# GEOLOGY, PARTICLE SIZE DISTRIBUTION AND CLAY FRACTION MINERALOGY OF SELECTED VINEYARD SOILS IN SOUTH AFRICA AND THE POSSIBLE RELATIONSHIP WITH GRAPEVINE PERFORMANCE

By

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Thesis presented in partial fulfilment of the requirements for the degree

Of

**MASTER OF AGRICULTURAL SCIENCE**

at the

**UNIVERSITY OF STELLENBOSCH**

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March 2001

# DECLARATION

I, the undersigned hereby declare that the work contained in this thesis is my own original work and has not previously in its entirety or in part been submitted at any university for a degree.

## SUMMARY

This study is an integral part of a multidisciplinary research project concerning the effects of soil and climate on wine quality. The motive, which led to the setting up of this project, was that producers could not determine beforehand whether a specific location would yield wines of high or low quality. If a specific cultivar were to be planted at the wrong location, then it was likely that wine of table quality would result, rather than the export quality wine that was intended. The long term objectives of this multidisciplinary project were the compilation of guidelines by means of which different sites may be classified according to their potential for the production of high quality wines, and the identification of the most important climatic and soil factors responsible for differences in wine quality and character. In this multidisciplinary project, measurements (soil water, leaf water potential, cane mass and yield) were made under dry land conditions in Sauvignon blanc vineyards at six different localities: five in the Stellenbosch district (Simonsberg, Kuils River, Helshoogte, Papegaaiberg and Devon Valley) and one in Durbanville. Each vineyard was owned by a private commercial producer. The vines were approximately 10 years old in all cases, and were trained on a hedge system. Measurements were made in plots, each of which contained 20 vines. Two different soil types were identified at each locality. Vine growth and wine quality differed markedly on these contrasting soils, even though they were located in close physical proximity. The measurements that were made at high and low production plots at each locality during this study were obtained from points which were not more than 60 m metres apart. An automatic weather station was erected halfway between the two, contrasting, experimental plots.

Within the overall scope of the multidisciplinary project, the study which forms the subject of this thesis, concentrated on the effects of soil parent material as a soil forming parameter and as a possible predetermining character with regard to vine growth and wine character. From literature it was clear at the outset of this work that the geology of the coastal wine region is very complex and varies over short distances. The geological history indicates different types of rock formation and rock forming process (sedimentary, igneous as well as metamorphic), plate tectonic activity, mountain building, erosion and weathering, over a period of approximately 1 000 million years. The present landscape includes a coastal plane, hills, and eroding mountains.

Statistical analyses indicated that the soils from the different localities could mainly be characterised in terms of differences in their sand size fractions. Soils from Durbanville are dominated by fine sand and correlates with the underlying phyllitic shales. Soils from Kuils River contain significantly more coarse sand when compared with the other sites. This appears to be a reflection of the underlying coarse granitic material, and implies that *in situ* weathering played an important role in soil development. The data did not, however, prove that the Kuils River soils formed solely from underlying rocks. The gravel and stone fraction

for the Kuils River soils were nevertheless correlated with those of the underlying parent material. Soils from Helshoogte and Simonsberg (both of which are underlain by granites), Papegaaiberg and Devon Valley (both underlain by hornfels) were not significantly dominated by any particular sand fraction. Soils from these localities therefore did not only reflect the underlying material as a source of soil parent material. This implied mixing of parent material and/or the incursion of eolian sand at Helshoogte, Simonsberg and Devon Valley. A marine incursion may have affected the soil parent material at Papegaaiberg.

In order to obtain more information concerning the origins and possible mixing of parent materials prior to and during soil formation, samples from the different soil horizons in each profile were subjected to a chemical analysis. Particular emphasis was placed on potassium, which is an extremely important nutrient mineral element, from the viewpoints of vine growth and wine quality. Because the soils used in this study were all located in production vineyards, the probability that fertiliser residues would have contaminated the soils was high. The lower soil horizons were considered to be least affected by this contamination and therefore most likely to be indicative of the natural soil chemical composition. However, the lower horizon K content of the soils in this study could not be reliably correlated with any known or predicted characteristic that might link the soil parent material with local rock types. At Durbanville, both soils contained small quantities of K in the lower horizons, reflecting the underlying phyllitic shales, but at Devon Valley and Papegaaiberg, the lower horizons contained more K than expected. The soils at these localities are situated on hornfels, containing low quantities of K. The large quantities of K in the soils may have indicated that these soils are situated close to a granite/Malmesbury contact zone. Soils from Kuils River, Simonsberg and Helshoogte are situated on K-rich porhyritic granites and it was expected that these soils would contain relatively large quantities of K in the lower horizons. This, however, was not the case. It was therefore concluded that dilution with K-poor material had taken place. Such material could have been derived from higher-lying sandstones, or from eolian processes during the Cenozoic. Alternatively, the K content of the soil might have been depleted by long continued leaching.

A semi-quantitative analysis of the minerals in the soil clay fractions was also carried out. The objective was to identify the clay minerals that were present in the different soil horizons and to relate the minerals to weathering conditions. Evidence linking the minerals in the clay fractions of the soil samples with the mineralogical composition of the soil parent materials was sought. The clay fraction mineralogy data indicated that all soils in the study area are in an advanced stage of weathering and are dominated by kaolinite, and in certain soils quartz. It was difficult to relate these minerals directly with soil parent material because the primary minerals originating from the soil parent materials have been extensively broken down. The simultaneous presence of quartz and gibbsite in the clay fraction of both soils at Simonsberg, Helshoogte and Durbanville as well as one soil form from both Kuils River and Simonsberg,

indicated non-uniform distribution of clay fraction minerals, indicating that different stages of weathering were present during soil formation. This could have been a result of mixing of parent materials, but may also reflect different periods of weathering of the same material. Both soils at Papegaaiberg, both soils at Devon Valley and other soils at Simonsberg and Kuils River indicated uniform clay fraction mineralogy distribution, mainly because the absence of gibbsite is related to the presence of quartz in the clay fraction.

The soil characteristics, as determined in this study, were also compared with vine growth, wine quality and wine character, as obtained in the broader multidisciplinary research project. For most soils in this study, an increase in clay fraction kaolinite was associated with a reduction in vegetative growth, overall wine quality, and fresh vegetative character. An increase in clay fraction quartz was associated with higher overall wine quality. Increased shoot growth also affected fresh vegetative character positively. Better growth occurred on higher altitudes and this resulted, for Sauvignon blanc, in higher wine quality. Wines produced from vines situated on both phyllitic shales and porhyritic granites showed high quality (Durbanville and Helshoogte), but both were related to low clay fraction kaolinite content and high altitude. It was not possible to relate parent material directly with vine growth, wine quality and/or wine character. The lowest quality wines, however, were produced from vines situated on hornfels (Papegaaiberg and Devon Valley), both containing high quantities of clay fraction kaolinite and situated on low altitudes. High levels of K in soils containing high levels of clay fraction kaolinite may have been partly responsible for low wine quality obtained on such soils.

# OPSOMMING

Hierdie studie vorm 'n integrale deel van 'n multi-dissiplinêre navorsingsprojek oor die effek van grond en klimaat op wynkwaliteit. Die motivering wat gelei het tot die beplanning van hierdie projek, was dat produsente nie vooraf kon bepaal of 'n spesifieke lokaliteit wyne kan produseer van hoë of lae kwaliteit nie. Indien 'n spesifieke kultivar op die verkeerde lokaliteit geplant word, sou dit waarskynlik tot 'n gewone tafelwyn lei, instede van 'n wyn van uitvoergehalte. Die langtermyn doelwitte van die multi-dissiplinêre projek was om riglyne te ontwikkel om verskillende lokaliteite te klassifiseer na aanleiding van hul potensiaal om hoë kwaliteit wyne te produseer, asook om die belangrikste klimaats- en grondfaktore verantwoordelik vir die produksie van hoë kwalitiet wyne te identifiseer. In hierdie multi-dissiplinêre projek was metings (plant beskikbare water, blaarwater potensiaal, lootmassa en oes) onder droëland toestande bepaal in Sauvignon blanc wingerde by ses verskillende lokaliteite: vyf in die Stellenbosch distrik (Simonsberg, Kuilsrivier, Helshoogte, Papegaaiberg and Devon Valley) en een in Durbanville. Elke wingerd is besit deur 'n kommersiële privaatprodusent. Die stokke was ongeveer 10 jaar oud in alle gevalle en opgelei op 'n heining sisteem. Metings was in eksperimentele blokke van 20 stokke elk uitgevoer. Twee verskillende grondtipes is by elke lokaliteit identifiseer. Lootgroei en wynkwaliteit het merkbaar verskil op die kontrasterende gronde, selfs waar gronde naby aanmekaar was. Die metings is uitgevoer op hoë- en lae produksie eksperimentele blokke waar gronde by spesifieke lokaliteite nie verder as 60 meter was nie. 'n Outomatiese weerstasie was halfpad tussen die twee kontrasterende grondtipes by elk van die ses lokaliteite opgerig.

Binne die algemene omvang van die multi-dissiplinêre projek, het die studie wat die onderwerp van hierdie tesis is, gekonsentreer op die effek van moedermateriaal as grondvormende parameter asook as moontlike voorspeller van wingerdgroei en wynkarakter. Dit was duidelik uit die literatuur dat die geologie van die Wynkusstreek baie kompleks is en oor kort afstande varieer. Die geologiese geskiedenis dui daarop dat verskillende tipes gesteentes en verskillende prosesse van gesteente-vorming (sedimentêr, stollings- en metamorfe), plaattektoniese aktiwiteit, orogenese, erosie en verwering, oor 'n periode van ongeveer 1 000 miljoen jaar plaasgevind het. Die huidige landskap sluit kusvlaktes, heuwels en geërodeerde berge in.

Statistiese analises het aangetoon dat die gronde van die verskillende lokaliteite hoofsaaklik in terme van verskille in sandgrootte fraksies onderskei kon word. Gronde van Durbanville is gedomineer deur fyn sand en korreleer met onderliggende fillietiese skalies. Gronde van Kuilsrivier bevat betekenisvol meer growwe sand wanneer dit vergelyk word met die ander lokaliteite. Dit is waarskynlik afkomstig vanaf die onderliggende growwe granitiese materiaal en impliseer dat *in situ* verwering 'n belangrike rol gespeel het in grondontwikkeling. Die data het egter nie bewys dat die gronde van Kuilsrivier slegs uit die onderliggende graniete gevorm

het nie. Die gruisfraksies in die gronde by Kuilsrivier was tog vergelykbaar met die onderliggende materiaal. Gronde vanaf Helshoogte and Simonsberg (beide onderlê deur graniete), Papegaaiberg and Devon Valley (beide onderlê deur hornfels) was nie betekenisvol gedomineer deur 'n spesifieke sandfraksie nie. Gronde vanaf hierdie lokaliteite het dus nie slegs die onderliggende gesteentes verteenwoordig nie. Dit dui op vermenging van moedermateriaal en/of eoliese prosesse by Helshoogte, Simonsberg and Devon Valley. 'n Styging in seevlak kon die moedermateriaal by Papegaaiberg beïnvloed het.

Om meer inligting omtrent die oorsprong en moontlike vermening van moedermateriaal voor grondvorming te verkry, is die verskillende grondmonsters chemies ontleed. Kalium is 'n uiters belangrike voedingselement wat lootgroei en wynkwaliteit kan beïnvloed. Aangesien die gronde in hierdie studie in bestaande produksieblokke voorkom, was daar 'n goeie kans dat bemestingstowwe die chemiese samestelling kon beïnvloed. Die C horisonte van die verskillende gronde was beskou as dié wat die minste deur bemesting beïnvloed sou word en die naaste aanduiding van natuurlike grondchemiese samestelling. Die C horison K-inhoude van die gronde in die studie het egter nie gekorreleer met enige eienskap wat die moedermateriaal van die gronde met die lokale gesteentetipe kon verbind nie. By Durbanville, het beide gronde klein hoeveelhede K in die C horisonte bevat, wat die onderliggende fillietiese skalies reflekteer, maar by Devon Valley en Papegaaiberg, het die C horisonte meer K bevat as wat verwag is. Die gronde by hierdie lokaliteite word onderlê deur hornfels, wat lae hoeveelhede K bevat. Die groot hoeveelhede K in hierdie gronde dui moontlik op 'n kontaksone tussen graniet en Malmesbury gesteentes in die area. Gronde vanaf Kuilsrivier, Simonsberg en Helshoogte word onderlê deur K-ryke porfiritiese graniete wat groot hoeveelhede K in die ondergronde sou bevat. Dit was egter nie die geval nie en dit was aanvaar dat verdunning van K-arme materiaal plaasgevind het. Die oorsprong van K-arme materiaal was waarskynlik vanaf hoër-liggende sandstene, of vanaf eoliese prosesse gedurende die Cenozoikum. Alternatiewelik is K inhoude van die gronde verlaag deur lang en aanhoudende loging.

'n Semi-kwantitatiewe analise van minerale in die kleifraksie was uitgevoer om te bepaal watter minerale in die kleifraksie van die verskillende gronde teenwoordig is en om die minerale met stadia van verwering te vergelyk. Dan kon die mineralogiese samestelling in verband met moedermateriaal gebring word. Resultate het aangetoon dat al die gronde in die studie in 'n gevorderde stadium van verwering is en gedomineer word deur kaoliniet, en in sekere gronde, klei fraksie kwarts. Aangesien die primêre minerale in 'n groot mate afgebreek is, was dit moeilik om die minerale in die kleifraksie direk in verband met moedermateriaal te bring. Die voorkoms van kwarts en gibbsiet in die kleifraksie in beide gronde van Simonsberg, Helshoogte en Durbanville asook een grondvorm vanaf beide Kuilsrivier en Simonsberg, het aangetoon dat verskillende stadia van verwering gedurende grondvorming in hierdie gronde voorgekom het. Dit kan die gevolg wees van vermenging van

verskillende moedermateriaal, maar kan ook verskillende periodes van verwering van dieselfde materiaal aandui. Beide gronde by Papegaaiberg, beide gronde van Devon Valley die ander gronde by Simonsberg en Kuilsrivier het slegs een fase van verwering tydens grondvorming aangedui, hoofsaaklik as gevolg van die afwesigheid van gibbsiet wanneer kwarts voorkom.

Grondeienskappe, soos bepaal in hierdie studie, was ook vergelyk met lootgroei, wynkwaliteit en wynkarakter, soos verkry uit die resultate van die multi-dissiplinêre projek. Vir die meeste gronde in die studie was 'n toename in kleifraksie kaoliniet geassosieer met afname in vegetatiewe groei, algemene wynkwaliteit, asook vars vegetatiewe wynkarakter. 'n Toename in kleifraksie kwarts was geassosieer met hoër algehele wynkwaliteit. 'n Toeneme in vegetatiewe groei het ook die vars vegetatiewe karakter van die wyn positief beïnvloed. Beter vegetatiewe groei het op hoër hoogtes voorgekom en dit het gelei tot hoër wynkwaliteit vir Sauvignon blanc. Wyne afkomstig van wingerde op beide fillietiese skalies en porfiritiese graniete, was van hoër kwaliteit (Durbanville and Helshoogte), maar beide was geassosieer met lae kleifraksie kaoliniet en hoë ligging. Dit was nie moontlik om moedermateriaal direk met vegetatiewe groei, wynkwaliteit en/of wynkarakter te vergelyk nie. Wyne met die laagste kwaliteit kom egter voor op hornfels (Papegaaiberg and Devon Valley), wat beide groot hoeveelhede kleifraksie kaoliniet bevat en geleë is op lae hoogtes. Hoë vlakke van K in gronde wat groot hoeveelhede kleifraksie kaoliniet bevat kan gedeeltelik verantwoordelik wees vir lae kwaliteit wyne op sulke gronde.

*"Net so kenmerkend van die mens as sy begeerte en wil om mee te deel is sy begeerte om verstaan te word. Elkeen wat meedeel wil ook hê dat iemand anders sal verstaan wat hy te sê het. En wat meer is, sommige mense sal alles in hul vermoë doen om nie net te verseker dat die ontvangers van hul boodskappe daarvan bewus is wat hulle wil hê en hoe hulle verstaan moet word nie, maar sal ook probeer om die ontvanger te oorreed en te dwing om net soos hy te dink en te doen. Die mededeling is inderdaad net die begin van 'n groter handeling omdat elke mededeling eers voltooi is wanneer dit ontvang en verstaan word. Die begeerte om mee te deel word in ewewig gehou deur die gewilligheid om te ontvang, te verstaan en oorreed te word. Die ontvanger van boodskappe is net so aktief as die mededeler van kennis en daarom is hy nie slegs 'n ontvanger nie, maar 'n vertolker van kennis. As vertolker gee die ontvanger ook sin aan kommunikasie. En dit is in hierdie tussenmenslike verkeer van mededeling en vertolking van boodskappe wat so kenmerkend van kommunikasie is dat die vraag na die sin van kommunikasie te berde kom."*

**Prof. Marthinus van Schoor**

## ACKNOWLEDGEMENTS

I would like to express my sincere thanks to the following:

Mr J.J.N. Lambrechts Mr D. Saayman for their assistance, guidance, patience and support with this study and with the preparation of the thesis.

Dr W.J. Conradie and Mr J. Wooldridge for their assistance and constructive criticism.

The Agricultural Research Council (ARC) for making this study possible and for permission to use the results for thesis purposes.

The staff of the Soil Science Section of the ARC-Fruit, Vine and Wine Research Institute for technical assistance and in particular Isabella van Huyssteen, Jaqueta Keet and Karen Herbst.

The wine industry for financial assistance.

My mother for her support over the years.

My heavenly Father for His grace, power and strength, without which this thesis would not have been possible.

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# CHAPTER 1

# LITERATURE REVIEW

## 1.1 INTRODUCTION

The possibility that links may exist between parent rock, soil, climate and viticulture has been the subject of several investigations, notably those by Seguin (1970), Rankine *et al.* (1971), Noble (1979) and Morlat (1989), Wilson (1998), Leneuf (in Wilson, 1998) and Lautel (in Wilson, 1998). These researchers sought to scientifically demarcate wine producing localities on the basis of specific environmental characteristics, in accordance with the concept of terroir. Amongst these characteristics must be included such geological parameters as parent rock type and clay-mineralogy, as well as the soil forming (pedogenetic) processes which variously lead to the formation of soils having specific, definable characteristics. The literature concerning terroir will be discussed in this chapter, and that concerning geology in Chapter 2.

## 1.2 SCIENTIFIC DEMARCATION OF LOCALITIES: THE TERROIR CONCEPT

The French concept of "terroir" embraces the sum total of the natural factors which prevail at a given site and which are capable of influencing the characteristics of agricultural products grown on that site. Central to this concept is the sentiment that sites, which differ in some aspect of terroir, are also likely to differ in terms of the characteristics of the wines produced from those of other terroirs (Bohmrich, 1996). Bohmrich noted that, since Roman times, it has been the practice to subdivide wine-growing regions into topographical areas which produce wines that differ conspicuously in character. Research aimed at placing such demarcation on a scientific basis commenced in the 1970's, and was mainly conducted in Europe (Stevenson, 1993). Stevenson (1993) stated that the proverbial question of whether the answer really lies in the soil and/or climate, and if so, what exactly is the relationship between soil and vine, is still to be answered (Stevenson, 1993). Central to current interpretations of terroir is the undisputed fact that soil properties, amongst other factors, vary widely across most winegrowing areas (Bohmrich, 1996). However, as pointed out by Bohmrich (1996), the extent to which soil type influences wine quality is controversial, notably amongst New World viticulturists. Saayman (1992) stated that the effect of soil type is without question the least understood natural factor with regard to wine quality, and noted that pioneering research in France disclosed that high quality wines owe their superiority to the ability of the soil to regulate the supply of water to the vines (Seguin 1983; Saayman, 1992). Other schools of thought place emphasis on geology as a contributor to wine quality and character. To this effect, Sittler & Marocke (1981) found that

Riesling, planted on soils that developed from granite, produced a fruity, subtle wine character, but that these wines had to be consumed soon after bottling. In comparison, Riesling from calcareous areas was more "energetic" and retained good quality for a longer period. Scienza *et al.* (1979) found that glacial deposits and porhyritic soils contributed to the synthesis of polyphenolic compounds in red wines grown in the Schiava area in Italy, and Champagnol (1997) described how the geo-pedological nature of the terroirs influenced the overall equilibrium in wine with regard to the phenolic and aromatic components. Champagnol (1997) stated that, in France, wines that originate from sandstone soils have a lower tannic character and lower aromatic richness than wines that originate from granite soils (Figure 1.1). On the other hand, Seguin (1983) compared wines from soils of different geological origin from the Medoc, France, and found no discernible difference in wine quality. Seguin (1983) also found that red wines from Saint-Emilon and Pomerol, which had been grown on soils derived from various types of parent material (Quaternary alluvial deposits, limestones, sandstones and clays) were of equally high quality. Seguin (1983) concluded that it is not possible to distinguish between high quality wines solely on a specific geological formation, although he conceded that aromatic- and taste properties, as well as colour, may vary depending on the type of parent rock. Wilson (1998) maintains that the character of French wines varies with geology, however, this standpoint was criticised by Hancock (1999), who believes that other factors, such as micro-climate, form an integral part of the terroir concept and cannot be ignored. In particular, Hancock (1999) is critical of the view expressed by Wilson (1998) that the variation in underlying geology is the main factor controlling wine character. Hancock (1999) believes that the temperature at different levels or some subtle combination of temperature and geology is more important.

Whatever the school of belief, there is no doubt that geology has at least an indirect effect on wine style and quality, principally because it contributes to the physical (e.g. water holding capacity) and chemical properties (e.g. potassium supplying power and potassium buffer capacity (Wooldridge, 1988) of the derived soils. However, it appears unlikely that European generalisations concerning wine and the various facets of terroir, including geology, will be directly applicable to South African situations (Saayman, 1992).

Although a discussion of links between climate and wine characteristics lies outside the scope of this thesis, it is nevertheless accepted that climate is an extremely important component of terroir and contributes substantially, and perhaps disproportionately, to those factors, such as parent material, soil and topography, which collectively affect wine quality and which are potentially capable of being defined in scientific terms.

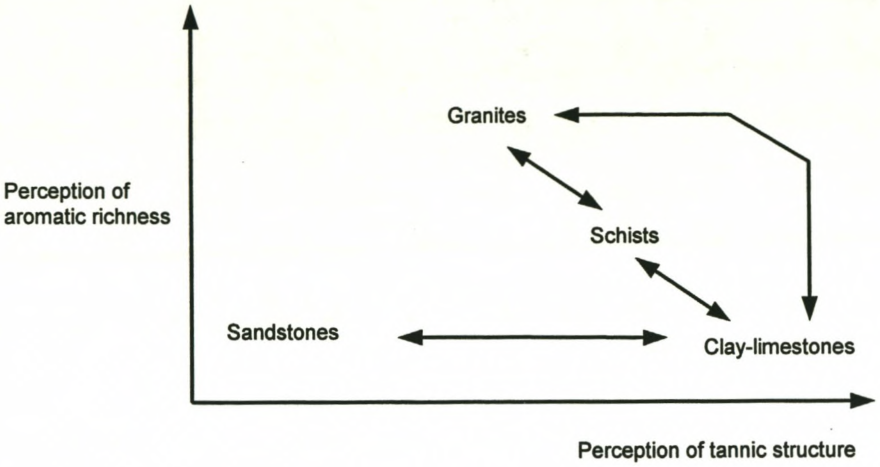


**Figure 1.1** Simplified representation of expression of wine character according to comparison of selected pairs of terroirs (after Champagnol, 1997).

## 1.3 PARENT MATERIAL, WEATHERING AND CLAY FRACTION MINERALOGY

Many textbooks describe the principles of the soil physical and chemical processes that play a role in the weathering of primary minerals contained in different geological parent materials. In "A treatise on rocks, rock-weathering and soils", Merrill (1897) systematically brought together many observations concerning rock weathering and soil formation. In this treatise, as a description of the overall process of weathering, breakdown, transport and deposition, Merrill (1897) included the following (unreferenced) quote from Hutton:

"*The ruins of an older world are visible in the present structure of our planet; and the strata which now compose our continents have been once beneath the sea, and were formed out of the waste of pre-existing continents. The same forces are still destroying, by chemical decomposition or mechanical violence, even the hardest rocks, and transport(ing) the materials to the sea, where they are spread out, and form strata analogous to those of more ancient date*".

Many years after the time of Merrill, Hans Jenny (Jenny, 1941) formulated his factor-function paradigm, according to which soils on geologically different but geographically adjacent rock materials may be compared in pedological terms provided that the soils on each parent material have developed under similar conditions of climate, flora and topography, and that no age differences apply.

