ₃	4.3%	MgO	2.1%
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Table 59 (cont): Characteristics of gypcrete in South Africa, including stratigraphy, geotechnical implications and geochemical composition.

Sample number	Locality, site description and stratigraphy	Geotechnical characteristics	Element composition																																
			Portable XRF results and additional ICP-MS and XRD results for selected samples (indicated) Only the 8 highest elements are indicated, see Appendix B (PXRF) and C (ICP-MS) for full analytical results. ICP-MS results excludes Si																																
B92 (cont)			Results in ppm ICP-MS <table><tr><td>Ca</td><td>Mg</td><td>Na</td><td>Al</td></tr><tr><td>222425</td><td>36950</td><td>8705</td><td>3548</td></tr><tr><td>I</td><td>K</td><td>Fe</td><td>Sr</td></tr><tr><td>2148</td><td>1414</td><td>1303</td><td>847</td></tr></table> S was not analysed with ICP-MS; therefore CaSO₄ could not be determined XRD <table><tr><td>Mineral</td><td>%</td></tr><tr><td>Calcite</td><td>45.27</td></tr><tr><td>Quartz</td><td>22.11</td></tr><tr><td>Kaolinite</td><td>19.06</td></tr><tr><td>Muscovite</td><td>7.81</td></tr><tr><td>Microcline</td><td>4.01</td></tr><tr><td>Illite</td><td>0.95</td></tr><tr><td>Plagioclase</td><td>0.8</td></tr></table>	Ca	Mg	Na	Al	222425	36950	8705	3548	I	K	Fe	Sr	2148	1414	1303	847	Mineral	%	Calcite	45.27	Quartz	22.11	Kaolinite	19.06	Muscovite	7.81	Microcline	4.01	Illite	0.95	Plagioclase	0.8
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Table 59 (cont): Characteristics of gypcrete in South Africa, including stratigraphy, geotechnical implications and geochemical composition.

Sample number	Locality, site description and stratigraphy	Geotechnical characteristics	Element composition				
			Portable XRF results and additional ICP-MS and XRD results for selected samples (indicated). Only the 8 highest elements are indicated, see Appendix B (PXRF) and C (ICP-MS) for full analytical results. ICP-MS results excludes Si				
B93	Hard gypcrete, beside the main road to Lutzville, Western Cape.	Gypcrete can be used for agricultural and building purposes (Fey, 2010).	Results in ppm				Recalculated PXRF analyses
			PXRF				
			Si	Ca	Al	Fe	
			173504	77254	70624	55961	
			K	Ti	S	Mn	
			18064	4695	2415	1031	
		Geochemistry		%			
CaSO ₄		48.92%					
SiO ₂		26.39%					
Al ₂ O ₃		12.10%					
Fe ₂ O ₃		12.57%					
B94	Soft gypcrete, beside the main road to Lutzville, Western Cape.	Gypcrete can be used as agricultural and building purposes (Fey, 2010).	Results in ppm				Recalculated PXRF analyses
			PXRF				
			Si	Ca	Al	Fe	
			205870	58703	55525	34607	
			K	Ti	Mn	S	
			9144	3959	2184	1239	
		Geochemistry		%			
CaSO ₄		43.11%					
SiO ₂		36.64%					
Al ₂ O ₃		11.13%					
Fe ₂ O ₃		9.1%					

Table 59 (cont): Characteristics of gypcrete in South Africa, including stratigraphy, geotechnical implications and geochemical composition.

Sample number	Locality, site description and stratigraphy	Geotechnical characteristics	Element composition																
			Portable XRF results and additional ICP-MS and XRD results for selected samples (indicated). Only the 8 highest elements are indicated, see Appendix B (PXRF) and C (ICP-MS) for full analytical results. ICP-MS results excludes Si																
B96	Gypsum mine (Maskam Mine), Vanrhynsdorp, Western Cape.	Gypcrete can be used as agricultural and building purposes (Fey, 2010).	Results in ppm PXRF																
			<table><tr><td>Ca</td><td>S</td><td>Si</td><td>Al</td></tr><tr><td>179491</td><td>121507</td><td>50349</td><td>25938</td></tr><tr><td>Fe</td><td>K</td><td>Ti</td><td>Sr</td></tr><tr><td>11511</td><td>1347</td><td>1137</td><td>458</td></tr></table>	Ca	S	Si	Al	179491	121507	50349	25938	Fe	K	Ti	Sr	11511	1347	1137	458
			Ca	S	Si	Al													
			179491	121507	50349	25938													
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Results in ppm ICP-MS																			
<table><tr><td>Ca</td><td>Al</td><td>Fe</td><td>Mg</td></tr><tr><td>150525</td><td>4720</td><td>4108</td><td>2895</td></tr><tr><td>I</td><td>K</td><td>Na</td><td>P</td></tr><tr><td>2292</td><td>1286</td><td>1051</td><td>456</td></tr></table>	Ca	Al	Fe	Mg	150525	4720	4108	2895	I	K	Na	P	2292	1286	1051	456			
Ca	Al	Fe	Mg																
150525	4720	4108	2895																
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Geochemistry	%																		
CaSO ₄	91.13%																		
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Fe ₂ O ₃	1.56%																		
			S was not analysed with ICP-MS; therefore CaSO₄ could not be determined																

4.5.6 Intergrade pedocretes

Intergrade samples were collected from various localities over South Africa (Figure 29). The locality, site description, stratigraphy and geochemical composition are discussed in Table 60 below. The main focus is on the variations in element composition.

The element compositions were determined for the intergrade pedocretes as seen in Table 60. This mainly indicated the variations in composition from different samples. The identification of these samples in specific categories was difficult during field work and therefore geochemical analyses are essential before classification can take place. The dorbank, gypcrete sample (B3) as identified in the field, contained 52.94% SiO_2 and 22.09% Al_2O_3 . The dorbank, calcrete and gypcrete sample (B10), as identified in the field, indicated a high CaSO_4 percentage of 64.82%, which results in this sample being a gypcrete in theory. In the calcrete, ferricrete and silcrete sample (B74) the SiO_2 content is the highest of 59.11%, as well as a moderately high Fe_2O_3 content of 23.74%. The calcrete and ferricrete sample (B108) was identified as a calcrete and ferricrete and contained a SiO_2 content of 48.27% and CaO content of 33.84%.

The photomicrograph (Figure 121), of the ferricrete and silcrete sample (B74) indicates quartz and calcite grains in a yellow carbonate matrix and a dark red iron matrix.

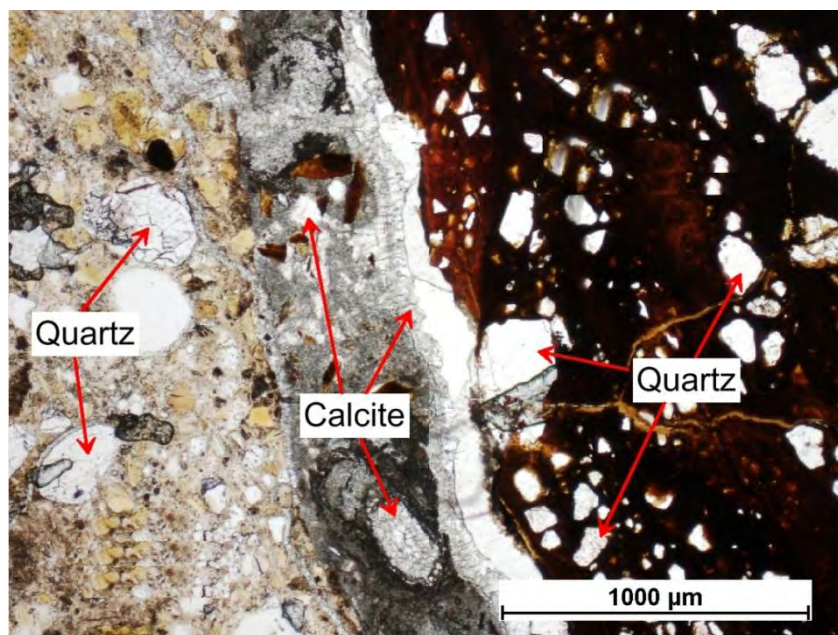


Figure 121: Photomicrograph of intergrade pedocretes sample (B74) (50X magnification, plane polarised light). Quartz and calcite grains are indicated in a carbonate matrix and iron-rich matrix.

Table 60: The characteristics of intergrade pedocretes as well as the geotechnical implications and geochemical composition.

Sample number	Locality, site description and stratigraphy	Element composition Portable XRF results and additional ICP-MS and XRD results for selected samples (indicated). Only the 8 highest elements are indicated, see Appendix A (PXRF), Appendix B (Portable XRF) and C (ICP-MS) for full analytical results. ICP-MS results excludes Si					
B3	A dorbank, gypcrete pedocrete form Garies area, Northern Cape	Results in ppm				Recalculated PXRF results	
		PXRF					
		Si	Al	Fe	K	Geochemistry	%
		227063	84123	44164	23499	SiO ₂	52.94%
		Ti	S	Mn	Zr	Al ₂ O ₃	22.09%
		4672	521	425	400	Fe ₂ O ₃	15.21%
					K ₂ O	9.7%	
B10	Dorbank, calcrete, gypcrete pedocrete from the Aggeneys area, Northern Cape	Results in ppm				Recalculated PXRF results	
		PXRF					
		Ca	Si	Fe	Al	Geochemistry	%
		231622	84353	48571	23286	CaO	24.42%
		Mg	Ti	S	P	SiO ₂	5.8%
		22036	2422	1197	862	CaSO ₄	64.82%
				Fe ₂ O ₃	4.94%		

Table 60 (cont): The characteristics of intergrade pedocretes as well as the geotechnical implications and geochemical composition.

Sample number	Locality, site description and stratigraphy	Element composition Portable XRF results and additional ICP-MS and XRD results for selected samples (indicated). Only the 8 highest elements are indicated, see Appendix A (XRF), Appendix B (PXRF) and C (ICP-MS) for full analytical results. ICP-MS results excludes Si																															
B74	Calcrete, ferricrete, silcrete pedocrete form the Vergeleë area, North-West	Results in ppm PXRF <table><tr><td>Si</td><td>Fe</td><td>Al</td><td>Ca</td></tr><tr><td>243261</td><td>66129</td><td>55709</td><td>5087</td></tr><tr><td>Ti</td><td>K</td><td>Mn</td><td>V</td></tr><tr><td>2288</td><td>1607</td><td>646</td><td>438</td></tr></table>				Si	Fe	Al	Ca	243261	66129	55709	5087	Ti	K	Mn	V	2288	1607	646	438	Recalculated PXRF results <table><tr><th>Geochemistry</th><th>%</th></tr><tr><td>SiO₂</td><td>59.11%</td></tr><tr><td>Fe₂O₃</td><td>23.74%</td></tr><tr><td>Al₂O₃</td><td>15.24%</td></tr><tr><td>CaO</td><td>1.89%</td></tr></table>		Geochemistry	%	SiO ₂	59.11%	Fe ₂ O ₃	23.74%	Al ₂ O ₃	15.24%	CaO	1.89%
Si	Fe	Al	Ca																														
243261	66129	55709	5087																														
Ti	K	Mn	V																														
2288	1607	646	438																														
Geochemistry	%																																
SiO ₂	59.11%																																
Fe ₂ O ₃	23.74%																																
Al ₂ O ₃	15.24%																																
CaO	1.89%																																
B108	Calcrete and ferricrete pedocrete form the Steenbokpan area, Limpopo	XRF (%) <table><tr><td>SiO₂</td><td>CaO</td><td>Fe₂O₃</td><td>MgO</td></tr><tr><td>48.27</td><td>33.84</td><td>7.6</td><td>6.5</td></tr><tr><td>Al₂O₃</td><td>K₂O</td><td>BaO</td><td>TiO₂</td></tr><tr><td>2.4</td><td>0.74</td><td>0.55</td><td>0.18</td></tr></table> 				SiO ₂	CaO	Fe ₂ O ₃	MgO	48.27	33.84	7.6	6.5	Al ₂ O ₃	K ₂ O	BaO	TiO ₂	2.4	0.74	0.55	0.18												
SiO ₂	CaO	Fe ₂ O ₃	MgO																														
48.27	33.84	7.6	6.5																														
Al ₂ O ₃	K ₂ O	BaO	TiO ₂																														
2.4	0.74	0.55	0.18																														

The intergrade pedocretes are very complex and further research must be done to compile a database with which classification can be conducted.

The geotechnical implications of pedocrete are mainly dependent on the stage of development as well as the host texture and matrix material (Brink, 1985 and Weinert and Caiger, 1983), therefore site specific investigations are required to determine the accurate implications.

4.6 Compiled Cenozoic Map and basic chronostratigraphic timeline

The compiled Cenozoic map (Figure 122) was constructed for all of the Cenozoic sample localities over South Africa and was compared with the Geological Map of Geoscience (2002). The GIS information used to indicate the „Cenozoic Deposits“ on the compiled map was obtained from Geoscience (with permission). It indicated that the Cenozoic localities overlapped the Cenozoic deposits of the Geoscience Map (2002), but also extended the distribution.

The chronographical timeline, as seen in Figure 123, was constructed from information obtained from literature as well as analytical results from this research. It must be noted that intergrade pedocretes have different stages of formation and therefore the exact ages and stratigraphic correlation are not well defined and identified. The intergrade between gypcrete, silcrete and calcrete layers are very typical.

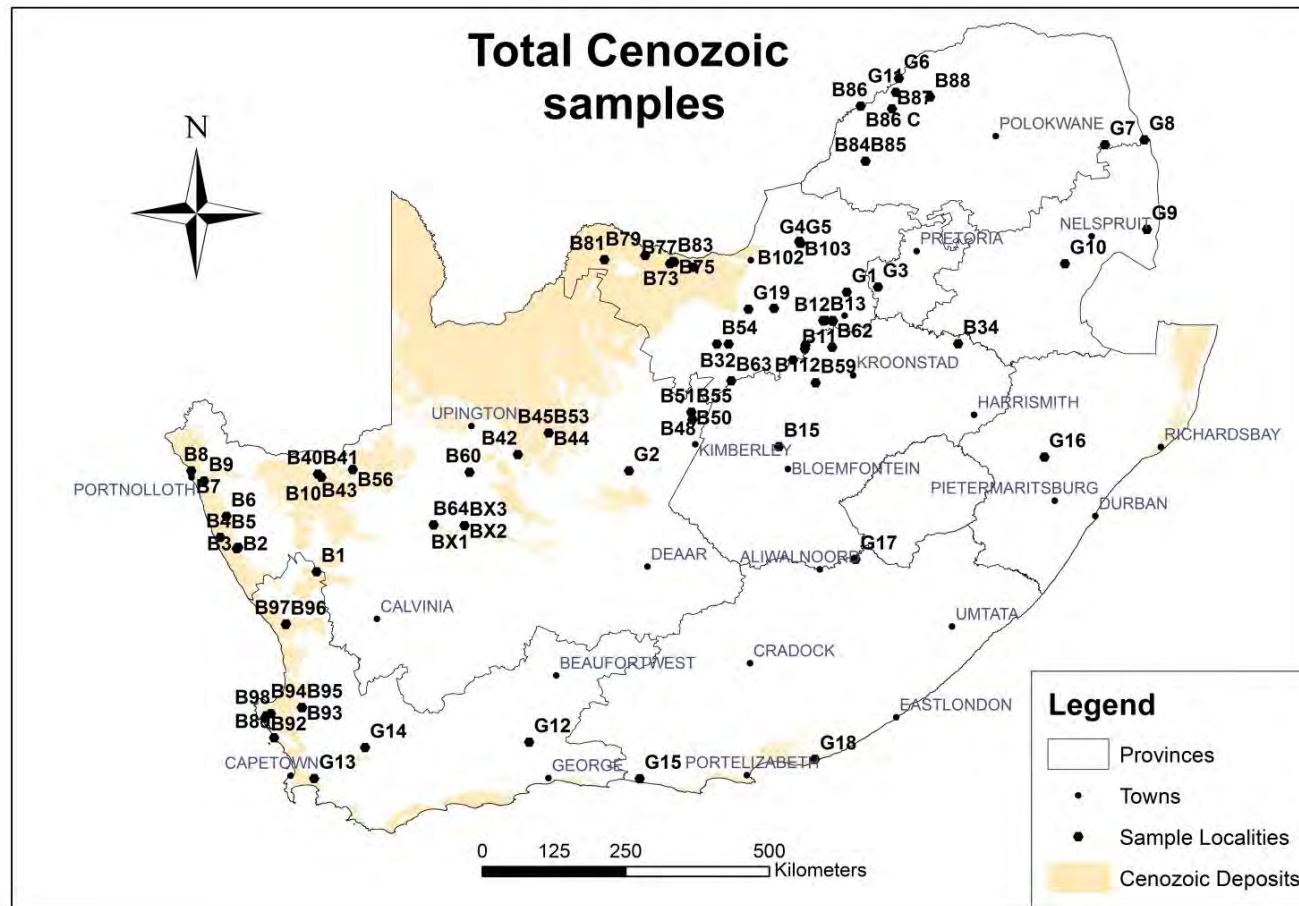


Figure 122: A compilation map indicating the total Cenozoic samples collected in this study overlapping and extending the area of Cenozoic Deposits proposed by Council for Geoscience (2015) map.