Brady (1984) stated that, together with climate, the nature and properties of parent materials are the most significant factors that affect the kind, and quality, of the world's soils. Knowledge of different parent materials, and of the mechanisms of weathering and transport, are essential if an understanding of soils is to be gained. Brady also observed that weathering is a combination of destruction and synthesis. Rocks, which are the original starting point in the weathering process, are first broken down physically into smaller rock fragments and eventually into the individual minerals of which they are composed. Simultaneously, chemical forces attack the exposed rock fragments and minerals. These forces chemically and progressively transform the minerals into new forms, either by minor modifications (alterations) or by radical changes in chemical composition and crystal form. These two basic processes, mechanical (disintegration) and chemical (decomposition) are illustrated in Figure 1.2 (Brady, 1984). Disintegration results in a decrease in the physical size of rock and mineral particles but does not appreciably affect their chemical composition. During decomposition, however, definite chemical changes take place. Soluble materials are released, and new minerals are synthesized. The end products of these processes are usually stable under the prevailing conditions. Mechanical breakdown processes include, amongst others, the fragmenting effects of temperature variation, whilst chemical decomposition may entail hydrolysis, hydration, oxi-

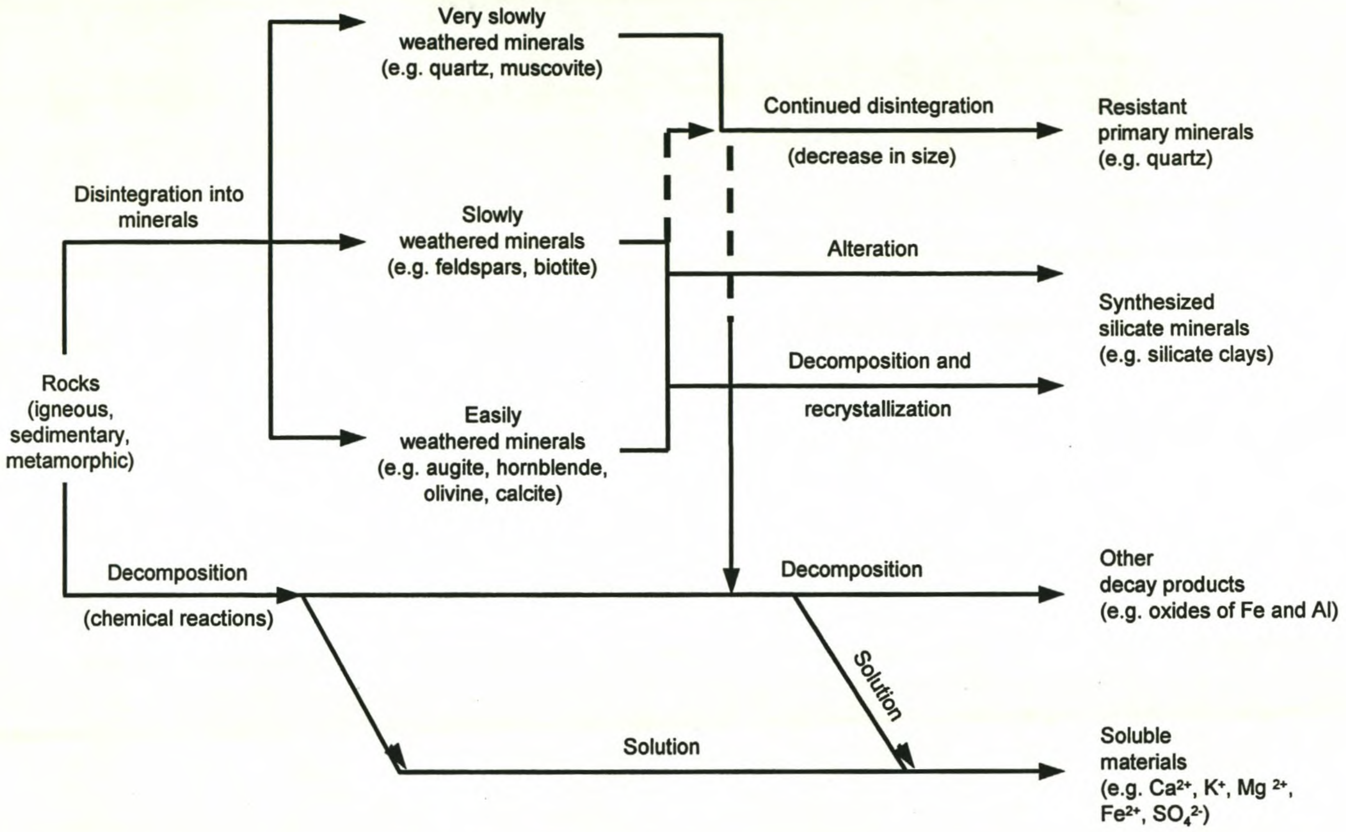


**Figure 1.2** Pathways of weathering that occur under moderately acid conditions common in humid temperate regions. Major weathering pathways are indicated by the solid lines, minor pathways by the broken lines. As one would expect, climate modifies the exact relationships. In arid regions physical breakdown (disintegration) would dominate, and soluble ions would not be lost in large quantities. In humid regions decomposition becomes more important, especially under tropical conditions (after Brady, 1984).

dation or solution. Two groups of new minerals may be formed, as indicated in Figure 1.2. The silicate clay minerals are formed by decomposition and recrystalisation, whilst the sesquioxides, which include iron and aluminium oxides/hydroxides, are decomposition products. Quartz, in contrast, persists because of its resistance to chemical weathering. Silicate clays, sesquioxides and quartz predominate in soils formed under temperate climatic conditions.

A representation of the Goldich weathering sequence for primary minerals is presented in Figure 1.3. This sequence (as described by White, 1987) demonstrates that the resistance of a mineral to weathering increases with the degree of sharing of oxygen atoms between adjacent $SiO_4$ tetrahedra in the crystal lattice. The Si-O bond has the highest energy of formation, followed by the Al-O bond, and the weaker bonds formed between O and the basic metal cations. Quartz consists entirely of linked $SiO^4$ tetrahedra. These forms of multiple linkage forms a rigid framework and confers high resistance to weathering. In the chain silicates (amphiboles and pyroxenes) and plate silicates (phyllosilicates), the weakest points are the O-metal cation bonds. The tetrahedra in olivine are only held together by O-metal cation bonds. As a result olivine weathers rapidly. Instability is also created by isomorphic substitution of Al for Si, where the proportion of Al-O to Si-O increases and increased numbers of O-metal cation bonds become necessary. Weathering continues in finely comminuted materials (< 2 mm diameter) in both soils and in unconsolidated sedimentary deposits. Weathering follows a sequence, from the least to the most stable minerals. This sequence, as described by Brady (1984), is presented in Table 1.1. A variant of this sequence, which includes certain characteristics of the associated soils and which was published by White (1987) is set out in Table 1.2.

Soils may form by *in situ* weathering of primary minerals in consolidated rock (residual soils), or they may develop in deposits of fragmentary material which may have been transported to their current location by water, wind, gravity or, at times, ice. Most of the earth's surface has undergone several cycles of submergence, uplift, erosion and denudation over hundreds of million years of geological time. During the transport and deposition phases, there is opportunity for mixing of materials from different rock formations. The interpretation of soil genesis in such heterogeneous soil parent materials is often complex (White, 1987).

Although studies concerning the effects of parent rock and of clay-fraction mineralogy on specific crops are rarely reported in the literature, the chemical- and physical properties of soils that originate from the weathering of a specific primary rock are nevertheless likely to play a major role in plant growth and performance, as was observed for Italian rye grass grown on Table Mountain sandstone-, Bokkeveld shale- and granite-derived soils by Wooldridge (1988). Soil texture is determined on the basis of the relative proportions of the

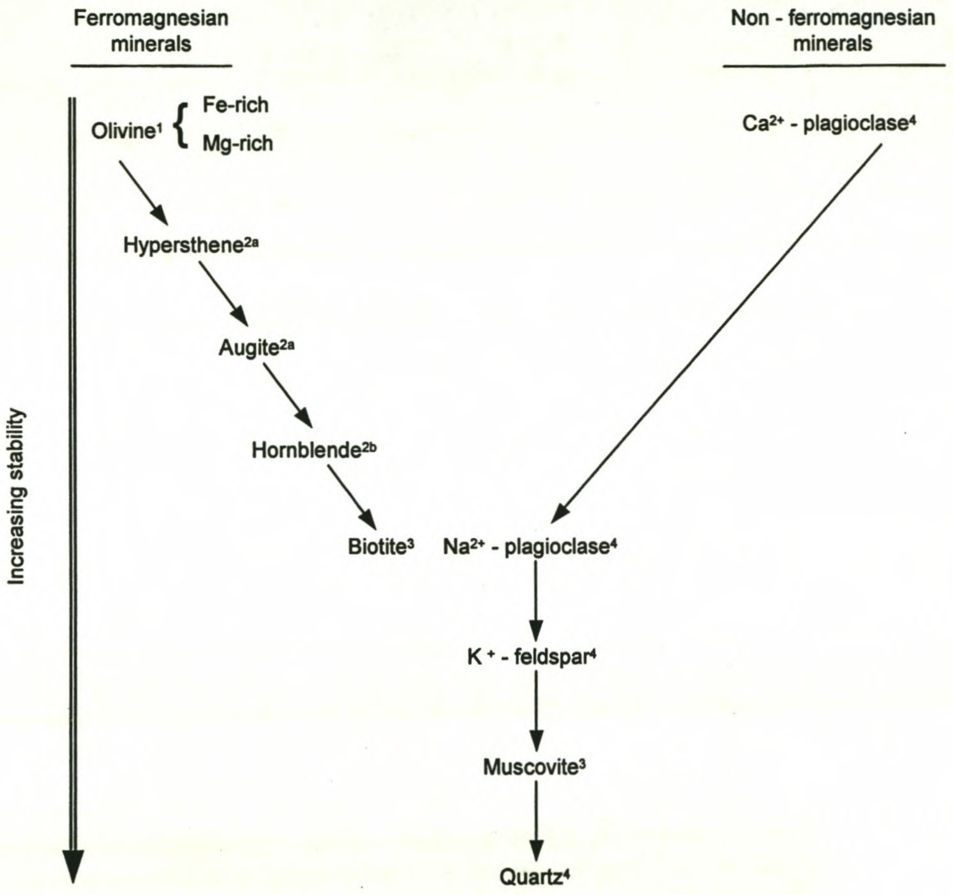


**Figure 1.3** Ranking of the common silicate minerals in order of increasing stability. The superscripts indicate the number of oxygens shared between adjacent $SiO_4^{4-}$ tetrahedra: 1 = none: 2a = two (single chain): 2b = 2 and 3 (double chain): 3 = three (sheet structure): 4 = four (three-dimensional structure) (after Goldich, 1938 in White, 1987).

**Table 1.1** The more important primary and secondary minerals found in soils listed in order of decreasing resistance to weathering under conditions common in humid temperate regions (after Brady, 1984).

*Primary minerals are found abundantly in igneous and metamorphic rocks. Secondary minerals are commonly found in sedimentary rocks.*

| **Primary Minerals** | | **Secondary Minerals** | | **Resistance to weathering** |
|---|---|---|---|---|
| | | Goethite | FeOOH | Most resistant |
| | | Hematite | $Fe_2O_3$ | ↕ |
| | | Gibbsite | $Al_2O_3.\ 3H_2O$ | |
| Quartz | $SiO_2$ | Clay minerals | Al silicates | |
| Muscovite | $KAl_3Si_3O_{10}(OH)_2$ | | | |
| Orthoclase | $KAlSi_3O_8$ | | | |
| Biotite | $Kal(Mg,Fe)_3Si_3O_{10}(OH)_2$ | | | |
| Albite | $NaAlSi_3O_8$ | | | |
| Hornblende[a] | $Ca_2Al_2Mg_2Fe_3Si_6O_{22}(OH)_2$ | | | |
| Augite[a] | $Ca_2(Al,Fe)_4(Mg,Fe)_4Si_6O_{24}$ | | | |
| Anorthite | $CaAl_2Si_2O_8$ | | | |
| Olivine | $(Mg,Fe)_2SiO_4$ | | | |
| | | Dolomite | $CaMg(CO_3)_2$ | |
| | | Calcite | $CaCO_3$ | |
| | | Gypsum | $CaSO_4.\ 2H_2O)$ | Least resistant |

[a] The given formula is only approximate since the mineral is highly variable in composition.

**Table 1.2** Stages in the weathering of minerals in the < 2 mm fraction of soils.

| Stage | Type mineral | Soil characteristics |
|---|---|---|
| Early weathering stages | | |
| 1 | Gypsum | These minerals occur in the silt and clay fractions of young soils all over the world, and in soils of arid regions where lack of water inhibits chemical weathering and leaching. |
| 2 | Calcite | |
| 3 | Hornblende | |
| 4 | Biotite | |
| 5 | Albite | |
| Intermediate weathering stages | | |
| 6 | Quartz | Soils found mainly in the temperate regions of the world, frequently on parent materials of glacial or periglacial origin; generally fertile, with grass or forest as the natural vegetation. |
| 7 | Muscovite (also illite) | |
| 8 | Vermiculite and mixed layer minerals | |
| 9 | Montmorillonite | |
| Advanced weathering stages | | |
| 10 | Kaolinite | The clay fractions of many highly weathered soils on old land surfaces of humid and hot intertropical regions are dominated by these minerals; often of low fertility. |
| 11 | Gibbsite | |
| 12 | Hematite (also goethite) | |
| 13 | Anatase | |

(After Jackson *et al.*, 1948 in White, 1987) soil particles that fall into designated size classes. Soil texture changes only slowly with time and is an important determinant of the soil's ability to store water and retain nutrients. Generally the amount of readily available water (RAW) increases with a decrease in particle size to a clay-loam texture when it starts to decrease slightly, although very fine sand fractions may in some cases retain more plant available water than do finer fractions (Winter, 1974; Hall *et al.*, 1977). The absorption of water and solutes by the finer fractions (silt and clay) depends not only on their large specific surface area, but also on the nature of the minerals present in the clay fraction (Marshall & Holmes, 1979; White, 1987), as well as on bulk density, although bulk density may be changed by tillage (Hall *et al.*, 1977), resulting in a decrease in RAW.

The clay minerals (aluminosilicates) are important sites for physical and chemical reactions in soil because of the high specific surface areas and electrical charges associated with these fine soil constituents. The cation exchange capacities (CEC) of certain types of clay minerals are listed in Table 1.3. The CEC stems from isomorphous substitution and the higher the CEC value, the more basic cations, many of which are mineral nutrient elements, can be absorbed. Kaolinite, which has very little isomorphous substitution, usually takes the form of large crystals. In consequence the specific surface area of kaolinite is far lower than that of montmorillonite, a smectitic mineral. On the other hand, the large kaolinite crystals have a relatively large edge area at which negative charges can develop and augment the total negative charge density of the clay. These unique characteristics of minerals in the clay fraction can be identified semi-quantitively by X-ray diffraction (XRD) (Brown, 1961; Carroll, 1970; Bridley & Brown, 1984; Dixon & Weed, 1989; Juang, 1989). Morlat (1989) identified different clay minerals by XRD in different soils where wine grapes were grown, but was not able to directly relate these minerals to wine quality or character.

From this literature review it is apparent that there is a considerable need for detailed studies to be carried out concerning the potential role of geology and clay mineralogy as parameters for the scientific demarcation of soils that are capable of producing wines of different quality and character under South African conditions. The Agricultural Research Council's Nietvoorbij Centre for Vine and Wine (NCVW) initiated a multidisciplinary research project into the effects of soil and climate on wine quality 1993 in Stellenbosch. The present study, which will focus specifically on descriptions of the geology and clay-fraction mineralogy at specific sites, will form a part of this project. A limited amount of wine quality and growth data from the broader project will be used in this study. The approach followed in this study will be to identify soil types that, though in close physical proximity, nevertheless differ significantly in terms of vine growth and wine quality. The objective will be to determine whether soil parent material plays a distinctive role in vine growth and wine character.

**Table 1.3** Cation exchange capacities of clay mineral groups (after White,1987).

| Clay mineral group | *CEC* (cmol$_c$ kg$^{-1}$) |
|---|---|
| Kaolinites | 3 - 20 |
| Illites | 10 - 40 |
| Smectites | 80 - 120 |
| Vermiculites | 100 - 150 |

## 1.4 REFERENCES

BOHMRICH, R., 1996. Terroir: Competing perspectives on the roles of soil, climate and people. *J. Wine Research*. **7**, 33-46.

BRADY, N.C., 1984. The nature and properties of soils. Ninth Edition. MacMillan Publishing Co., New York.

BRIDLEY, S.W. & BROWN, G., 1984. Crystal structures of clay minerals and their X-ray identification. Miner. Soc., London.

BROWN, G., 1961. The X-ray identification and crystal structures of clay minerals. Min. Soc., London.

CARROLL, D., 1970. Clay minerals: A guide to their x-ray identification. *Geol. Soc. Am., Spec. Paper* **126,** 1-80.

CHAMPAGNOL, F., 1997. Caractiristiques edaphiques et potentialités qualitatives des terroirs du vignoble languedocien. *Progrés agricole et viticole* **114,** 157-166.

DIXON, J.B. & WEED, S.B., 1989. Minerals in soil environments. Second edition. SSSA, Madison, Wisconsin, USA.

HALL, D.G.M.; REEVE, M.J.; THOMASSON, A.J. & WRIGHT, V.F., 1977. Water retention porosity and density of field soils. *Brit. Soil Survey Tech. Mongr*. **9**, 51-73.

HANCOCK, J, 1999. Feature review: Terroir: The role of geology, climate and culture in the making of French wines (Wilson, E.J., 1998). *J. Wine Research* **10,** 43-49.

JENNY, H., 1941. Factors of soil formation. McGraw-Hill, New York.

JUANG, T.C., 1989. Clay mineralogical characteristics of some latosols of Taiwan. *Proc. Natl. Sci. Counc. B. ROC*. **13**, 160-170.

MARSHALL T.J. AND HOLMES, J.W., 1979. Soil physics. Cambridge University Press, Cambridge.

MERRILL, G.P., 1897. A treatise on rocks, rock weathering and soils. The Macmillan Company, New York.

MORLAT, R., 1989. Le terroir vitcole: contribution a l'etude de sa caracterisation et de son influence sur les vins. Applications aux vignobles rouges de la moyenne vallee de la Loire. These Doct. Atat, Bordeaux II.

NOBLE, A.C., 1979. Evaluation of Chardonnay wines obtained from sites with different soil compositions. *Am. J. vitic. Eon.* **30**, 214-217.

RANKINE, B.C., FORNACHON, J.C.M, BOEHM, E.N. & CELLIER, K.M., 1971. Influence of grape variety, climate and soil on grape composition and on the composition and quality of table wines. *Vitis* **10**, 33-50.

SAAYMAN, D., 1992. Natural influences and wine quality: Part 2: The role of soil. *Wynboer.* August, 49-51.

SCIENZA, A., FREGONI, M. & BOSELLI, M., 1979. Rapporti tra origine geologica del terreno e composizione polifenolica del vino di "Schiava" in Alto Adige. Symp. Int. de la vinification en rouge. Siklos, Hongrie, 22-23 Novembre 1979.

SEGUIN, G., 1970. Les sols gravelo-sableux du vignoble Bordelais: Proprietes physiques et chimiques; alimentation en eau de la vigne et consequences sur la qualite des vendanges. Rel. Sol/Vigne, Colloque Franco-Roumain. Bordeaux.

SEGUIN, G., 1983. Influence des terroirs viticoles sur la constitution et la qualite des vendanges. *Bull. O.I.V.* **56-623**, 3-18.

SITTLER, C. & MAROKE, R., 1981. Terroirs et vins d'Alsace. Sciences geologiques. Ed. Inst. Geol. Universite Louis Pasteur. Strasbourg.

STEVENSON, T., 1993. The wines of Alsace. London: Faber and Faber Ltd.

WHITE, R.E., 1987. Introduction to the principles and practise of soil science. Second edition. Blackwell Scientific Publications, Oxford.

WILSON, J.E., 1998. Terroir. The role of geology, climate and culture in the making of French wines. University of California Press, Berkeley and Los Angeles, California, U.S.A.

WINTER, E.J., 1974. Water, soil and the plant. Macmillan Press Ltd., London.

WOOLDRIDGE, J., 1988. The potassium supplying power of certain virgin upland soils of the Western Cape. M.Sc. thesis, University of Stellenbosch, Stellenbosch, South Africa.

# CHAPTER 2

# GEOLOGY OF THE STUDY AREA

## 2.1 INTRODUCTION

This chapter describes the geological history and main geological formations in the study area with regard to the role that parent material might have played in soil development. The geology of the localities where this study was conducted is presented in map form in Figure 2.1a - c. The underlying geology of the individual localities used in this study will be discussed in Chapter 3.

Theron *et al.* (1992) conducted a detailed study of the geology of the Cape Town area and presented his findings as an explanation to Geological Sheet 3318 (scale 1:250 000). In the present description of the geology of the Coastal Region, this detailed study will be used as primary reference source. Where no other references are mentioned, the reader must assume that the information is from Theron *et al.* (1992).

## 2.2 GEOLOGICAL HISTORY OF THE MALMESBURY GROUP AND CAPE GRANITES, AND SUBSEQUENT GEOLOGICAL EVENTS

### 2.2.1 General

Approximately 50 000 hectares of wine grapes are grown in the coastal region, between Moorreesburg in the north and Constantia in the south (Theron, 1998). Much of this area is underlain by sedimentary formations of the Malmesbury Group. These rocks were mobilised from a pre-existing landmass to the east and deposited in a marine basin during the late Precambrian Era, some 550 - 1 000 million years ago (a geological time-scale representing the rocks in the study area is presented in Table 2.1). Deep burial caused the sediments to become compacted, hard and indurated, forming dark, fine-grained rocks. Tectonic movements during the Pan African event which culminated 550 ± 100 million years ago caused the basin and its sediments to be uplifted into a mountain chain in which the deeper strata were folded into a series of northwest-trending anticlines and synclines with half-wave-lengths in the Tygerberg area of between 0,5 and 1,5 km. This folding was accompanied by the intrusion of the Cape Granite Suite between about 610 and 505 million years ago (Truswell, 1977). Intense heating at the base of the mountain chain, probably associated with the descending limb of a consuming plate margin (Truswell, 1977), caused the lighter components to melt and rise into the overlying Malmesbury sediments in the form of granite plutons. The pre-existing country rock was either forced aside or assimilated by the hot intruding granites. Initially fine-grained rocks gradually developed new, coarser metamorphic minerals such as large clots of bluish grey cordierite and flakes of biotite.

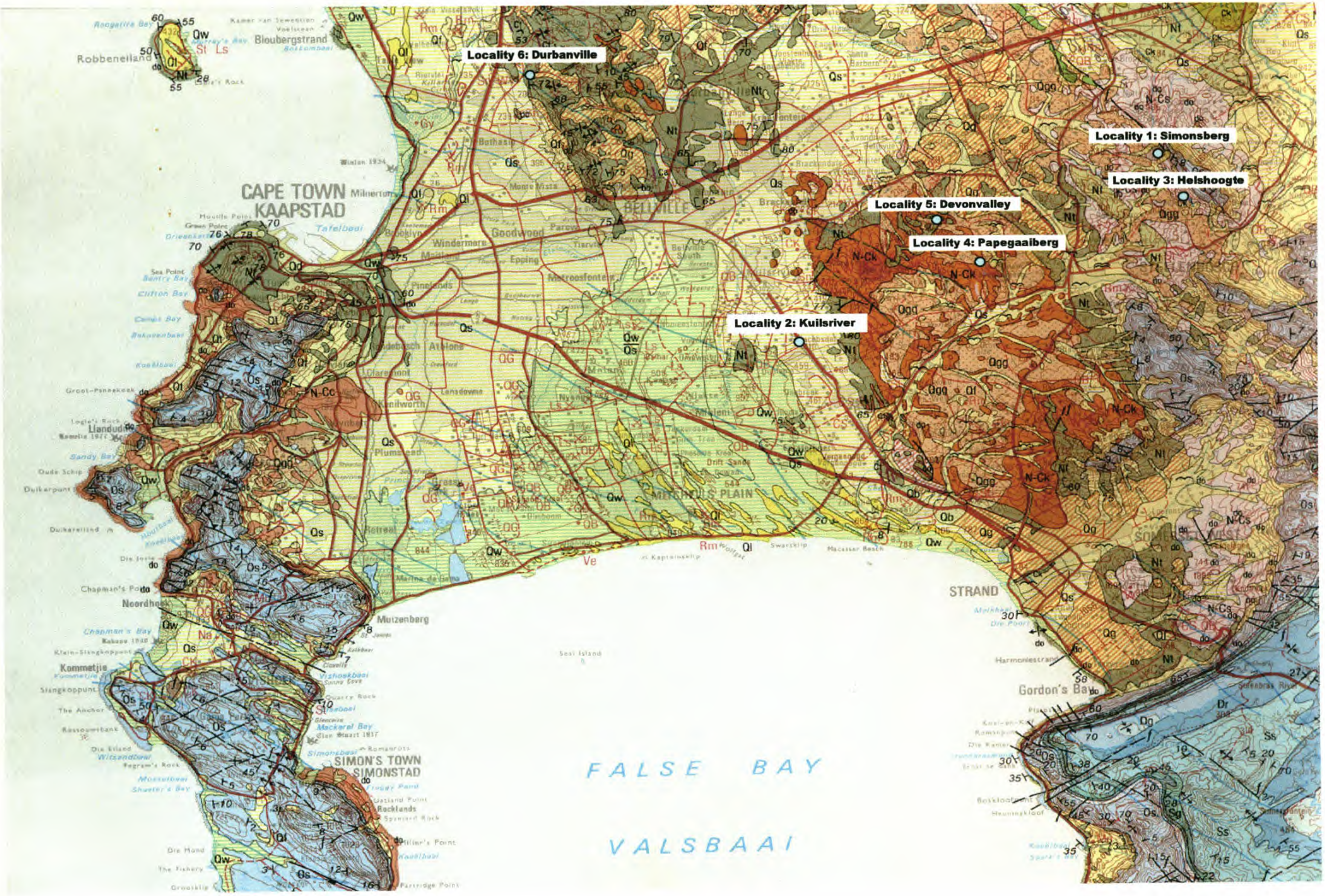


Figure 2.1(a) Geological map of the study area.