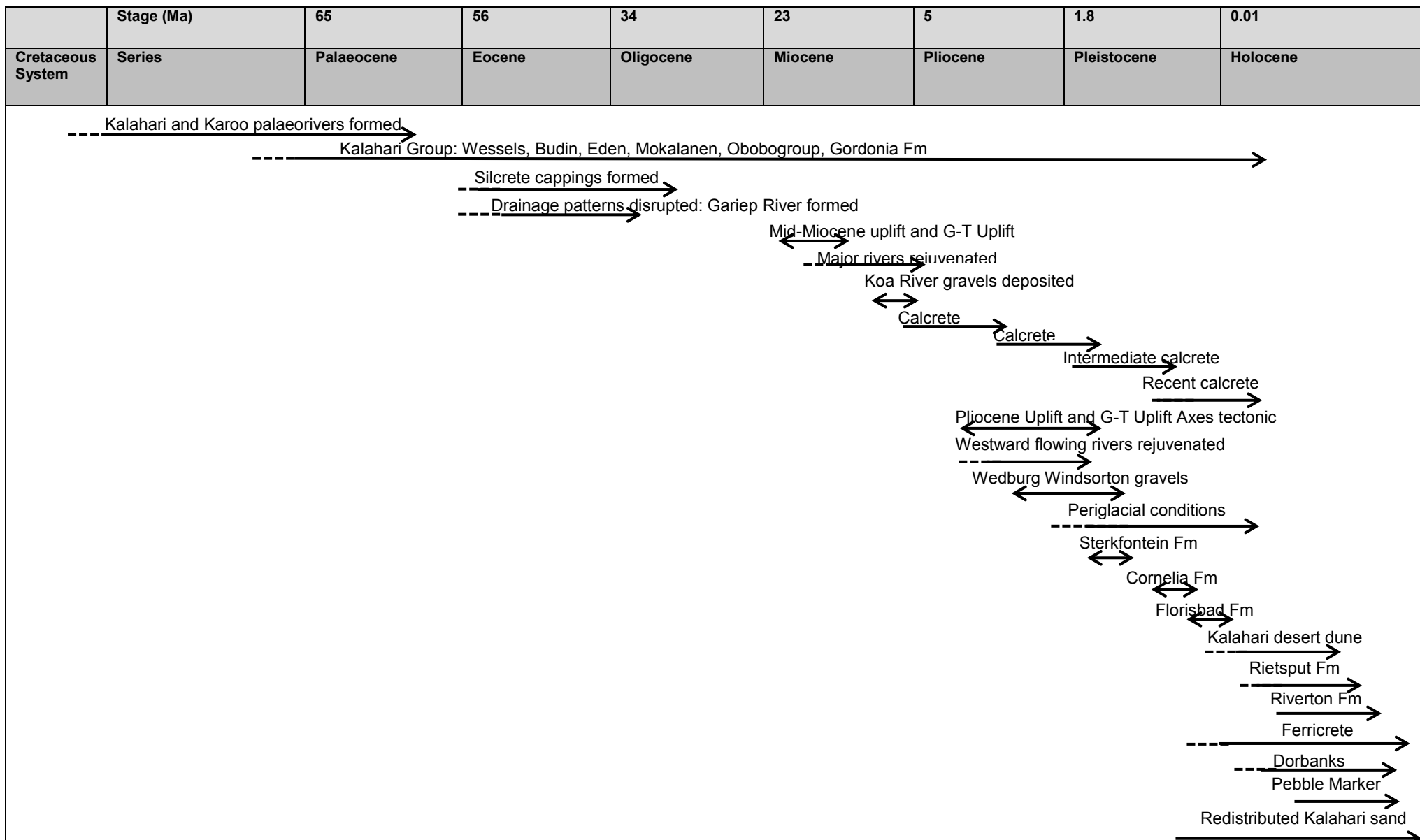


Figure 123: Chronostratigraphic timeline of the Cenozoic Deposits of South Africa (Fm = Formation; G-T = Griqualand Transvaal Uplift Axes).

The chronostratigraphic timeline as seen in Figure 123 indicates different geomorphological features and geological formations. It is indicated that the Cretaceous System was more humid and warm in respect to the more arid Cenozoic Era, and resulted in palaeodrainage systems such as the Kalahari and the Karoo rivers to form. In the beginning of the Cenozoic Era the Kalahari Group sediments started to form and continued up to the Holocene Period. Silcrete started to form in the beginning of the Eocene Series and was associated with semi-arid conditions. In the middle of the Eocene Series, palaeodrainage systems such as the Kalahari and Karoo Rivers disrupted and the Gariep River started to form. The Koa River dried up at the end of the Miocene, indicating arid conditions. Two distinct uplift episodes existed in the Miocene and the Pliocene Series, which resulted in the Griqualand Transvaal Uplift Axes to reactivate. This resulted in the existing river systems to rejuvenate and erosion to occur. Calcretes were associated with four different stages of formation, starting at the end of the Pliocene up to the Holocene and indicated different stages of aridification Periods. Different gravel deposits were linked to the Cenozoic Era, at the beginning of the Pliocene (Wedburg gravels) and the beginning of the Holocene (Rietsput and Riverton gravels). The gravel deposits can indirectly be linked to fluvial episodes that took place. Periglacial conditions were linked to the mid-Pleistocene up to the Holocene, indicating wetter conditions. The Sterkfontein Formation, Cornelia Formation and Florisbad Formation are linked to Pleistocene Series, and may indicate varying climatic conditions resulting in palaeosols and cave sediments to form. At the end of the Pleistocene the Kalahari dunes started to form, indirectly linked to more arid conditions. Ferricrete started to form at the end of the Pleistocene and dorbanks at the beginning of the Holocene, both related to semi-arid conditions. The Pebble Marker can be related to periglacial conditions, indicating wetter conditions followed by drier conditions. The Kalahari sand started to redistribute in the middle of the Pleistocene indicating more arid conditions.

The interpretations made from the chronostratigraphic timeline indicate that many different climatic conditions existed in the Cenozoic Era which resulted in various geomorphological features and geological deposits to form. It must be noted that the climatic conditions were very complex and therefore resulted in different formations to develop in different regions or formed as interlinked deposits such the intergrade pedocretes. This basic chronostratigraphical timeline, presented here is a progress from what presently exists. Further research is required to determine a detailed chronostratigraphic timeline in respect to climatic change, geomorphological features and geological formations.

Due to the significant degrees of variation in the climatic data over such a considerable time Period, the interpretation of the data and the chronostratigraphic timeline in this study are based on the most widely accepted understanding of the ages in the literature, and the referencing of

these ages to the analytical data obtained in this study. Further study would be required whereby the Series within the given Era/Period were each analysed in further detail, and from which more accurate extrapolations could be made with regard to the climatic data.

It must be noted that a distinction must be made between chronostratigraphic terms; System, Series and Stage, used in the description of the chronostratigraphic timeline, and geochronostratigraphic terms; Period, Epoch and Age, used throughout the study.

CHAPTER 5: CONCLUSIONS

This project was mainly intended to compile a comprehensive framework of literature; and combine selected field and analytical data to evaluate the effects of environmental events on the Cenozoic deposits over the last 65 million years. This project focussed on three main sections: palaeosols, clastic sediments and pedogenic deposits. The hypothesis stating that the Cenozoic deposits had a major impact on modern day living was proven.

The palaeosol sites at Cornelia and Florisbad localities both correlated well with literature regarding the chronostratigraphic columns and palaeoenvironmental conditions. The lithostratigraphy and horizon characteristics of the observed palaeosol profiles in this study corresponded and supported the results obtained from literature. The faunal evolutionary stages started with the Cornelia Formation also referred to as the Cornelian Land Mammal Age and has an age of 0.7–1.1 Ma which represented the initial stages of an environment dominated by treeless grasslands. The next stage was the Florisbad Formation which can be referred to as the Florisian Land Mammal age. This represented a Period from the Middle to the Late Pleistocene where grasslands and wetlands were fully established. The last stage is during the Holocene where present day environmental conditions prevail. These known stages with distinct palaeoenvironmental conditions and ages allowed the palaeosols to be linked to the chronostratigraphy of the Cenozoic deposits of South Africa.

The clastic sediments investigated in the caves included information regarding the geochemical and microbial characteristics. This indicated the variations that exists in cave sediments and can be used as a baseline for future studies. Information obtained from literature regarding known caves, such as the Sterkfontein cave, is used in the chronostratigraphic timeline. The gravel deposit of Windsorton was linked to the Riverton and Rietsputs gravel formations obtained from literature and can therefore be used in the chronostratigraphic timeline of the Cenozoic deposits. This can also be linked to an increase in rainfall in this region. The textural characteristics of the different horizons indicated non uniform horizon grading and sorting. The Setlagole River gravels can also be linked to a fluvial episode, but can not be used in the chronostratigraphy as no sediments were dated. The Pebble Marker was linked to periglacial conditions approximately 19 Ka ago, and can be used in the chronostratigraphical timeline. The periglacial deposit at Groot Marico indicated that the distribution of periglacial deposits were more extensive than was found in literature. The deposit was linked to a Period between 300 000 years - 1.7 million years ago, as Acheulean stone tools were found in the deposit. This allowed the periglacial Period and indirectly wetter environmental conditions to be allocated to the chronostratigraphic timeline. The Kalahari Group stratigraphy obtained from three borehole logs compared well to the stratigraphy described by Thomas (1981). The Kalahari and coastal

sand deposits mainly consisted of SiO_2 and the SEM images indicated that wind was the main agent of transportation. The geotechnical analyses indicated that the sand deposits had the potential to collapse when build on. The agricultural potential was low due to low water retention potential and cation exchange capacity.

The drainage depressions indicated high electrical conductivity values due to high salt contents from pollution sources or high salt concentrations due to evaporation. The geotechnical evaluation indicated that the drainage depressions have the potential to shrink and swell and are not suitable to be used as a base for foundations. The agricultural potential was low due to the water being retained by the soil and is not available to the plants.

The evaluated pedogenic deposit distributions were linked to certain „boundaries“ in respect to climatic conditions. This implies that pedogenic material requires specific climate conditions to be able form. Calcrete, silcrete and ferricrete were compared to the Weinert Climatic N-value map and correlated well. It can be deduced that calcretes formed under semi-arid to arid conditions, silcrete also formed under semi-arid conditions and ferricrete formed under more humid conditions or semi-arid conditions. Calcrete, silcrete and dorbanks, and ferricrete were also compared to the distribution of calcic, silicic, and oxidic soils in South Africa, respectively. While calcrete, ferricrete and dorbanks correlated well with the distribution of calcic, oxidic and silicic soils respectively, silcrete did not. This can be due to silcrete being seen as a palaeo-feature and does not correspond to the younger silicic soils of Fey (2010). The distribution and geochemical analyses of phoscrete and gypcrete deposits correlated well with literature. The intergrade pedocretes correlated well with the Cenozoic deposits distribution map and indicated variation in geochemical analyses, which may be an effect of microenvironmental change or rapid environmental change. It was evaluated that the geotechnical implications of the pedogenic deposits are mainly dependent on the stage of development of the pedocrete and hence are very inconsistent due to variability in the deposit therefore it was concluded that a geotechnical investigation must be conducted site specifically.

The economic and tourism potential were also summarised and concluded that some of the Cenozoic deposits have a high economic potential such as the cave deposits and palaeosol sites as well as the ability to improve the tourism industry.

From all the results and interpretations mentioned above the main aims were to compile a map as well as a chronostratigraphic timeline of the terrestrial Cenozoic deposits of South Africa. It was possible to assemble a basic chronostratigraphic timeline by compiling literature and interpreted results from this study. This indicated that various geomorphological features and geological deposits formed in the Cenozoic Era as a result of differing climatic conditions that existed. This will aid in understanding the changes that occurred in the Cenozoic Period as well

as summarise the deposits related to the Cenozoic Era. The map compiled (Figure 122) indicates all the sampled Cenozoic deposits of this research project. The sample localities overlap the Cenozoic deposits from the Council for Geoscience (2004) map but also extend the distribution. This implies that the terrestrial Cenozoic deposits covers wider areas of South Africa in comparison to deposits indicated in the original South-African map.

From the research framework compiled from literature, fieldwork and analytical data it was proven that the Cenozoic Deposits contribute too many aspects of the modern civilisation. This indicated the significance of the Cenozoic Deposits on present day living.

CHAPTER 6: RECOMMENDATIONS

Knowledge gaps were identified regarding the Cenozoic deposits of South Africa. These gaps are listed below and will aid in compiling future project objective:

- The interaction between the surface Cenozoic geology and groundwater relationship is not well known. This can result in future research aiming to clarify the chemical interaction, infiltration and recharge rates of certain Cenozoic deposits regarding groundwater.
- The ages of certain Cenozoic deposits such as the pedocretes can be determined and a unique geochronostratigraphic timeline can be conducted and used to link palaeoenvironmental change to specific pedocrete deposits over South Africa. This will aid in understanding the microclimatic changes that took place.
- A combined research project can be initiated, which focuses on the relationship between the Cenozoic surfaces geology and the underlying regional geology, in regards to geological stability. This can also include the effect of the Cenozoic deposits on the reactivation of palaeosinkholes. The study can apply geotechnical and geophysical ground penetration radar techniques as well as gravity surveillance.
- An agricultural capability map relative to different Cenozoic deposits can be compiled, indicating low and high potential agricultural zones and recommendations.
- The chemical composition of gypcrete can be investigated to identify the source of the high iodine concentration present, as indicated in this project, and may be linked to palaeoenvironmental conditions or changes.
- Further research must be done to improve existing maps of the Cenozoic deposits of South Africa.

It must be taken into consideration that the distribution of the different Cenozoic deposits vary in size, abundance and thickness, this said, future research must focus on a few selected aspects to allow more detailed results to be obtained.

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Appendix A: XRF analyses

The XRF analyses were conducted and analysed by Ms. Belinda Venter at the Geo XRF/XRD Laboratory, North-West University.

A1: XRF analyses for Intergrade pedocretes (B108).

Major elements	PbO	CuO	Fe ₂ O ₃	Mn ₃ O ₄	Cr ₂ O ₃	BaO	TiO ₂	CaO	K ₂ O	SO ₃	P ₂ O ₅	SrO	SiO ₂	Al ₂ O ₃	MgO	Na ₂ O	Total
Percentage	0	0	7.6	0.06	0.02	0.55	0.18	33.83	0.73	0.08	0.01	0.05	48.27	2.4	6.05	0.05	100

Trace elements	Sc	V	Co	Ni	Zn	Ga	Ge	As	Se	Br	Rb	Y	Zr	Nb	Mo	Ag
ppm	25.40	108.20	40.60	36.60	10.90	2.80	0.00	73.70	17.80	19.20	17.20	6.80	73.40	1.90	1.50	0.00

Trace elements	Cd	Sn	Sb	Te	I	Cs	La	Ce	Nd	Sm	Yb	Hf	Ta	W	Hg	Tl	Bi	Th	U
ppm	5.70	10.80	0.00	0.00	38.90	0.00	20.10	26.40	16.20	0.00	0.00	1.50	0.00	141.90	0.20	19.00	29.40	10.10	0.00

Appendix B: Portable XRF (PXRF) analyses for selected samples

The portable XRF analyses were done for palaeosols; Florisbad and Cornelia-Uitzoek, Windsorton gravels, terrestrial sand; Kalahari and coastal sands, calcretes, silcretes, dorbanks, ferricretes, manganocrete and gypcrete, at the Soil Laboratory of the North-West University.

B1: PXRF analyses for Florisbad palaeohorizons.

Date	Time	Reading	Mode	Mg	Mg +/-	Al	Al +/-	Si	Si +/-	P	P +/-	S	S +/-
5/25/2015	13:17:20	B15	Geochem	ND		46113.56	867.31	302754.3	1106.88	ND		1052.7	57.17
5/25/2015	13:22:03	B16	Geochem	ND		56768.81	879.02	269384.7	997.64	ND		553.29	47.52
5/25/2015	08:56:14	B17	Geochem	ND		57928.91	876.28	298501.9	1007.88	ND		569.55	48.01
5/25/2015	09:05:19	B18	Geochem	ND		21602.87	612.52	401500.8	1071.24	ND		754.47	47.98
5/25/2015	13:12:50	B49	Geochem	ND		56704.98	897.37	258864.8	999.93	ND		817.06	48.61

Date	Time	Reading	Mode	Cl	Cl +/-	K	K +/-	Ca	Ca +/-	Ti	Ti +/-	V	V +/-
5/25/2015	13:17:20	B15	Geochem	ND		5850.51	87.27	3736.84	83.2	3080.65	91.11	158.4	36.85
5/25/2015	13:22:03	B16	Geochem	ND		8180.94	86.57	16037.13	111.65	3841.1	92.94	159.67	35.49
5/25/2015	08:56:14	B17	Geochem	ND		7739.29	83.65	12175.87	98.46	4162.08	93.7	ND	
5/25/2015	09:05:19	B18	Geochem	ND		ND		ND		3923.31	92.5	122.79	34.92
5/25/2015	13:12:50	B49	Geochem	ND		11110.21	95.43	9262.58	93.9	3631.91	89.81	213.53	35.16

Date	Time	Reading	Mode	Cr	Cr +/-	Mn	Mn +/-	Fe	Fe +/-	Co	Co +/-	Ni	Ni +/-
5/25/2015	13:17:20	B15	Geochem	46.95	15.12	206.19	13.91	14422.39	83.49	ND		ND	
5/25/2015	13:22:03	B16	Geochem	66.2	14.45	189.7	13.03	18420.22	93.62	ND		17.53	4.79
5/25/2015	08:56:14	B17	Geochem	77.84	14.16	102.25	11.13	13977.61	75.54	ND		ND	
5/25/2015	09:05:19	B18	Geochem	65.88	13.92	31.94	9.36	3782.1	35.78	ND		ND	
5/25/2015	13:12:50	B49	Geochem	97.78	14.97	465.63	17	27744.22	124.64	ND		18.45	4.93

B1 (cont): PXRF analyses for Florisbad palaeohorizons.