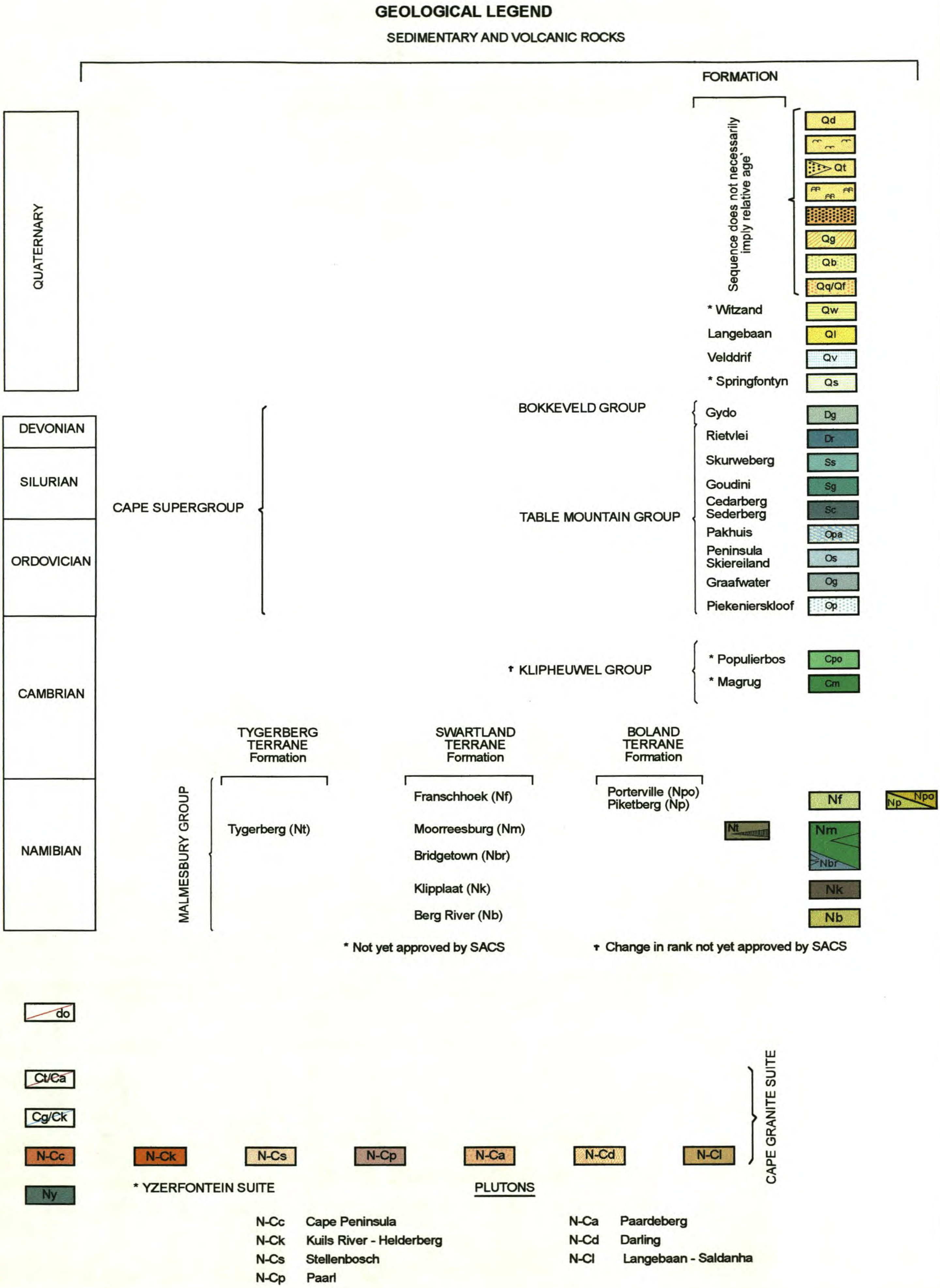
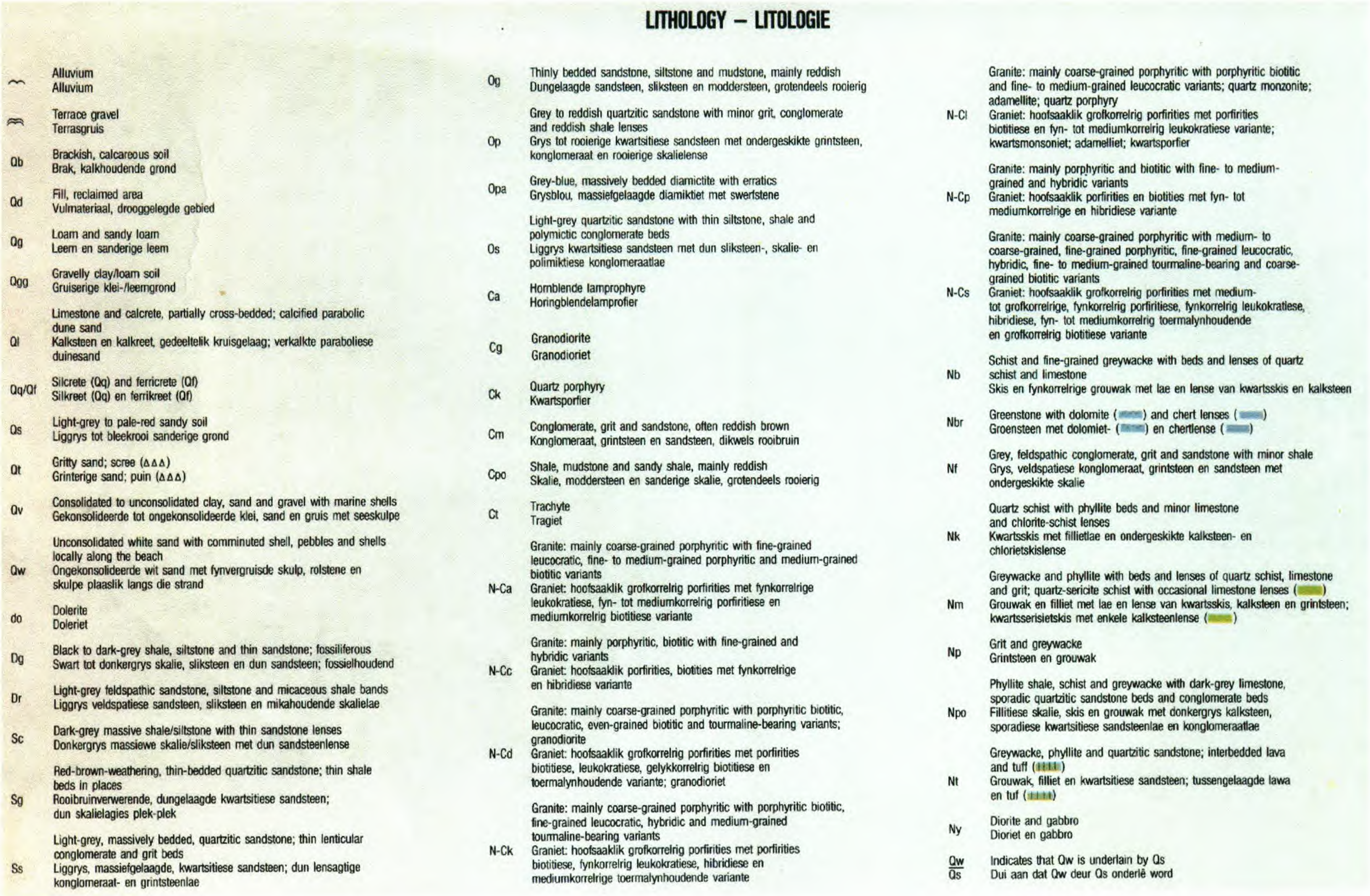


**Figure 2.1(b)** Legend of geological map of the study area.



# LITHOLOGY – LITOLOGIE

| | |
|---|---|
| ⌒ | Alluvium<br>Alluvium |
| ≈ | Terrace gravel<br>Terrasgruis |
| Qb | Brackish, calcareous soil<br>Brak, kalkhoudende grond |
| Qd | Fill, reclaimed area<br>Vulmateriaal, drooggelegde gebied |
| Qg | Loam and sandy loam<br>Leem en sanderige leem |
| Qgg | Gravelly clay/loam soil<br>Gruiserige klei-/leemgrond |
| Ql | Limestone and calcrete, partially cross-bedded; calcified parabolic dune sand<br>Kalksteen en kalkreet, gedeeltelik kruisgelaag; verkalkte paraboliese duinesand |
| Qq/Qf | Silcrete (Qq) and ferricrete (Qf)<br>Silkreet (Qq) en ferrikreet (Qf) |
| Qs | Light-grey to pale-red sandy soil<br>Liggrys tot bleekrooi sanderige grond |
| Qt | Gritty sand; scree (ΔΔΔ)<br>Grinterige sand; puin (ΔΔΔ) |
| Qv | Consolidated to unconsolidated clay, sand and gravel with marine shells<br>Gekonsolideerde tot ongekonsolideerde klei, sand en gruis met seeskulpe |
| Qw | Unconsolidated white sand with comminuted shell, pebbles and shells locally along the beach<br>Ongekonsolideerde wit sand met fynvergruisde skulp, rolstene en skulpe plaaslik langs die strand |
| do | Dolerite<br>Doleriet |
| Dg | Black to dark-grey shale, siltstone and thin sandstone; fossiliferous<br>Swart tot donkergrys skalie, sliksteen en dun sandsteen; fossielhoudend |
| Dr | Light-grey feldspathic sandstone, siltstone and micaceous shale bands<br>Liggrys veldspatiese sandsteen, sliksteen en mikahoudende skalielae |
| Sc | Dark-grey massive shale/siltstone with thin sandstone lenses<br>Donkergrys massiewe skalie/sliksteen met dun sandsteenlense |
| Sg | Red-brown-weathering, thin-bedded quartzitic sandstone; thin shale beds in places<br>Rooibruinverwerende, dungelaagde kwartsitiese sandsteen; dun skalielagies plek-plek |
| Ss | Light-grey, massively bedded, quartzitic sandstone; thin lenticular conglomerate and grit beds<br>Liggrys, massiefgelaagde, kwartsitiese sandsteen; dun lensagtige konglomeraat- en grintsteenlae |
| Og | Thinly bedded sandstone, siltstone and mudstone, mainly reddish<br>Dungelaagde sandsteen, sliksteen en moddersteen, grotendeels rooierig |
| Op | Grey to reddish quartzitic sandstone with minor grit, conglomerate and reddish shale lenses<br>Grys tot rooierige kwartsitiese sandsteen met ondergeskikte grintsteen, konglomeraat en rooierige skalielense |
| Opa | Grey-blue, massively bedded diamictite with erratics<br>Grysblou, massiefgelaagde diamiktiet met swerfstene |
| Os | Light-grey quartzitic sandstone with thin siltstone, shale and polymictic conglomerate beds<br>Liggrys kwartsitiese sandsteen met dun sliksteen-, skalie- en polimiktiese konglomeraatlae |
| Ca | Hornblende lamprophyre<br>Horingblendelamprofier |
| Cg | Granodiorite<br>Granodioriet |
| Ck | Quartz porphyry<br>Kwartsporfier |
| Cm | Conglomerate, grit and sandstone, often reddish brown<br>Konglomeraat, grintsteen en sandsteen, dikwels rooibruin |
| Cpo | Shale, mudstone and sandy shale, mainly reddish<br>Skalie, moddersteen en sanderige skalie, grotendeels rooierig |
| Ct | Trachyte<br>Tragiet |
| N-Ca | Granite: mainly coarse-grained porphyritic with fine-grained leucocratic, fine- to medium-grained porphyritic and medium-grained biotitic variants<br>Graniet: hoofsaaklik grofkorrelrig porfirities met fynkorrelrige leukokratiese, fyn- tot mediumkorrelrig porfiritiese en mediumkorrelrig biotitiese variante |
| N-Cc | Granite: mainly porphyritic, biotitic with fine-grained and hybridic variants<br>Graniet: hoofsaaklik porfirities, biotities met fynkorrelrige en hibridiese variante |
| N-Cd | Granite: mainly coarse-grained porphyritic with porphyritic biotitic, leucocratic, even-grained biotitic and tourmaline-bearing variants; granodiorite<br>Graniet: hoofsaaklik grofkorrelrig porfirities met porfirities biotitiese, leukokratiese, gelykkorrelrig biotitiese en toermalynhoudende variante; granodioriet |
| N-Ck | Granite: mainly coarse-grained porphyritic with porphyritic biotitic, fine-grained leucocratic, hybridic and medium-grained tourmaline-bearing variants<br>Graniet: hoofsaaklik grofkorrelrig porfirities met porfirities biotitiese, fynkorrelrig leukokratiese, hibridiese en mediumkorrelrige toermalynhoudende variante |
| N-Cl | Granite: mainly coarse-grained porphyritic with porphyritic biotitic and fine- to medium-grained leucocratic variants; quartz monzonite; adamellite; quartz porphyry<br>Graniet: hoofsaaklik grofkorrelrig porfirities met porfirities biotitiese en fyn- tot mediumkorrelrig leukokratiese variante; kwartsmonsoniet; adamelliet; kwartsporfier |
| N-Cp | Granite: mainly porphyritic and biotitic with fine- to medium-grained and hybridic variants<br>Graniet: hoofsaaklik porfirities en biotities met fyn- tot mediumkorrelrige en hibridiese variante |
| N-Cs | Granite: mainly coarse-grained porphyritic with medium- to coarse-grained, fine-grained porphyritic, fine-grained leucocratic, hybridic, fine- to medium-grained tourmaline-bearing and coarse-grained biotitic variants<br>Graniet: hoofsaaklik grofkorrelrig porfirities met medium- tot grofkorrelrige, fynkorrelrig porfiritiese, fynkorrelrig leukokratiese, hibridiese, fyn- tot mediumkorrelrig toermalynhoudende en grofkorrelrig biotitiese variante |
| Nb | Schist and fine-grained greywacke with beds and lenses of quartz schist and limestone<br>Skis en fynkorrelrige grouwak met lae en lense van kwartsskis en kalksteen |
| Nbr | Greenstone with dolomite (🟦) and chert lenses (🟦)<br>Groensteen met dolomiet- (🟦) en chertlense (🟦) |
| Nf | Grey, feldspathic conglomerate, grit and sandstone with minor shale<br>Grys, veldspatiese konglomeraat, grintsteen en sandsteen met ondergeskikte skalie |
| Nk | Quartz schist with phyllite beds and minor limestone and chlorite-schist lenses<br>Kwartsskis met fillietlae en ondergeskikte kalksteen- en chlorietskislense |
| Nm | Greywacke and phyllite with beds and lenses of quartz schist, limestone and grit; quartz-sericite schist with occasional limestone lenses (🟩)<br>Grouwak en filliet met lae en lense van kwartsskis, kalksteen en grintsteen; kwartsserisietskis met enkele kalksteenlense (🟩) |
| Np | Grit and greywacke<br>Grintsteen en grouwak |
| Npo | Phyllite shale, schist and greywacke with dark-grey limestone, sporadic quartzitic sandstone beds and conglomerate beds<br>Fillitiese skalie, skis en grouwak met donkergrys kalksteen, sporadiese kwartsitiese sandsteenlae en konglomeraatlae |
| Nt | Greywacke, phyllite and quartzitic sandstone; interbedded lava and tuff (▥)<br>Grouwak, filliet en kwartsitiese sandsteen; tussengelaagde lawa en tuf (▥) |
| Ny | Diorite and gabbro<br>Dioriet en gabbro |
| $\frac{Qw}{Qs}$ | Indicates that Qw is underlain by Qs<br>Dui aan dat Qw deur Qs onderlê word |

**Figure 2.1(c)** Lithology of geological map of the study area.

**Table 2.1** Geological time-scale representing the rocks in the study area (after Theron *et al.*, 1992).

| Era | Chronostratigraphic Unit | Time scale x$10^6$ yrs |
|---|---|---|
| **Cenozoic** | Quaternary | 0-2 |
| | Tertiary | 2-65 |
| **Mesozoic** | Cretaceous | 65-140 |
| | Jurassic | 140-195 |
| | Triassic | 195-395 |
| | Permian | |
| **Palaeozoic** | Carboniferous | |
| | Devonian | |
| | Silurian | 395-500 |
| | Ordovician | |
| | Cambrian | |

The mountain belt that formed, with its granitic intrusions, was subsequently eroded to a featureless landscape over a period of about 50 million years. This surface then subsided along an axis, which broadly parallels the present southern coastline of South Africa, allowing the deposition from the north of several thousand metres of sediments of the Cape Supergroup, and thereafter of the Karoo Supergroup. During the Permian Cape orogeny (episode of mountain building), about 250 million years ago, these formations were folded, uplifted, fractured and carved into ranges and valleys. The sandstones and shales of the Cape Supergroup, which once extended beyond the present coastal plain, were eroded away except for such remnants as the Cape Peninsula, Simonsberg and Riebeek-Kasteel.

### 2.2.2 The Malmesbury Group

Rocks of the Malmesbury Group (approximate age 1000 - 550 million years) constitute a large area in the coastal wine region. Two Formations *viz* Tygerberg and Franchhoek feature prominently. The Tygerberg Formation consists mainly of medium- to fine-grained greywacke, phyllitic shale, siltstone and immature quartzite. The greywacke consists predominantly of quartz and feldspar (microcline and plagioclase) in a clayey matrix. The phyllitic shales consist mainly of mica with scattered quartz and feldspar grains. In some pelitic (metamorphosed sedimentary) layers, cordierite and chlorite porphyroblasts developed to form so-called spotted slates. Closer to the granite contact, the Tygerberg rocks were altered to massive bluish-grey hornfels. Northeast of Stellenbosch, the Franchhoek Formation forms a range of hills and is characterised by feldspathic conglomerate and grit horizons with light-grey arenite (containing sand-size quartz and altered feldspar) with conglomerate and grit horizons. Shales occur only intermittently. The area is extensively faulted. Quartz porphyry dykes intruded the Franchhoek Formation, as well as the hornfels and granites.

The Malmesbury sediments are mainly turbidity-current deposits that formed in a eugeosynclinal (deep water) environment. They grade north-eastwards into a prograding deltaic sequence deposited in a miogeosynclinal environment where shallow marine conditions at times prevailed. In the aureole-zones (the contact zones where the granite intruded the surrounding rocks), the greywacke was metamorphosed to hornfels.

The Malmesbury rocks are mainly overlain by quartzitic sandstones, siltstones, shales and conglomerates of the Cape Supergroup (600-425 million years approximately). Dolerite dykes are present in various shapes and sizes throughout the Coastal region. These usually contain augite and feldspar as major constituents. Variable amounts of olivine, biotite, quartz, ilmenite and magnetite also occur.

### 2.2.3 Cape Granite Suite

The granite plutons in the coastal region of the Western Cape contain good examples of multiple granite injections (Siegfried *et al.*, 1984). Radiometric dating indicates an age range of 622 to 642 Ma for the earliest phase and 515 to 545 Ma for the youngest phase (Leygonie, 1977). The Cape granites, which intruded the Malmesbury Group of sedimentary rocks, are high-level diapiric plutons, which crystallised from magmas which were themselves formed by regeneration of magma from pre-existing rocks (anatexis) at progressive higher levels in the crust (Schoch *et al.*, 1977). Siegfried *et al.* (1984) described the intrusive history of the Cape Granite Suite, inferred from contact relationships and mineralogical evidence. The generation of the granitic magma probably occurred by melting of crustal rocks at a depth of approximately 30-40 km. This melt then moved upward and formed a granitic magma reservoir, probably about 14 km below the earth's surface. Different magma fractions at approximately 700 degrees Celsius, then intruded the country rock in stages, to a depth of about 8 km. The stages as described by Siegfried *et al.* (1984) as follows:

Stage 1: Injection of a wedge of medium-grained granite into the older Malmesbury sediments and formation of hybrid granite through reaction of magma with the wall rock. Heat changed the country rocks to hornfels.

Stage 2: Intrusion of coarse porphyritic granite, adjacent to the first intrusion, by displacement of the wall rocks and formation of a wider band of hornfels.

Stage 3: Injection of fine-grained granite in separate conduits through the porhyritic granite. Quartz porphyry dykes were intruded along fractures and quickly chilled.

In the study area the Kuils River-Helderberg- and Stellenbosch plutons (Figure 2.2 and 2.3) are prominent.

### The Kuils River-Helderberg pluton

The Kuils River-Helderberg pluton (Figure 2.2) is elongated to the northwest with approximate dimensions of 25 km by 11 km. To the north, near Durbanville, various similarly orientated minor granite bodies are present, which probably represent the higher parts of a larger, unexposed extension if this pluton. Several varieties of granite are present. Coarse-grained porphyritic granite with large single K-feldspar (microcline) crystals builds the major part of the pluton. This leucocratic rock has a coarse texture and the large K-feldspar crystals are held in a matrix of plagioclase, quartz, biotite and muscovite. The contact between the porhyritic granite and the Malmesbury sediments is only rarely exposed, but biotite xenoliths of various shapes and sizes and assimilation from material of Malmesbury derivation occur erratically throughout the coarse porphyritic granite. Patches of medium-grained granite occur sporadically throughout the coarse grained granite pluton. Small bodies of fine-grained granite appear in the north, northwest and western sectors. This fine-grained granite is richer in plagioclase and muscovite and contains zircon, tourmaline, chlorite and black metalliferous minerals as main accessories. In the northwest and western peripheral zone of the pluton hybrid granite occurs, distinguished from the porhyritic granite by its higher biotite content. Fine- to medium-grained leucocratic tourmaline granite occurs at various localities and contains tourmaline-rich nodules or patches, which are surrounded almost invariably by white collars of coarsely crystalline feldspar, quartz and muscovite. Irregular veins of fine-grained aplite and coarse-grained pegmatite occur sporadically throughout the pluton.

### The Stellenbosch pluton

Defining the perimeter of the Stellenbosch pluton (Figure 2.3) proved to be problematical (Theron *et al.*, 1992). To the north it is fragmented by a series of northwesterly striking faults, whilst to the south and east it disappears beneath the Table Mountain Group. Several granite types have been recognised in the Stellenbosch pluton. A porphyritic biotite granite with large alkali-feldspar phenocrysts is predominant. In the southern sector of the pluton, a medium to coarse-grained granite occurs. Alkali-feldspars and biotite are the dominant minerals in this granite. A leucocratic fine-grained porphyritic granite occurs in small bodies in the south of the pluton. Between this granite and the Malmesbury hornfels, a fine-grained leucocratic granite occurs, whereas a fine to medium-grained tourmaline-rich granite occurs between the fine-grained porhyritic granite and the hornfels. In the centre part of the northern sector a melanocratic hybrid granite, fine to medium grained, occurs. Adjacent to the hybrid granite (eastern-side), lies a porhyritic coarse-grained biotite granite with a darker colour than the porphyritic granite. Alternating bands of mylonitised granitic rocks are present throughout the northern sector of the pluton.

In the northern sector of the pluton, cross-bedded sandstone, conglomerate and shales of the Klipheuwel Group occur in long narrow strips overlying the coarse porphyritic granite in an upward-fining tendency. These rocks, which are younger than the Cape Granite Suite, were

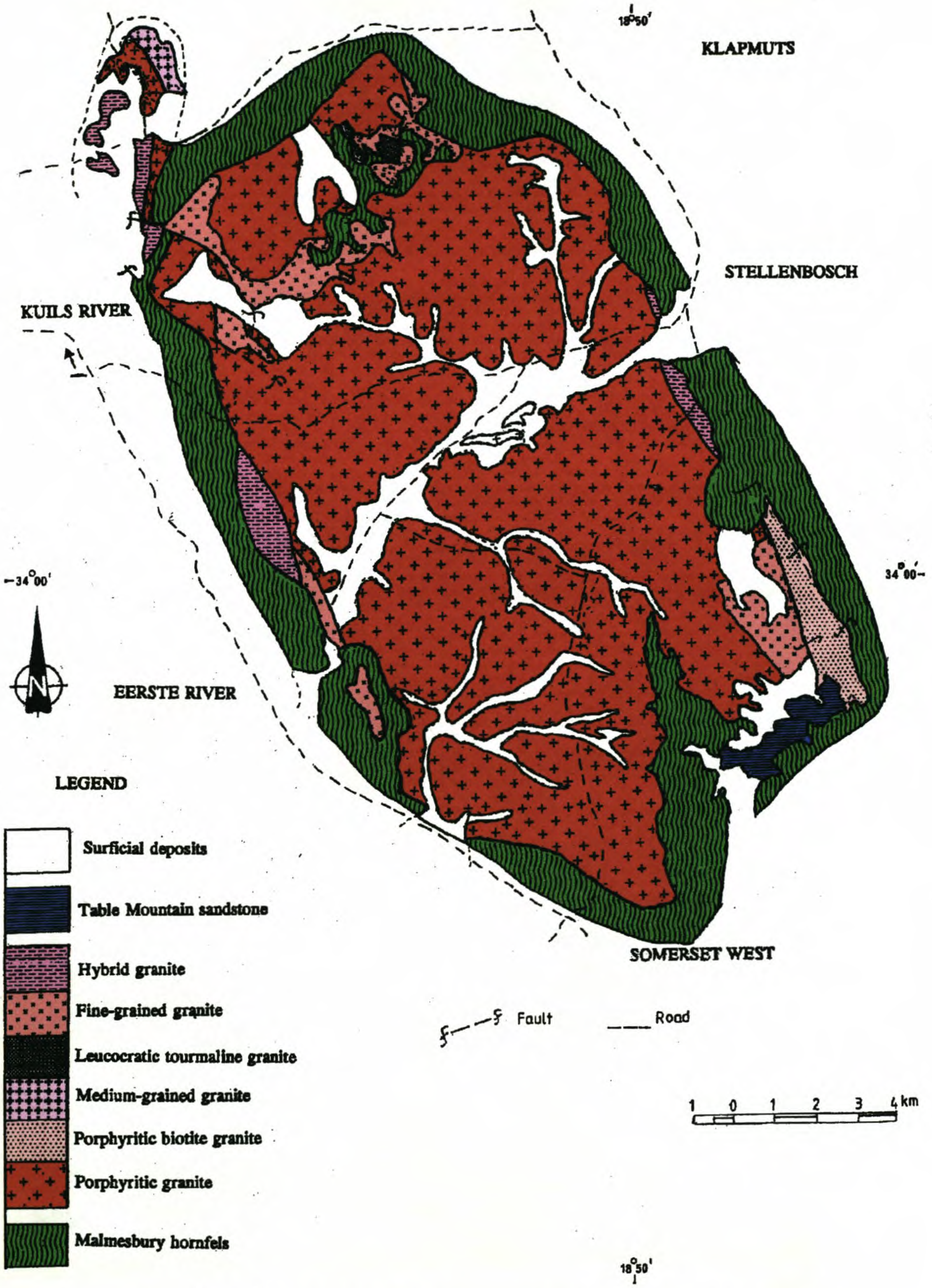


**Figure 2.2** The geology of the Kuilsriver-Helderberg pluton (after Theron *et al.*, 1992).

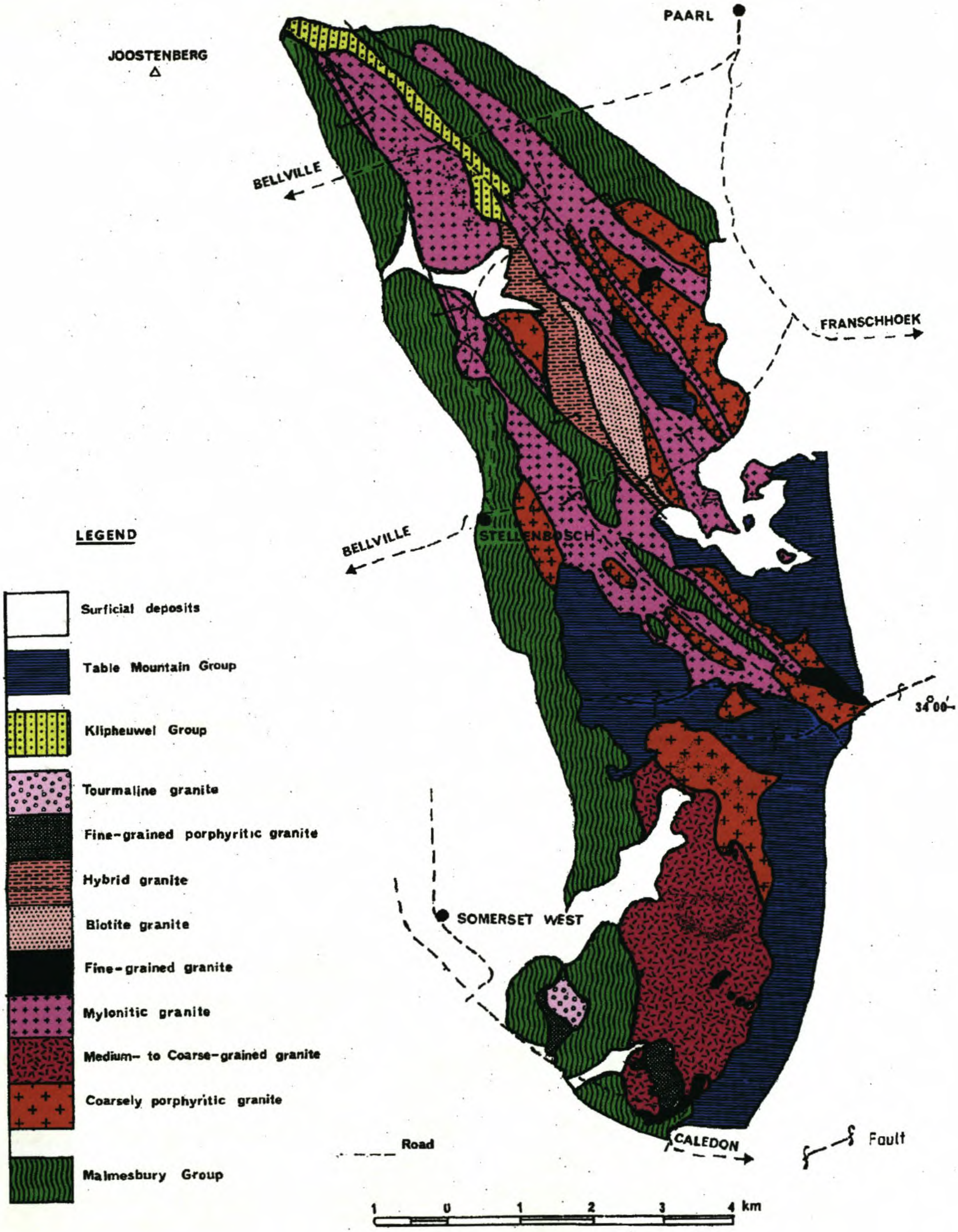


**Figure 2.3** The geology of the Stellenbosch pluton (after Theron *et al.*, 1992).

probably the result of alluvial-fan sediments (conglomerate and sandstone), followed by lacustrine sedimentation (shales). These rocks were deformed as the result of major shear zones that were reactivated into deep reverse faults. This event probably occurred later than 500 Ma.