Date	Time	Reading	Mode	Cu	Cu +/-	Zn	Zn +/-	As	As +/-	Se	Se +/-	Rb	Rb +/-
5/25/2015	13:17:20	B15	Geochem	17.5	2.81	42.12	2.19	3.18	0.98	ND		38.22	0.86
5/25/2015	13:22:03	B16	Geochem	9.64	2.62	17.03	1.76	3.28	0.91	ND		71.02	1.06
5/25/2015	08:56:14	B17	Geochem	ND		17.2	1.74	ND		ND		75.19	1.04
5/25/2015	09:05:19	B18	Geochem	ND		ND		ND		ND		19.25	0.6
5/25/2015	13:12:50	B49	Geochem	23.05	2.91	42.13	2.13	4.58	1.02	ND		56.09	0.99

Date	Time	Reading	Mode	Sr	Sr +/-	Y	Y +/-	Zr	Zr +/-	Mo	Mo +/-	Ag	Ag +/-
5/25/2015	13:17:20	B15	Geochem	54.62	0.91	7.78	0.77	227.79	1.79	4.87	1.09	ND	
5/25/2015	13:22:03	B16	Geochem	106.71	1.18	7.86	0.79	270.41	1.89	ND		ND	
5/25/2015	08:56:14	B17	Geochem	159.97	1.36	8.06	0.76	209.92	1.62	ND		ND	
5/25/2015	09:05:19	B18	Geochem	42.68	0.72	1.87	0.59	68.85	1.01	ND		ND	
5/25/2015	13:12:50	B49	Geochem	115	1.25	14.12	0.84	231.72	1.81	ND		ND	

Date	Time	Reading	Mode	Cd	Cd +/-	Sn	Sn +/-	Sb	Sb +/-	W	W +/-	Hg	Hg +/-
5/25/2015	13:17:20	B15	Geochem	ND		ND		ND		24.7	3.96	4.98	1.58
5/25/2015	13:22:03	B16	Geochem	ND		ND		ND		50.64	4.38	11.76	1.81
5/25/2015	08:56:14	B17	Geochem	ND		ND		ND		77.29	4.67	12.93	1.87
5/25/2015	09:05:19	B18	Geochem	ND		ND		ND		33.66	3.52	ND	
5/25/2015	13:12:50	B49	Geochem	ND		ND		ND		ND		4.93	1.47

B1 (cont): PXRF analyses for Florisbad palaeohorizons.

Date	Time	Reading	Mode	Pb	Pb +/-	Bi	Bi +/-	Th	Th +/-	U	U +/-	LE	LE +/-
5/25/2015	13:17:20	B15	Geochem	11.21	1.34	ND		10.38	3.04	ND		622130.2	1323.76
5/25/2015	13:22:03	B16	Geochem	7.14	1.24	ND		ND		ND		625825.3	1279.23
5/25/2015	08:56:14	B17	Geochem	5.89	1.16	ND		ND		ND		604198.3	1244.55
5/25/2015	09:05:19	B18	Geochem	ND		ND		ND		ND		568049.4	1139.27
5/25/2015	13:12:50	B49	Geochem	11.7	1.38	ND		ND		ND		630565.6	1306.66

B2: PXRF analyses for Cornelia- Uitzoek palaeosol horizons.

Date	Time	Reading	Mode	Mg	Mg +/-	Al	Al +/-	Si	Si +/-	P	P +/-	S	S +/-
5/25/2015	12:53:47	B35	Geochem	ND		67790.98	883.45	271580.9	959.38	1427.51	125.84	692.84	43.08
5/25/2015	13:15:50	B36	Geochem	ND		72104.78	952.32	261199.6	987.85	ND		207.17	42.85
5/25/2015	12:50:40	B37	Geochem	ND		67867.08	1027.63	235877.6	1025.24	ND		587.61	50.17
5/25/2015	12:47:27	B38	Geochem	ND		75121.19	1046.18	210860.8	965.76	ND		427.79	46.08
5/25/2015	13:23:33	B39	Geochem	ND		73384.2	957.58	249008.5	979.21	ND		797.2	46.37

Date	Time	Reading	Mode	Cl	Cl +/-	K	K +/-	Ca	Ca +/-	Ti	Ti +/-	V	V +/-
5/25/2015	12:53:47	B35	Geochem	ND		15617.79	103.12	3250.49	77.86	3888.91	86.09	383.33	35
5/25/2015	13:15:50	B36	Geochem	ND		17990.13	115.67	ND		3548.77	86.48	321.59	35.3
5/25/2015	12:50:40	B37	Geochem	ND		16367.3	117.64	ND		3382.15	88.37	425.01	37.43
5/25/2015	12:47:27	B38	Geochem	ND		8491.06	84.52	ND		3144.97	83.43	370.89	34.9
5/25/2015	13:23:33	B39	Geochem	ND		9708.27	88.12	ND		3934.95	88.88	218.92	34.06

B2 (cont): PXRF analyses for Cornelia-Uitzoek palaeosol horizons.

Date	Time	Reading	Mode	Cr	Cr +/-	Mn	Mn +/-	Fe	Fe +/-	Co	Co +/-	Ni	Ni +/-
5/25/2015	12:53:47	B35	Geochem	80.7	14.16	1094.72	22.2	36788.91	143.4	ND		32.3	4.91
5/25/2015	13:15:50	B36	Geochem	ND		390.54	15.8	36702.65	149.39	ND		29.21	5.08
5/25/2015	12:50:40	B37	Geochem	64.92	15.12	1559.42	28.03	42588.77	181.43	ND		36.74	5.57
5/25/2015	12:47:27	B38	Geochem	136.54	15.49	2257.93	32.31	50327.08	206.88	ND		78.73	6.13
5/25/2015	13:23:33	B39	Geochem	163.9	15.56	369.42	15.75	42491.58	168.93	ND		29.88	5.16

Date	Time	Reading	Mode	Cu	Cu +/-	Zn	Zn +/-	As	As +/-	Se	Se +/-	Rb	Rb +/-
5/25/2015	12:53:47	B35	Geochem	25.58	2.88	64.58	2.4	6.67	1.14	ND		114.48	1.32
5/25/2015	13:15:50	B36	Geochem	29.24	3.05	78.34	2.68	7.53	1.21	ND		143.39	1.52
5/25/2015	12:50:40	B37	Geochem	34.01	3.43	79.97	2.93	10.12	1.46	ND		153.98	1.71
5/25/2015	12:47:27	B38	Geochem	30.46	3.38	63.29	2.65	6.07	1.23	ND		100.14	1.38
5/25/2015	13:23:33	B39	Geochem	34.45	3.18	64.55	2.51	6.25	1.12	ND		109.19	1.35

Date	Time	Reading	Mode	Sr	Sr +/-	Y	Y +/-	Zr	Zr +/-	Mo	Mo +/-	Ag	Ag +/-
5/25/2015	12:53:47	B35	Geochem	149.85	1.38	27.48	0.97	320.82	2.06	ND		ND	
5/25/2015	13:15:50	B36	Geochem	134.72	1.36	28.21	1.03	178.78	1.65	ND		ND	
5/25/2015	12:50:40	B37	Geochem	135.67	1.48	32.23	1.15	157.69	1.71	ND		ND	
5/25/2015	12:47:27	B38	Geochem	81.07	1.15	20.6	1	143.23	1.61	ND		ND	
5/25/2015	13:23:33	B39	Geochem	79.25	1.08	26.33	1	245.42	1.89	ND		ND	

B2 (cont): PXRF analyses for Cornelia-Uitzoek palaeosol horizons.

Date	Time	Reading	Mode	Cd	Cd +/-	Sn	Sn +/-	Sb	Sb +/-	W	W +/-	Hg	Hg +/-
5/25/2015	12:53:47	B35	Geochem	ND		ND		ND		ND		ND	
5/25/2015	13:15:50	B36	Geochem	ND		ND		ND		ND		ND	
5/25/2015	12:50:40	B37	Geochem	ND		ND		ND		ND		ND	
5/25/2015	12:47:27	B38	Geochem	ND		ND		ND		ND		ND	
5/25/2015	13:23:33	B39	Geochem	ND		ND		ND		ND		ND	

Date	Time	Reading	Mode	Pb	Pb +/-	Bi	Bi +/-	Th	Th +/-	U	U +/-	LE	LE +/-
5/25/2015	12:53:47	B35	Geochem	20.93	1.54	ND		ND		ND		596640.2	1274.42
5/25/2015	13:15:50	B36	Geochem	23.19	1.63	ND		15.23	3.09	ND		606866.9	1328.33
5/25/2015	12:50:40	B37	Geochem	33.68	1.94	ND		17.57	3.37	ND		630588.5	1427.59
5/25/2015	12:47:27	B38	Geochem	18.87	1.68	ND		9.78	3.25	ND		648309.6	1412.17
5/25/2015	13:23:33	B39	Geochem	15.03	1.52	ND		13.39	3.11	ND		619299.3	1337.89

B3: PXRF analyses for Windsorton Gravel Deposit.

Date	Time	Reading	Mode	Mg	Mg +/-	Al	Al +/-	Si	Si +/-	P	P +/-	S	S +/-
5/25/2015	13:19:01	B19	Geochem	ND		65814.97	978.74	248534.3	1029.46	ND		614.66	49.53
5/25/2015	13:03:03	B20	Geochem	ND		58344.09	947.48	236141.2	1012.21	ND		514.67	47.57
5/25/2015	13:04:30	B22	Geochem	ND		59419.3	847.82	290822.7	998.06	ND		351.98	43.47
5/25/2015	13:20:30	B23	Geochem	ND		59130.88	942.55	280847.6	1074.01	ND		668.29	53.62
5/25/2015	13:14:17	B25	Geochem	ND		67373.38	907.68	246828.6	953.07	ND		621.39	42.83
5/25/2015	12:42:36	B26	Geochem	ND		61802.52	865.04	265430.4	957.96	ND		1520.02	49.77
5/25/2015	12:40:58	B27	Geochem	ND		63537.98	873.44	267238.8	970.4	ND		801.5	45.23
5/25/2015	13:07:39	B28	Geochem	ND		130307	1863.48	204104.2	917.55	ND		1607.53	48.27
5/25/2015	13:06:08	B29	Geochem	ND		20656.42	654.32	128675.3	670.87	ND		534.72	37.16

B3 (cont): PXRF analyses for Windsorton Gravel Deposit.

Date	Time	Reading	Mode	Cl	Cl +/-	K	K +/-	Ca	Ca +/-	Ti	Ti +/-	V	V +/-
5/25/2015	12:32:51	B30	Geochem	ND		51930.74	795.99	228168	867.07	837.48	123.05	678.24	39.47
5/25/2015	13:19:01	B19	Geochem	ND		8482.24	90.6	ND		3848.66	92.85	189.43	35.23
5/25/2015	13:03:03	B20	Geochem	ND		7707.65	85.71	1411.53	68.77	4175.63	92.81	161.88	34.25
5/25/2015	13:04:30	B22	Geochem	ND		2067.21	66.42	ND		1207.02	64.05	160.28	30.25
5/25/2015	13:20:30	B23	Geochem	ND		5785.45	86.69	726.44	76.14	1528.29	73.14	110.77	32.85
5/25/2015	13:14:17	B25	Geochem	ND		11889.27	128.61	613	67.18	3942.48	86.09	232.79	32.95
5/25/2015	12:42:36	B26	Geochem	ND		4789.76	71.67	1621.29	67.51	2357.78	73.93	157.88	30.68
5/25/2015	12:40:58	B27	Geochem	ND		2835.63	66.39	11651.3	93.72	2565.4	76.27	223.93	31.83
5/25/2015	13:07:39	B28	Geochem	ND		2335.05	58.83	25557.38	134.91	2902.59	78.37	169.59	31.25
5/25/2015	13:06:08	B29	Geochem	ND		523.23	41.52	195949.8	655	2778.87	92.49	206.33	38.93
5/25/2015	12:32:51	B30	Geochem	ND		7084.84	70.93	41485.86	168.45	3445.37	82.77	210.29	32.61

Date	Time	Reading	Mode	Cr	Cr +/-	Mn	Mn +/-	Fe	Fe +/-	Co	Co +/-	Ni	Ni +/-
5/25/2015	13:19:01	B19	Geochem	83.43	14.92	672.43	19.71	38934.71	165.49	ND		31.68	5.38
5/25/2015	13:03:03	B20	Geochem	116.26	14.93	491.04	17.32	37457.39	159.66	ND		47.66	5.63
5/25/2015	13:04:30	B22	Geochem	61.64	13.42	86	10.55	15604.69	80.01	ND		ND	
5/25/2015	13:20:30	B23	Geochem	60.72	14.71	57.63	10.98	15820.83	87.58	ND		ND	
5/25/2015	13:14:17	B25	Geochem	101.43	14.1	972.52	21.22	43687.24	168.82	ND		52.03	5.3
5/25/2015	12:42:36	B26	Geochem	80.99	13.41	500.56	16.21	22371.49	100.93	ND		13.53	4.45
5/25/2015	12:40:58	B27	Geochem	107.79	14.15	149.57	12.05	31290.73	129.11	ND		21.54	4.74
5/25/2015	13:07:39	B28	Geochem	65.31	13.24	93.92	10.79	25854.97	123.23	ND		14.8	4.47
5/25/2015	13:06:08	B29	Geochem	72.66	16.45	280.65	16.17	18065.39	102.86	ND		20.89	5.41
5/25/2015	12:32:51	B30	Geochem	120.6	14.45	759.41	19.27	35679.27	141.93	ND		40.78	4.97

B3 (cont): PXRF analyses for Windsorton Gravel Deposit.

Date	Time	Reading	Mode	Cu	Cu +/-	Zn	Zn +/-	As	As +/-	Se	Se +/-	Rb	Rb +/-
5/25/2015	13:19:01	B19	Geochem	25.21	3.13	41.07	2.21	7.77	1.08	ND		67.73	1.13
5/25/2015	13:03:03	B20	Geochem	44.9	3.53	48.26	2.39	9.38	1.12	ND		66.01	1.12
5/25/2015	13:04:30	B22	Geochem	8.57	2.37	12.69	1.39	ND		ND		18.31	0.61
5/25/2015	13:20:30	B23	Geochem	16.89	2.76	10.66	1.48	ND		ND		32.38	0.79
5/25/2015	13:14:17	B25	Geochem	33.05	3.11	54.98	2.33	7.91	1.07	ND		69.77	1.08
5/25/2015	12:42:36	B26	Geochem	14.14	2.51	24.47	1.65	ND		ND		28.84	0.71
5/25/2015	12:40:58	B27	Geochem	12.08	2.6	26.15	1.78	ND		ND		36.21	0.81
5/25/2015	13:07:39	B28	Geochem	14.19	2.53	27.27	1.75	ND		ND		31.21	0.75
5/25/2015	13:06:08	B29	Geochem	ND		16.54	1.76	ND		ND		19.51	0.75
5/25/2015	12:32:51	B30	Geochem	32.77	2.98	33.58	1.92	3.02	0.91	ND		47.47	0.9

Date	Time	Reading	Mode	Sr	Sr +/-	Y	Y +/-	Zr	Zr +/-	Mo	Mo +/-	Ag	Ag +/-
5/25/2015	13:19:01	B19	Geochem	62.17	1.01	19.48	0.95	451.16	2.7	6.23	1.22	ND	
5/25/2015	13:03:03	B20	Geochem	81.27	1.14	19.92	0.95	372.65	2.45	ND		ND	
5/25/2015	13:04:30	B22	Geochem	20.81	0.6	3.99	0.63	51.35	0.97	ND		ND	
5/25/2015	13:20:30	B23	Geochem	31.75	0.74	8.21	0.75	140.09	1.43	6.84	1.07	ND	
5/25/2015	13:14:17	B25	Geochem	82.2	1.07	20.59	0.89	213.62	1.73	ND		ND	
5/25/2015	12:42:36	B26	Geochem	33.94	0.7	8.47	0.69	89.46	1.14	ND		ND	
5/25/2015	12:40:58	B27	Geochem	48.42	0.83	12.05	0.76	210.48	1.64	ND		ND	
5/25/2015	13:07:39	B28	Geochem	57.52	0.89	9.18	0.72	231.89	1.76	ND		ND	
5/25/2015	13:06:08	B29	Geochem	86.51	1.2	10.92	0.83	156.13	1.67	ND		ND	
5/25/2015	12:32:51	B30	Geochem	88.89	1.08	11.78	0.78	207.23	1.66	ND		ND	

B3 (cont): PXRF analyses for Windsorton Gravel Deposit.

Date	Time	Reading	Mode	Cd	Cd +/-	Sn	Sn +/-	Sb	Sb +/-	W	W +/-	Hg	Hg +/-
5/25/2015	13:19:01	B19	Geochem	ND		ND		ND		ND		ND	
5/25/2015	13:03:03	B20	Geochem	ND		ND		ND		13.44	3.86	ND	
5/25/2015	13:04:30	B22	Geochem	ND		ND		ND		ND		ND	
5/25/2015	13:20:30	B23	Geochem	ND		ND		ND		ND		ND	
5/25/2015	13:14:17	B25	Geochem	ND		ND		ND		ND		ND	
5/25/2015	12:42:36	B26	Geochem	ND		ND		ND		ND		ND	
5/25/2015	12:40:58	B27	Geochem	ND		ND		ND		10.37	3.29	ND	
5/25/2015	13:07:39	B28	Geochem	ND		ND		ND		ND		ND	
5/25/2015	13:06:08	B29	Geochem	ND		ND		ND		ND		ND	
5/25/2015	12:32:51	B30	Geochem	ND		ND		ND		ND		ND	

Date	Time	Reading	Mode	Pb	Pb +/-	Bi	Bi +/-	Th	Th +/-	U	U +/-	LE	LE +/-
5/25/2015	13:19:01	B19	Geochem	8.82	1.44	ND		12.53	3.25	ND		632091.3	1383.21
5/25/2015	13:03:03	B20	Geochem	9.34	1.46	ND		13.45	3.27	ND		652752.4	1365.47
5/25/2015	13:04:30	B22	Geochem	5.57	1.09	ND		ND		ND		630097.9	1219.16
5/25/2015	13:20:30	B23	Geochem	7.05	1.23	ND		ND		ND		635009.3	1332.74
5/25/2015	13:14:17	B25	Geochem	11.96	1.42	ND		ND		ND		623191.8	1300.89
5/25/2015	12:42:36	B26	Geochem	7.74	1.17	ND		ND		ND		639146.6	1224.86
5/25/2015	12:40:58	B27	Geochem	11.33	1.3	ND		ND		ND		619208.7	1262.6
5/25/2015	13:07:39	B28	Geochem	7.22	1.19	ND		ND		ND		606609.3	1712.29
5/25/2015	13:06:08	B29	Geochem	6.07	1.35	ND		ND		ND		631940.1	1273.55
5/25/2015	12:32:51	B30	Geochem	7.73	1.26	ND		ND		ND		629126.6	1222.19

B4: PXRF analyses for terrestrial sand deposit.

Date	Time	Reading	Mode	Mg	Mg +/-	Al	Al +/-	Si	Si +/-	P	P +/-	S	S +/-
5/25/2015	08:49:16	B1	Geochem	ND		80365.44	989.78	286333	993.81	1064.5	132.62	341.79	44.65
5/25/2015	12:59:59	B2	Geochem	ND		69831.48	1097.22	246644	1068.25	ND		1036.99	60.1
5/25/2015	12:35:16	B4	Geochem	ND		56161.2	815.88	332015	1025.67	710.32	128.69	956.87	48.61
5/25/2015	12:58:22	B5	Geochem	ND		27298.07	689.87	398304	1167.72	ND		592.01	54.71
5/25/2015	12:55:21	B6	Geochem	ND		45888.41	750.69	361428	1056.47	ND		587.26	47.14
5/25/2015	12:56:53	B7	Geochem	22185.95	3348.3	24091.85	711.09	288171	1410.55	ND		865.42	49.65
5/25/2015	13:01:31	B8	Geochem	14474.58	2890.85	49403.1	829.92	311522	1367.33	856.63	128.6	536.12	45.43
5/25/2015	13:11:14	B40	Geochem	ND		74393.95	996.31	280510	1034.54	ND		709.13	51.92
5/25/2015	10:12:45	B42	Geochem	ND		52168.42	815.3	346216	1062.72	ND		423.97	46.8
5/25/2015	09:40:05	B44	Geochem	ND		21738.2	592.73	409793	1069.99	ND		395.49	43.67
5/25/2015	10:39:14	B45	Geochem	ND		24231.6	600.83	415323	1066.95	ND		418.2	44.01
5/25/2015	10:24:44	B54	Geochem	ND		69345.59	1034.65	287240	1111.13	ND		605.69	56.06
5/23/2015	22:16:59	B71	Geochem	66578.95	3666.31	11127.84	483.5	119035	729.41	ND		2569.63	46.07
5/25/2015	10:21:49	B77	Geochem	ND		38583.62	863.61	325268	1178.14	ND		769.59	60.73

Date	Time	Reading	Mode	Cl	Cl +/-	K	K +/-	Ca	Ca +/-	Ti	Ti +/-	V	V +/-
5/25/2015	08:49:16	B1	Geochem	ND		32555.61	154.04	2549.32	88.14	4582.55	96.8	410.46	38.55
5/25/2015	12:59:59	B2	Geochem	ND		27441.83	162.52	ND		2955.04	93.47	167.11	38.45
5/25/2015	12:35:16	B4	Geochem	ND		9641.91	91.24	ND		1532.99	68.99	115.28	31.09
5/25/2015	12:58:22	B5	Geochem	ND		ND		ND		1967.31	81.38	ND	
5/25/2015	12:55:21	B6	Geochem	ND		ND		ND		1248.09	66.75	ND	
5/25/2015	12:56:53	B7	Geochem	ND		9473.08	93.81	35596.26	202.12	935.6	66.83	103.36	33.11
5/25/2015	13:01:31	B8	Geochem	ND		15582.88	116.3	ND		2829.45	83.28	213.26	34.66
5/25/2015	13:11:14	B40	Geochem	ND		23296	138.28	ND		1684.3	74.98	209.45	34.95
5/25/2015	10:12:45	B42	Geochem	ND		2319.43	71.24	ND		1624.43	70.55	109.79	31.34
5/25/2015	09:40:05	B44	Geochem	ND		ND		ND		403.5	54.76	ND	

B4 (cont): PXRF analyses for terrestrial sand deposits.

Date	Time	Reading	Mode	Cl	Cl +/-	K	K +/-	Ca	Ca +/-	Ti	Ti +/-	V	V +/-
5/25/2015	10:39:14	B45	Geochem	ND		ND		ND		583.24	58.4	ND	
5/25/2015	10:24:44	B54	Geochem	ND		11555.46	108.99	ND		3515.15	95.39	209.01	37.97
5/23/2015	22:16:59	B71	Geochem	41195.07	751.49	1781.12	46.6	208170.4	1002.91	1438.69	71.72	255.27	34.76
5/25/2015	10:21:49	B77	Geochem	ND		ND		ND		1517.07	77.35	ND	

Date	Time	Reading	Mode	Cr	Cr +/-	Mn	Mn +/-	Fe	Fe +/-	Co	Co +/-	Ni	Ni +/-
5/25/2015	08:49:16	B1	Geochem	ND		530.63	17.52	28038.23	119.8	ND		16.32	4.76
5/25/2015	12:59:59	B2	Geochem	ND		172.11	14.15	20455.25	110.85	ND		ND	
5/25/2015	12:35:16	B4	Geochem	ND		109.77	10.95	10071.71	61.34	ND		ND	
5/25/2015	12:58:22	B5	Geochem	ND		42.61	10.52	2326.5	30.68	ND		ND	
5/25/2015	12:55:21	B6	Geochem	ND		64.31	10.05	4651.63	40.29	ND		ND	
5/25/2015	12:56:53	B7	Geochem	ND		112.72	11.87	5623.1	51.62	ND		ND	
5/25/2015	13:01:31	B8	Geochem	48.12	14.21	169.92	12.53	17669.86	101.95	ND		ND	
5/25/2015	13:11:14	B40	Geochem	ND		304.5	15	12204.56	73.85	ND		ND	
5/25/2015	10:12:45	B42	Geochem	63.84	13.93	114.79	11.28	12179.9	68.87	ND		ND	
5/25/2015	09:40:05	B44	Geochem	ND		ND		2037.89	26.03	ND		ND	
5/25/2015	10:39:14	B45	Geochem	ND		ND		1509.55	22.82	ND		ND	
5/25/2015	10:24:44	B54	Geochem	57.96	15.52	222.86	14.44	20410.12	105.45	ND		20.02	5.15
5/23/2015	22:16:59	B71	Geochem	109.95	15.91	299.21	15.4	16584.75	109.44	ND		19.73	4.84
5/25/2015	10:21:49	B77	Geochem	ND		61.93	11.33	8887.26	63.89	ND		ND	

B4 (cont): PXRF analyses for terrestrial sand deposits.

Date	Time	Reading	Mode	Cu	Cu +/-	Zn	Zn +/-	As	As +/-	Se	Se +/-	Rb	Rb +/-
5/25/2015	08:49:16	B1	Geochem	21.85	2.81	42.76	2.09	ND		ND		196.27	1.72
5/25/2015	12:59:59	B2	Geochem	10.49	2.88	20.3	1.85	ND		ND		273.32	2.28
5/25/2015	12:35:16	B4	Geochem	ND		11.46	1.37	ND		ND		53.74	0.87
5/25/2015	12:58:22	B5	Geochem	ND		10.42	1.45	ND		ND		8.02	0.54
5/25/2015	12:55:21	B6	Geochem	ND		7.4	1.26	ND		ND		11.52	0.53
5/25/2015	12:56:53	B7	Geochem	ND		5.77	1.32	ND		ND		62.72	1.02
5/25/2015	13:01:31	B8	Geochem	12.62	2.55	20.13	1.64	ND		ND		95.29	1.21
5/25/2015	13:11:14	B40	Geochem	10.66	2.57	22.49	1.72	ND		ND		223.1	1.85
5/25/2015	10:12:45	B42	Geochem	10.7	2.41	9.23	1.32	ND		ND		23.91	0.66
5/25/2015	09:40:05	B44	Geochem	ND		ND		ND		ND		2.5	0.41
5/25/2015	10:39:14	B45	Geochem	ND		ND		ND		ND		3.14	0.42
5/25/2015	10:24:44	B54	Geochem	17.24	2.91	16.71	1.72	3.3	1.09	ND		87.33	1.23
5/23/2015	22:16:59	B71	Geochem	22.76	2.85	19.75	1.72	5.05	0.97	ND		34.67	0.91
5/25/2015	10:21:49	B77	Geochem	ND		6.58	1.41	ND		ND		13.48	0.62

Date	Time	Reading	Mode	Sr	Sr +/-	Y	Y +/-	Zr	Zr +/-	Mo	Mo +/-	Ag	Ag +/-
5/25/2015	08:49:16	B1	Geochem	154.64	1.41	30.74	1.07	251.65	1.85	ND		ND	
5/25/2015	12:59:59	B2	Geochem	46.76	0.92	14.28	1.17	232.91	1.95	7.87	1.19	ND	
5/25/2015	12:35:16	B4	Geochem	46.89	0.77	9.99	0.72	169.89	1.4	ND		ND	
5/25/2015	12:58:22	B5	Geochem	14.44	0.58	5.11	0.69	369.41	2.13	6.5	1.08	ND	
5/25/2015	12:55:21	B6	Geochem	14.77	0.54	3.66	0.61	190.24	1.43	ND		ND	
5/25/2015	12:56:53	B7	Geochem	99.63	1.18	8.17	0.78	179.92	1.69	4.86	1.03	ND	
5/25/2015	13:01:31	B8	Geochem	85.79	1.07	15.88	0.86	288.68	2.06	ND		ND	
5/25/2015	13:11:14	B40	Geochem	40.91	0.8	13.67	1	91.75	1.23	ND		ND	
5/25/2015	10:12:45	B42	Geochem	23.84	0.62	5.24	0.65	127.46	1.27	ND		ND	
5/25/2015	09:40:05	B44	Geochem	ND		ND		108.62	1.12	ND		ND	

B4 (cont): PXRF analyses for terrestrial sand deposits.

Date	Time	Reading	Mode	Sr	Sr +/-	Y	Y +/-	Zr	Zr +/-	Mo	Mo +/-	Ag	Ag +/-
5/25/2015	10:39:14	B45	Geochem	1.35	0.4	ND		29.77	0.82	ND		ND	
5/25/2015	10:24:44	B54	Geochem	59.64	0.97	9.09	0.87	243.35	1.9	4.19	1.12	ND	
5/23/2015	22:16:59	B71	Geochem	813.66	4.92	3.25	0.73	53.02	1.53	ND		ND	
5/25/2015	10:21:49	B77	Geochem	8.3	0.54	5.2	0.7	111.42	1.33	8.19	1.06	ND	

Date	Time	Reading	Mode	Cd	Cd +/-	Sn	Sn +/-	Sb	Sb +/-	W	W +/-	Hg	Hg +/-
5/25/2015	08:49:16	B1	Geochem	ND		ND		ND		ND		ND	
5/25/2015	12:59:59	B2	Geochem	ND		ND		ND		ND		ND	
5/25/2015	12:35:16	B4	Geochem	ND		ND		ND		ND		ND	
5/25/2015	12:58:22	B5	Geochem	ND		ND		ND		ND		ND	
5/25/2015	12:55:21	B6	Geochem	ND		ND		ND		ND		ND	
5/25/2015	12:56:53	B7	Geochem	ND		ND		ND		ND		ND	
5/25/2015	13:01:31	B8	Geochem	ND		ND		ND		ND		4.03	1.34
5/25/2015	13:11:14	B40	Geochem	ND		ND		ND		ND		ND	
5/25/2015	10:12:45	B42	Geochem	ND		ND		ND		ND		ND	
5/25/2015	09:40:05	B44	Geochem	ND		ND		ND		ND		ND	
5/25/2015	10:39:14	B45	Geochem	ND		ND		ND		ND		ND	
5/25/2015	10:24:44	B54	Geochem	ND		27.85	9.17	ND		ND		ND	
5/23/2015	22:16:59	B71	Geochem	ND		ND		ND		11.19	3.62	ND	
5/25/2015	10:21:49	B77	Geochem	ND		ND		ND		ND		ND	

Date	Time	Reading	Mode	Pb	Pb +/-	Bi	Bi +/-	Th	Th +/-	U	U +/-	LE
5/25/2015	08:49:16	B1	Geochem	36.92	1.78	ND		13.67	3.02	ND		562464
5/25/2015	12:59:59	B2	Geochem	31.59	1.89	ND		25.8	3.37	ND		630633.2
5/25/2015	12:35:16	B4	Geochem	11.16	1.19	ND		ND		ND		588382.3

B4 (cont): PXRF analyses for terrestrial sand deposits.

Date	Time	Reading	Mode	Pb	Pb +/-	Bi	Bi +/-	Th	Th +/-	U	U +/-	LE
5/25/2015	12:58:22	B5	Geochem	6.99	1.19	ND		16.66	2.94	3.96	1.27	569027.8
5/25/2015	12:55:21	B6	Geochem	5.38	1.06	ND		ND		ND		585899.6
5/25/2015	12:56:53	B7	Geochem	10.25	1.29	ND		9.69	2.94	ND		612460.9
5/25/2015	13:01:31	B8	Geochem	17.8	1.4	ND		ND		ND		586154.1
5/25/2015	13:11:14	B40	Geochem	68.57	2.12	ND		9.84	2.92	ND		606206.8
5/25/2015	10:12:45	B42	Geochem	5.51	1.09	ND		ND		ND		584573.8
5/25/2015	09:40:05	B44	Geochem	ND		ND		ND		ND		565520.4
5/25/2015	10:39:14	B45	Geochem	ND		ND		ND		ND		557900
5/25/2015	10:24:44	B54	Geochem	16.44	1.51	ND		13.78	3.15	ND		606319.6
5/23/2015	22:16:59	B71	Geochem	5.58	1.3	ND		ND		ND		529865.3
5/25/2015	10:21:49	B77	Geochem	4.43	1.19	ND		10.84	2.99	ND		624744.4

B5: PXRF analyses for drainage depressions.

Date	Time	Reading	Mode	Mg	Mg +/-	Al	Al +/-	Si	Si +/-	P	P +/-	S	S +/-
5/25/2015	12:44:28	B13	Geochem	22762.34	3860.29	44959.3	931.89	189662.6	1184.88	1191.11	130.85	1399.17	52.57
5/25/2015	10:48:44	B47	Geochem	ND		57158.5	917.86	248908	998.13	ND		1708.6	54.22
5/25/2015	12:46:02	B48	Geochem	ND		64792.01	1018.54	200865.9	964.7	1657.29	135.3	960.9	49.66
5/25/2015	10:45:22	B50	Geochem	ND		70866.53	1139.38	187884.7	998.59	ND		527.89	51.31
5/25/2015	10:33:24	B51	Geochem	12729.96	3426.12	63400.16	1008.43	183080.5	1086.81	ND		342.29	40.03
5/25/2015	09:43:20	B59	Geochem	ND		53818.56	844.83	333832.5	1056.87	ND		11595.5	105.4
5/25/2015	10:15:48	B62	Geochem	23401.44	4238.27	42392.03	953.94	141415.7	1007.71	902.41	142.89	5006.9	75.36
5/25/2015	11:12:03	B63	Geochem	ND		60811.12	1128.63	176748.2	1018.52	ND		1033.78	58.19
5/23/2015	22:16:59	B71	Geochem	66578.95	3666.31	11127.84	483.5	119035.2	729.41	ND		2569.63	46.07

B5 (cont): PXRF analyses for drainage depressions.

Date	Time	Reading	Mode	Mg	Mg +/-	Al	Al +/-	Si	Si +/-	P	P +/-	S	S +/-
5/25/2015	11:17:35	B64	Geochem	15476.61	3066.12	85801.77	1049.76	213683.7	1100.01	658.99	113.27	816.63	43.68
5/25/2015	09:55:51	B83	Geochem	ND		61255.36	929.1	226038	939.17	ND		663.26	44.15
5/25/2015	10:18:39	B84	Geochem	52848.42	3963.02	22986.41	637.5	157811	1004.16	ND		635.85	41.24
5/25/2015	09:37:19	B85	Geochem	61189.24	4138.85	38977.25	866.67	179052.2	1122.43	ND		471.2	41.73

Date	Time	Reading	Mode	Cl	Cl +/-	K	K +/-	Ca	Ca +/-	Ti	Ti +/-	V	V +/-
5/25/2015	12:44:28	B13	Geochem	ND		6245.72	79.86	8606.87	90.45	3061.59	82.43	130.19	31.54
5/25/2015	10:48:44	B47	Geochem	ND		7285.23	82.1	9450.55	90.48	3877.02	90.01	311.96	35.57
5/25/2015	12:46:02	B48	Geochem	ND		7225.02	77.39	405.65	68.27	5102.09	98.72	243.32	35.6
5/25/2015	10:45:22	B50	Geochem	ND		8377.64	90.32	1615.02	55.29	5379.82	106.93	245.82	37.88
5/25/2015	10:33:24	B51	Geochem	ND		7984.41	82.06	11204.5	96.32	4280.34	80.57	183.43	23.99
5/25/2015	09:43:20	B59	Geochem	ND		2232.23	73.56	5821.08	86.45	1659.61	71.94	124.58	32.32
5/25/2015	10:15:48	B62	Geochem	16674.6	1072.92	9986.08	99.75	58969.79	365.04	2745.08	88.12	174.69	35.64
5/25/2015	11:12:03	B63	Geochem	ND		2306.92	70.73	7525.3	86.72	5704.29	100.17	217.37	26.47
5/23/2015	22:16:59	B71	Geochem	41195.07	751.49	1781.12	46.6	208170.4	1002.91	1438.69	71.72	255.27	34.76
5/25/2015	11:17:35	B64	Geochem	ND		22871.48	141.8	8942.72	93.89	2702.52	71.66	252.22	27.72
5/25/2015	09:55:51	B83	Geochem	ND		4749.98	67.84	ND		3075.74	78.83	194.39	31.18
5/25/2015	10:18:39	B84	Geochem	5062.57	917.87	10835.6	92.5	55680.3	318.31	1763.63	71.42	253.56	32.81
5/25/2015	09:37:19	B85	Geochem	ND		12770.88	105.13	64255.32	368.89	2312.43	79.16	278.98	34.99

Date	Time	Reading	Mode	Cr	Cr +/-	Mn	Mn +/-	Fe	Fe +/-	Co	Co +/-	Ni	Ni +/-
5/25/2015	12:44:28	B13	Geochem	116.81	14.7	5149.13	52.92	43785.05	254.47	ND		29.68	5.46
5/25/2015	10:48:44	B47	Geochem	79.86	14.54	817.55	20.63	35693.02	150.63	ND		33.53	5.2
5/25/2015	12:46:02	B48	Geochem	60.1	14.26	371.76	16.41	62764.8	256.3	ND		57.55	6.15

B5 (cont): PXRF analyses for drainage depressions.