## 2.3 SPECULATIONS ON WEATHERING PRODUCTS

### 2.3.1 General

The geology of the coastal wine-producing region is complex, and varies over short distances. The geological history includes sedimentary rock formation, granite intrusion, metamorphism, plate tectonic activity, mountain building, erosion and weathering. These processes took place over a period of approximately 1 000 million years. As discussed in Chapter 1, the lithology of the parent material plays a major role in soil development. The complexity of the geology is therefore likely to be reflected in the products of soil development, although few soils in the study area are likely to have developed solely from *in situ* weathered parent rocks. Wine-grapes are grown on the slopes (mostly granites and hornfels) as well as on topographically lower areas underlain by greywackes and shales/slates. Certain vineyards in the study area are located near higher elevations mountains composed of Table Mountain Sandstones. Dolerites dykes also occur in small patches throughout the coastal wine region.

The fact that grapes are grown on the hills does not imply a solely granitic or hornfelsic soil origin, because of the likelihood of admixture of material derived by erosion and colluviation from the higher-lying sandstones and shales of the Cape Supergroup.

The chemical, mineralogical and physical properties of different soil parent rocks should be reflected in the soil itself, as discussed in Chapter 1. However, in complex geological areas, such as the study area, it is unlikely that any soil property could be directly attributed to the characteristics of a given rock type. Certain properties of weathering material might, however, be used to identify parent materials.

### 2.3.2 Mineralogy of the rocks

The predominant rocks in the coastal wine region are the greywackes, phyllitic shales, conglomerates and hornfels of the Malmesbury Group, the porphyritic granites from the Cape Granite Suite, and the sandstones and shales from the Cape Supergroup, in addition to the occasional dolerite dyke, and to quartz veins. The Tygerberg-Durbanville area consists mainly of greywackes and phyllitic shales. The greywackes contain predominant quartz, plagioclase and microcline (K-feldspar) while the phyllitic shales contain mainly mica and, in certain areas, cordierite (Mg, Fe-rich Al-silicate) and chlorite, especially where the shales have been metamorphosed to hornfels. In the greywackes the quartz will weather slower than will the micas and chlorites in the phyllitic shales and hornfels (see Figure 1.2).

The porphyritic granites that occur in the Stellenbosch and Kuils River areas contain mainly K-feldspars and biotite, with variable quantities of plagioclase, quartz, muscovite and tourmaline (B-silicate). Because these granites are up to 400 million years younger than the greywackes, phyllitic shales and hornfels, and because the plutons were not exposed to weathering until after the overlying Cape Supergroup rocks have been weathered and eroded away, their time of exposure to weathering was relatively short. The younger sandstones of the Cape Supergroup that occur throughout the Stellenbosch area contain quartz and vein quartz while the shales contain mica and clay minerals.

### 2.3.3 Physical and chemical composition of weathered products

As previously noted, the chemical properties of rocks could be reflected in the derived soils. Table 2.2 shows the whole-rock chemical composition (Visser, 1964) of each of the major rocks in the Coastal Wine region. Whole-rock chemistry, however, does not always reflect the levels of plant available nutrients. Plant availability may be affected by:

a. disintegration of minerals (which is a function of resistance to weathering and time of exposure to weathering) and
b. rhizosphere conditions, such as pH. It is believed, however, that these properties will still reflect at least a semi-quantitative indication of nutrients in soils, especially in lower horizons that are the closest to active weathering of primary parent material.

Granitic soils are likely to contain a relative abundance of potassium (Table 2.2) as a consequence of the presence of biotite, muscovite and K-feldspars, relative to soils developing from other rocks in the study-area, although time of exposure to weathering may play an important role, as discussed previously. Dolerites contain higher levels of Fe, Ca and Mg when compared to other rocks, although granites and shales also contain Fe-minerals (Table 2.2). Dolerites, however, are relatively limited in this area. Sandstones contain up to 96% $SiO_2$ (data not shown) and are very poorly supplied with plant mineral nutrients. Hornfels contains abundant sodium (3.44 % $Na_2O$). It is, however, important to realise that variation in chemical composition may occur in contact zones where granites and dolerites intruded the sedimentary rocks.

Amongst the mineral nutrient elements that are found in primary minerals, potassium is perceived as having the greatest effect on wine quality. In granite-derived soils, the release of potassium from silt and sand grains was observed by Munn *et al.* (1976). McCallister (1987) noted that potassium could be extracted from the silt and very fine sand fraction of sandy feldspathic soils, notably from micas and feldspars. However, Doll *et al.* (1965) found that the amount of potassium that could be extracted from a range of particle size fractions decreased as the particle size decreased, probably because the content of K-depleted weathering products increased. Working with a Hutton soil from Paarl mountain, Wooldridge (1988) found that the total potassium content of the < 0.25 mm fraction was 6.8% greater than that of the whole (≤ 2.0 mm) soil. However, $NH_4Cl$ exchangeable potassium was 72.7%

lower, and Bray 2 extractable potassium 23.1% higher, from the < 0.25 mm fraction than from the ≤ 2.0 mm soil. A similar release pattern was observed in a Bokkeveld shale derived soil. Particle size therefore appears to have an effect on potassium exchangeability and extractability. The fact that potassium may potentially be supplied to vine roots from the sand fractions of granite soils implies that the sand fractions assume considerable importance, particularly in view of the possibility that the availability of potassium may vary with sand grade, and also with silt content. Evidence for the occurrence of sorting processes during transport and deposition, by whatever means, or of pedogenic processes that alter particle size distribution in *in situ* or transported soil parent materials, is therefore likely to be of importance in nutritional and wine-making terms.

**Table 2.2** Typical whole-rock chemistry data (single samples) for dominant rocks in the Coastal wine region, South Africa (after Visser, 1964).

| **Analyses (%)** | **Porphyritic granite (Kuils River)** | **Malmesbury hornfels** | **Table Mountain sandstone** | **Malmesbury shale** | **Paarl dolerite** |
|---|---|---|---|---|---|
| **CaO** | 1.31 | 2.39 | 0.10 | 1.82 | 10.20 |
| **MgO** | 0.62 | 2.01 | 0.54 | 2.64 | 5.84 |
| **$K_2O$** | 4.98 | 1.90 | 0.95 | 2.80 | 0.63 |
| **$Na_2O$** | 3.55 | 3.44 | 0.2 | 2.30 | 2.28 |
| **$Fe_2O_3$** | 0.22 | 3.25 | 1.60 | 2.18 | 4.53 |
| **FeO** | 1.97 | 2.69 | 0 | 5.34 | 10.10 |
| **$Al_2O_3$** | 13.05 | 12.0 | 1.01 | 16.98 | 13.92 |
| **$P_2O_5$** | 0.29 | 0.30 | 0.06 | 0 | 0.35 |

Literature on soils in the study area indicates that soils which are derived from granite contain coarser fragments than do soils which are derived from Malmesbury rocks, in which clay, silt and fine sand are more abundant (Theron *et al.*, 1992). In contrast, soils derived predominantly from Table Mountain sandstones tend to be rich in particles of sand size. Theron *et al.* (1992) found that soil parent materials that formed *in situ* on Malmesbury rocks differed markedly from soil parent materials that formed on granite. They stated that soils that formed from the Malmesbury-derived parent materials were predominantly clayey and yellow, red or brown, and contained small nodules of ferricrete and fragments of vein quartz, in addition to a variable quantity of sand. Brackish patches also occur in Malmesbury soils. In the Tygerberg-Durbanville area, the soil is loamy and the thickness of these loamy soils is greatest in the valleys north of Durbanville. A red to light-brown, sandy to gritty, clayey soil representing the weathering products of granite, can be found over most of the area where granitic bedrock occurs. Thin layers of grit and pebbles are sometimes present in granitic soils. The clasts include vein-quartz, quartz, small granite pebbles and ferricrete, and may be angular or rounded. In areas around Stellenbosch, material of granitic derivation was found to fill old drainage channels incised into the underlying Malmesbury basement. The Malmesbury rocks are not uniform in texture and mineralogical composition, and show evidence of folding. As a result, soils that developed on the Malmesbury basement vary in texture and composition, often over short distances. Folds, faults and veins within the Malmesbury may also affect modern topography and soil characteristics.

### 2.3.4 Clay mineralogy

Due to the complex geological history of the coastal wine-producing region, one might expect that the weathering of primary minerals over such a long period would result in extensive structural breakdown and the generation of those products which are associated with the terminal stages of weathering, notably kaolinite, gibbsite, hematite, illite and quartz (Table 1.2). Since such minerals are characterised by low cation exchange capacity (CEC) values, it is likely that the observed CEC will vary between 3 - 40 $\text{cmol}_c\,\text{kg}^{-1}$ (see Table 1.3).

In the case of deep soil horizons where *in situ* parent material is being weathered, it is possible that the exposure of the rock to subaerial weathering conditions may be of relatively recent origin. In these materials the stage of weathering is likely to be no more than mild to intermediate, especially in saprolite. The simultaneous presence of clay fraction minerals such as quartz and mixed layer minerals (generally indicating intermediate weathering stages) and gibbsite, hematite and goethite (generally indicating advanced weathering stages) may therefore occur in the same soil profile. In such cases, however, A- and B-horizons with "older material" will then indicate a higher degree of weathering when compared with the lower saprolite. To identify the possible mixing of parent materials in these soils, the chemistry of the soils (as discussed previously), but also analysis of particle size distribution, could be used as tools.

### 2.3.5 Paleo-geomorphology of the landscape, and landscape evolution

The break-up of Gondwanaland, the southern hemisphere supercontinent in which the present continents of South America, South Africa, Antarctica, Australia and peninsula India were joined, began to rift apart about 150 million years ago. This followed a period of volcanics (Drakensberg) implying the development of at least one hot spot beneath the insulating continental blanket, the development of tensional, southerly dipping faulting in the Cape Fold Belt, and the formation of a series of triple junctions. This came to define the line of separation between South America and South Africa. Rifting was protracted over a period of about 20 million years, but by 130 Ma (100 Ma according to Hendey, (1983)) ago the South Atlantic ocean was a reality at all latitudes and sea floor spreading was actively taking place, with the western African coastline forming a passive continental margin to the edge of the Atlantic ocean basin (Truswell, 1977).

Faulting and erosion continued to take place at, and inland from, the new South African coastline, and rivers began to incise the old Gondwana surface, leading to the accumulation of a thickness of about 10 000 m of sediment in the widening ocean basin in late Jurassic and Cretaceous times. Relative stability was achieved by the beginning of the Cenozoic, about 65 million years ago, by which time the topography of the subcontinent more or less resembled that of the present time. The fact that the best fit between South America and South Africa is at the 1 000m depth contour (Truswell, 1977) is an indication of the extent to which the continental margins underwent erosion during, and after, plate separation. The Cape Fold Mountains and outliers such as the Cape Peninsula and Piketberg were in existence throughout the Cenozoic, although their form has certainly altered somewhat due to subaerial erosion. Most subject to change were the coastal lowlands that varied in extent with fluctuations in sea level. Evidence of raised sea levels is fragmentary. Nevertheless, Hendey (1983) has cited examples of several former shorelines. These decreased progressively in height above present mean sea level as the Quaternary progressed, commencing with a 150-200 m marine platform of Eocene/Palaeocene age, at which time virtually all of the coastal lowlands would have been submerged, and decreasing to a 20 m shoreline and 12 m marine terrace in late Pliocene. This decrease apparently reflected a progressively more subdued trend in tectono-eustatic changes.

Sea levels during the Holocene and Pleistocene did not exceed present sea levels by more than 6 m. These data suggest that the Papegaaiberg site (Figure 2.1), with an altitude of 148 m, would have been submerged during the Eocene/Palaeocene incursion, about 65 million years ago, and again during early/mid Miocene times, 22 million years ago, when the shoreline reached 150 m above present sea level. On this site alone is it possible that Cenozoic marine incursion may have had a direct effect on soil parent material and its textural differentiation. None of the other sites (altitudes exceed 200 m) used in this work are likely to have been inundated more recently than the end of the Tertiary, if at all. Marine incursions are generally slow and associated with mild climates, increased rainfall, luxuriant vegetation and deep chemical weathering of the bedrock. Conversely, marine regressions are invariably relatively fast and associated with increasing aridity, contributing to rapid riverine downcutting and severe erosion (Hendey, 1983). Sea level regressions have occurred at intervals during the Tertiary, and throughout the past 65 million years. Notable Cenozoic regressions occurred in the mid Oligocene, late Miocene and mid/late Pliocene. These were mainly tectono/eustatic in origin. Further fluctuations of glacio/eustatic origin, occurred during the Pleistocene. According to Truswell (1977), on one occasion at least, in the late Pleistocene about 22 000 years ago, the sea level was about 140 m lower than at present, exposing the entire Agulhas bank. By 10 000 years ago the Agulhas bank was once more inundated, indicating that sea level changes can be of considerable rapidity during alternations between ice ages and interstadials.

The link between sea level and terrestrial erosion planes appears to be poorly defined. Schloms *et al*. (1983) has described a section running from the Eerste River to the Stellenbosch Mountain that consists of a series of terraces. This series commenced with valley flats between 50m and 100 m above seal level. Further upslope, at 125 m, was a terrace in which the soils contained river gravels. This was succeeded at 200 m by a terrace on which the soils contain hard plinthite. The highest, 300 m, terrace was situated on highly weathered, ferruginised granite. Lambrechts (1983) noted that present-day soils tend to retain relic, fossil features inherited from previous weathering regimes and were rarely, if ever, totally in equilibrium with present climatic and environmental conditions. In the ice-free early Cenozoic, weathering took place under conditions that were warmer and more humid than those which occurred subsequently. Under these conditions deep chemical weathering occurred. To this effect Lambrechts (1983) has described a laterite-topped, dissected granite landscape in the Stellenbosch area in which the granite has been chemically altered to a depth of over 50 m. Chemical weathering, combined with free drainage, leads to extensive primary mineral breakdown, kaolinisation and accumulation of hydrated iron, manganese and aluminium oxides. Under conditions of restricted drainage, as may occur in upland, terrace or bottomland situations, iron and manganese may accumulate at the oxidation/reduction interface to form hard plinthite/laterite. Weathering and deflation commonly releases nodular concretionary plinthite fragments which often become concentrated to form the gravel layers which are observed in present day soil profiles. On terrains that are associated with granite the gravel layers may be composed of quartz, usually with some weathered feldspar crystal cores. The occurrence of such gravel layers implies that the soil parent materials are not *in situ* and have undergone some form of transport, during which sorting is likely to have taken place. Some soils have, however, developed *in situ*, as evidenced by the presence of intact quartz veins.

From the above comments it is apparent that the soils of the Western Cape coastal belt have developed over an extraordinarily protracted period of time, and that much transport and mixing might have taken place: marine and riverine at lower elevations, and gravity-induced at higher altitudes and slope angles. In consequence considerable diversity may be expected within some soil profiles, less diversity in others.

## 2.4 REFERENCES

DOLL, E.C., MORTLAND, M.M., LAWTON, K. & ELLIS, B.G., 1965. Release of potassium from soil fractions during cropping. *Soil Sci. Soc. Amer. Proc.* **29**, 699-702.

HENDEY, Q.B., 1993. Palaeontology and palaeoecology of the fynbos region. In H.J. Deacon, Q.B. Hendey & J.J.N. Lambrechts. Fynbos palaeoecology: a preliminary synthesis. South African National Scientific Programmes Report No. 75, Council for Scientific and industrial Research, Pretoria. Pp. 35-60.

LAMBRECHTS, J.J.N., 1983. Soils, soil processes and soil distribution in the Fynbos region; an introduction. In H.J. Deacon, Q.B. Hendey & J.J.N. Lambrechts. Fynbos palaeoecology: a preliminary synthesis. South African National Scientific Programmes Report No. 75, Council for Scientific and industrial Research, Pretoria. Pp. 61-99.

LEYGONIE, F.E., 1977. Die graniete van die Langebaan, Kaapprovinsie. Annals University of Stellenbosch. **A1**: 2.

MCCALLISTER, D.L.., 1987. Distribution and extractability of potassium in size fractions of sandy, feldspathic soils. *Soil Sci.* **144**, 274-281.

MUNN, D.A., WILDING, L.P. & MCLEAN, E.O., 1976. Potassium release from sand, silt and clay soil separates. *Soil Sci. Soc. Amer. J.*, **40**, 364-366.

SCHLOMS, B.H.A., ELLIS, F. & LAMBRECHTS, J.J.N., 1983. Soils of the Cape Coastal platform. In H.J. Deacon, Q.B. Hendey & J.J.N. Lambrechts. Fynbos palaeoecology: a preliminary synthesis. South African National Scientific Programmes Report No. 75, Council for Scientific and industrial Research, Pretoria. pp.70-86.

SCHOCH, A.E., LETERRIER, J. & LA ROCHE, H.D., 1977. Major element geochemical trends in the Cape granites: *Trans. Geol. Soc. South Africa.* **80:3**, 197-209.

SIEGFRIED, H.P., DE BRUIN, D. & BOSHOFF, A., 1984. The geology and geochemistry of the Paarl granite pluton, Cape Granite Suite, south-western Cape. *Bull. Geol. Surv. South Africa.* **77**, 1-44.

THERON, J.N., GRESSE, P.G.; SIEGFRIED, H.P. & ROGERS, J., 1992. The geology of the Cape Town area. Geological Society of South Africa, Pretoria.

THERON, K., 1998. Wine of origin. Wine and Spirit Board, Stellenbosch, South Africa. p22 - 24.

TRUSWELL, J.F., 1977. The geological evolution of South Africa. Purnell, Cape Town.

VISSER, J.N.J, 1964. Analyses of rocks, minerals and ores. Handbook 5. Geological Society of South Africa, Pretoria.

WOOLDRIDGE, J., 1988. The potassium supplying power of certain virgin upland soils of the Western Cape. M.Sc thesis, University of Stellenbosch, Stellenbosch.

# CHAPTER 3

# SITE DESCRIPTION, SAMPLING PROCEDURES AND LABORATORY METHODS

## 3.1 INTRODUCTION

This study forms an integral part of a multidisciplinary research project on the effect of soil and climate on wine quality, which commenced in 1993 and has still to be completed. Participants in this project are the ARC Nietvoorbij Centre for Vine and Wine (NCVW), the ARC Institute for Soils, Climate and Water (ISCW) and the University of Stellenbosch. The motivation behind this multidisciplinary project was that producers cannot determine beforehand whether a specific location will yield wines of high or low quality. If a specific cultivar is planted at the wrong location, wine quality may be reduced from high quality export to an ordinary table wine. The long term objectives of this multidisciplinary project are to develop guidelines by which different sites can be classified according to their potential for the production of high quality wines, and to identify the most important climatic and soil factors responsible for differences in wine quality and -character. This study will concentrate on the effect of parent material as a factor of soil formation, and as a possible factor in the determination of vine growth and wine character.

Measurements such as soil water, leaf water potential, cane mass and yield were and are made under dry land conditions in Sauvignon blanc vineyards at six different localities: five in the Stellenbosch district and one in Durbanville. All were owned by private commercial producers. In all cases, the vines were approximately 10 years old and were trained on a hedge system. Each of the plots in which measurements were made contained 20 vines. Two different soil types were identified at each locality. These were not more than 60 metres apart and differed markedly in terms of vine growth and wine quality. An automatic weather station was erected halfway between the two experimental plots. Identification of the different soil types and diagnostic horizon description was carried out by Saayman (in Conradie, 1998) according to the Soil Classification Working Group (1991). Soil colours (Munsell notation) are presented in Appendix 3.1. As discussed in Chapter 2, the geology of the study area is very complex and mixed parent material was expected. In this study, the main objective was to compare physical and chemical properties of soils at different localities as first priority, followed by a comparison between the two soils at the same locality and soils horizons in a particular soil as second and third priority respectively. These results were then compared with vine performance and topo-climate.

## 3.2 SITE DESCRIPTIONS

A summary of the latitude, longitude, altitude, aspect, slope, distance from the sea, soil form and soil family for each locality are presented in Table 3.1.

**Table 3.1** Physical descriptions of the sites in the study (after Conradie, 1998).

| Site | Soil form | Soil family number | Location | Altitude (m) | Direction | Slope (%) | Shortest distance from the sea (km) |
|---|---|---|---|---|---|---|---|
| **Simonsberg** | Hutton (Hu) | 2100 | 33°54′12″ S | 342 | NW | 8.6 | 26 |
| | Tukulu (Tu) | 1/21/220 | 18°55′15″ E | | | | |
| **Kuils River** | Tukulu (Tu) | 2110 | 33°57′18″ S | 250 | ESE | 14.5 | 13 |
| | Vilafontes (Vf) | 1110 | 18°44′05″ E | | | | |
| **Helshoogte** | Oakleaf (Oa) | 1/2110 | 33°54′12″ S | 413 | S | 5.2 | 24 |
| | Hutton (Hu) | 2100 | 18°55′15″ E | | | | |
| **Papegaaiberg** | Avalon (Av) | 2200 | 33°55′46″ S | 148 | NW | 5.7 | 18 |
| | Tukulu (Tu) | 2110 | 18°50′06″ E | | | | |
| **Devon Valley** | Oakleaf (Oa) | 2210 | 33°54′44″ S | 200 | WNW | 6.4 | 20 |
| | Glenrosa (Gs) | 211/21 | 18°49′55″ E | | | | |
| **Durbanville** | Westleigh (We) | 2000 | 33°50′00″ S | 230 | SE | 8.6 | 12 |
| | Tukulu (Tu) | 1110 | 18°36′47″ E | | | | |

The Simonsberg locality, near Stellenbosch, is situated at 33°54′12″ S and 18°55′15″ E, 342 metres above sea level, with a northwestly aspect on an 9 % slope. Underlying both soils at this site is porhyritic biotite granite of the Stellenbosch pluton, which is overlain by Cambrian Table Mountain sandstones (Theron *et al.*, 1992). The soils are Hu 2100 and Tu 1/21/220. The Hutton 2100 is as soil form with a prominent red colour and weak horizon differentiation (Conradie, 1998). The profile consists of a 30 cm thick structureless reddish orthic A horizon, overlying a 50 cm thick mesotrophic, non-luvic, apedal red B horizon with relic plinthic characteristics. Advanced physical and strong chemical weathering of the granite are present. The Tu 1/21/220 is a Tukulu soil form with a yellow-brown orthic A horizon (25 cm thick) overlying a neocutanic B horizon (35 cm thick) on a lithocutanic, blocky structured C horizon with signs of wetness showing strong physical and chemical weathering (Conradie, 1998). For the purposes of this study, the soils are referred to as Simonsberg Hu and Simonsberg Tu.

The Kuils River locality (Figure 2.1) is situated at 33° 57′18″ S and 18° 44′05″ E on the southeastern slopes of the Kuils River-Helderberg Granite Pluton (see Chapter 2) with a 15 % slope at 250 metres above sea level. The soils are Tu 2110 and Vf 1110. Tu 2110 is a Tukulu form with a bleached orthic A horizon (35 cm thick) and non-red, non-luvic neocutanic B horizon (30 cm thick). The underlying C horizon shows signs of wetness and soft plinthic character (Conradie, 1998). The Vf 1110 is a Vilafontes soil form, with an Orthic A (35 cm thick), a 15 cm pale-coloured, structureless E horizon and a neocutanic B (20 cm thick) horizon. The colour of the E horizon is grey when moist. An underlying C horizon has a lithocutanic character and blocky structure, showing advanced physical and strong chemical weathering.

The Helshoogte locality (Figure 2.1) is situated at 33° 54′12¨ S and 18° 55′15¨ E on a south-easterly slope (5 % slope) on Helshoogte near Stellenbosch at 413 m altitude. The soils are Oa 1110/2110 and Hu 2100. Oa 1110/2110 is an Oakleaf soil form and Hu 2100 a Hutton soil form (Conradie, 1998). The underlying geology is similar to the Simonsberg locality and consists of porphyritic biotite granite of the Stellenbosch Pluton topped by Table Mountain sandstones (see Chapter 2). The Oakleaf soil form consist of a 40 cm thick yellow-brown orthic A horizon overlying a yellow-brown neocutanic non-luvic B-horizon (40 cm thick). The C horizon consist of semi-weathered granitic rock showing advanced physical and strong chemical weathering. Hu 2100 has a bleached orthic A horizon (30 cm thick) on a red apedal, mesotrophic and non-luvic B (40 cm thick) horizon, overlying a semi-weathered granitic C horizon.

The Papegaaiberg locality is situated 148 m above sea level on a north-western slope (6 % slope) of the Papegaaiberg mountain at 33° 55′46¨ S and 18° 50′06¨ E (Figure 2.1). The underlying geology on the site is hornfels, which formed when the Kuils River-Helderberg Granite Pluton intruded in the Malmesbury sediments (see Chapter 2). Surrounding the site are different granites from this pluton. The soils are Av 2200 and Tu 2110 of the Avalon and Hutton forms respectively. The Avalon form has a 25 cm thick orthic A horizon overlying a yellow-brown, mesotrophic and luvic apedal B horizon (35 cm thickness) which overly a mottled and concretionary (Fe- and Mn-oxides) soft plintic B horizon on a C horizon. The Tukulu form has a 25 cm thick bleached orthic A horizon, overlying a yellow-brown, non-luvic, neocutanic B horizon (25 cm thick), overlying a gleyey clay C horizon.