Date	Time	Reading	Mode	Cr	Cr +/-	Mn	Mn +/-	Fe	Fe +/-	Co	Co +/-	Ni	Ni +/-
5/25/2015	10:45:22	B50	Geochem	78.87	15.41	1164.83	25.77	71016.29	305.18	ND		83.99	7.09
5/25/2015	10:33:24	B51	Geochem	55.27	16.33	1783.09	31.12	94163.95	483.07	ND		107.37	6.97
5/25/2015	09:43:20	B59	Geochem	110.45	15.18	150.79	12.23	11163.21	66.49	ND		51.53	4.96
5/25/2015	10:15:48	B62	Geochem	99.04	16.09	711.47	21.58	36725.38	235.97	ND		42.09	5.76
5/25/2015	11:12:03	B63	Geochem	174.13	18.67	2298.41	36.94	79656.28	360.25	ND		78.57	7.48
5/23/2015	22:16:59	B71	Geochem	109.95	15.91	299.21	15.4	16584.75	109.44	ND		19.73	4.84
5/25/2015	11:17:35	B64	Geochem	2127.37	502.68	ND		81793.71	382.96	ND		41.31	5.5
5/25/2015	09:55:51	B83	Geochem	117.16	14.01	262.98	13.61	38407.14	155.26	ND		33.04	4.95
5/25/2015	10:18:39	B84	Geochem	52.04	13.76	438.48	16.19	16783.4	113	ND		28.71	4.74
5/25/2015	09:37:19	B85	Geochem	82.11	15.14	567.35	18.47	23809.74	152.65	ND		42.05	5.14

Date	Time	Reading	Mode	Cu	Cu +/-	Zn	Zn +/-	As	As +/-	Se	Se +/-	Rb	Rb +/-
5/25/2015	12:44:28	B13	Geochem	39.09	3.44	67.84	2.71	4.6	1.15	ND		63.93	1.15
5/25/2015	10:48:44	B47	Geochem	37.26	3.23	41.4	2.16	4.91	1.04	ND		59.71	1.04
5/25/2015	12:46:02	B48	Geochem	90.35	4.47	69.88	2.88	4.62	1.16	ND		51.28	1.09
5/25/2015	10:45:22	B50	Geochem	117.46	5.28	79.25	3.28	ND		ND		54.6	1.2
5/25/2015	10:33:24	B51	Geochem	196.51	6.03	95.23	3.4	ND		ND		31.91	0.95
5/25/2015	09:43:20	B59	Geochem	27.81	2.83	52.73	2.14	25.33	1.22	ND		33.4	0.78
5/25/2015	10:15:48	B62	Geochem	28.54	3.36	56.4	2.61	5.82	1.15	ND		67.69	1.25
5/25/2015	11:12:03	B63	Geochem	85.72	5.1	70.97	3.3	5.71	1.32	ND		43.44	1.16
5/23/2015	22:16:59	B71	Geochem	22.76	2.85	19.75	1.72	5.05	0.97	ND		34.67	0.91
5/25/2015	11:17:35	B64	Geochem	53.66	3.62	121.34	3.36	13.23	1.38	ND		161.59	1.75
5/25/2015	09:55:51	B83	Geochem	26.11	2.9	36.49	1.98	3.7	0.94	ND		70.27	1.06
5/25/2015	10:18:39	B84	Geochem	12.78	2.57	33.92	1.89	ND		ND		60.68	1.05
5/25/2015	09:37:19	B85	Geochem	24.94	2.94	48.48	2.22	4.66	1.01	ND		75.06	1.2

B5 (cont): PXRF analyses for drainage depressions.

Date	Time	Reading	Mode	Sr	Sr +/-	Y	Y +/-	Zr	Zr +/-	Mo	Mo +/-	Ag	Ag +/-
5/25/2015	12:44:28	B13	Geochem	23.3	0.73	15.06	0.91	149.48	1.7	3.55	1.16	ND	
5/25/2015	10:48:44	B47	Geochem	112.32	1.27	19.07	0.9	413.22	2.49	ND		ND	
5/25/2015	12:46:02	B48	Geochem	165.34	1.69	23.35	1	217.84	2.03	ND		ND	
5/25/2015	10:45:22	B50	Geochem	119.26	1.54	20.47	1.06	200.73	2.09	ND		ND	
5/25/2015	10:33:24	B51	Geochem	238.46	2.24	20.64	0.97	157.79	1.93	ND		ND	
5/25/2015	09:43:20	B59	Geochem	107.18	1.12	7.43	0.69	119.19	1.3	ND		ND	
5/25/2015	10:15:48	B62	Geochem	425.93	3.42	15.79	0.95	130.03	1.86	4.42	1.17	ND	
5/25/2015	11:12:03	B63	Geochem	65.39	1.26	28.67	1.18	238.84	2.38	7.8	1.42	ND	
5/23/2015	22:16:59	B71	Geochem	813.66	4.92	3.25	0.73	53.02	1.53	ND		ND	
5/25/2015	11:17:35	B64	Geochem	143.62	1.52	27.14	1.08	114.15	1.52	ND		ND	
5/25/2015	09:55:51	B83	Geochem	26.41	0.69	23.55	0.88	123.57	1.36	ND		ND	
5/25/2015	10:18:39	B84	Geochem	557.47	3.76	6.58	0.75	74.64	1.42	ND		ND	
5/25/2015	09:37:19	B85	Geochem	666.34	4.45	10.11	0.83	76.87	1.55	ND		ND	

Date	Time	Reading	Mode	Cd	Cd +/-	Sn	Sn +/-	Sb	Sb +/-	W	W +/-	Hg	Hg +/-
5/25/2015	12:44:28	B13	Geochem	ND		ND		ND		ND		ND	
5/25/2015	10:48:44	B47	Geochem	ND		ND		ND		ND		ND	
5/25/2015	12:46:02	B48	Geochem	ND		ND		ND		ND		ND	
5/25/2015	10:45:22	B50	Geochem	ND		ND		ND		ND		ND	
5/25/2015	10:33:24	B51	Geochem	ND		ND		ND		ND		ND	
5/25/2015	09:43:20	B59	Geochem	ND		ND		ND		ND		ND	
5/25/2015	10:15:48	B62	Geochem	ND		ND		ND		ND		ND	
5/25/2015	11:12:03	B63	Geochem	ND		ND		ND		ND		ND	
5/23/2015	22:16:59	B71	Geochem	ND		ND		ND		11.19	3.62	ND	
5/25/2015	11:17:35	B64	Geochem	ND		ND		ND		ND		6.38	1.64

B5 (cont): PXRF analyses for drainage depressions.

Date	Time	Reading	Mode	Cd	Cd +/-	Sn	Sn +/-	Sb	Sb +/-	W	W +/-	Hg	Hg +/-
5/25/2015	09:55:51	B83	Geochem	ND		ND		ND		ND		ND	
5/25/2015	10:18:39	B84	Geochem	ND		ND		ND		ND		ND	
5/25/2015	09:37:19	B85	Geochem	ND		ND		ND		ND		ND	

Date	Time	Reading	Mode	Pb	Pb +/-	Bi	Bi +/-	Th	Th +/-	U	U +/-	LE	LE +/-
5/25/2015	12:44:28	B13	Geochem	15.73	1.58	ND		ND		ND		672517.9	2977.92
5/25/2015	10:48:44	B47	Geochem	11.61	1.42	ND		ND		ND		633976.7	1330.08
5/25/2015	12:46:02	B48	Geochem	11.32	1.64	ND		15.58	3.48	ND		654844.1	1437.08
5/25/2015	10:45:22	B50	Geochem	5.89	1.7	ND		14.1	3.71	ND		652146.9	1556.45
5/25/2015	10:33:24	B51	Geochem	9.17	1.76	ND		ND		ND		619935	2591.85
5/25/2015	09:43:20	B59	Geochem	15.93	1.34	ND		ND		13.43	1.43	579037.6	1248.58
5/25/2015	10:15:48	B62	Geochem	11.52	1.57	ND		11.77	3.49	ND		659995.4	3255.31
5/25/2015	11:12:03	B63	Geochem	8.35	1.89	ND		21.9	3.99	ND		662868.9	1613.25
5/23/2015	22:16:59	B71	Geochem	5.58	1.3	ND		ND		ND		529865.3	2436.28
5/25/2015	11:17:35	B64	Geochem	24.29	1.82	ND		14.39	3.18	ND		564151.2	2252.31
5/25/2015	09:55:51	B83	Geochem	9.17	1.32	ND		8.9	2.91	ND		664874.8	1280.59
5/25/2015	10:18:39	B84	Geochem	6.82	1.24	ND		ND		ND		674066.9	3096.97
5/25/2015	09:37:19	B85	Geochem	10.38	1.4	ND		ND		ND		615274.5	2989.01

B6: PXRF analyses for calcretes.

Date	Time	Reading	Mode	Mg	Mg +/-	Al	Al +/-	Si	Si +/-	P	P +/-	S	S +/-
5/25/2015	13:06:08	B29	Geochem	ND		20656.42	654.32	128675.3	670.87	ND		534.72	37.16
5/25/2015	08:59:25	B60	Geochem	31892.58	4198.71	ND		109760.9	770.77	1526.39	170.97	766.77	40.74
5/25/2015	09:14:05	B70	Geochem	ND		12473.25	678.37	64042.47	502.08	ND		452.44	39.3
5/25/2015	10:30:21	B72	Geochem	14966.01	3773.22	23822.05	736.87	235489.7	1320.16	ND		698.7	48.85
5/25/2015	11:50:09	B81	Geochem	ND		3985.15	535.66	118638.8	650.79	ND		1189.08	44.31
5/25/2015	11:55:44	B82	Geochem	ND		2494.21	498.81	79371.68	510.46	ND		965.21	39.62
5/25/2015	08:46:25	B90	Geochem	24477.1	3276.54	37025.73	745.62	266965.4	1406.93	ND		1026.55	38.24
5/25/2015	11:23:17	B103A	Geochem	21709.3	3075.05	76771.02	970.34	189642.5	989.38	ND		391.06	38.08

Date	Time	Reading	Mode	Cl	Cl +/-	K	K +/-	Ca	Ca +/-	Ti	Ti +/-	V	V +/-
5/25/2015	13:06:08	B29	Geochem	ND		523.23	41.52	195949.8	655	2778.87	92.49	206.33	38.93
5/25/2015	08:59:25	B60	Geochem	ND		6190.62	67.96	238577.7	1271.39	2234.46	90.06	274.51	40.72
5/25/2015	09:14:05	B70	Geochem	ND		284.34	41.39	298519.3	1056.69	1197.06	86.28	150.33	41.3
5/25/2015	10:30:21	B72	Geochem	ND		1112.41	57.27	66190	359.59	1597.61	75.48	242.52	35.66
5/25/2015	11:50:09	B81	Geochem	ND		ND		275095.6	900.47	974.59	78.55	564.47	47.01
5/25/2015	11:55:44	B82	Geochem	ND		ND		321909	1033.26	816.39	74.19	321.2	41.9
5/25/2015	08:46:25	B90	Geochem	ND		3187.86	50.43	138910.3	623.36	2545.68	79	165.14	32.73
5/25/2015	11:23:17	B103A	Geochem	ND		6545.61	73.14	78739.3	365.98	4191.3	92.02	263.68	35.13

Date	Time	Reading	Mode	Cr	Cr +/-	Mn	Mn +/-	Fe	Fe +/-	Co	Co +/-	Ni	Ni +/-
5/25/2015	13:06:08	B29	Geochem	72.66	16.45	280.65	16.17	18065.39	102.86	ND		20.89	5.41
5/25/2015	08:59:25	B60	Geochem	69.13	17.47	472.15	19.79	22088.12	150.39	ND		25.93	5.72
5/25/2015	09:14:05	B70	Geochem	ND		242	18.19	26562.38	148.69	ND		ND	
5/25/2015	10:30:21	B72	Geochem	47.27	14.95	242.65	14.43	11072.58	83.68	ND		ND	

B6 (cont): PXRF analyses for calcretes

Date	Time	Reading	Mode	Cr	Cr +/-	Mn	Mn +/-	Fe	Fe +/-	Co	Co +/-	Ni	Ni +/-
5/25/2015	11:50:09	B81	Geochem	ND		638.54	23.4	3264.84	43.78	ND		ND	
5/25/2015	11:55:44	B82	Geochem	ND		435.19	19.99	2225.86	35.85	ND		ND	
5/25/2015	08:46:25	B90	Geochem	52.91	13.48	114.29	10.87	4644.22	44.32	ND		ND	
5/25/2015	11:23:17	B103A	Geochem	315.69	17.96	324.85	15.93	55893.27	267.28	ND		77.99	5.86

Date	Time	Reading	Mode	Cu	Cu +/-	Zn	Zn +/-	As	As +/-	Se	Se +/-	Rb	Rb +/-
5/25/2015	13:06:08	B29	Geochem	ND		16.54	1.76	ND		ND		19.51	0.75
5/25/2015	08:59:25	B60	Geochem	34.42	3.51	35.85	2.29	6.57	1.18	ND		95.47	1.47
5/25/2015	09:14:05	B70	Geochem	16.12	3.57	11.69	1.96	3.97	1.09	ND		12.58	0.78
5/25/2015	10:30:21	B72	Geochem	10.59	2.66	13.93	1.58	ND		ND		20.77	0.73
5/25/2015	11:50:09	B81	Geochem	9.89	3.26	5.97	1.66	3.59	1.01	ND		4.11	0.7
5/25/2015	11:55:44	B82	Geochem	ND		5.96	1.65	3.42	1.04	ND		5.01	0.71
5/25/2015	08:46:25	B90	Geochem	64.46	3.23	11.13	1.41	3.1	0.97	ND		44.38	0.88
5/25/2015	11:23:17	B103A	Geochem	45.91	3.5	39.09	2.19	13.55	1.26	ND		71.94	1.19

Date	Time	Reading	Mode	Sr	Sr +/-	Y	Y +/-	Zr	Zr +/-	Mo	Mo +/-	Ag	Ag +/-
5/25/2015	13:06:08	B29	Geochem	86.51	1.2	10.92	0.83	156.13	1.67	ND		ND	
5/25/2015	08:59:25	B60	Geochem	230.84	2.22	19.3	1.04	170.28	1.99	ND		ND	
5/25/2015	09:14:05	B70	Geochem	61.9	1.2	6.65	0.9	101.74	1.66	4.23	1.36	ND	
5/25/2015	10:30:21	B72	Geochem	155.33	1.59	8.52	0.75	118.83	1.52	ND		ND	
5/25/2015	11:50:09	B81	Geochem	542.56	3.39	3.03	0.8	15.67	1.48	ND		ND	
5/25/2015	11:55:44	B82	Geochem	636.57	3.71	ND		25.67	1.55	ND		ND	
5/25/2015	08:46:25	B90	Geochem	442.69	2.85	8.82	0.71	105.36	1.44	ND		ND	
5/25/2015	11:23:17	B103A	Geochem	290.27	2.27	21.82	0.94	136.89	1.67	ND		ND	

B6 (cont): PXRF analyses for calcretes.

Date	Time	Reading	Mode	Cd	Cd +/-	Sn	Sn +/-	Sb	Sb +/-	W	W +/-	Hg	Hg +/-
5/25/2015	13:06:08	B29	Geochem	ND		ND		ND		ND		ND	
5/25/2015	08:59:25	B60	Geochem	ND		ND		ND		ND		ND	
5/25/2015	09:14:05	B70	Geochem	ND		ND		ND		ND		6.96	1.99
5/25/2015	10:30:21	B72	Geochem	ND		ND		ND		ND		ND	
5/25/2015	11:50:09	B81	Geochem	ND		ND		ND		ND		ND	
5/25/2015	11:55:44	B82	Geochem	ND		ND		ND		ND		ND	
5/25/2015	08:46:25	B90	Geochem	ND		ND		ND		ND		ND	
5/25/2015	11:23:17	B103A	Geochem	ND		ND		ND		ND		ND	

Date	Time	Reading	Mode	Pb	Pb +/-	Bi	Bi +/-	Th	Th +/-	U	U +/-	LE	LE +/-
5/25/2015	13:06:08	B29	Geochem	6.07	1.35	ND		ND		ND		631940.1	1273.55
5/25/2015	08:59:25	B60	Geochem	11.01	1.57	ND		10.76	3.53	ND		585506.3	2876.83
5/25/2015	09:14:05	B70	Geochem	ND		ND		ND		ND		595850.6	1458.96
5/25/2015	10:30:21	B72	Geochem	ND		ND		ND		ND		644190.6	2772.35
5/25/2015	11:50:09	B81	Geochem	ND		ND		ND		ND		595064.2	1344.65
5/25/2015	11:55:44	B82	Geochem	ND		ND		ND		ND		590784.7	1331.72
5/25/2015	08:46:25	B90	Geochem	17.02	1.33	ND		ND		ND		520187.9	2200.35
5/25/2015	11:23:17	B103A	Geochem	15.59	1.6	ND		ND		8.17	1.75	564491.2	2215.54

B7: PXRF analyses for silcretes.

Date	Time	Reading	Mode	Mg	Mg +/-	Al	Al +/-	Si	Si +/-	P	P +/-	S	S +/-
5/25/2015	09:46:06	B79	Geochem	64425.78	3530.25	42611.74	797.47	195290.2	1075.41	ND		1102.99	41.22
			Mode	Cl	Cl +/-	K	K +/-	Ca	Ca +/-	Ti	Ti +/-	V	V +/-
			Geochem	ND		ND		55690.76	287.04	2056.96	70.77	108.21	29.15
			Mode	Cr	Cr +/-	Mn	Mn +/-	Fe	Fe +/-	Co	Co +/-	Ni	Ni +/-
			Geochem	627.49	20.53	605.83	18.4	35479.01	191.12	ND		226.17	6.85
			Mode	Cu	Cu +/-	Zn	Zn +/-	As	As +/-	Se	Se +/-	Rb	Rb +/-
			Geochem	28.8	3.13	35.83	1.93	3.13	0.79	ND		10.74	0.58
			Mode	Sr	Sr +/-	Y	Y +/-	Zr	Zr +/-	Mo	Mo +/-	Ag	Ag +/-
			Geochem	109.08	1.23	6.18	0.67	199.51	1.77	ND		ND	

B8: PRF analyses for dorbanks.

Date	Time	Reading	Mode	Mg	Mg +/-	Al	Al +/-	Si	Si +/-	P	P +/-	S	S +/-
5/25/2015	10:27:38	B43	Geochem	24633.9	4713.68	57276.54	1172.09	238653.1	1615.26	ND		962.13	66.15
5/25/2015	11:20:28	B56	Geochem	ND		55456.65	1346.88	204943.8	1264.24	753.07	199.77	1176.99	84.31

Date	Time	Reading	Mode	Cl	Cl +/-	K	K +/-	Ca	Ca +/-	Ti	Ti +/-	V	V +/-
5/25/2015	10:27:38	B43	Geochem	ND		14666.81	145.03	ND		1617.82	80.99	127.22	36.15
5/25/2015	11:20:28	B56	Geochem	ND		19469.55	170.25	1719.95	99.94	4307.69	123.1	399.72	49.83

Date	Time	Reading	Mode	Cr	Cr +/-	Mn	Mn +/-	Fe	Fe +/-	Co	Co +/-	Ni	Ni +/-
5/25/2015	10:27:38	B43	Geochem	ND		244.33	15.92	27432.98	193.48	ND		20.85	5.73
5/25/2015	11:20:28	B56	Geochem	ND		262.25	19.16	38159.92	218.72	ND		39.7	7.47

B8 (cont): PRF analyses for dorbanks.

Date	Time	Reading	Mode	Cu	Cu +/-	Zn	Zn +/-	As	As +/-	Se	Se +/-	Rb	Rb +/-
5/25/2015	10:27:38	B43	Geochem	24.44	3.37	35.66	2.29	5	1.49	ND		183.52	2.13
5/25/2015	11:20:28	B56	Geochem	46.11	4.68	49.25	3.14	5.36	1.69	ND		187.59	2.39

Date	Time	Reading	Mode	Sr	Sr +/-	Y	Y +/-	Zr	Zr +/-	Mo	Mo +/-	Ag	Ag +/-
5/25/2015	10:27:38	B43	Geochem	40.67	0.94	33.05	1.24	132.97	1.75	6.31	1.2	ND	
5/25/2015	11:20:28	B56	Geochem	151.54	1.98	25.58	1.46	213.67	2.48	15.77	1.55	ND	

Date	Time	Reading	Mode	Cd	Cd +/-	Sn	Sn +/-	Sb	Sb +/-	W	W +/-	Hg	Hg +/-
5/25/2015	10:27:38	B43	Geochem	ND		ND		ND		ND		6.02	1.66
5/25/2015	11:20:28	B56	Geochem	ND		ND		ND		15.7	5.15	ND	

Date	Time	Reading	Mode	Pb	Pb +/-	Bi	Bi +/-	Th	Th +/-	U	U +/-	LE	LE +/-
5/25/2015	10:27:38	B43	Geochem	37.92	2.06	ND		27.34	3.52	ND		633831.5	3423.95
5/25/2015	11:20:28	B56	Geochem	26.92	2.37	ND		45.96	4.52	ND		672527.3	1817.57

B9: PXRF analyses for ferricretes.

Date	Time	Reading	Mode	Mg	Mg +/-	Al	Al +/-	Si	Si +/-	P	P +/-	S	S +/-
5/25/2015	09:11:02	B14	Geochem	ND		82223.41	1117.84	176171.3	913.62	ND		349.09	28.47
5/25/2015	09:34:30	B75	Geochem	ND		70148.54	905.81	292350	996.79	ND		612.9	45.15

B9 (cont): PXRF analyses for ferricretes.

Date	Time	Reading	Mode	Cl	Cl +/-	K	K +/-	Ca	Ca +/-	Ti	Ti +/-	V	V +/-
5/25/2015	09:11:02	B14	Geochem	ND		4309.97	74.25	ND		4224	85.84	1004.45	38.51
5/25/2015	09:34:30	B75	Geochem	ND		2521.6	67.6	ND		2553.92	75.83	167.67	31.19

Date	Time	Reading	Mode	Cr	Cr +/-	Mn	Mn +/-	Fe	Fe +/-	Co	Co +/-	Ni	Ni +/-
5/25/2015	09:11:02	B14	Geochem	311.72	17.99	11753.76	77.94	170899.4	651.99	ND		218.78	10.31
5/25/2015	09:34:30	B75	Geochem	51.28	13.09	168.41	11.89	23566.82	102.91	ND		30.79	4.64

Date	Time	Reading	Mode	Cu	Cu +/-	Zn	Zn +/-	As	As +/-	Se	Se +/-	Rb	Rb +/-
5/25/2015	09:11:02	B14	Geochem	121.57	6.43	42.72	3.32	56.86	3.04	ND		56.9	1.45
5/25/2015	09:34:30	B75	Geochem	21.59	2.65	13.62	1.45	3.64	0.81	ND		35.02	0.75

Date	Time	Reading	Mode	Sr	Sr +/-	Y	Y +/-	Zr	Zr +/-	Mo	Mo +/-	Ag	Ag +/-
5/25/2015	09:11:02	B14	Geochem	17.14	0.87	20.22	1.22	192.62	2.25	6.64	1.47	ND	
5/25/2015	09:34:30	B75	Geochem	40.63	0.74	5.78	0.68	178.99	1.47	ND		ND	

Date	Time	Reading	Mode	Cd	Cd +/-	Sn	Sn +/-	Sb	Sb +/-	W	W +/-	Hg	Hg +/-
5/25/2015	09:11:02	B14	Geochem	ND		40.83	12.03	ND		20.38	5.52	ND	
5/25/2015	09:34:30	B75	Geochem	ND		ND		ND		ND		ND	

B9 (cont): PXRF analyses for ferricretes.

Date	Time	Reading	Mode	Pb	Pb +/-	Bi	Bi +/-	Th	Th +/-	U	U +/-	LE	LE +/-
5/25/2015	09:11:02	B14	Geochem	78.27	3.93	ND		19.15	4.13	ND		547860.9	1717
5/25/2015	09:34:30	B75	Geochem	3.73	1.09	ND		ND		ND		607525.1	1246.76

B10: PXRF analyses for manganocrete.

Date	Time	Reading	Mode	Mg	Mg +/-	Al	Al +/-	Si	Si +/-	P	P +/-	S	S +/-
5/25/2015	11:47:22	B12	Geochem	ND		81270.15	1344.38	126877.4	911.74	ND		447.99	53.83
				Cl	Cl +/-	K	K +/-	Ca	Ca +/-	Ti	Ti +/-	V	V +/-
				ND		5379.38	86.09	ND		3852.85	86.2	907.84	39.52
				Cr	Cr +/-	Mn	Mn +/-	Fe	Fe +/-	Co	Co +/-	Ni	Ni +/-
				313.59	20.17	61031.95	318.91	175268.1	829.73	ND		353.93	15.39
				Cu	Cu +/-	Zn	Zn +/-	As	As +/-	Se	Se +/-	Rb	Rb +/-
				95.98	8.17	17.51	3.79	18.13	3.91	ND		58.44	1.86
				Sr	Sr +/-	Y	Y +/-	Zr	Zr +/-	Mo	Mo +/-	Ag	Ag +/-
				86.81	1.9	49.85	1.87	191.82	2.91	14.82	1.94	ND	
				Cd	Cd +/-	Sn	Sn +/-	Sb	Sb +/-	W	W +/-	Hg	Hg +/-
				ND		ND		ND		ND		ND	
				Pb	Pb +/-	Bi	Bi +/-	Th	Th +/-	U	U +/-	LE	LE +/-
				118.98	5.72	ND		29.04	5.46	ND		543615.5	2149.14

B11: PXRF analyses for gypcretes.

Date	Time	Reading	Mode	Mg	Mg +/-	Al	Al +/-	Si	Si +/-	P	P +/-	S	S +/-
5/25/2015	10:04:20	B91A	Geochem	ND		111879	1042.18	252918.2	918.96	ND		2712.78	56.4
5/25/2015	09:49:05	B92	Geochem	16420.95	4048.3	37455.11	874.82	99319.31	735.1	ND		3090.93	56.12
5/25/2015	11:06:09	B93	Geochem	ND		70624.63	1062.28	173503.8	866.52	ND		2415	58.76
5/25/2015	09:58:30	B94	Geochem	ND		55525.04	885.21	205870.4	867.62	ND		1239.43	46.38
5/25/2015	10:01:29	B96	Geochem	ND		25937.97	743.31	50348.46	406.14	ND		121507	430.92

Date	Time	Reading	Mode	Cl	Cl +/-	K	K +/-	Ca	Ca +/-	Ti	Ti +/-	V	V +/-
5/25/2015	10:04:20	B91A	Geochem	ND		16339.88	108.95	ND		3992.7	86.7	538.18	36.76
5/25/2015	09:49:05	B92	Geochem	ND		6912.16	73.35	196371.7	1047.33	1629.72	80.99	138.68	37.62
5/25/2015	11:06:09	B93	Geochem	ND		18063.86	118.41	77254.02	312.45	4695.45	107.09	613.16	44.87
5/25/2015	09:58:30	B94	Geochem	ND		9144.21	80.32	58702.82	227.39	3958.89	91.76	522.81	38.83
5/25/2015	10:01:29	B96	Geochem	ND		1347.43	57.55	179490.8	603.51	1136.87	71.15	138.77	34.28

Date	Time	Reading	Mode	Cr	Cr +/-	Mn	Mn +/-	Fe	Fe +/-	Co	Co +/-	Ni	Ni +/-
5/25/2015	10:04:20	B91A	Geochem	83.56	14.43	122.15	11.53	32730.34	129.19	ND		17.53	4.58
5/25/2015	09:49:05	B92	Geochem	ND		59.27	11.82	4936.49	53.38	ND		ND	
5/25/2015	11:06:09	B93	Geochem	100.84	17.99	1030.54	25.73	55960.58	235.34	ND		26.38	6.06
5/25/2015	09:58:30	B94	Geochem	68.2	15.1	2183.98	31.91	34606.59	146.92	ND		31.39	5.15
5/25/2015	10:01:29	B96	Geochem	ND		88.02	11.98	11510.59	77.25	ND		ND	

B11 (cont): PXRF analyses for gypcretes.

Date	Time	Reading	Mode	Cu	Cu +/-	Zn	Zn +/-	As	As +/-	Se	Se +/-	Rb	Rb +/-
5/25/2015	10:04:20	B91A	Geochem	27.52	2.8	30.77	1.84	19.32	1.22	ND		119.66	1.3
5/25/2015	09:49:05	B92	Geochem	33.64	3.29	12.01	1.66	4.24	1.16	ND		79.74	1.34
5/25/2015	11:06:09	B93	Geochem	44.88	3.92	69.78	3.02	6.41	1.29	ND		143.38	1.79
5/25/2015	09:58:30	B94	Geochem	53.68	3.49	51.39	2.33	3.94	1.11	ND		79.05	1.18
5/25/2015	10:01:29	B96	Geochem	14.07	2.79	12.42	1.61	3.45	0.88	ND		17.82	0.75

Date	Time	Reading	Mode	Sr	Sr +/-	Y	Y +/-	Zr	Zr +/-	Mo	Mo +/-	Ag	Ag +/-
5/25/2015	10:04:20	B91A	Geochem	94.47	1.08	19.64	0.9	369.37	2.14	ND		ND	
5/25/2015	09:49:05	B92	Geochem	695.95	4.74	10.46	0.92	104.5	1.82	ND		ND	
5/25/2015	11:06:09	B93	Geochem	277.44	2.32	33.18	1.25	141.68	1.87	4.4	1.26	ND	
5/25/2015	09:58:30	B94	Geochem	160.41	1.51	30.06	1	383.98	2.4	ND		ND	
5/25/2015	10:01:29	B96	Geochem	457.87	2.81	5.29	0.72	21.91	1.27	ND		ND	

Date	Time	Reading	Mode	Cd	Cd +/-	Sn	Sn +/-	Sb	Sb +/-	W	W +/-	Hg	Hg +/-
5/25/2015	10:04:20	B91A	Geochem	ND		ND		ND		ND		5.93	1.41
5/25/2015	09:49:05	B92	Geochem	ND		ND		ND		ND		ND	
5/25/2015	11:06:09	B93	Geochem	ND		ND		ND		ND		ND	
5/25/2015	09:58:30	B94	Geochem	ND		ND		ND		ND		ND	
5/25/2015	10:01:29	B96	Geochem	ND		ND		ND		ND		ND	

B11 (cont): PXRF analyses for gypcretes.

Date	Time	Reading	Mode	Pb	Pb +/-	Bi	Bi +/-	Th	Th +/-	U	U +/-	LE	LE +/-
5/25/2015	10:04:20	B91A	Geochem	19.44	1.46	ND		11.21	2.87	ND		577948.3	1296.19
5/25/2015	09:49:05	B92	Geochem	15.77	1.62	ND		16.13	3.59	ND		632693.2	2917.88
5/25/2015	11:06:09	B93	Geochem	14	1.82	ND		28.95	3.8	ND		594947.6	1507.26
5/25/2015	09:58:30	B94	Geochem	16.93	1.52	ND		ND		ND		627366.8	1299.19
5/25/2015	10:01:29	B96	Geochem	ND		ND		ND		ND		607961.3	1311.29

B12: PXRF analyses for intergrade pedocretes.

Date	Time	Reading	Mode	Mg	Mg +/-	Al	Al +/-	Si	Si +/-	P	P +/-	S	S +/-
5/25/2015	09:02:30	B3	Geochem	ND		84122.5	1112.97	227062.5	987.67	ND		520.96	48.71
5/25/2015	09:08:14	B10	Geochem	22035.48	4284.69	23286.16	761.48	84353.24	677.13	861.97	169	1197.35	44.41
5/25/2015	09:31:33	B74	Geochem	ND		55708.83	893.22	243260.8	985.7	ND		414.08	41.38

Date	Time	Reading	Mode	Cl	Cl +/-	K	K +/-	Ca	Ca +/-	Ti	Ti +/-	V	V +/-
5/25/2015	09:02:30	B3	Geochem	ND		23499.09	137.35	ND		4671.98	97.18	282.17	36.69
5/25/2015	09:08:14	B10	Geochem	ND		607.35	44.07	231622.4	1293.17	2421.81	96.99	279.33	42.81
5/25/2015	09:31:33	B74	Geochem	ND		1607.16	53.79	5086.52	81.75	2287.58	73.12	437.78	32.81

Date	Time	Reading	Mode	Cr	Cr +/-	Mn	Mn +/-	Fe	Fe +/-	Co	Co +/-	Ni	Ni +/-
5/25/2015	09:02:30	B3	Geochem	65.31	14.8	424.58	16.8	44163.49	181.7	ND		31.28	5.45
5/25/2015	09:08:14	B10	Geochem	157.48	20.47	754.87	25.27	48571.37	303.13	ND		40.88	6.67
5/25/2015	09:31:33	B74	Geochem	59.7	13.71	645.76	18.44	66129.26	243.89	ND		26.27	5.39

B12 (cont): PXRF analyses for intergrade pedocretes.

Date	Time	Reading	Mode	Cu	Cu +/-	Zn	Zn +/-	As	As +/-	Se	Se +/-	Rb	Rb +/-
5/25/2015	09:02:30	B3	Geochem	34.32	3.34	88.42	2.97	4.44	1.34	ND		182.42	1.82
5/25/2015	09:08:14	B10	Geochem	47.76	4.21	43.81	2.75	6.84	1.21	ND		14.48	0.98
5/25/2015	09:31:33	B74	Geochem	31.81	3.27	18.33	1.82	7.23	1.17	ND		33.87	0.87

Date	Time	Reading	Mode	Sr	Sr +/-	Y	Y +/-	Zr	Zr +/-	Mo	Mo +/-	Ag	Ag +/-
5/25/2015	09:02:30	B3	Geochem	233.32	1.91	27.33	1.15	399.74	2.6	ND		ND	
5/25/2015	09:08:14	B10	Geochem	1409.37	9.16	11.45	0.97	49.56	2.19	ND		ND	
5/25/2015	09:31:33	B74	Geochem	54.24	0.95	10.08	0.81	126.96	1.49	ND		ND	

Date	Time	Reading	Mode	Cd	Cd +/-	Sn	Sn +/-	Sb	Sb +/-	W	W +/-	Hg	Hg +/-
5/25/2015	09:02:30	B3	Geochem	ND		ND		ND		ND		ND	
5/25/2015	09:08:14	B10	Geochem	ND		ND		ND		ND		ND	
5/25/2015	09:31:33	B74	Geochem	ND		ND		ND		ND		ND	

Date	Time	Reading	Mode	Pb	Pb +/-	Bi	Bi +/-	Th	Th +/-	U	U +/-	LE	LE +/-
5/25/2015	09:02:30	B3	Geochem	30.16	1.89	ND		26.55	3.44	ND		614129.4	1437.8
5/25/2015	09:08:14	B10	Geochem	ND		ND		18.14	4.43	ND		582208.9	2937.94
5/25/2015	09:31:33	B74	Geochem	13.93	1.59	ND		ND		ND		624039.8	1347.79

Appendix C: ICP-MS analyses for selected samples

ICP-MS analyses were conducted on selected samples of caves sediments, drainage depressions, calcrete, silcrete, dorbanks, ferricrete, manganocrete, phoscretes, gypcretes, and intergrade pedocretes. (Analyst: Terina Vermeulen, Eco-Analytica Laboratory, NWU).

C1: The ICP-MS analyses for caves sediments.