Devon Valley is situated at 33° 54′44¨ S and 18° 49′55¨ E (Figure 2.1), 200 m above sea level, facing northwesternly with a 6 % slope. The geology is similar to Papegaaiberg with underlying hornfels (metamorphosed Malmesbury sediments) surrounded by granites of the Kuils River-Helderberg pluton (see Chapter 2). The soils of Devon Valley were identified as Oa 2210 of the Oakleaf form and Gs 211/21 of the Glenrosa form. The Oakleaf form has a bleached orthic A horizon (35 cm thick) overlying a red structureless neocutanic B horizon (35 cm thick), overlying a gravelly horizon with relic plintic character. The Glenrosa soil form has a bleached, stony A horizon (30 cm thick), overlying a lithocutanic horizon (60 cm and not hard) that merges with the underlying hornfels saprolite, which show a cutanic character expressed as tongues. The B-horizon tends towards wetness and is non-calcareous.

The Durbanville locality is the only locality not situated in the Stellenbosch district, but in the Durbanville area at 33° 50′00¨ S and 18° 36′47¨ E (Figure 2.1), 230 m above sea level on a 9 % southeast-facing slope. The underlying geology of the area is described in Chapter 2, and consists mainly of phyllitic shales of the Tygerberg formation of the Malmesbury Group. The two soil types described by Saayman (Conradie, 1998) are We 2000 of the Westleigh soil form and Tu 1110 of the Tukulu form. The Westleigh has an organic-rich orthic A-horizon (30 cm thick), overlying a 60cm thick soft plinthic B horizon, overlying a yellow-brown, clay-loam C horizon with neocutanic character. The Tukulu is an organic-rich, orthic A horizon (30 cm thick) with a yellow-brown, non-luvic neocutanic B horizon overlying a clayey C horizon with signs of wetness.

## 3.3 SAMPLING PROCEDURE AND LABORATORY METHODS

### 3.3.1 Introduction

Profile pits were dug in each of the two plots at all localities and sampled on a master horizon basis. Representative samples were taken of each horizon. Undisturbed soil samples were taken for measurements of available soil water, so called readily available water (RAW). For particle size analysis, soil chemical analysis and semi-quantitative estimation of the clay fraction minerals, however, air-dried soil samples were crushed gently with a mortar and pestle and sieved to separate coarse fragments (> 2 mm).

### 3.3.2 Particle size distribution

Particle size distribution was determined by the procedure described by Day (1965). The < 2 mm fractions were treated with IM NaOAc buffered at pH 5,0 to remove carbonates. Organic matter was destroyed with 30-35 volume percent $H_2O_2$. Samples were then treated with 5% Calgon dispersing agent. The silt and clay fractions were determined with a Lowy pipette (Soil Classification Working Group, 1991) while the sand fractions were determined by dry sieving. The soils were separated in the following fractions:

- coarse sand (2,0 –0,5 mm)
- medium sand (0,5 – 0,3 mm & 0,3 – 0,25 mm)
- fine sand (0,25 – 0,1 mm)
- very fine sand (0,1 – 0,075 mm; 0.075 – 0,053 mm & 0,053 – 0,050 mm)
- coarse silt (0,05 – 0,02 mm)
- fine silt (0,02 – 0, 002 mm)
- clay (<0,002 mm)

The > 2 mm fractions were used for qualitative description of the gravel and stone material.

### 3.3.3 Readily available water (RAW)

Undisturbed soil samples were tested in a pressure-pot laboratory system. This is routinely used to determine water retention over the range from -10 to -1500 kPa, in accordance with the method of Klute (1986). RAW was determined for each sample using the standard NCVW procedure. In this procedure, RAW is defined as the amount of water that is available between tensions of –100 kPa and –10 kPa.

### 3.3.4 Mineralogy of the clay fraction

The clay fraction, separated by particle size distribution as described above, were prepared for X-Ray diffraction (XRD) analyses using porous ceramic tiles. Preferred orientated aggregates with Mg- and K-saturation and glycerol solvated were used (Carroll, 1970). Samples were continuously scanned with CoK radiation generated at 45 kV and 40 mÅ in a Philips PW 1710 X-Ray diffractometer at the Research Institute for Soil, Climate and Water in Pretoria, South Africa. Time constants during scans were 10 seconds. Using the most significant peaks on the diffractograms, a semi-quantitative estimate of the clay minerals was made.

### 3.3.5 Chemical analyses

A brief description of the techniques that were employed for soil chemical analysis methods is outlined below:

**pH:** pH was determined in a suspension of 4 g soil in 10,0 $cm^3$ 1 M KCl suspension. A magnetic stirring device was used to keep the soil in suspension whilst the determination was being carried out. A combined glass/calomel electrode, with temperature compensation, was used for the pH determination.

**Resistance (ohm):** The resistance (ohm) of a saturated soil/water paste was determined in a standard USDA soil cup.

**P:** The Bray 2 method described by Bray & Kurtz (1945) was used.

**Total extractable acidity ($H^+$):** $H^+$ was determined by extraction with $K_2SO_4$, adjusted to pH 7, and titration of the leachate to pH 8 with NaOH.

**Extractable cations:** Soils were leached with 0,2 M $NH_4Oac$, buffered at pH 7, to a total volume of 200 $cm^3$. Extractable cations ($Ca^{2+}$, $Mg^{2+}$, $K^+$, $Na^+$) were determined in the ammonium acetate ($NH_4Oac$) leachate by atomic absorption spectrophotometry.

**T-value:** T-values were calculated as equivalent to the sum of the exchangeable $Ca^{2+}$, $Mg^{2+}$, $K^+$ and $Na^+$, plus the total extractable acidity at pH 7.

**Fe-oxides and Al-hydroxides:** Extractable Fe-oxides and Al-hydroxides were determined by the standard dithionite-citrate-bicarbonate (DCB) method (Barnard *et al.*, 1990).

## 3.4 REFERENCES

BARNARD, R.O., BUYS, A.J., COETZEE, J.G.K., DU PREEZ, C.C., MEYER, J.H., VAN DER MERWE, A.J., VAN VUUREN, J.A.J., VOLSCHENK, J.E., BESSINGER, F., LAMBRECHTS, J.J.N., LOOCK, A. & DE VILLIERS, M., 1990. Handbook of soil testing methods for advisory purposes. Soil Science Society of South Africa.

BRAY, R.H. & KURTZ, L.T., 1945. Determination of total organic and available forms of phosphate in soils. *Soil Sci.* 59, 39-45.

CARROLL, D., 1970. Clay minerals: A guide to their x-ray identification. *Geol. Soc. Am., Spec. Paper* 126.

CONRADIE, W.J., 1998. Die kwantifisering van die invloed van grond en klimaat op wynkwaliteit en –karakter met die oog op wetenskaplike gebiedsafbakening. NCVW-1993/98 research report, unpublished. Private Bag X5026, 7599 Stellenbosch.

DAY, P.R., 1965. Particle fractionation and particle size analysis. *In* C.A. Black *et al.*(ed.), Methods of soils analysis. Part 1. Agronomy 9, 545 – 547.

KLUTE, A. 1986. Water retention: Laboratory methods. In: Klute, A. (ed.). Methods of soil analysis, Part I: Physical and mineralogical methods. American Society for Agronomy, Madison, Wisconsin, U.S.A.

SOIL CLASSIFICATION WORKING GROUP, 1991. Soil classification: A taxonomic system for South Africa. Mem. Nat. Agric. Recources of South Africa. **15**.

THERON, J.N., GRESSE, P.G.; SIEGFRIED, H.P. & ROGERS, J., 1992. The geology of the Cape Town Area. Geological Society of South Africa, Pretoria.

**Appendix 3.1:** Soil matrix colours for each diagnostic horizon at the six localities using the Munsell soil colour chart (after Conradie, 1998).

| Locality | Depth (cm) | Munsell notation |
|---|---|---|
| **Simonsberg Hu** | 0-30 | 5 YR 4/4 |
| | 30-80 | 2.5 YR 4/6 |
| | 80-120 | 2.5 YR 4/6 |
| **Simonsberg Tu** | 0-25 | 5 YR 3/4 |
| | 25-70 | 5 YR 4/4-6 |
| | 70-100 | 10 YR 5/8 |
| **Kuilsriver Tu** | 0-35 | 7.5 YR 3/2 |
| | 35-65 | 10 YR 4/4-6 |
| | 65-110 | 2.5 Y 6/4-6 |
| **Kuilsriver Vf** | 0-35 | 7.5 YR 3/3 |
| | 35-50 | 2.5 Y 6/4-6 |
| | 50-70 | 10 YR 4/4 |
| | 70-150 | 2.5 Y 6/4-6 |
| **Helshoogte Oa** | 0-40 | 7.5 YR 3/3 |
| | 40-80 | 7.5 YR 4-3/4 |
| | 80-110 | 7.5 YR 5/6-8 |
| **Helshoogte Hu** | 0-30 | 5 YR 3/3-4 |
| | 30-70 | 5 YR 4-3/4 |
| | 70-100 | 5 YR 4-3/4 |
| **Papegaaiberg Av** | 0-25 | 5 YR 3/4 |
| | 25-60 | 5 YR 4/6 |
| | 60-95 | 7.5 YR 5/8 |
| | 95-120 | 10 YR 5/6 |
| **Papegaaiberg Tu** | 0-25 | 5 YR 3/4 |
| | 25-50 | 5 YR 4/6 |
| | 50-80 | 10 YR 5/8 |
| | 80-130 | 10 YR 5/6 |
| **Devonvalley Oa** | 0-35 | 7.5 YR 3/4 |
| | 35-70 | 5 YR 4/6-3 |
| | 70-110 | 5 YR 4/4 |
| **Devonvalley Gs** | 0-30 | 10 YR 4/4 |
| | 30-60 | 10 YR 5/6 |
| | 60-110 | - |
| **Durbanville We** | 0-30 | 10 YR 2/2 |
| | 30-90 | 10 YR 2/1 |
| | 90-120 | 7.5 YR 3/4 |
| **Durbanville Tu** | 0-30 | 7.5 YR 3/3 |
| | 30-80 | 7.5 YR 3/3 |
| | 80-130 | 7.5 YR 5-4/6 |

# CHAPTER 4

# PARTICLE SIZE ANALYSIS

## 4.1 INTRODUCTION

The purpose of particle size distribution (PSD) analysis and calculation of the cumulative distribution of these particles in soils and sediments may vary depending on the purpose of a particular study (Van Rooyen, 1971). In this study the PSD was used to determine the possible lithological origin of the parent material for the soils at the different localities. Particles that are resistant to weathering (mainly those in the gravel and sand fractions) generally give the best indication of parent material characteristics. These materials were therefore compared at the different localities in the study. Although the formation of clay and silt may also be a function of parent material, the translocation and accumulation of these particles are predominantly the result of pedogenitic processes (Millar *et al.*,1965). The clay and silt fractions nevertheless play an important role in the soil's capacity to retain water, the so-called readily available water (RAW) in the soils. The main objective of this chapter was to compare sand fraction distribution in an attempt to determine origin of parent material and available water in the soils at the six sites, followed by on-site comparisons between soils as second priority.

## 4.2 RESULTS AND DISCUSSION

### 4.2.1 General

The results of the particle size distribution analyses are presented in Appendix 4.1. The macroscopic description of the gravel and stone material (>2 mm fraction) is presented in Appendix 4.2. An analysis of variance for the different sand size fractions from all the horizons was carried out to identify possible significant differences between localities.

To determine differences in sand size fractions of soils at the same locality, and also between soil horizons in a particular soil, the cumulative mass percentages of the different sand particles were plotted against grain-size on linear graph paper, using phi-units ($\varphi$), where:
phi = $-\log_2 x$ (diameter in mm) as described in Krumbein & Pettijohn (1938).

The RAW from the different soils was determined using the standard Nietvoorbij Centre for Vine and Wine (NCVW) diagnostic laboratory method for the determination of RAW, as discussed in Chapter 3.

The gravel and stone content and different sand size fraction data from the soil horizons were subjected to a canonical discriminant analysis using PROC DISCRIM with the CAN option of the SAS statistical software (Bennett & Bowers, 1976; Srivastava & Carter, 1983; SAS, 1990). The objective of this analysis was to determine if the combinations made by the gravel and stone and different sand size fractions could be used to separate the localities in the study.

### 4.2.2 Sand fraction distribution

#### 4.2.2.1 Differentiating between localities

The results of an analysis of variance, which was carried out on the sand size fractions obtained from the different localities, are presented in Table 4.1.

**Table 4.1** Mean values for the different sand size fractions using all the horizons from the six localities.

| **Locality** | **Coarse sand (2.0-0.5 mm)** | **Medium sand (0.5-0.3 mm)** | **Medium sand (0.3-0.25 mm)** | **Fine sand (0.25-0.1 mm)** | **Very fine sand (0.1-0.075 mm)** | **Very fine sand (0.075-0.05 mm)** |
|---|---|---|---|---|---|---|
| Simonsberg | 21.51a(1) | 10.87a | 17.48a | 33.23a | 10.17a | 6.74a |
| Kuils River | 48.27b | 11.33a | 6.59b | 22.94b | 6.78b | 4.10b |
| Helshoogte | 28.39ac | 10.49a | 12.48c | 29.32ac | 10.85ac | 8.52c |
| Papegaaiberg | 22.61ac | 12.00a | 13.64c | 31.43ac | 11.91ac | 8.41c |
| Devon Valley | 29.83c | 7.20b | 6.10b | 28.84c | 12.81c | 15.22d |
| Durbanville | 8.25d | 5.80b | 8.45b | 37.82d | 19.67d | 19.94e |
| **Significance** | 99 % | 99 % | 99 % | 99 % | 99 % | 99 % |
| **LSD** | 7.49 | 2.11 | 3.22 | 4.31 | 1.97 | 1.61 |

(1) Values followed by the same letters do not differ significantly ($p \leq 0.05$)

From these results it is apparent that the soils from the different localities differed markedly in terms of the particle size distribution within their sand fractions. Soils from the Durbanville site contain significantly greater contents of fine and very fine sand when compared with the other localities (Table 4.1). This was expected, as discussed in Chapter 2, mainly because phyllitic shales, which contain predominantly fine particles, are shown by the geological map to lie beneath the soils of the Durbanville area. Soils from the Kuils River locality, however, contain significantly more coarse sand when compared with all the other sites (Table 4.1). This coarse sand may have been conferred by the underlying porphyritic granitic material. This, however, does not imply that the soils from Durbanville and Kuils River developed solely from phyllitic shales or porphyritic granites respectively, but are dominated by these materials respectively. Except for the Devon Valley locality, soils from all the other localities contain significantly more medium sand in at least one of the medium sand fractions when compared with the Kuils River and Durbanville soils. This cannot be directly related to the underlying granite (Simonsberg and Helshoogte), that is expected to contain predominantly coarse material (except for patches of medium grained granite), or hornfels (Papegaaiberg) that is expected to contain predominantly fine sand material. This could indicate mixing of parent material and/or the effect of eolian sand and/or marine incursions (Papegaaiberg) during the Cenosoicum, as discussed in Chapter 2. Soils at the Devon Valley locality, however, contain both coarse (29.8%) and very fine sand (28.0%) in almost equal quantities. The finer fractions could be related to the underlying hornfels at this site, but the coarser fraction could indicate contribution from surrounding granitic and/or sandstone material, again indicating a possibility of more than one source of parent material.

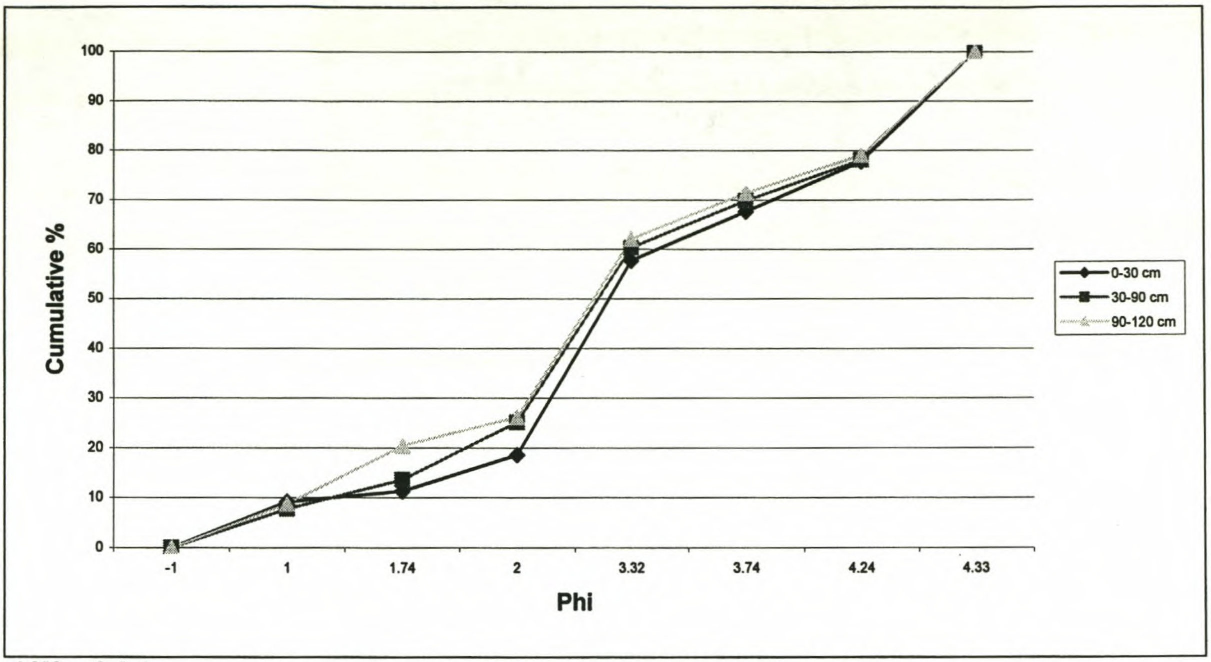
### 4.2.2.2 Particle size distribution of soils developed from phyllitic shale, granite and hornfels

The sand size fractions of the Durbanville, Kuils River and Devon Valley soils were selected and presented in Table 4.2.

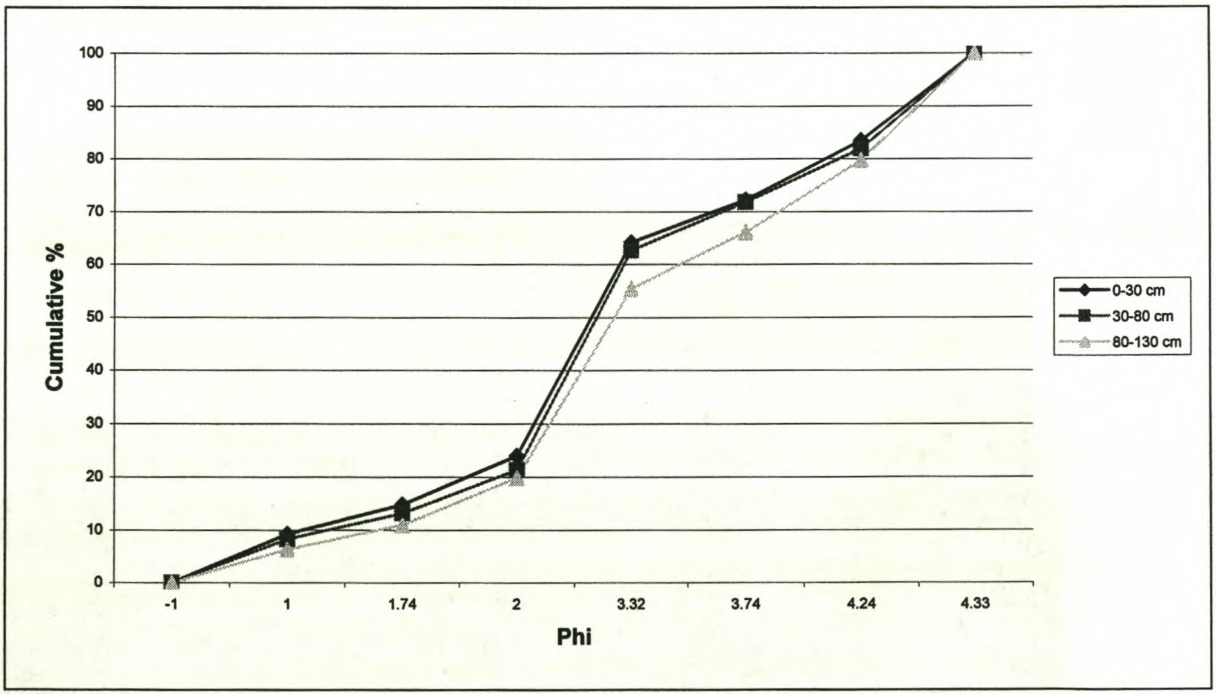
**Table 4.2.** Sand size fraction distribution of horizons at the Durbanville, Kuils River and Devon Valley localities.

| Locality | Soil type | Depth (cm) | Coarse sand (2.0-0.5 mm) | Medium sand (0.5-0.3 mm) | Medium sand (0.3-0.25 mm) | Fine sand (0.25-0.1 mm) | Very fine sand (0.1-0.075 mm) | Very fine sand (0.075-0.053 mm) | Very fine sand (0.053-0.05 mm) |
|---|---|---|---|---|---|---|---|---|---|
| **Durbanville** | **We** | 0-30 | 9.17 | 2.17 | 7.21 | 39.17 | 20.15 | 9.94 | 12.21 |
| **Durbanville** | **We** | 30-90 | 7.76 | 5.85 | 11.55 | 35.22 | 17.78 | 9.50 | 12.37 |
| **Durbanville** | **We** | 90-120 | 8.80 | 11.65 | 5.73 | 35.89 | 17.07 | 9.32 | 11.53 |
| **Durbanville** | **Tu** | 0-30 | 9.22 | 5.59 | 9.20 | 40.12 | 19.33 | 8.05 | 8.48 |
| **Durbanville** | **Tu** | 30-80 | 8.26 | 4.94 | 8.12 | 41.29 | 19.37 | 9.21 | 8.80 |
| **Durbanville** | **Tu** | 80-130 | 6.32 | 4.64 | 8.90 | 35.55 | 24.36 | 10.70 | 9.51 |
| **Kuils River** | **Tu** | 0-35 | 48.91 | 11.19 | 6.98 | 21.99 | 7.10 | 1.93 | 1.90 |
| **Kuils River** | **Tu** | 35-65 | 49.73 | 10.94 | 5.78 | 23.13 | 6.78 | 1.83 | 1.82 |
| **Kuils River** | **Tu** | 65-110 | 54.94 | 10.24 | 6.35 | 16.74 | 6.57 | 2.78 | 2.39 |
| **Kuils River** | **Vf** | 0-35 | 39.28 | 11.51 | 7.91 | 28.55 | 8.39 | 2.22 | 2.15 |
| **Kuils River** | **Vf** | 35-50 | 50.53 | 11.18 | 5.57 | 24.60 | 4.84 | 1.68 | 1.60 |
| **Kuils River** | **Vf** | 50-70 | 46.21 | 12.93 | 6.96 | 22.60 | 7.00 | 2.24 | 2.06 |
| **Kuils River** | **Vf** | 70-150 | 47.16 | 12.23 | 8.07 | 19.21 | 7.14 | 3.49 | 2.69 |
| **Devon Valley** | **Oa** | 0-35 | 13.70 | 5.61 | 8.74 | 37.39 | 16.24 | 9.63 | 8.70 |
| **Devon Valley** | **Oa** | 35-70 | 11.86 | 5.52 | 8.92 | 36.86 | 17.45 | 8.76 | 10.64 |
| **Devon Valley** | **Oa** | 70-110 | 17.14 | 5.77 | 7.74 | 35.33 | 16.29 | 8.31 | 9.43 |
| **Devon Valley** | **Gs** | 0-30 | 30.95 | 8.12 | 4.98 | 27.86 | 12.81 | 7.05 | 8.24 |
| **Devon Valley** | **Gs** | 30-60 | 47.63 | 9.56 | 2.75 | 19.87 | 8.62 | 5.01 | 6.56 |
| **Devon Valley** | **Gs** | 60-110 | 57.70 | 8.62 | 3.51 | 15.74 | 5.48 | 3.57 | 5.38 |

The cumulative mass percentages of the different sand size particles for the Durbanville, Kuils River and Devon Valley soils are presented in Figures 4.1, 4.2 and 4.3 respectively and those of the other localities in Appendix 4.4. Although both soils at the Durbanville site is dominated by fine and very fine sand (73.8% - 81.5% of the total sand fraction), the Westleigh soil show a slight medium sand increase on the distribution curve, especially in the C horizon (90-120 cm), and to a lesser extent, the soft plintic B horizon (30-90 cm) (Figure 4.1a). This suggests that the C horizon may have acquired some medium sand at some stage during parent material deposition or soil development. This process also applied to the B horizon, though to a lesser extent. It also suggests that the C horizon could contain semi-weathered or saprolitic material originating from the underlying phyllitic shales, and to a lesser extent in the B horizon, resulting in the contribution of coarser material. The translocation of fine and very fine sand, originating from weathered surrounding phyllitic shales by continuous wind and/or water and/or soil creep processes, could result in the deposition of this material downwards to form part of the A horizons of soils down-slope.

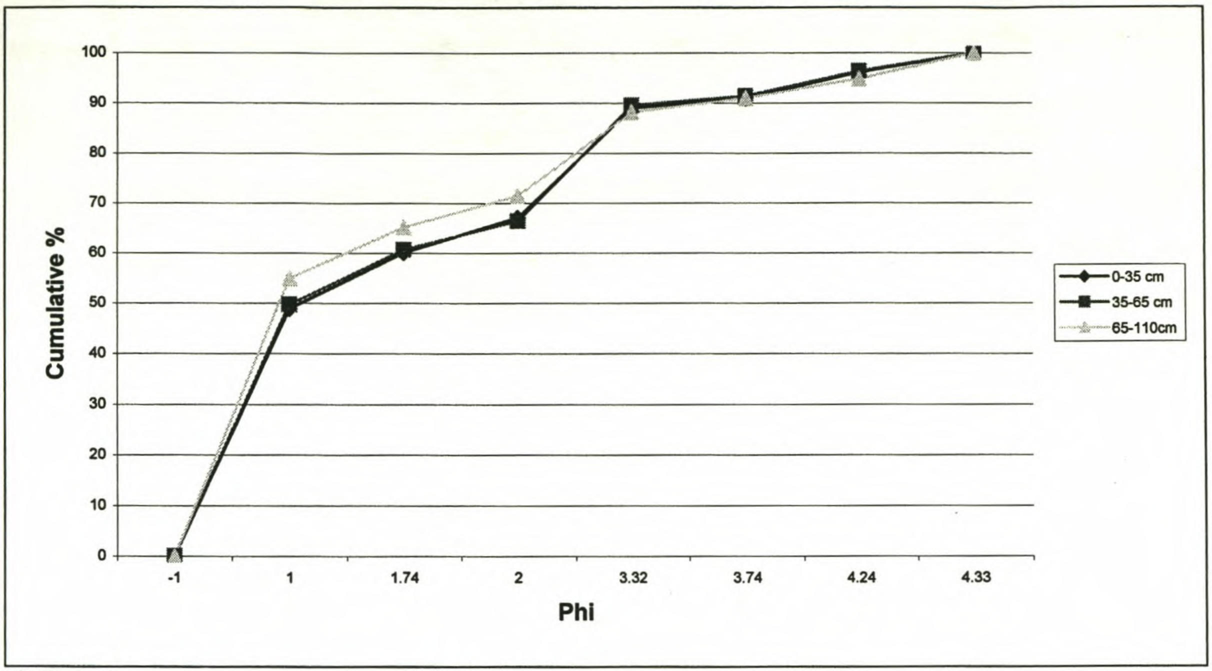


**a) Westleigh**

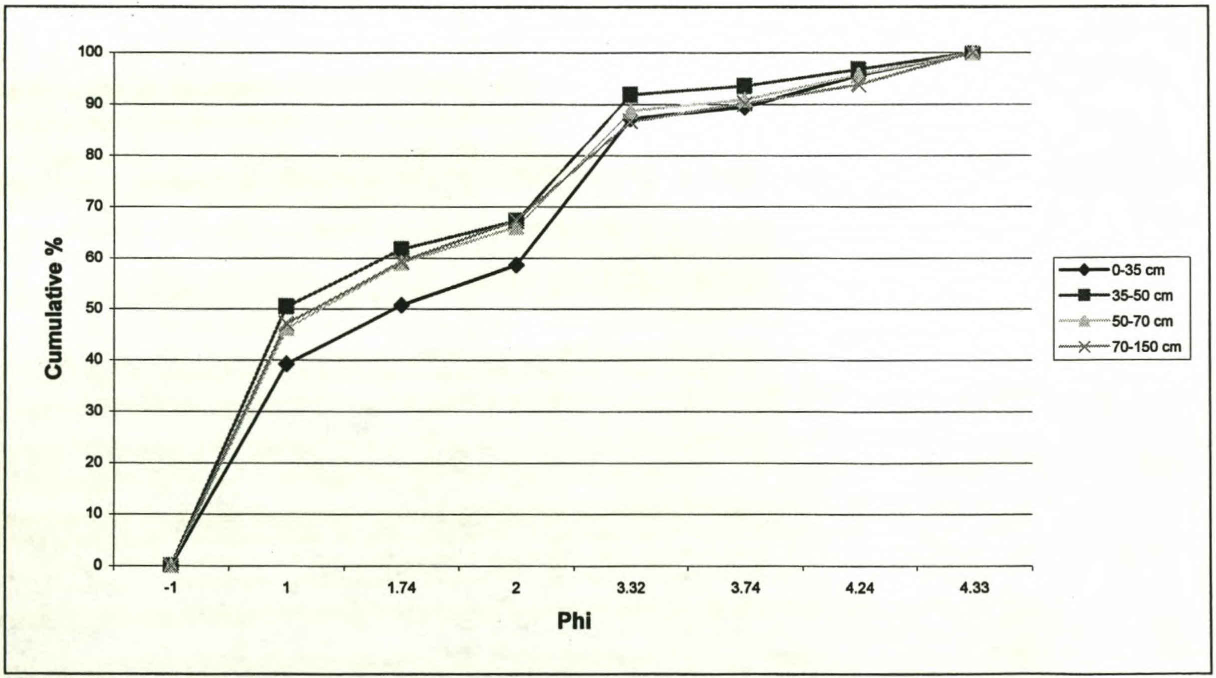


**b) Tukulu**

**Figure 4.1** Cumulative mass percentage sand plotted against grain-size (phi) for Durbanville.

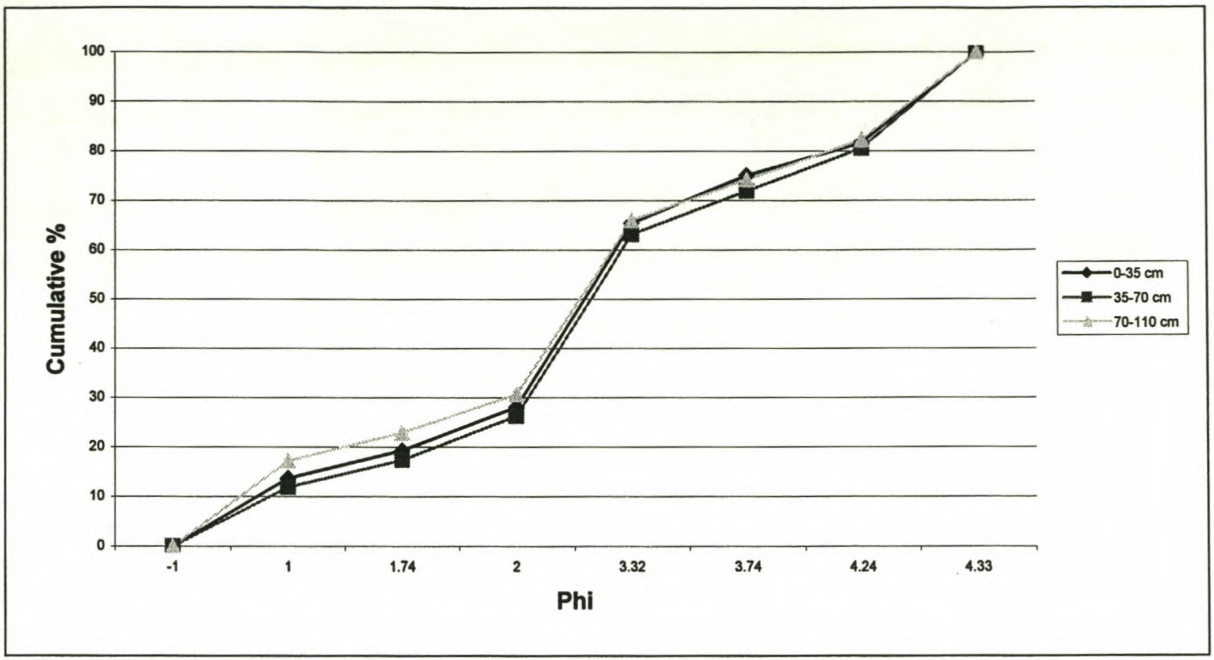


**a) Tukulu**

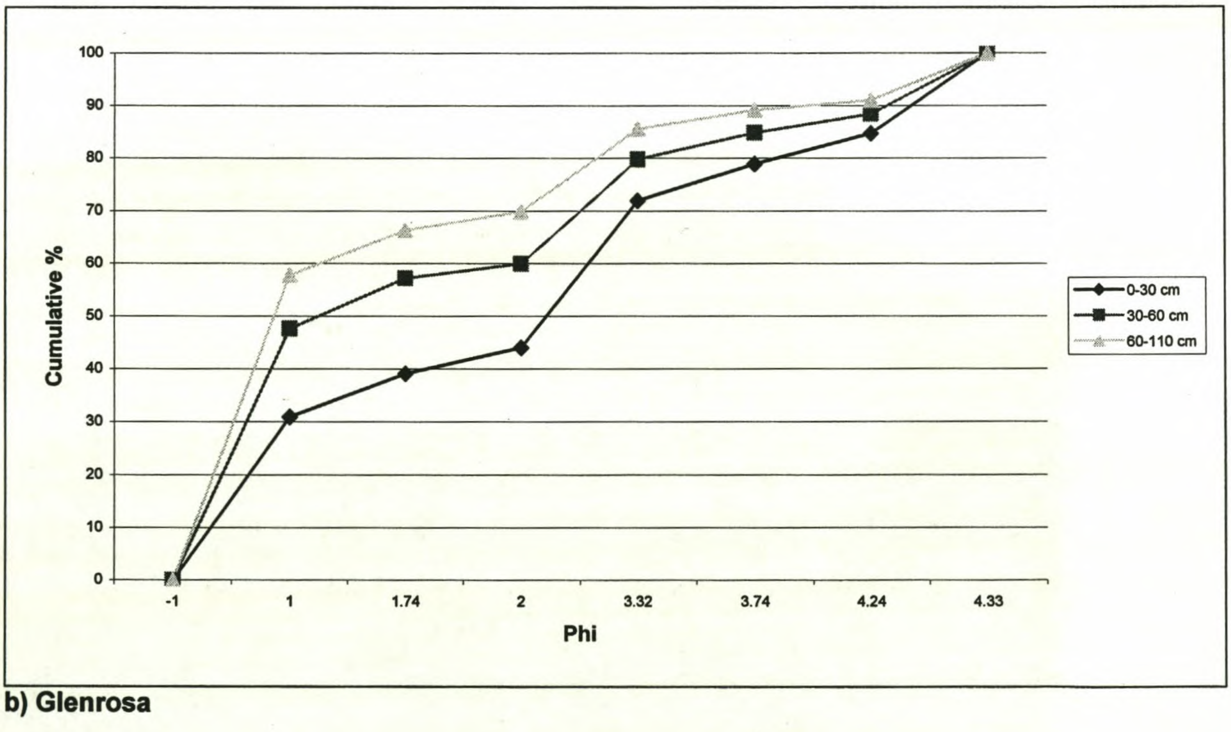


**b) Vilafontes**

**Figure 4.2** Cumulative mass percentage sand plotted against grain-size (phi) for Kuils River.



**a) Oakleaf**



**b) Glenrosa**

**Figure 4.3** Cumulative mass percentage sand plotted against grain-size (phi) for Devon Valley.

This could be the reason for the higher quantity fine and very fine sand in the A horizon of the Westleigh soil (Table 4.2). The distribution curve for the Tukulu soil at the Durbanville site does not reflect the same increase in medium sand when compared with the Westleigh soil (Figure 4.1b). The C horizon of the Tukulu soil is similar to the A horizon of the Westleigh soil, both containing the highest quantity of total fine sand and very fine sand (80.16% and 81.5% of the total sand fraction respectively) (Table 4.2). From these results it was concluded that two soils, more or less 60 metres apart, and on the same elevation, containing predominantly fine and very fine sand fractions, can differ to a significant extent when comparing cumulative sand fraction distribution curves, and that micro-topography as well as different processes of weathering, erosion and deposition probably played a major role in soil development.

The cumulative mass percentages of the different sand classes for the Kuils River soils are presented in Figures 4.2a and 4.2b. As discussed previously, the soils at this locality are dominated by the coarse sand fraction (inherited from granitic parent material) and differ significantly form the other localities in the study (Table 4.1). The cumulative graphs for distribution of the sand fractions in the two soils at this locality indicate that the A horizon of the Vilafontes soil is distinctive. This is the only horizon at this locality that contain less than 40% coarse sand and more than 40% fine + very fine sand of the total sand fraction (Table 4.2). Down-slope movement of finer material due to colluvium action, wind action or soil creep might be indicated by this horizon. This phenomenon, however, is not that distinctive in the A horizon of the Tukulu soil. Distribution curves for all the other horizons show that the C horizon of the Tukulu soil contains more coarse and less fine sand when compared with the neocutanic B and C horizons of the Vilafontes form. The coarse material in the C horizon may indicate *in situ* weathering of the porhyritic granite underlying this soil. The C horizon of the Vilafontes soil also contains more coarse sand when compared with the A and neocutanic B horizons, but the E horizon contains slightly higher quantities coarse sand. Again, the coarse material in the lower horizon may indicate *in situ* weathering of the porhyritic granite underlying this soil. The E horizon, however, is more a function of other pedogenetic processes than soil parent material and does not necessarily reflect differences in parent rocks.

As discussed previously, no specific parent rock could be identified as the predominant parent rock at the Devon Valley locality, although it is a clear from geological data that the soils at this locality are underlain by hornfels and surrounded by porhyritic granites (Chapter 2) and that more than one source of parent material could be present. The cumulative mass percentages of the different sand size classes for the Devon Valley soils are presented in Figures 4.3a and 4.3b. From these graphs it is clear that these soils are different and that the Oakleaf soil contain more fine sand (probably originating from the hornfels) when compared with the Glenrosa soil. The Glenrosa soil contains almost 60% coarse sand in the saprolitic horizon, suggesting *in situ* weathering of the hornfels. The lithocutanic B horizon also contains high quantities of coarse sand (48%), also the result of *in situ* weathering of hornfels. It is suggested that the 31% coarse sand in the A horizon of this soil was the result of granitic material from the surrounding granites, especially when this soil is compared with the Oakleaf soil. Not one of the horizons in this soil contains more than 20% coarse sand. A possibility that may explain these major differences between the two soils in close proximity is that the removal of an entire soil profile could have taken place downslope, exposing saprolitic material. If one suggests that the lower horizon of the Oakleaf soil is also underlain by hornfels saprolite, but was not sampled to such a depth in this study and therefore do not show high quantities of coarse sand, it could be possible that the removal of the entire Oakleaf soil would result in the exposure of semi-weathered rocks with high quantities of sand. It is then possible that an orthic A horizon could form on such exposed material to form a Glenrosa soil. This could mean that the Glenrosa soil at the Devon Valley locality formed after an Oakleaf (or similar) soil was removed by erosion or soil creep.

The data for the other localities are presented in Appendix 4.3.

### 4.2.3 Readily available water (RAW)

Readily available water (RAW), clay (%), total clay + silt (%) and total clay + silt + fine sand (%) for the different soils (as weighted averages up to one meter soil depth) are presented in Table 4.3. RAW was not determined for Devon Valley Gs due to the very high content of gravel and stone (>2,0 mm) that prevented undisturbed sampling. The results for individual horizons in the different soils are presented in Appendix 4.5. The relationship between RAW and clay (%), RAW and clay + silt (%) and RAW and clay + silt + fine sand (%) using all the data for all the soil samples showed no statistically significant relationships. When comparing the weighted RAW results of the two soils at Simonsberg, Kuils River, and Durbanville, the soil with the lowest clay (%), lowest clay + silt (%) and lowest clay + silt + fine sand (%) show the highest RAW. At Helshoogte and Devon Valley, the particle size distribution of the two soils at each locality is very similar, but both Oakleaf soils contain more RAW.

## 4.3 GRAVEL AND STONE MATERIAL

The macroscopic description of the gravel and stone material (> 2 mm) for the different soil samples (Appendix 4.2) indicated that all the soils in the study contain Fe and/or Al concretions. Altered rocks fragments were highly ferricised and probably represents transported material, except at the Kuils River, where original granite rock fragments occur. Altered rock fragments indicated that granitic material was the only rock type found in the Hutton soil at Simonsberg, in both soils from Kuils River and in both soils from Helshoogte. The Tukulu soil from Simonsberg, however, contains both granitic and ferricised sandstone material. The soils at Papegaaiberg and Devon Valley contain both ferricised hornfelsic and granitic material. The soils at the Durbanville locality, however, contain only highly ferricised phyllitic shale material as rock fragments in the > 2mm fraction.

**Table 4.3** Readily available water, clay, total clay + silt and total clay + silt + fine sand and gravel + stone for the different soils as weighed average to 1 meter depth.

| Locality | RAW (mm $m^{-1}$) | Clay (%) | Clay + Silt (%) | Clay + silt + fine sand (%) | Gravel + stone (%) |
|---|---|---|---|---|---|
| **Simonsberg Hu** | 149 | 40.6 | 57.6 | 79.3 | 3.5 |
| **Simonsberg Tu** | 113 | 42.1 | 59.8 | 87.5 | 14.0 |
| **Kuils River Tu** | 120 | 8.0 | 26.1 | 49.0 | 37.2 |
| **Kuils River Vf** | 99 | 20.4 | 40.1 | 62.2 | 30.6 |
| **Helshoogte Oa** | 109 | 30.6 | 55.2 | 75.1 | 9.8 |
| **Helshoogte Hu** | 145 | 31.8 | 53.1 | 75.8 | 13.0 |
| **Papegaaiberg Av** | 193 | 32.7 | 46.1 | 72.3 | 2.1 |
| **Papegaaiberg Tu** | 161 | 33.1 | 49.9 | 74.3 | 36.1 |
| **Devon Valley Oa** | 191 | 29.5 | 55.9 | 85.5 | 26.0 |
| **Devon Valley Gs** | Not determined | 32.7 | 63.1 | 77.6 | 57.0 |
| **Durbanville We** | 182 | 19.5 | 46.2 | 82.7 | 3.4 |
| **Durbanville Tu** | 237 | 8.9 | 31.2 | 81.9 | 3.8 |

## 4.4 CANONICAL DISCRIMINANT ANALYSIS

The graphical presentation of the canonical discriminant analysis is presented in Figure 4.4. As discussed, the objective of this analysis was to determine if the combinations made by the gravel and stone and different sand size fractions could be used to separate the localities in the study. Coefficients of the linear canonical variable (r) is positively discriminating when values exceed 0.5. Canonical variable 1 had the most discriminating power (79.9%) and is the best in separating the localities. This variable is positively correlated with coarse sand (r = 0.53) and the 0.5 - 0.3 mm fraction of medium sand (r = 0.71). Canonical variable 2 has the second most discriminating power (12.2%) and is positively correlated with coarse sand (r = 0.83). These variables indicated that combinations of the > 2 mm fraction and the different sand sizes separated Durbanville, Devon Valley and Kuils River.

## 4.5 CONCLUSIONS

Statistical analysis indicates that soils from the different localities are characterised by different sand size fraction distributions. Soils from Durbanville are dominated by fine sand and correlates with the underlying phyllitic shales. Soils from Kuils River contain significantly more coarse sand when compared with the other sites and correlates with the underlying coarse granitic material. This could imply that *in situ* weathering played an important role in soil development, but does not prove that these soils formed solely from underlying rocks. In both soils, the material in the gravel and stone fraction seem to have been derived from single sources (granitic at Kuils River and shale at Durbanville). The soils from Helshoogte and

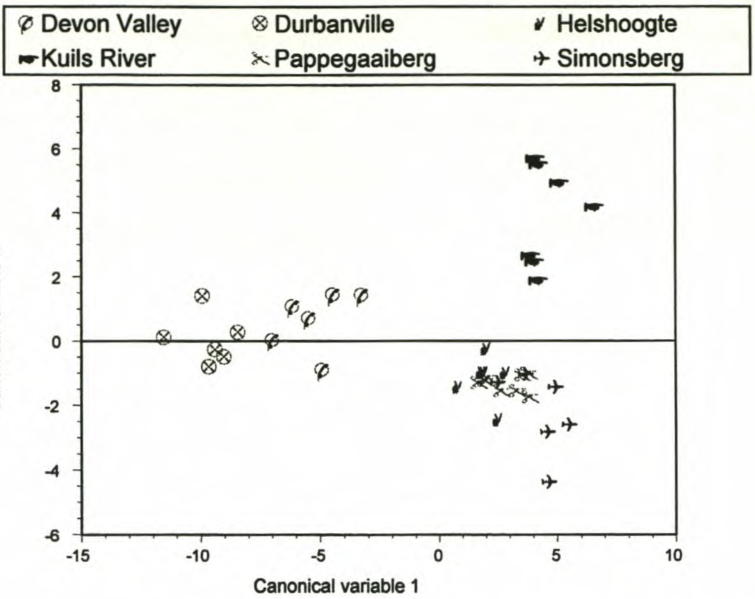


**Figure 4.4** Graphical presentation of a canonical discriminant analysis, differentiating between the different localities. (Each marker style on the graph represents a different locality).

Simonsberg (both underlain by granites), Papegaaiberg and Devon Valley (both underlain by hornfels) are not significantly dominated by a particular sand fraction. Soils from these localities therefore do not only reflect underlying material as parent material. This could imply mixing of parent material and/or effects of aeolian sand at Helshoogte, Simonsberg and Devon Valley and/or marine processes (Papegaaiberg). These suggestions, however, should be confirmed by clay mineral analysis (discussed in Chapter 5). Canonical discriminant analysis indicated that different combinations of gravel and stone and sand size fractions could separate the Durbanville, Papegaaiberg and Kuils River localities. These localities also differ with regard to underlying rock types.

## 4.5 REFERENCES

BENNETT, S & BOWERS, D., 1976. An introduction to multivariate techniques for social and behavioural sciences.

KRUMBEIN, W.C. & PETTIJOHN, F.J., 1938. Manual of sedimentary petrology. Appleton-Century-Crofts, Inc., New York, USA.

MILLAR, C.E., TURK, L.M. & FOTH, H.D., 1965. Fundamentals of soil science. Forth Edition. John Wiley & Sons, New York.

SRIVASTAVA, M.S. & CARTER, E.M., 1983. An introduction to applied multivariate Statistics, North-Holland.

SAS.1990. SAS/STAT. User's Guide. Version 6. Fourth Edition, Vol. 2, SAS Institute.

VAN ROOYEN, T.H., 1971. Soils of the central Orange River basin. PhD-thesis. University of the Orange Free State, Bloemfontein, South Africa. December 1971.

**Appendix 4.1** Particle size analysis of diagnostic horizons at the six localities.

| Locality and soil type | Depth (cm) | Gravel + Stone (>2mm) | Goarse Sand (2.0-0.5mm) | Medium Sand (0.5-0.3mm) | Medium Sand (0.3-0.25mm) | Fine Sand (0.25-0.1mm) | Very Fine Sand (0.1-0.075mm) | Very Fine Sand (0.075-0.053mm) | Very Fine Sand (0.053-0.050 mm) | Total Sand (2.0-0.5mm) | Coarse Silt (0.05-0.02mm) | Fine Silt (0.02-0.002mm) | Total Silt (0.05-0.002mm) | Clay (<0.002mm) | Total Soil (<2.0mm) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Simonsberg Hu | 0-30 | 1.6 | 7.5 | 4.64 | 7.56 | 14.5 | 4.8 | 1.58 | 1.52 | 42.1 | 7.0 | 11.0 | 18.0 | 38.6 | 98.7 |
| | 30-80 | 3.4 | 7.6 | 4.05 | 6.65 | 13.7 | 4.30 | 1.26 | 1.34 | 38.9 | 6.5 | 8.7 | 15.2 | 44.9 | 99.0 |
| | 80-120 | 6.6 | 11.8 | 4.90 | 5.40 | 13.6 | 5.48 | 1.96 | 2.16 | 45.3 | 9.0 | 11.2 | 20.2 | 32.6 | 98.1 |
| Simonsberg Tu | 0-25 | 31.9 | 13.6 | 6.18 | 6.82 | 12.8 | 3.63 | 1.22 | 1.25 | 45.5 | 5.3 | 9.5 | 14.8 | 38.0 | 98.3 |
| | 25-70 | 16.4 | 10.4 | 4.31 | 6.09 | 11.5 | 3.60 | 1.22 | 1.18 | 38.3 | 4.9 | 9.7 | 14.6 | 45.9 | 98.8 |
| | 70-100 | 1.0 | 3.1 | 2.94 | 9.76 | 15.0 | 3.27 | 1.08 | 0.95 | 36.1 | 6.1 | 18.5 | 24.6 | 39.8 | 100.5 |
| Kuils River Tu | 0-35 | 28.8 | 35.8 | 8.19 | 5.11 | 16.1 | 5.2 | 1.41 | 1.39 | 73.2 | 6.5 | 8.7 | 15.2 | 9.9 | 98.3 |
| | 35-65 | 40.3 | 37.2 | 8.18 | 4.32 | 17.3 | 5.07 | 1.37 | 1.36 | 74.8 | 6.1 | 9.4 | 15.5 | 7.8 | 98.1 |
| | 65-110 | 43.0 | 38.4 | 7.16 | 4.44 | 11.7 | 4.59 | 1.94 | 1.67 | 69.9 | 7.5 | 15.6 | 23.1 | 6.3 | 99.3 |
| Kuils River Vf | 0-35 | 30.1 | 27.1 | 7.94 | 5.46 | 19.7 | 5.79 | 1.53 | 1.48 | 69.0 | 3.6 | 9.2 | 12.8 | 16.6 | 98.4 |
| | 35-50 | 37.8 | 38.0 | 8.41 | 4.19 | 18.5 | 3.64 | 1.26 | 1.20 | 75.2 | 7.0 | 13.2 | 20.2 | 4.1 | 99.5 |
| | 50-70 | 39.5 | 27.4 | 7.67 | 4.13 | 13.4 | 4.15 | 1.33 | 1.22 | 59.3 | 5.9 | 11.3 | 17.2 | 22.1 | 98.6 |
| | 70-150 | 21.6 | 21.6 | 5.60 | 3.70 | 8.8 | 3.27 | 1.60 | 1.23 | 45.8 | 6.8 | 14.3 | 21.1 | 31.9 | 98.8 |
| Helshoogte Oa | 0-40 | 5.2 | 14.7 | 4.17 | 4.73 | 11.3 | 4.58 | 1.93 | 2.19 | 43.6 | 9.3 | 14.8 | 24.1 | 30.3 | 98.0 |
| | 40-80 | 5.0 | 14.5 | 4.6 | 4.6 | 11.7 | 4.50 | 1.61 | 1.89 | 43.4 | 11.1 | 14.7 | 25.8 | 29.1 | 98.3 |
| | 80-110 | 28.8 | 11.4 | 4.79 | 5.21 | 11.7 | 4.71 | 1.75 | 2.04 | 41.6 | 9.5 | 13.5 | 23.0 | 34.2 | 98.8 |
| Helshoogte Hu | 0-30 | 0 | 12.9 | 5.09 | 5.41 | 14.2 | 4.93 | 2.02 | 2.15 | 46.7 | 10.4 | 14.5 | 24.9 | 26.4 | 98.0 |
| | 30-70 | 2.3 | 13.6 | 4.97 | 5.53 | 13.7 | 5.12 | 1.86 | 2.22 | 47.0 | 8.4 | 14.3 | 22.7 | 28.1 | 97.8 |
| | 70-100 | 40.1 | 7.9 | 3.91 | 7.19 | 14.5 | 4.69 | 1.32 | 1.49 | 41.0 | 6.5 | 9.2 | 15.7 | 42.1 | 98.8 |
| Papegaaiberg Av | 0-25 | 1.3 | 12.7 | 7.38 | 8.62 | 17.5 | 6.64 | 2.28 | 2.18 | 57.3 | 6.9 | 7.9 | 14.8 | 25.1 | 97.2 |
| | 25-60 | 0 | 9.6 | 5.63 | 6.87 | 15.8 | 6.01 | 2.18 | 2.21 | 48.3 | 5.2 | 8.5 | 13.7 | 34.4 | 96.4 |
| | 60-95 | 4.1 | 12.7 | 6.46 | 7.04 | 15.2 | 5.50 | 1.92 | 2.08 | 50.9 | 4.3 | 7.7 | 12.0 | 35.0 | 97.9 |
| | 95-120 | 6.5 | 9.9 | 5.44 | 5.56 | 15.3 | 5.63 | 1.97 | 2.00 | 46.8 | 4.8 | 7.4 | 12.2 | 36.9 | 95.9 |
| Papegaaiberg Tu | 0-25 | 10.4 | 10.9 | 5.59 | 7.15 | 17.7 | 7.13 | 2.37 | 2.5 | 53.7 | 5.1 | 8.0 | 13.1 | 30.1 | 96.9 |
| | 25-50 | 20.7 | 11.0 | 5.88 | 6.32 | 16.2 | 6.02 | 2.01 | 2.37 | 49.8 | 6.1 | 6.8 | 12.9 | 36.3 | 99.0 |
| | 50-80 | 57.1 | 13.1 | 6.26 | 6.34 | 14.9 | 5.60 | 1.89 | 2.01 | 50.1 | 14.7 | 7.0 | 21.7 | 35.0 | 96.8 |
| | 80-130 | 55.7 | 15.1 | 6.97 | 6.71 | 16.4 | 1.10 | 0.40 | 0.40 | 46.9 | 13.0 | 7.3 | 20.3 | 31.3 | 98.5 |
| Devon Valley Oa | 0-35 | 10.3 | 6.3 | 2.58 | 4.02 | 17.2 | 7.47 | 4.43 | 4.00 | 46.0 | 15.5 | 12.7 | 28.2 | 22.4 | 96.6 |
| | 35-70 | 10.4 | 4.6 | 2.14 | 3.46 | 14.3 | 6.77 | 3.40 | 4.13 | 38.8 | 13.6 | 12.2 | 25.8 | 32.9 | 97.5 |
| | 70-110 | 62.3 | 6.6 | 2.22 | 2.98 | 13.6 | 6.27 | 3.20 | 3.63 | 38.5 | 14.0 | 10.8 | 24.8 | 33.9 | 97.2 |
| Devon Valley Gs | 0-30 | 36.9 | 13.0 | 3.41 | 2.09 | 11.7 | 5.38 | 2.96 | 3.46 | 42.0 | 12.9 | 18.8 | 31.7 | 24.0 | 97.7 |
| | 30-60 | 59.3 | 15.1 | 3.03 | 0.87 | 6.3 | 2.73 | 1.59 | 2.08 | 31.7 | 9.5 | 15.1 | 24.6 | 39.6 | 95.9 |
| | 60-110 | 70.4 | 17.6 | 2.63 | 1.07 | 4.8 | 1.67 | 1.09 | 1.64 | 30.5 | 7.8 | 25.9 | 33.7 | 34.0 | 98.2 |
| Durbanville We | 0-30 | 7.1 | 4.4 | 1.04 | 3.46 | 18.8 | 9.67 | 4.77 | 5.86 | 48.0 | 14.4 | 13.4 | 27.8 | 15.1 | 90.9 |
| | 30-90 | 1.9 | 3.7 | 2.79 | 5.51 | 16.8 | 8.48 | 4.52 | 5.9 | 47.7 | 13.5 | 13.2 | 26.7 | 20.3 | 94.7 |
| | 90-120 | 1.4 | 3.9 | 5.16 | 2.54 | 15.9 | 7.56 | 4.13 | 5.11 | 44.3 | 12.8 | 11.5 | 24.3 | 26.5 | 95.1 |
| Durbanville Tu | 0-30 | 4.0 | 6.3 | 3.82 | 6.28 | 27.4 | 13.2 | 5.50 | 5.79 | 68.3 | 8.9 | 9.3 | 18.2 | 9.6 | 96.1 |
| | 30-80 | 4.4 | 5.5 | 3.29 | 5.41 | 27.5 | 12.9 | 6.14 | 5.87 | 66.7 | 10.4 | 11.1 | 21.5 | 8.6 | 96.8 |
| | 80-130 | 1.8 | 3.5 | 2.57 | 4.93 | 19.7 | 13.5 | 5.94 | 5.28 | 55.5 | 12.0 | 18.3 | 30.3 | 8.5 | 94.2 |