	B109A	B109B	B110A	B110B	B111A	B111B	B112A
	<i>ppm</i>	<i>ppm</i>	<i>ppm</i>	<i>ppm</i>	<i>ppm</i>	<i>ppm</i>	<i>ppm</i>
Be 9	0.0224	0.01355	0.02122	0.01722	0.02125	0.02256	0.001217
B 11	0.1179	0.07497	0.08637	0.05271	0.3898	0.03751	0.0001732
Na 23	11.1	9.558	10.41	7.755	13.69	13.5	0.909
Mg 24	60.27	54.63	83.26	598.3	137.4	86.26	1.586
Al 27	588.4	487.3	424.9	289.7	296.9	218.5	72.33
P 31	213.7	498.8	98.86	21.42	132.9	24.45	6.262
K 39	67.02	113.4	28.92	14.9	96.74	77.66	3.221
Ca 43	265.2	443.3	966.4	1408	501.7	189.2	6.34
Ti 47	11.77	20.33	6.715	3.901	6.982	4.477	0.5463
V 51	1.512	1.031	1.278	0.9744	1.192	1.182	0.2186
Cr 53	3.28	3.023	2.35	1.749	2.243	1.974	0.4478
Mn 55	130.7	125.5	289.6	317.7	175.7	176.6	11.33
Fe 57	853.4	981.5	671.5	572.8	637.7	625.2	113.7
Co 59	0.3337	0.317	0.472	0.3459	0.318	0.3111	0.07688
Ni 60	0.7536	0.1817	1.485	0.7851	0.7467	0.5377	0.0003801
Cu 63	1.209	3.047	1.022	0.3812	1.264	0.4747	0.1445
Zn 66	3.185	2.874	2.151	0.5034	4.695	0.9337	0.1536
As 75	0.2557	0.3149	0.1916	0.1846	0.2263	0.1386	0.04835
Se 82	0.02766	0.007529	0.006499	0.00001982	0.04011	0.00002299	0.0002338
Rb 85	0.5083	0.3632	0.3871	0.195	0.337	0.1713	0.06984
Sr 88	0.574	1.498	0.4829	0.281	1.352	0.745	0.03962
Mo 95	0.04522	0.04074	0.0502	0.03426	0.04986	0.01769	0.006752
Pd 105	0.08627	0.07092	0.08673	0.07216	0.09353	0.08448	0.01572

C1 (cont): The ICP-MS analyses for caves sediments.

	B109A	B109B	B110A	B110B	B111A	B111B	B112A
	<i>ppm</i>	<i>ppm</i>	<i>ppm</i>	<i>ppm</i>	<i>ppm</i>	<i>ppm</i>	<i>ppm</i>
Ag 107	0.02136	0.02342	0.02055	0.002923	0.02311	0.01923	0.00003106
Cd 111	0.001033	0.00000222	0.00164	0.000003621	0.002288	3.16E-05	0.00002471
Sb 121	0.01308	0.01108	0.01435	0.0122	0.01163	0.00698	0.002087
Ba 137	9.751	18.81	15.64	8.987	10.43	8.394	0.6331
Pt 195	0.000008936	0.00001373	0.00001393	0.00001537	0.00001234	0.00001385	0.00001583
Au 197	0.0112	0.007311	0.006318	0.007875	0.005871	0.005758	0.004347
Hg 202	0.000007942	0.00001624	0.00001753	0.00001796	0.00002313	0.00002394	0.00002492
Tl 205	0.005633	0.007168	0.008507	0.00526	0.004951	0.004561	0.001033
Pb 208	0.435	0.4178	0.5121	0.2712	0.3699	0.3073	0.0413
Bi 209	0.01962	0.01618	0.01655	0.01572	0.01588	0.01556	0.01266
Th 232	0.1371	0.1374	0.1503	0.2036	0.09698	0.1146	0.01981
U 238	0.01667	0.02085	0.01159	0.006234	0.0126	0.01377	0.006027
Na 23	277.5	238.95	260.25	193.875	342.25	337.5	22.725
Mg 24	1506.75	1365.75	2081.5	14957.5	3435	2156.5	39.65
Al 27	14710	12182.5	10622.5	7242.5	7422.5	5462.5	1808.25
P 31	5342.5	12470	2471.5	535.5	3322.5	611.25	156.55
K 39	1675.5	2835	723	372.5	2418.5	1941.5	80.525
Ca 43	6630	11082.5	24160	35200	12542.5	4730	158.5
Ti 47	294.25	508.25	167.875	97.525	174.55	111.925	13.6575
Mn 55	3267.5	3137.5	7240	7942.5	4392.5	4415	283.25
Fe 57	21335	24537.5	16787.5	14320	15942.5	15630	2842.5
Co 59	8.3425	7.925	11.8	8.6475	7.95	7.7775	1.922
Ni 60	18.84	4.5425	37.125	19.6275	18.6675	13.4425	0.0095025
Cu 63	30.225	76.175	25.55	9.53	31.6	11.8675	3.6125
Zn 66	79.625	71.85	53.775	12.585	117.375	23.3425	3.84
As 75	6.3925	7.8725	4.79	4.615	5.6575	3.465	1.20875
Se 82	0.6915	0.188225	0.162475	0.0004955	1.00275	0.00057475	0.005845
Rb 85	12.7075	9.08	9.6775	4.875	8.425	4.2825	1.746
Sr 88	14.35	37.45	12.0725	7.025	33.8	18.625	0.9905

C1 (cont): The ICP-MS analyses for caves sediments.

	B109A	B109B	B110A	B110B	B111A	B111B	B112A
	<i>ppm</i>	<i>ppm</i>	<i>ppm</i>	<i>ppm</i>	<i>ppm</i>	<i>ppm</i>	<i>ppm</i>
Mo 95	1.1305	1.0185	1.255	0.8565	1.2465	0.44225	0.1688
Pd 105	2.15675	1.773	2.16825	1.804	2.33825	2.112	0.393
Ag 107	0.534	0.5855	0.51375	0.073075	0.57775	0.48075	0.0007765
Cd 111	0.025825	0.0000555	0.041	0.000090525	0.0572	0.0007905	0.00061775
Sb 121	0.327	0.277	0.35875	0.305	0.29075	0.1745	0.052175
Ba 137	243.775	470.25	391	224.675	260.75	209.85	15.8275
Pt 195	0.0002234	0.00034325	0.00034825	0.00038425	0.0003085	0.00034625	0.00039575
Au 197	0.28	0.182775	0.15795	0.196875	0.146775	0.14395	0.108675
Hg 202	0.00019855	0.000406	0.00043825	0.000449	0.00057825	0.0005985	0.000623
Tl 205	0.140825	0.1792	0.212675	0.1315	0.123775	0.114025	0.025825
Pb 208	10.875	10.445	12.8025	6.78	9.2475	7.6825	1.0325
Bi 209	0.4905	0.4045	0.41375	0.393	0.397	0.389	0.3165
Th 232	3.4275	3.435	3.7575	5.09	2.4245	2.865	0.49525
U 238	0.41675	0.52125	0.28975	0.15585	0.315	0.34425	0.150675

C2: The ICP-MS analyses for drainage depression samples.

	B13A	B50A	B59A	B62A	B63A	B83A	B85A
	<i>ppm</i>	<i>ppm</i>	<i>ppm</i>	<i>ppm</i>	<i>ppm</i>	<i>ppm</i>	<i>ppm</i>
Be 9	0.8725	1.0215	0.1381	0.94725	0.947	1.11675	1.24425
B 11	8.6025	2.8775	6.09	31.725	4.2975	1.01025	65.35
Na 23	223.7	287.5	11292.5	15730	648.5	338.75	20890
Mg 24	14582.5	6120	2243.25	28275	5125	2917.5	78375
Al 27	21110	28275	3567.5	24280	35950	14492.5	24470
P 31	756.75	382.75	486.25	1038.75	573.5	565.25	978.25
K 39	3835	5812.5	451.75	7727.5	1961.75	1772.25	11822.5
Ca 43	8577.5	3437.5	10140	48650	6682.5	1545.5	72000

C2 (cont): The ICP-MS analyses for drainage depression samples.

	B13A	B50A	B59A	B62A	B63A	B83A	B85A
	<i>ppm</i>	<i>ppm</i>	<i>ppm</i>	<i>ppm</i>	<i>ppm</i>	<i>ppm</i>	<i>ppm</i>
Ti 47	154.05	253.25	19.745	154.575	322.75	23.245	129.525
V 51	48.65	64.775	4.6575	66.275	169.675	24.115	63.225
Cr 53	90.05	62.875	21.7275	76.55	149.025	41.275	63.025
Mn 55	13587.5	1063.5	89.35	515	3047.5	131.6	395.25
Fe 57	28225	42025	5722.5	20485	43600	11987.5	13017.5
Co 59	22.3375	34.5	29.425	15.5925	81.7	22.51	19.02
Ni 60	33.875	68.2	40.025	28.525	60.65	13.09	32.325
Cu 63	22.325	84.15	23.035	20.835	63.85	13.5	18.455
Zn 66	43.475	48.85	39.9	36.475	41.75	13.39	31.9
As 75	2.7575	1.4755	20.46	2.7975	1.464	1.00125	2.67
Se 82	0.47525	0.4905	0.32925	0.6375	0.90675	0.51625	0.545
Rb 85	34.625	29.625	1.9705	32.025	21.6175	26.6	52.8
Sr 88	39.45	21.9525	77.3	358	29.625	8.9175	651.75
Mo 95	0.607	0.18615	0.7965	0.50175	0.3635	0.17105	0.10665
Pd 105	0.246625	0.351	0.16205	0.57125	0.38025	0.2387	0.90775
Ag 107	0.072975	0.115925	0.08315	0.000145	0.0517	0.000354	0.066075
Cd 111	0.1911	0.0696	0.10225	0.08335	0.080125	0.059225	0.077375
Sb 121	0.26475	0.138425	0.4865	0.16915	0.172925	0.46725	0.138125
I 127	1741.25	699.75	292.25	592.25	9892.5	2010.25	2468.25
Ba 137	683.5	170.825	10.78	190.625	363.5	63.75	665.5
Pt 195	0.01549	0.02061	0.013783	0.01574	0.020653	0.014033	0.016303
Au 197	0.10945	0.20665	0.156725	0.0929	0.093575	0.08585	0.100625
Hg 202	0.237	0.102625	0.783	2.6025	2.505	0.17745	0.121075
Tl 205	0.54575	0.1551	0.0332	0.226875	0.19725	0.133625	0.162675
Pb 208	11.63	5.6525	12.01	7.25	10.645	4.6675	6.8125
Bi 209	0.434	0.38775	0.45	0.41875	0.377	0.36375	0.35625
Th 232	3.2625	3.0725	3.08	4.125	3.86	3.3225	3.9625
U 238	0.44575	0.36875	8.66	2.13	0.46025	0.34975	2.2065

C3: The ICP-MS analyses for calcretes.

B70			
	<i>ppm</i>		<i>ppm</i>
Be 9	0.626	Ag 107	0.2304
B 11	3.5625	Cd 111	0.06345
Na 23	530.25	Sb 121	0.109575
Mg 24	17352.5	I 127	4715
Al 27	9785	Ba 137	302
P 31	475.5	Pt 195	0.0146775
K 39	1995.75	Au 197	0.088925
Ca 43	164600	Hg 202	0.527
Ti 47	65.975	Tl 205	0.09475
V 51	19.035	Pb 208	2.1655
Cr 53	21.9875	Bi 209	0.3285
Mn 55	330.75	Th 232	1.405
Fe 57	7415	U 238	0.54625
Co 59	14.3675		
Ni 60	8.955		
Cu 63	5.8575		
Zn 66	9.895		
As 75	0.923		
Se 82	0.31375		
Rb 85	16.625		
Sr 88	400.75		
Mo 95	0.0832		
Pd 105	0.55475		

C4: The ICP-MS analyses for silcretes

B73			
	<i>ppm</i>		<i>ppm</i>
Be 9	2.302	Pd 105	0.36425
B 11	1.57375	Ag 107	0.00068675
Na 23	392.5	Cd 111	0.046225
Mg 24	4025	Sb 121	0.10235
Al 27	9245	I 127	406.25
P 31	432.25	Ba 137	186.825
K 39	1392	Pt 195	0.0147825
Ca 43	1805.25	Au 197	0.086675
Ti 47	3.815	Hg 202	0.200525
V 51	22.7	Tl 205	0.137175
Cr 53	33.375	Pb 208	2.01175
Mn 55	165.575	Bi 209	0.327
Fe 57	12195	Th 232	1.73725
Co 59	36.225	U 238	0.32875
Ni 60	22.7525		
Cu 63	11.9075		
Zn 66	6.3475		
As 75	1.04125		
Se 82	0.50575		
Rb 85	18.5375		
Sr 88	22.4825		
Mo 95	0.0956		

C5: The ICP-MS analyses for dorbanks.

B56			
	<i>ppm</i>		<i>ppm</i>
Be 9	0.52625	I 127	170.125
B 11	2.19575	Ba 137	118.15
Na 23	345.5	Pt 195	0.014075
Mg 24	2349	Au 197	0.091725
Al 27	8525	Hg 202	0.42725
P 31	572	Tl 205	0.178325
K 39	2505	Pb 208	8.695
Ca 43	709.25	Bi 209	0.45875
Ti 47	348.5	Th 232	12.58
V 51	41.3	U 238	1.3005
Cr 53	23.665		
Mn 55	93.125		
Fe 57	17357.5		
Co 59	28.35		
Ni 60	6.49		
Cu 63	25.5		
Zn 66	22.2975		
As 75	1.89825		
Se 82	0.64625		
Rb 85	30.325		
Sr 88	15.15		
Mo 95	0.44475		
Pd 105	0.236125		
Ag 107	0.0053		
Cd 111	0.0517		
Sb 121	0.1641		

C6: The ICP-MS analyses for ferricretes

B14			
	<i>ppm</i>		<i>ppm</i>
Be 9	2.056	I 127	975.75
B 11	1.55075	Ba 137	728.5
Na 23	153.825	Pt 195	0.0266
Mg 24	385.5	Au 197	0.09425
Al 27	19430	Hg 202	0.45925
P 31	851.75	Tl 205	1.1525
K 39	838	Pb 208	28.475
Ca 43	169.5	Bi 209	0.52625
Ti 47	236.75	Th 232	4.4375
V 51	243.525	U 238	1.99775
Cr 53	411.75		
Mn 55	3585		
Fe 57	150225		
Co 59	58.375		
Ni 60	79.6		
Cu 63	105.325		
Zn 66	44.15		
As 75	77.9		
Se 82	1.35275		
Rb 85	10.47		
Sr 88	4.3875		
Mo 95	3.4975		
Pd 105	0.15635		
Ag 107	0.161775		
Cd 111	0.109225		
Sb 121	2.01775		

C7: The ICP-MS analyses for manganoncrete.

B12			
	<i>ppm</i>		<i>ppm</i>
Be 9	2.51	I 127	950
B 11	2.595	Ba 137	3490
Na 23	153.025	Pt 195	0.028325
Mg 24	448	Au 197	0.119225
Al 27	22967.5	Hg 202	1.811
P 31	351.5	Tl 205	1.554
K 39	2106.5	Pb 208	54
Ca 43	877.25	Bi 209	0.56025
Ti 47	322.75	Th 232	5.25
V 51	264	U 238	1.371
Cr 53	274		
Mn 55	63325		
F^e 57	118775		
Co 59	105.125		
Ni 60	317.25		
Cu 63	66.525		
Zn 66	14.8925		
As 75	21.66		
Se 82	1.368		
Rb 85	9.84		
Sr 88	86.35		
Mo 95	5.145		
Pd 105	0.682		
Ag 107	1.73275		
Cd 111	0.58125		
Sb 121	0.6035		

C8: The ICP-MS analyses for phoscrete.

B98			
	<i>ppm</i>		<i>ppm</i>
Be 9	0.60975	I 127	6535
B 11	13.155	Ba 137	38.3
Na 23	2252.75	Pt 195	0.01347
Mg 24	1941.25	Au 197	0.104625
Al 27	4210	Hg 202	1.287
P 31	75075	Tl 205	0.45675
K 39	1165	Pb 208	4.4275
Ca 43	169400	Bi 209	0.33325
Ti 47	136.025	Th 232	2.288
V 51	20.0675	U 238	10.225
Cr 53	120.75		
Mn 55	28.575		
Fe 57	3000		
Co 59	25.575		
Ni 60	31.85		
Cu 63	5.26		
Zn 66	5.42		
As 75	5.44		
Se 82	0.8745		
Rb 85	8.075		
Sr 88	469.75		
Mo 95	1.3125		
Pd 105	0.94225		
Ag 107	0.1259		
Cd 111	0.82825		
Sb 121	0.55375		

C9: The ICP-MS analyses for gypcrete.

	B92	B96
	ppm	ppm
Be 9	0.265	0.313
B 11	22.865	15.9225
Na 23	8705	1050.75
Mg 24	36950	2895
Al 27	3547.5	4720
P 31	516.5	455.5
K 39	1414.25	1285.75
Ca 43	222425	150525
Ti 47	9.1	37.525
V 51	12.6075	9.005
Cr 53	6.7675	11.7325
Mn 55	19.9525	60.7
Fe 57	1302.75	4107.5
Co 59	9.6325	2.6625
Ni 60	3.3725	2.8275
Cu 63	29.175	4.5025
Zn 66	1.99575	6.0175
As 75	3.26	1.1005
Se 82	1.0435	0.3655
Rb 85	4.2175	7.875
Sr 88	847.25	219.375
Mo 95	0.24175	0.23085
Pd 105	1.045	0.306
Ag 107	0.039175	0.007898
Cd 111	0.04125	0.061775
Sb 121	0.23335	0.1506
I 127	2148	2292
Ba 137	93.85	35.5
Pt 195	0.0139275	0.014095
Au 197	0.1101	0.09335
Hg 202	0.3355	0.073625
Tl 205	0.037125	0.057375
Pb 208	2.99	1.66175
Bi 209	0.3515	0.33775
Th 232	2.3835	1.01025
U 238	0.78075	1.0515

C10: The ICP-MS analyses for intergrade pedocretes.