**Appendix 4.2** Macroscopic description of gravel and stone material (>2 mm fraction) for each diagnostic horizon at the six localities.

| Locality and soil | Soil depth (cm) | Fe and/or Al concretions | Altered rock fragments(1) | | | |
|---|---|---|---|---|---|---|
| | | | Granitic origin | Sandstone origin | Hornfelsic origin | Phyllitic shale origin |
| Simonsberg Hu | 0-30 | ** | *** | - | - | - |
| | 30-80 | *** | *** | - | - | - |
| | 80-120 | *** | ** | - | - | - |
| Simonsberg Tu | 0-25 | * | *** | ** | - | - |
| | 25-70 | * | *** | ** | - | - |
| | 70-100 | * | *** | ** | - | - |
| Kuils River Tu | 0-35 | * | *** | - | - | - |
| | 35-65 | * | *** | - | - | - |
| | 65-110 | * | ** | - | - | - |
| Kuils River Vf | 0-35 | ** | ** | - | - | - |
| | 35-50 | ** | ** | - | - | - |
| | 50-70 | ** | ** | - | - | - |
| | 70-150 | * | ** | - | - | - |
| Helshoogte Oa | 0-40 | ** | *** | - | - | - |
| | 40-80 | ** | *** | - | - | - |
| | 80-110 | *** | *** | - | - | - |
| Helshoogte Hu | 0-30 | ** | *** | - | - | - |
| | 30-70 | ** | *** | - | - | - |
| | 70-100 | *** | *** | - | - | - |
| Papegaaiberg Av | 0-25 | *** | ** | - | * | - |
| | 25-60 | *** | ** | - | * | - |
| | 60-95 | *** | ** | - | * | - |
| | 95-120 | *** | ** | - | * | - |
| Papegaaiberg Tu | 0-25 | *** | ** | - | * | - |
| | 25-50 | ** | ** | - | * | - |
| | 50-80 | *** | ** | - | * | - |
| | 80-130 | *** | ** | - | * | - |
| Devon Valley Oa | 0-35 | * | * | - | *** | - |
| | 35-70 | * | * | - | *** | - |
| | 70-110 | ** | * | - | ** | - |
| Devon Valley Gs | 0-30 | n.s. | n.s | n.s | n.s | n.s |
| | 30-60 | n.s. | n.s | n.s | n.s | n.s |
| | 60-110 | n.s. | n.s | n.s | n.s | n.s |
| Durbanville We | 0-30 | * | - | - | - | ** |
| | 30-90 | ** | - | - | - | ** |
| | 90-120 | ** | - | - | - | *** |
| Durbanville Tu | 0-30 | *** | - | - | - | ** |
| | 30-80 | *** | - | - | - | ** |
| | 80-130 | *** | - | - | - | ** |

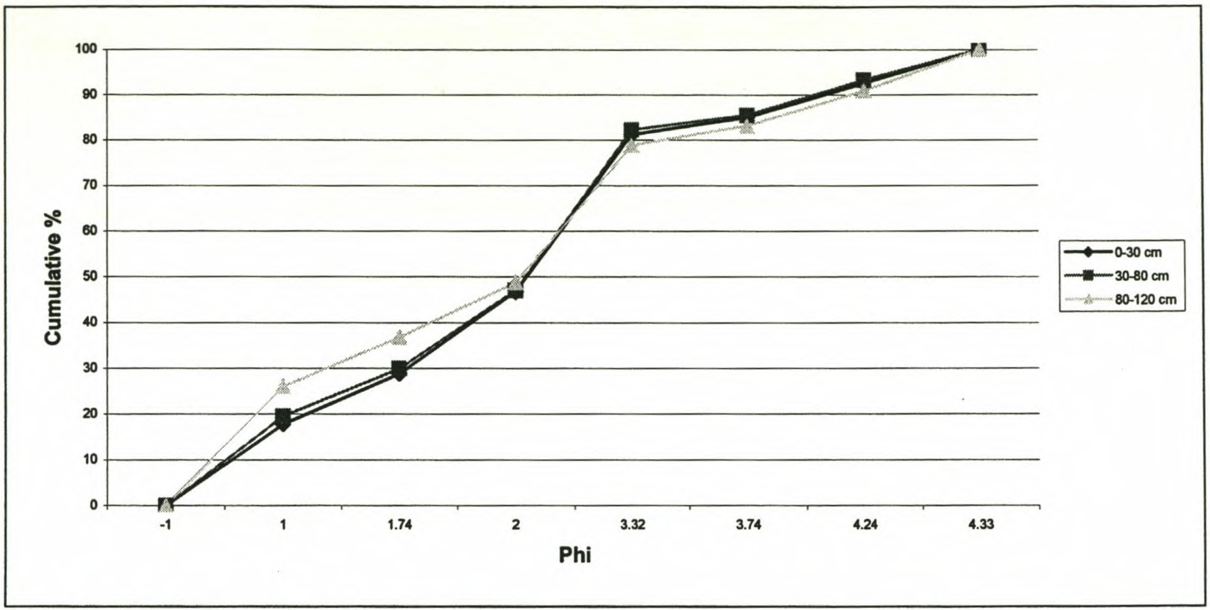
(1) = Majority of samples is highly ferricised

*** = abundant
** = common
* = rare
- = absent
n.s. = not sampled

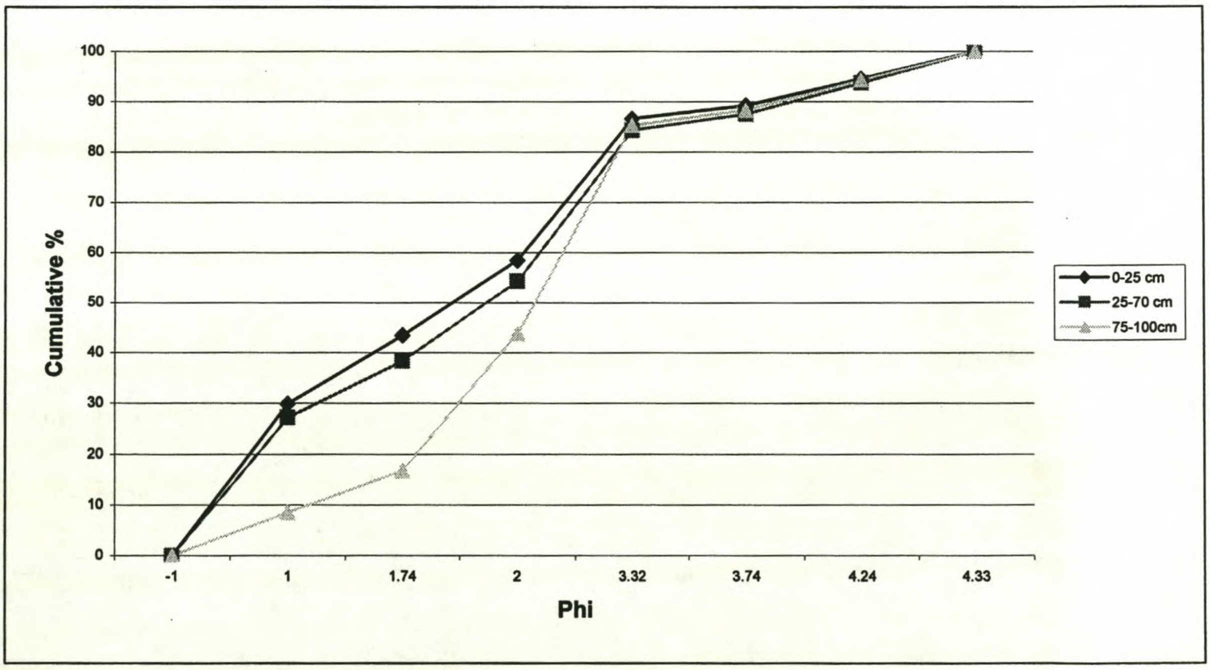
**Appendix 4.3** Sand fraction distribution of horizons at the Simonsberg, Helshoogte and Papegaaiberg localities.

| Locality | Soil type | Depth (cm) | Coarse sand (2.0-0.5 mm) | Medium sand (0.5-0.3 mm) | Medium sand (0.3-0.25 mm) | Fine Sand (0.25-0.1 mm) | Very Fine Sand (0.1-0.075 mm) | Very fine sand (0.075-0.053 mm) | Very fine sand (0.053-0.05 mm) |
|---|---|---|---|---|---|---|---|---|---|
| Simonsberg | Hu | 0-30 | 17.82 | 11.02 | 17.96 | 34.44 | 11.40 | 3.75 | 3.61 |
| Simonsberg | Hu | 30-80 | 19.54 | 10.41 | 17.10 | 35.22 | 11.05 | 3.24 | 3.44 |
| Simonsberg | Hu | 80-120 | 26.05 | 10.82 | 11.92 | 30.02 | 12.10 | 4.33 | 4.77 |
| Simonsberg | Tu | 0-25 | 29.90 | 13.58 | 14.99 | 28.13 | 7.98 | 2.68 | 2.75 |
| Simonsberg | Tu | 25-70 | 27.15 | 11.25 | 15.90 | 30.03 | 9.40 | 3.18 | 3.08 |
| Simonsberg | Tu | 70-100 | 8.59 | 8.14 | 27.04 | 41.55 | 9.06 | 2.99 | 2.63 |
| Helshoogte | Oa | 0-40 | 33.72 | 9.56 | 10.85 | 25.92 | 10.51 | 4.42 | 5.02 |
| Helshoogte | Oa | 40-80 | 33.41 | 10.60 | 10.60 | 26.96 | 10.37 | 3.71 | 4.35 |
| Helshoogte | Oa | 80-110 | 27.40 | 11.51 | 12.52 | 28.13 | 11.32 | 4.21 | 4.90 |
| Helshoogte | Hu | 0-30 | 27.62 | 10.90 | 11.59 | 30.41 | 10.56 | 4.33 | 4.60 |
| Helshoogte | Hu | 30-70 | 28.94 | 10.57 | 11.77 | 29.15 | 10.89 | 3.96 | 4.72 |
| Helshoogte | Hu | 70-100 | 19.27 | 9.54 | 17.54 | 35.37 | 11.44 | 3.22 | 3.63 |
| Papegaaiberg | Av | 0-25 | 22.16 | 12.88 | 15.04 | 30.54 | 11.59 | 3.98 | 3.80 |
| Papegaaiberg | Av | 25-60 | 19.88 | 11.66 | 14.22 | 32.71 | 12.44 | 4.51 | 4.58 |
| Papegaaiberg | Av | 60-95 | 24.95 | 12.69 | 13.83 | 29.86 | 10.81 | 3.77 | 4.09 |
| Papegaaiberg | Av | 95-120 | 21.62 | 11.87 | 12.14 | 33.41 | 12.29 | 4.21 | 4.27 |
| Papegaaiberg | Tu | 0-25 | 20.43 | 10.48 | 13.40 | 33.18 | 13.37 | 4.41 | 4.66 |
| Papegaaiberg | Tu | 25-50 | 22.09 | 11.81 | 12.69 | 32.53 | 12.09 | 4.04 | 4.76 |
| Papegaaiberg | Tu | 50-80 | 26.15 | 12.50 | 12.66 | 29.75 | 11.18 | 3.77 | 4.01 |
| Papegaaiberg | Tu | 80-130 | 32.07 | 14.80 | 14.25 | 34.83 | 2.34 | 0.85 | 0.85 |

**Appendix 4.4** Cumulative mass percentage of sand plotted against grain-size expressed in phi.

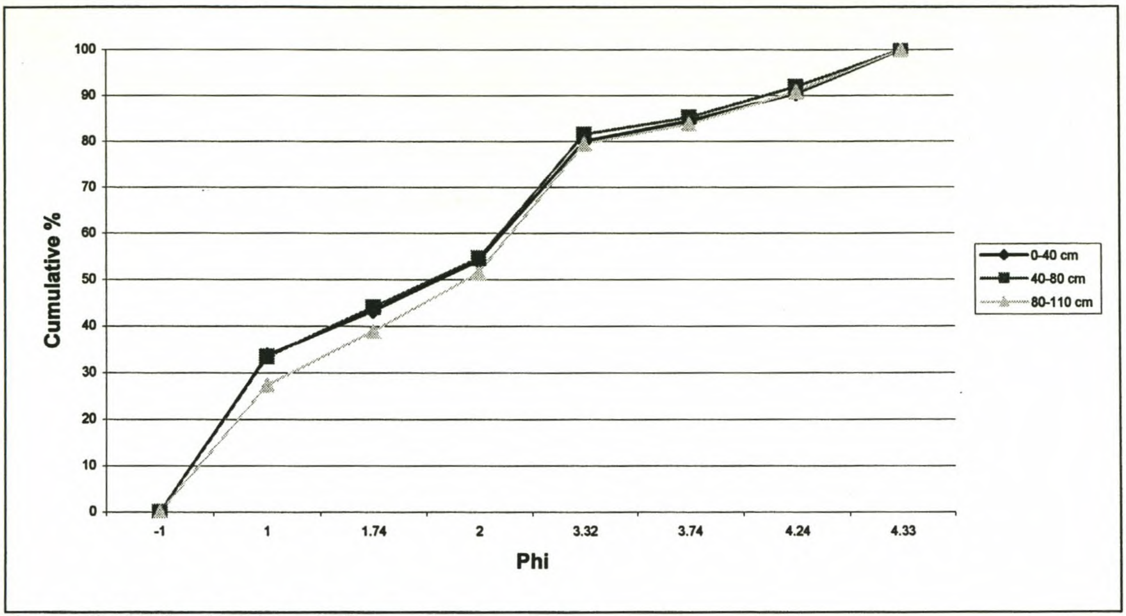


**Appendix 4.4.1.a Simonsberg Hu**

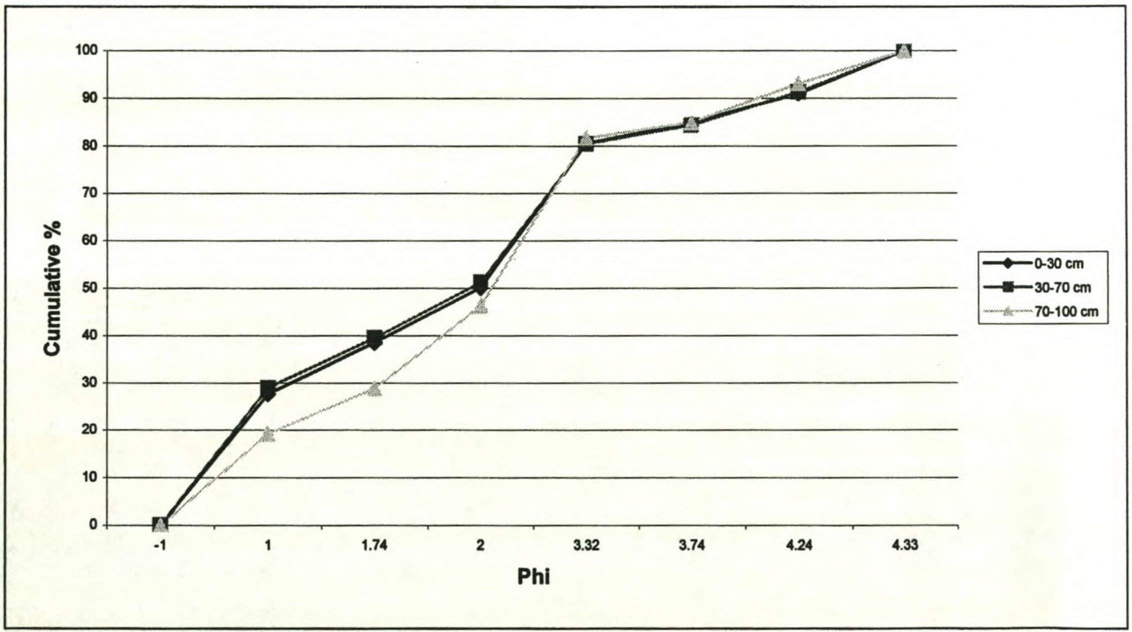


**Appendix 4.4.1.b Simonsberg Tu**

**Appendix 4.4 continues**

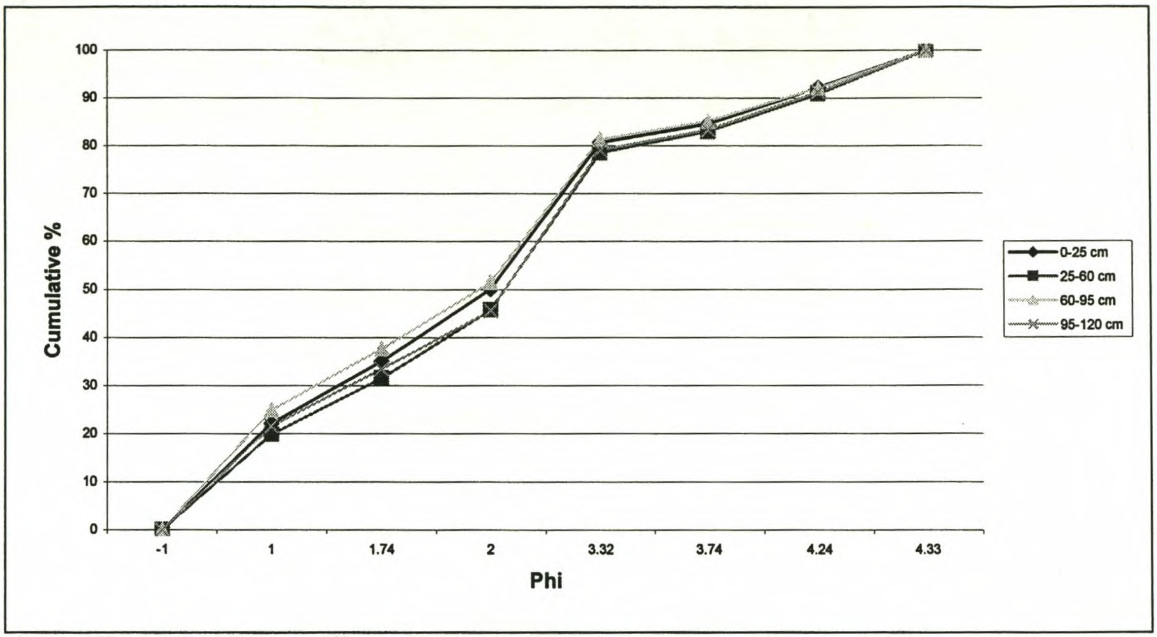


**Appendix 4.4.2.a Helshoogte Oa**

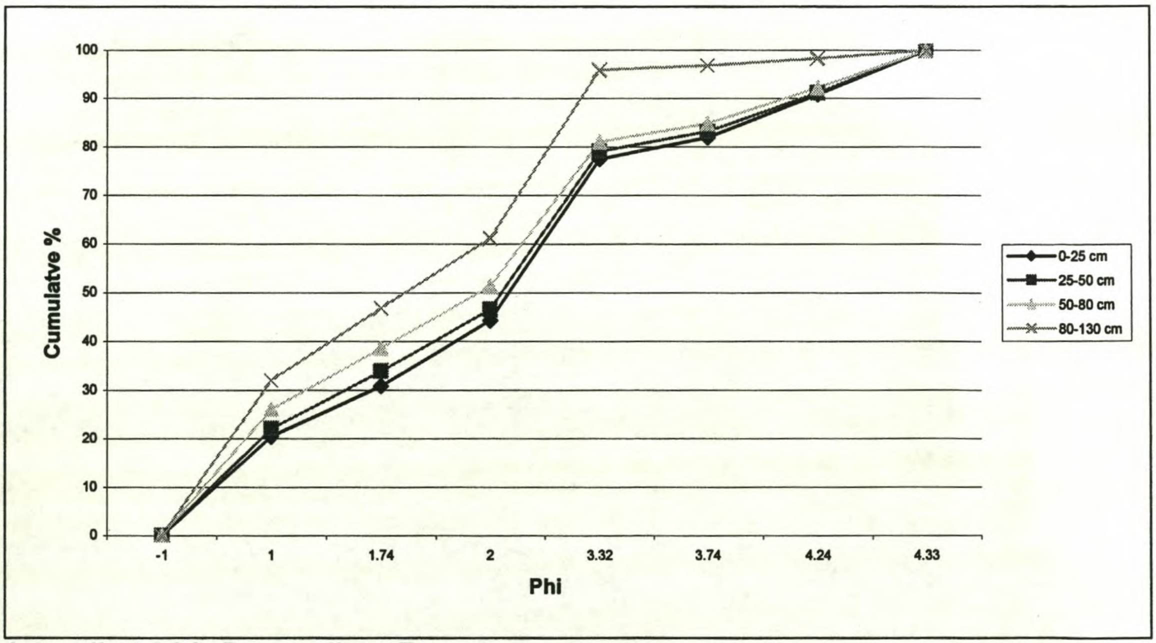


**Appendix 4.4.2.b Helshoogte Hu**

**Appendix 4.4 continues**



**Appendix 4.4.3.a Papegaaiberg Av**



**Appendix 4.4.3.b Papegaaiberg Tu**

**Appendix 4.5:** Readily available water (RAW), particle size fractions and bulk density values for the diagnostic horizons at the six localities.

| Locality and soil type | Depth (cm) | RAW: mm horizon$^{-1}$ | RAW: mm m$^{-1}$ | Bulk density (g cm$^{-3}$) | Clay (%) | Clay + silt (%) | Clay + silt + fine sand (%) |
|---|---|---|---|---|---|---|---|
| **Simonsberg Hu** | 0-30 | 42.9 | 143 | 1.37 | 38.6 | 56.6 | 79 |
| | 30-80 | 82.0 | 164 | 1.31 | 44.9 | 60.1 | 80.7 |
| | 80-120 | 46.8 | 117 | 1.51 | 32.6 | 52.8 | 76 |
| **Simonsberg Tu** | 0-25 | 27.5 | 110 | 1.37 | 38.0 | 52.8 | 71.7 |
| | 25-70 | 62.5 | 139 | 1.50 | 45.9 | 60.5 | 98.2 |
| | 70-100 | 22.5 | 75 | 1.35 | 39.8 | 64.4 | 84.7 |
| **Kuils River Tu** | 0-35 | 39.5 | 113 | 1.58 | 9.9 | 25.1 | 49.2 |
| | 35-65 | 42.5 | 141 | 1.51 | 7.8 | 23.3 | 48.4 |
| | 65-110 | 49.0 | 109 | 1.46 | 6.3 | 29.4 | 49.3 |
| **Kuils River Vf** | 0-35 | 37.8 | 108 | 1.61 | 16.6 | 29.4 | 57.9 |
| | 35-50 | 13.4 | 89 | 1.57 | 4.1 | 24.3 | 48.9 |
| | 50-70 | 25.0 | 125 | 1.48 | 22.1 | 39.3 | 59.2 |
| | 70-150 | 60.5 | 76 | 1.62 | 31.9 | 61.0 | 75.9 |
| **Helshoogte Oa** | 0-40 | 45.9 | 115 | 1.12 | 30.3 | 54.4 | 74.4 |
| | 40-80 | 37.0 | 93 | 1.25 | 29.1 | 54.9 | 74.6 |
| | 80-110 | 39.0 | 129 | 1.22 | 34.2 | 57.2 | 77.4 |
| **Helshoogte Hu** | 0-30 | 31.1 | 104 | 1.19 | 26.4 | 51.3 | 74.6 |
| | 30-70 | 42.4 | 106 | 1.34 | 28.1 | 50.8 | 73.7 |
| | 70-100 | 71.8 | 240 | 1.31 | 42.1 | 57.8 | 79.8 |
| **Papegaaiberg Av** | 0-25 | 66.1 | 265 | 1.40 | 25.1 | 39.9 | 68.5 |
| | 25-60 | 85.0 | 243 | 1.39 | 34.4 | 48.1 | 74.3 |
| | 60-120 | 62.5 | 156 | 1.51 | 36.0 | 48.1 | 72.9 |
| **Papegaaiberg Tu** | 0-25 | 42.0 | 168 | 1.38 | 30.1 | 43.2 | 72.9 |
| | 25-50 | 96.5 | 386 | 1.54 | 36.3 | 49.2 | 75.8 |
| | 50-130 | 35.7 | 45 | 1.90 | 33.0 | 53.5 | 74.1 |
| **Devon Valley Oa** | 0-35 | 63.1 | 180 | 1.49 | 22.4 | 50.6 | 83.7 |
| | 35-70 | 55.1 | 158 | 1.55 | 32.9 | 58.7 | 87.3 |
| | 70-110 | 97.1 | 243 | 1.53 | 33.9 | 58.7 | 85.4 |
| **Devon Valley Gs** | 0-30 | n.d.* | n.d. | n.d. | 24.0 | 55.7 | 79.2 |
| | 30-60 | n.d. | n.d. | n.d. | 39.6 | 64.2 | 76.9 |
| | 60-110 | n.d. | n.d. | n.d. | 34.0 | 67.7 | 76.9 |
| **Durbanville We** | 0-30 | 50.2 | 168 | 1.29 | 15.1 | 42.9 | 82.0 |
| | 30-90 | 115.3 | 192 | 1.26 | 20.5 | 47.2 | 82.9 |
| | 90-120 | 49.3 | 164 | 1.41 | 26.5 | 50.8 | 83.5 |
| **Durbanville Tu** | 0-30 | 81.7 | 272 | 1.33 | 9.6 | 27.8 | 79.7 |
| | 30-80 | 132.4 | 265 | 1.23 | 8.6 | 30.1 | 82.6 |
| | 80-130 | 57.7 | 115 | 1.66 | 8.5 | 38.8 | 83.2 |

* = not determined

# CHAPTER 5

# SOIL POTASSIUM AND MINERALOGY OF THE CLAY FRACTION

## 5.1 INTRODUCTION

In order to obtain an indication of the origin and possible mixing of parent materials prior to and during soil formation, samples from the different soil horizons in each profile were chemically analysed. The chemical composition of the soils was then related to that of the underlying material, and of the surrounding geology. Particular emphasis was placed on potassium, which is an extremely important nutrient element from the viewpoint of vine growth and wine quality. Because the soils used in this study are all located in production vineyards, the probability that fertilisers could contribute to nutrients in the soils, notably potassium, was high. The lower soil horizons were considered to be least affected by this contamination and therefore most likely to be indicative of the natural soil chemical composition.