	B108				
	<i>ppm</i>				
Be 9	0.483	Zn 66	9.6675	Bi 209	0.39725
B 11	12.5875	As 75	5.0775	Th 232	1.8435
Na 23	353	Se 82	0.55975	U 238	0.483
Mg 24	17515	Rb 85	14.82		
Al 27	6152.5	Sr 88	236.075		
P 31	307.5	Mo 95	1.05525		
K 39	3727.5	Pd 105	0.7455		
Ca 43	118500	Ag 107	0.13605		
Ti 47	33.6	Cd 111	0.02625		
V 51	81	Sb 121	0.170025		
Cr 53	52.825	Ba 137	983		
Mn 55	166.875	Pt 195	0.0328		
Fe 57	20265	Au 197	0.3025		
Co 59	8.8	Hg 202	0.0366		
Ni 60	23.83	Tl 205	0.061225		
Cu 63	21.34	Pb 208	5.0725		

Appendix D: Particle size distribution

D1: Particle size distribution of the soil samples for most of the samples collected in the study area (Analyst: Terina Vermeulen, Eco-Analytica Laboratory, NWU).

Sample	>2mm %	Very coarse sand %	Coarse sand %	Medium sand %	Fine sand %	Very fine sand %	Silt %	Clay %
B1	0.1	3.9	20.2	36.1	26.9	8.0	3.3	1.6
B2	4.0	6.7	12.2	22.7	30.2	18.3	8.3	1.7
B4	0.0	0.5	4.3	51.1	34.1	5.2	3.2	1.5
B5	0.0	0.0	0.0	42.5	54.6	0.3	1.1	1.4
B6	0.1	0.3	0.4	43.8	51.5	1.4	1.1	1.5
B7	0.0	0.4	17.2	44.3	32.5	2.9	1.2	1.5
B9	0.7	1.3	4.5	44.0	33.1	14.3	1.2	1.6
B10	0.3	27.0	20.2	18.1	15.9	9.8	7.2	1.7
B11	20.2	15.3	12.3	16.2	19.8	21.7	9.9	4.9
B12	12.2	20.4	16.4	18.1	16.3	15.9	11.0	2.0
B13	9.3	9.5	10.4	16.1	15.3	14.5	22.4	11.8
B14	0.2	26.4	17.4	15.9	15.5	13.5	7.3	4.1
B15	0.0	0.4	1.2	10.1	64.4	20.8	0.2	3.0
B16	0.0	0.4	0.3	4.1	57.0	30.0	2.6	5.6
B17	0.0	0.0	0.2	4.6	48.3	35.9	3.6	7.4
B18	0.0	0.0	0.6	22.0	59.5	16.4	1.1	0.4
B19	0.0	0.3	1.1	9.7	41.9	22.8	13.8	10.4
B20	0.0	1.3	2.8	11.1	29.3	18.2	17.8	19.5
B21	0.0	12.0	15.2	22.5	16.6	7.1	8.8	17.8
B22	0.0	8.2	53.6	31.8	4.3	0.5	1.1	0.4
B23	0.0	15.0	37.0	33.6	9.2	1.5	1.2	2.5

D1 (cont): Particle size distribution of the soil samples for most of the samples collected in the study area.

Sample	>2mm %	Very coarse sand %	Coarse sand %	Medium sand %	Fine sand %	Very fine sand %	Silt %	Clay %
B24	0.0	21.8	31.4	21.7	19.1	4.5	1.2	0.4
B25	0.0	2.4	10.3	16.8	15.6	12.3	13.2	29.4
B26	0.0	9.2	39.2	29.8	7.6	3.6	3.5	7.1
B27	0.0	1.5	10.6	32.2	26.8	7.7	3.8	17.4
B28	0.0	3.6	7.3	28.9	29.9	9.1	8.6	12.6
B29	0.0	22.2	16.7	24.0	19.6	11.3	3.5	2.6
B30	0.3	2.8	4.2	12.5	40.7	26.6	8.1	5.0
B31	0.0	8.1	10.6	10.5	33.1	29.0	4.4	4.3
B32	0.0	11.4	10.4	11.5	30.8	27.2	4.4	4.3
B33	0.0	19.7	19.0	16.6	18.3	12.8	6.8	6.7
B35	0.0	21.1	20.8	18.8	11.0	2.9	15.3	10.1
B36	0.0	3.2	5.7	4.2	2.6	2.0	52.8	29.6
B37	0.0	1.7	2.2	1.3	1.3	1.1	61.7	30.7
B38	0.0	12.3	14.6	14.1	8.4	3.5	20.7	26.5
B39	0.0	5.0	8.5	9.4	10.3	7.4	31.3	28.1
B40	0.0	2.6	22.5	41.6	24.8	6.5	0.0	2.0
B41	0.0	3.2	22.6	40.5	25.2	6.6	0.0	2.0
B42	0.0	0.1	4.7	31.3	52.4	9.5	0.0	1.9
B44	0.0	0.0	0.0	43.8	54.1	0.1	0.0	1.9
B45	0.0	0.0	0.1	40.3	56.1	1.7	0.0	1.9
B47	0.0	5.0	9.6	16.4	18.8	15.7	18.7	15.9
B48	0.0	1.3	2.5	6.1	27.9	24.1	13.9	24.1
B49	0.0	0.4	0.6	5.2	39.1	34.0	9.5	11.2
B50	0.0	5.5	3.3	4.9	19.2	18.3	6.1	42.7
B51	0.1	14.2	12.3	15.1	16.7	12.2	12.6	16.9

D1 (cont): Particle size distribution of the soil samples for most of the samples collected in the study area.

Sample	>2mm %	Very coarse sand %	Coarse sand %	Medium sand %	Fine sand %	Very fine sand %	Silt %	Clay %
B52	0.0	2.3	3.5	11.9	36.0	27.3	7.4	11.5
B53	0.0	0.0	0.0	6.5	90.3	1.3	0.2	1.7
B54	5.3	11.6	10.2	9.6	30.6	28.6	2.6	6.7
B55	0.3	10.4	9.5	12.0	17.3	14.7	13.2	22.9
B60	0.4	32.5	22.2	18.6	14.4	6.2	4.5	1.6
B62	0.0	2.3	3.0	7.8	23.6	15.8	22.2	25.4
B63	2.7	15.0	9.3	6.7	6.7	5.4	23.5	33.4
B64	0.0	0.6	0.9	3.0	8.1	4.6	31.2	51.5
B70	0.1	31.3	16.9	13.9	21.0	8.9	5.2	2.9
B71	6.4	9.8	10.8	13.7	18.6	11.9	32.2	3.1
B72	0.0	9.2	7.2	11.6	49.7	18.4	3.0	0.9
B77	0.0	0.6	2.9	10.5	61.7	20.7	0.7	2.9
B78	0.3	33.4	15.1	7.9	21.1	8.9	5.6	8.1
B79	0.3	14.7	9.9	12.7	31.4	15.2	10.4	5.8
B80	0.3	2.6	2.5	3.9	9.3	7.9	22.8	51.0
B80	0.0	1.9	2.4	4.3	10.4	9.0	21.1	50.8
B81	0.2	10.1	6.5	8.2	16.6	13.6	24.3	20.7
B83	0.0	1.6	4.7	9.1	30.3	16.4	9.2	28.7
B83	0.0	1.0	3.9	9.2	32.3	16.1	6.9	30.6
B84	1.7	3.5	9.4	10.8	8.2	6.7	35.3	26.1
B84	0.0	3.3	10.2	10.2	7.6	6.5	39.8	22.5
B85	0.0	0.8	2.7	4.6	6.2	6.8	42.0	36.8
B85	0.1	1.1	3.2	5.5	6.4	6.8	42.2	34.9
B88	0.6	8.4	14.0	30.7	24.3	9.9	1.8	10.9
B89	0.1	35.8	16.5	9.4	11.1	9.6	11.2	6.4

D1 (cont): Particle size distribution of the soil samples for most of the samples collected in the study area.

Sample	>2mm %	Very coarse sand %	Coarse sand %	Medium sand %	Fine sand %	Very fine sand %	Silt %	Clay %
B91A	0.1	27.4	20.0	19.2	17.6	7.7	4.1	4.0
B92A	0.1	17.7	18.7	21.5	19.9	9.7	8.6	4.0
B93A	0.1	32.5	23.1	16.4	11.6	5.9	6.5	4.0
B94A	0.0	21.5	15.4	19.2	20.5	9.8	9.3	4.3
B96A	0.0	28.1	26.0	21.2	13.0	4.0	3.9	3.8
B100A	0.0	17.8	23.5	24.7	20.6	8.0	3.9	1.6
B101A	0.1	11.0	15.1	15.9	19.4	14.0	17.5	7.1
B102	0.2	7.7	5.5	6.5	11.4	12.2	20.4	36.3
B103	0.1	30.3	20.3	15.6	12.4	7.4	10.8	3.2
B104	0.0	0.7	1.2	11.0	35.4	16.3	17.8	17.7
B105	1.8	45.3	26.1	17.5	7.5	2.3	0.7	0.6
B106	1.4	29.5	13.0	9.8	9.0	5.9	17.9	15.0
B107	0.0	5.6	4.0	2.2	5.4	9.9	43.6	29.3
B108	0.4	36.0	21.3	18.1	14.8	6.3	2.9	0.6
B109A	0.0	3.9	6.7	10.1	19.2	32.7	24.3	3.1
B109B	0.1	5.9	11.3	17.8	26.5	25.0	10.6	2.9
B110A	0.0	8.7	14.6	19.6	21.0	17.0	16.1	3.0
B110B	0.0	1.3	2.4	7.3	25.3	36.1	21.9	5.7
B111A	0.0	5.0	9.7	13.7	23.4	17.7	22.0	8.4
B111B	0.0	4.5	5.8	9.4	21.1	36.6	16.8	5.8
B112A	0.0	5.7	7.5	10.7	19.3	20.3	26.4	10.1
BX-1	0.9	26.2	22.0	19.9	16.8	9.2	5.9	2.2
BX-2	2.6	44.5	22.7	14.5	9.5	5.1	3.7	2.2
BX-3	1.5	34.8	23.4	19.5	12.9	5.9	3.6	2.1

D1 (cont): Particle size distribution of the soil samples for most of the samples collected in the study area.

Sample	>2mm %	Very coarse sand %	Coarse sand %	Medium sand %	Fine sand %	Very fine sand %	Silt %	Clay %
BX-4	0.1	2.5	3.1	3.9	17.7	8.8	64.0	48.8
BX-5	0.5	9.7	7.1	6.5	9.5	4.5	62.6	46.9

Appendix E: Organic carbon (LOI Method)

Organic carbon was determined using the Loss-On-Ignition method for selected samples at the Soil Laboratory of the North-West University. Three repetitions were conducted for each sample and the average values were determined.

E1: The organic carbon percentages of the Florisbad palaeohorizons.

Sample name	LOI Rep 1					LOI Rep 2					LOI Rep 3				
	Weight total	OC weight loss (g)	LOI%	OC		Weight total	OC weight loss (g)	LOI%	OC		Weight total	OC weight loss (g)	LOI%	OC	Average OC %
B15	460.34	1.12	0.24	0.069097		460.3	1.08	0.23	0.066635		459.85	1.05	0.23	0.064847	0.05
B16	427.36	0.79	0.18	0.052499		426.86	1.04	0.24	0.069194		426.56	1.1	0.26	0.073237	0.05
B17	473.74	1.11	0.23	0.066543		473.69	1	0.21	0.059955		473.17	1.07	0.23	0.064222	0.05
B18	437.41	0.1	0.02	0.006493		437.53	0.36	0.08	0.023368		437.34	0.2	0.05	0.012988	0.01
B49	455.33	3.63	0.80	0.226412		455.68	1.35	0.30	0.084138		455.39	1.45	0.32	0.090428	0.10

E2: The organic carbon percentages of the terrestrial sand deposits.

Sample name	LOI Rep 1					LOI Rep 2					LOI Rep 3				
	Weight total	OC weight loss (g)	LOI%	OC		Weight total	OC weight loss (g)	LOI%	OC		Weight total	OC weight loss (g)	LOI%	OC	Average OC %
B1	14.96	0.16	1.07	0.303743		15	0.23	1.53	0.435177		15.01	0.24	1.60	0.454097	0.40
B2	14.92	0.31	2.08	0.59008		15	0.33	2.20	0.6248		15	0.36	2.40	0.6816	0.63
B4	14.99	0.26	1.73	0.492595		14.99	0.27	1.80	0.5112		15.01	0.31	2.07	0.586542	0.53

E2 (cont): The organic carbon percentages of the terrestrial sand deposits

Sample name	LOI Rep 1					LOI Rep 2					LOI Rep 3				
	Weight total	OC weight loss (g)	LOI%	OC		Weight total	OC weight loss (g)	LOI %	OC		Weight total	OC weight loss (g)	LOI %	OC	Average OC %
B5	14.99	0.05	0.33	0.09473		15	0.13	0.87	0.24596 9		15.01	0.15	1.00	0.28381 1	0.21
B6	14.97	0.1	0.67	0.18971 3		15.01	0.14	0.93	0.26506 7		15.01	0.15	1.00	0.28381 1	0.25
B7	14.96	0.08	0.53	0.15187 2		15.01	0.11	0.73	0.20812 8		15	0.12	0.80	0.2272	0.20
B9	14.97	0.06	0.40	0.11382 8		14.98	0.1	0.67	0.18958 6		15	0.14	0.93	0.26506 7	0.19
B30	14.99	0.29	1.93	0.54943 3		15	0.33	2.20	0.6248		15	0.37	2.47	0.70053 3	0.62
B40	15	0.07	0.47	0.13253 3		15.01	0.07	0.47	0.13244 5		15.01	0.07	0.47	0.13244 5	0.13
B42	15	0.18	1.20	0.3408		15.01	0.21	1.40	0.39733 5		15.01	0.21	1.40	0.39733 5	0.38
B44	15	0.1	0.67	0.18933 3		15.03	0.1	0.67	0.18895 5		15	0.13	0.87	0.24613 3	0.21
B45	15	0.1	0.67	0.18933 3		15.02	0.11	0.73	0.20798 9		15	0.12	0.80	0.2272	0.21
B54	15	0.1	0.67	0.18933 3		15.02	0.11	0.73	0.20826 7		15	0.12	0.80	0.2272	0.21
B77	15.01	0.21	1.40	0.39733 5		15.01	0.16	1.07	0.30273 2		15.01	0.21	1.40	0.39733 5	0.37

E3: The organic carbon percentages of the drainage depressions.

Sample name	LOI Rep 1				LOI Rep 2				LOI Rep 3				Average OC %
	Weight total	OC weight loss (g)	LOI%	OC	Weight total	OC weight loss (g)	LOI%	OC	Weight total	OC weight loss (g)	LOI%	OC	
B13	14.41	1.21	8.40	2.384733	15.01	1.37	9.13	2.592139	15	1.53	10.20	2.8968	2.62
B47	15	0.47	3.13	0.889867	15.02	0.59	3.93	1.115579	15	0.6	4.00	1.136	1.05
B48	14.99	0.95	6.34	1.799867	15	0.99	6.60	1.8744	15.01	0.02	0.13	0.037841	1.24
B50	14.99	0.66	4.40	1.250434	15	0.76	5.07	1.438933	15	0.75	5.00	1.42	1.37
B51	15	0.7	4.67	1.325333	15.01	0.74	4.93	1.400133	15	0.72	4.80	1.3632	1.36
B55	15.01	0.72	4.80	1.362292	15.01	0.8	5.33	1.513658	15.01	0.87	5.80	1.646103	1.51
B59	15.01	0.27	1.80	0.510859	15.01	0.3	2.00	0.567622	15	0.3	2.00	0.568	0.55
B62	15.01	1.97	13.12	3.727382	15.01	2.01	13.39	3.803065	15.01	1.98	13.19	3.746302	3.76
B63	15.01	2	13.32	3.784144	15.01	2.13	14.19	4.030113	15.01	2.02	13.46	3.821985	3.88
B64	15.01	0.82	5.46	1.551499	15.01	0.92	6.13	1.740706	15.01	0.87	5.80	1.646103	1.65
B71	13.81	1.19	8.62	2.447212	13.78	1.23	8.93	2.534978	13.71	1.3	9.48	2.692925	2.56
B83	14.99	1.09	7.27	2.06511	15.01	0.81	5.40	1.532578	15.01	0.78	5.20	1.475816	1.69
B84	15.01	1.21	8.06	2.289407	15	1.21	8.07	2.290933	15.01	1.18	7.86	2.232645	2.27
B85	15.02	0.78	5.19	1.474834	15	0.79	5.27	1.495733	15.01	0.66	4.40	1.248767	1.41

Appendix F: Plant Available Water

The Plant Available Water was determined for selected sample using an Excel worksheet supplied by Me. Astrid Hatting. The bulk density of 1.6 g/cm^3 was used for sand samples and 1.3 g/cm^3 for clay samples. Table 49 was used to determine the plant available water percentage relative to the texture class.

F1: The calculated plant available water for a sand sample (B54) in mm/m.

B54	Plant available water %	Density g/cm^3	Thickness of layer cm	mm/m	
Layer num e.g. A	5	1.6	100	80	
		Thickness of profile	100	80	mm/profile
				80	mm/m

F2: The calculated plant available water for a sand sample (B7) in mm/m.

B7	Plant available water %	Density g/cm^3	Thickness of layer cm	mm/m	
Layer num e.g. A	5	1.6	100	80	
		Thickness of profile	100	80	mm/profile
				80	mm/m

F3: The calculated plant available water for a clay sample (Bentonite) in mm/m.

Bentonite	Plant available water %	Density g/cm^3	Thickness of layer cm	mm/m	
Layer num e.g. A	12	1.3	100	144	
		Thickness of profile	100	156	mm/profile
				156	mm/m

F4: The calculated plant available water for a clay sample (B63) in mm/m.

B63	Plant available water %	Density g/cm³	Thickness of layer cm	mm/m	
Layer num e.g. A	14	1.3	100	168	
		Thickness of profile	100	168	mm/profile
				168	mm/m

F5: The calculated plant available water for a clay sample (B64) in mm/m.

B64	Plant available water %	Density g/cm³	Thickness of layer cm	mm/m	
Layer num e.g. A	12	1.3	100	144	
		Thickness of profile	100	144	mm/profile
				144	mm/m