A semi-quantitative analysis of the minerals in the clay fractions was also carried out. The objective was to identify the clay minerals that were present in the different soil horizons and to relate the minerals to weathering stages. Evidence linking the minerals in the clay fractions of the soil samples with the mineralogical composition of the soil parent materials was sought. Relationships between the clay fraction minerals and the T-values were also calculated and examined.

## 5.2 RESULTS AND DISCUSSION

### 5.2.1 Chemical results

Results obtained from the chemical analysis of the individual soil horizons are presented in Appendices 5.1 and 5.2. As discussed in Chapter 2, potassium was the most important element distinguishing the different rock types in the study. Lower horizon K values are listed in Table 5.1. The extractable Fe and Al (dithionite-citrate-bicarbonate method or DCB) values, and the T-values (sum of the exchangeable base cations: Ca, Mg, K and Na, plus the total exchangeable acidity) were compared with clay fraction mineralogy.

The average lower horizon K value of the two soil forms per locality was the lowest for the soils at Durbanville (17.6 mg kg$^{-1}$) (Table 5.1). This low level of potassium in the soil was predictable in view of the fact that the phyllitic shales that underlie the Durbanville locality contain very little potassium (Table 2.1). In contrast, the Devon Valley and Papegaaiberg lower horizons were characterised by relatively large amounts of K. However, because the hornfels that underlies these localities contains only minor amounts of K, an external source for this K is indicated. This K could have been derived from fertilisers that were leached into the subsoil. Alternatively, the lower horizon materials may have been derived from K-rich porphyritic granite at a contact zone and transported to the present localities. In the case of the Kuils River, Simonsberg and Helshoogte localities, each of which is situated on porphyritic granite, the lower horizon soil K levels are nevertheless low when compared with Devon Valley and Papegaaiberg. It is possible that the potassium may have been diluted by transportation of low-K material, such as quartz sand, transported to the site by wind, water, soil creep or colluviation. Alternatively, K may have been lost from the profiles through leaching.

**Table 5.1** Lower horizon potassium for the different soils in the study.

| LOCALITY | SOIL TYPE | LOWER HORIZON K (mg kg$^{-1}$) | AVERAGE LOWER HORIZON K (mg kg$^{-1}$) |
|---|---|---|---|
| **Simonsberg** | Hu | 35 | 55 |
| **Simonsberg** | Tu | 74 | |
| **Kuils River** | Tu | 35 | 70 |
| **Kuils River** | Vf | 106 | |
| **Helshoogte** | Oa | 55 | 59 |
| **Helshoogte** | Hu | 63 | |
| **Papegaaiberg** | Av | 113 | 100 |
| **Papegaaiberg** | Tu | 86 | |
| **Devon Valley** | Oa | 98 | 90 |
| **Devon Valley** | Gs | 82 | |
| **Durbanville** | We | 31 | 18 |
| **Durbanville** | Tu | 4 | |

At the Simonsberg locality the lower horizon of the Tukulu soil contains more K (74 mg kg$^{-1}$) than the Hutton soil (35 mg kg$^{-1}$). The Tukulu soil at Kuils River also contains 35 mg K kg$^{-1}$. However, the Vilafontes soil at Kuils River contains 106 mg K kg$^{-1}$. As discussed in Chapter 3, porphyritic biotite granites underlie these soils. From the analytical data it appears probable that both soils at the Simonsberg and Kuils River localities inherited K from the underlying granites, but that the Hutton soil at Simonsberg, and the Tukulu soil at Kuils River were more influenced by K-poor material, resulting in smaller quantities of K being detected in the mixed soil material. Both of the soils at the Helshoogte locality, which are situated on porphyritic granites, are relatively low in lower horizon K. Exposure to K-poor material during soil development is a possibility.

The lower horizon of the Avalon soil at the Papegaaiberg locality contains a large quantity of K (113 mg kg$^{-1}$), and the lower horizon K content of the Tukulu soil is also high (86 mg kg$^{-1}$). Country rocks which lie close to the contact zone between granite and Malmesbury metasediments could conceivably be enriched in potassium through outward movement of minerals in fluids migrating out of the hot granite. This process could be reflected in a slightly raised content in soils derived from the affected rocks. The results for Papegaaiberg therefore suggest that the two soils at this locality are close to the contact zone, and that the

Avalon soil is situated closest to the granite. It is not realistic to conclude that different types of parent material have been involved in soil formation at Papegaaiberg because the parent material may have been igneous material assimilated into sedimentary rocks prior to metamorphism and later weathering. The possibility mixing of soil parent materials is discussed in Chapter 4.

Potassium concentrations in the lower horizons of the Devon Valley locality (Table 5.1) are relatively high and are similar to the Papegaaiberg locality. Both soils show high K-concentrations indicating that this soil could have formed in close proximity to granitic material, though overlying K-poor hornfels. As in the case of the Papegaaiberg locality, the possibility that soil materials from different parent materials were mixed prior to the formation of the Devon Valley soils are discussed in Chapter 4.

A low potassium level in the Malmesbury shales was expected to reflect in soils from the Durbanville locality. Low quantities of K in the lower horizons of the soils at this locality were therefore to be expected. The very low K concentration in the Tukulu soil, however, indicates that a contribution was made by K-poor material.

### 5.2.2 Minerals in the clay fraction: General

The results of the semi quantitative mineral analysis of the clay fraction are presented in Table 5.2 and generalised X-ray diffraction patterns for each of the treatments that were applied to the soil clay fraction from each soil horizon are presented in Appendix 5.3. Clay fraction kaolinite and quartz weighted for clay content and coarse fragments is presented in Appendix 5.4. From Table 5.2 it is clear that the dominant mineral in the clay fraction in most of the diagnostic horizons at most localities is kaolinite. Illite, hydroxy-interstratified vermiculite (HIV), gibbsite, goethite, hematite, quartz and feldspar occur in different quantities in the different soils. As discussed in Chapter 1.3, the occurrence of kaolinite, gibbsite and Fe-oxides in soil clay fractions indicates an advanced stage of weathering (Dixon & Weed, 1989). When quartz, illite and HIV are dominant, however, an intermediate stage of weathering is indicated (Jackson *et al.*, 1984). A decrease in kaolinite, coupled with an increase in gibbsite, indicates a more intense degree of weathering. Kaolinite is transformed to gibbsite over time, or as the degree of weathering increases. In terms of the Garrels & Christ stability diagrams (Marshall, 1977) the simultaneous presence of quartz and gibbsite in the clay fraction can only indicate the prevalence of non-equilibrium weathering conditions, probably the influence of different parent materials. In strongly weathered soils, feldspars are present only in small quantities or are completely absent (Hseung & Jackson, 1952). It is therefore clear that the simultaneous presence of minerals in the clay fraction representing different weathering stages, would indicate mixing of materials from different parent rocks and/or mixing of the same material associated with different weathering stages and/or mixing of material associated with different weathering processes within a particular soil horizon.

**Table 5.2** Semi-quantitive mineral analyses of the clay fraction for each diagnostic horizon at the six localities.

| Locality and soil | Depth (cm) | Kaolinite | Illite/mica | Hydroxy-interstratified vermiculite (HIV) | Gibbsite | Goethite + hematite | Quartz | Feldspar |
|---|---|---|---|---|---|---|---|---|
| Simonsberg Hu | 0-30 | *** | * | n.d. | n.d. | * | * | * |
| | 30-80 | *** | * | n.d. | n.d. | * | * | * |
| | 80-120 | * | n.d. | * | ** | * | ** | * |
| Simonsberg Tu | 0-25 | **** | * | n.d. | n.d. | * | * | * |
| | 25-70 | *** | * | n.d. | n.d. | * | * | * |
| | 70-100 | **** | * | n.d. | n.d. | * | * | * |
| Kuils River Tu | 0-35 | ** | * | n.d. | * | * | ** | * |
| | 35-65 | ** | * | n.d. | * | * | ** | * |
| | 65-110 | *** | * | n.d. | * | * | * | * |
| Kuils River Vf | 0-35 | *** | * | n.d. | n.d. | * | * | * |
| | 35-50 | *** | * | n.d. | n.d. | * | * | * |
| | 50-70 | *** | * | n.d. | n.d. | * | * | * |
| | 70-150 | *** | * | n.d. | n.d. | * | * | * |
| Helshoogte Oa | 0-40 | * | n.d. | n.d. | ** | * | ** | * |
| | 40-80 | * | n.d. | n.d. | * | * | ** | * |
| | 80-110 | * | n.d. | n.d. | * | * | ** | * |
| Helshoogte Hu | 0-30 | * | n.d. | n.d. | ** | * | ** | * |
| | 30-70 | * | n.d. | n.d. | ** | * | ** | * |
| | 70-100 | *** | * | n.d. | * | * | * | * |
| Papegaaiberg Av | 0-25 | **** | * | n.d. | n.d. | * | * | n.d. |
| | 25-60 | **** | * | n.d. | n.d. | * | * | n.d. |
| | 60-95 | *** | * | n.d. | n.d. | * | ** | n.d. |
| | 95-120 | *** | * | n.d. | n.d. | * | ** | n.d. |
| Papegaaiberg Tu | 0-25 | **** | * | * | n.d. | * | ** | n.d. |
| | 25-50 | **** | * | n.d. | n.d. | * | * | n.d. |
| | 50-80 | **** | * | n.d. | n.d. | * | * | n.d. |
| | 80-130 | **** | * | n.d. | n.d. | * | * | n.d. |
| Devon Valley Oa | 0-35 | ** | * | n.d. | n.d. | * | ** | * |
| | 35-70 | *** | * | n.d. | n.d. | * | * | n.d. |
| | 70-110 | *** | * | n.d. | n.d. | * | * | n.d. |
| Devon Valley Gs | 0-30 | ** | * | n.d. | n.d. | * | ** | n.d. |
| | 30-60 | *** | * | n.d. | n.d. | * | * | n.d. |
| | 60-110 | *** | * | n.d. | n.d. | * | * | n.d. |
| Durbanville We | 0-30 | ** | n.d. | * | * | * | ** | * |
| | 30-90 | ** | n.d. | * | * | * | ** | * |
| | 90-120 | ** | * | * | * | * | * | * |
| Durbanville Tu | 0-30 | ** | n.d. | * | * | * | ** | * |
| | 30-80 | * | n.d. | * | * | * | ** | * |
| | 80-130 | ** | * | * | * | * | *** | * |

**** = dominant
*** = major
** = intermediate
* = minor
n.d. = not detected

### 5.2.3 Clay fraction mineralogy for each locality

#### 5.2.3.1 Simonsberg

In the Simonsberg Hu soil, the A horizon and red apedal B horizon have a similar clay mineral composition with major quantities of kaolinite and minor illite, Fe-oxides, quartz and feldspar (Table 5.2). The lower horizon of this soil form, however, contains only minor amounts of kaolinite with intermediate gibbsite and HIV (both absent in the overlying horizons). Quartz occurs in minor quantities while the Fe-oxide and feldspar content are similar to that of the overlying horizons. In the Simonsberg Tu, kaolinite occurs in dominant quantities in the A- and lower horizons and in a major quantity in the neocutanic B horizon. Minor quantities of illite, Fe-oxides, quartz and feldspars occur throughout the soil form. As discussed in Par 5.2.2, the occurrence of kaolinite, gibbsite and Fe-oxides in the clay fraction of both these soils indicates an advanced stage of weathering. The decrease in kaolinite and increase in gibbsite in the C horizon of Simonsberg Hu could indicate more intense weathering (kaolinite transformed to gibbsite). The occurrence of HIV and quartz in this horizon, however, could indicate less intense weathering. The simultaneous presence of quartz and gibbsite in this horizon indicates non-uniform distribution of clay fraction minerals, probably as result of the mixing of *in situ* porhyritic biotite granite and deposition of Cambrian Table Mountain sandstones during accumulation of parent material. A decrease in clay % in this horizon (Appendix 4.1) confirmed this.

#### 5.2.3.2 Kuils River

In the Kuils River Tu soil form, kaolinite occurs in intermediate quantities in the orthic A horizon and neocutanic B horizon and increases to a major quantity in the lower horizon (Table 5.2). Quartz shows the opposite trend with intermediate quantities in the A- and neocutanic B horizon and minor in the C horizon. Illite, gibbsite, Fe-oxides and feldspar occur in minor amounts throughout this profile. In the Kuils River Vf, however, kaolinite is present in major amounts throughout the soil form. Gibbsite is absent in this soil form and illite, Fe-oxides, quartz and feldspar occur in minor quantities (similar to Kuils River Tu), except for the lower horizon where feldspar is absent. The presence of gibbsite in the Kuils River Tu indicates a higher degree of weathering in comparison with Kuils River Vf, where kaolinite is more prominent. The simultaneous presence of quartz and gibbsite in the Kuils River Tu soil form, indicate, as in the Hutton soil at the Simonsberg locality, that non-uniform distribution of clay fraction minerals, probably as result of mixing of parent materials of different origins and/or mixing of the same material associated with different weathering stages and/or mixing of material associated with different weathering processes.

#### 5.2.3.3 Helshoogte

At this locality, kaolinite is not the dominant mineral in the clay fraction, although it is not totally absent (Table 5.2). Minor quantities of kaolinite occur throughout Helshoogte Oa and in the A horizon and apedal B horizon of Helshoogte Hu. The C horizon of Helshoogte Hu, however, contains a major quantity of kaolinite. Illite only occurs in this horizon, but only in a minor amount. Fe-oxides and feldspar also occur in minor quantities throughout both soil forms, while gibbsite occur in intermediate quantities in both A horizons and in the apedal B horizon (Helshoogte Hu). The occurrence of intermediate amounts of quartz in combination with gibbsite, especially where both minerals occur in intermediate amounts, indicates different weathering stages in each soil, probably as result of mixing of parent materials of different origins and/or mixing of the same material and/or mixing of material associated with different weathering processes. As at the Simonsberg and Helshoogte localities, an increase or decrease in kaolinite resulted in a decrease or increase, respectively, in quartz-content.

#### 5.2.3.4 Papegaaiberg

In both soil forms at this locality, dominant quantities of kaolinite occur in the A and apedal B horizons of Papegaaiberg Av and throughout Papegaaiberg Tu. In the soft plinthic B and the lower horizons of Papegaaiberg Av, the kaolinite content is major. Illite and Fe-oxides occur in minor quantities throughout both soil forms, indicating a high degree of weathering, while HIV (indicating less severe weathering) only occurs in the A-horizon of the Papegaaiberg Tu soil form. Quartz occurs in intermediate quantities whereas the kaolinite occurs in major quantities, while it occurs in minor amounts where the kaolinite occurs in dominant quantities (showing the same trend as the previous localities). The absence of gibbsite throughout both soil forms may indicate that the soils from this locality are less weathered than the previous localities.

#### 5.2.3.5 Devon Valley

At the Devon Valley locality, kaolinite occurs in intermediate amounts in both A horizons and in major quantities in the other horizons (Table 5.2). Gibbsite is absent and illite and Fe-oxides occur in minor quantities throughout the two soil forms. Feldspar only occurs in the A horizon of Devon Valley Oa. As was the trend at the previous localities, the quartz content decreased as the kaolinite content increased, and occurs in intermediate quantities in the two A horizons and in minor quantities in all other horizons. The absence of gibbsite throughout both soil forms indicate that the soils from this locality is similar to Papegaaiberg and are less weathered than the other localities. The occurrence of kaolinite in the lower horizon of the Glenrosa soil, however, could indicate that the original Malmesbury sediments contained kaolinitic material before it was influenced by the granite intrusions to form the hornfels.

#### 5.2.3.6 Durbanville

In the Durbanville We, kaolinite occurs in intermediate quantities throughout the soil profile (Table 5.2). Illite only occurs in the lower horizon and gibbsite, HIV, Fe-oxides and feldspar occur in minor quantities throughout the soil form. Quartz occurs in intermediate quantities in the A- and soft plintic B horizons, but decreases to minor quantities in the lower horizon. The illite, HIV, gibbsite and feldspar content throughout the Durbanville Tu soil form are similar to Durbanville We, but the quartz content increases in the lower horizon to a major quantity while the kaolinite show a lower (minor) quantity in the neocutanic B horizon in comparison with all other horizons. Again, simultaneous presence of quartz and gibbsite in these soils indicate non-uniform distribution of clay fraction minerals.

### 5.3 Relationship between T-value and organic carbon, clay (%) and silt (%)

In this study, the T-value for each soil sample was determined. From the viewpoint of nutritional advisory work the T-value is a useful substitute for cation exchange capacity (CEC). In soils the majority of the charge sites that are accessible for cation exchange are located on clays and organic material, and the content of these in soil is often used as a broad indicator of CEC. However, silt may also contain exchange sites, and thereby contribute to CEC, as was demonstrated by the use of multiple regression analysis by Satyavathi *et al.* (1994). A multiple linear regression model (using *Statgraphics Plus*: version 4.1), which describes the relationship between T-value (calculated as equivalent to the sum of the exchangeable $Ca^{2+}$, $Mg^{2+}$, $K^+$ and $Na^+$, plus the total extractable acidity at pH 7) and the independent variables organic carbon (%), clay (%) and total silt (%), is as follows:

T = -0.695221 + 2.0482(C%) + 0.00982487(clay%) + 0.209295 (silt%)
(R-square = 57.58%, statistically significance = 99%)

According to this prediction model, the T-value of the independent variables is:
0.98 $\text{cmol}_c\,\text{kg}^{-1}$ if the soil population contained 100 % clay (significance = 34%);
20.93 $\text{cmol}_c\,\text{kg}^{-1}$ if the soil population contained 100 % silt (significance = 99%);
204.82 $\text{cmol}_c\,\text{kg}^{-1}$ if the soil population contained 100 % organic carbon (significance = 99%).

The low contribution represented by clay confirms the presence of predominant kaolinite (low CEC), quartz and gibbsite (both very low CEC) in the clay fraction of all soils. A T-value of 0.98 $\text{cmol}_c\,\text{kg}^{-1}$ for clay, however, is very low and a T-value of 20.93 $\text{cmol}_c\,\text{kg}^{-1}$ for silt is very high. It is known that certain highly weathered, sesquioxide rich soils do not completely disperse with Calgon as dispersing agent (used in this study), resulting in higher silt content. A multiple linear regression model which describes the relationship between T-value and the independent variables organic carbon (%), clay + fine silt (%) and coarse silt (%) was therefore carried out. The relationship, which was obtained, may be described as follows:

T = 1.07084 + 1.99903 (C%) + 0.0269834 (clay% + fine silt%) + 0.205634 (coarse silt%)
(R-square = 42.87%, statistically significance = 99%)

According to this prediction model, the T-value of the independent variables is:
2.70 $\text{cmol}_c\,\text{kg}^{-1}$ if the soil population contained 100 % clay + fine silt (significance = 71%);

20.56 cmol$_c$ kg$^{-1}$ if the soil population contained 100 % coarse silt (significance = 99%);
199.90 cmol$_c$ kg$^{-1}$ if the soil population contained 100 % organic carbon (significance = 99%).

Although the contribution of clay + fine silt (%) increased when compared with only clay (%), the T-value for coarse silt is still very high (this model indicate that the T-values for coarse silt (is 20.56 cmol$_c$ kg$^{-1}$). It was therefore assumed that the dispersion of the silt and clay in the laboratory was incomplete.

## 5.4 Relationship between Al$_{(DCB)}$ and gibbsite

Gibbsite [Al(OH)$_3$] is the most common Al-hydroxide mineral in soils and is generally associated with the latter stages of weathering, when Si removal has progressed to such an extent that phyllosilicate minerals are no longer stable. To determine the relationship between gibbsite and Al$_{(DCB)}$ in the clay fractions of the soils used in the study, a regression analysis was carried out on the total soil (Figure 5.1). The relationship was statistically significant and the the equation for the fitted model is:

Al$_{(DCB)}$ = 0.623237 + 0.270188 x gibbsite (4-point scale)
(R-square = 36.21 %, Significance = 99 %)

The gibbsite contents of the clay fractions therefore correlate with the Al$_{(DCB)}$ contents of the clay fractions of the different soil samples in the study.

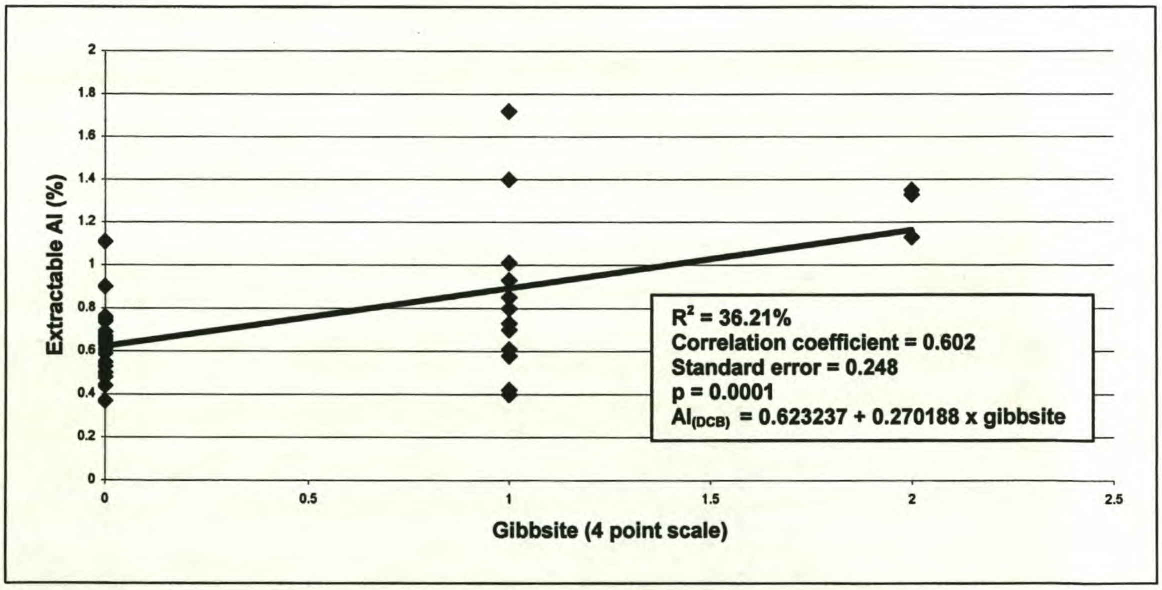


**Figure 5.1** The relationship between clay fraction gibbsite and extractable Al$_{(DCB)}$ % in the different soils in the study on.

## 5.5 Relationship between and Fe$_{(DCB)}$ & Fe-oxides

Iron oxides (total goethite and hematite) occur in minor quantities (Table 5.2) in the clay fraction of all soils in the study. All the samples showed that goethite + hematite occurred in minor quantities (values of 1) . The $Fe_{(DCB)}$ values nevertheless varied. It was, however, not possible to develop a regression relationship between $Fe_{(DCB)}$ and total goethite + hematite in the clay fraction of the soils in the study.

### 5.6 Relationships between lower horizon potassium and clay fraction mineralogy

The occurrence of K in the lower horizons could be related to the relative abundance of certain clay fraction minerals. In the soils used in this study certain clay minerals were found to occur in quantities that qualified them as either intermediate or dominant. These minerals were kaolinite and quartz. Conversely, gibbsite occurred in intermediate to minor quantities, or was not detected. Illite, hydroxy interstratified vermiculite and feldspar, as well as goethite and hematite, were represented only in minor quantities in the semi-quantitative analyses, or not detected. In view of the imprecisions that are inherent in clay mineral analytical methods, very little can be reliably inferred from, or about, clay minerals that are present in very small amounts. For this reason those clay minerals that were present in only minor amounts were not included in any of the statistical treatments. The simple linear regression analysis between K and clay fraction kaolinite in the lower horizons resulted in a linear relationship, which was significant at the 90% confidence level (Figure 5.2). The equation of the fitted model is as follows:

Lower horizon K = 13.75 + 19.18 x lower horizon kaolinite (4-point scale)
(R-square = 31.31%)

This model indicates a positive correlation between potassium and kaolinite.

A regression analysis between lower horizon K and quartz in the lower horizons showed no significant relationship, while the relationship between K and gibbsite in the lower horizons was moderately strong (99% confidence level) (Figure 5.3). The equation of the fitted model is as follows:

Lower horizon K = 88.68 - 40.31 x lower horizon gibbsite (4-point scale).
(R-square = 63.06%)

As discussed previously, the presence of gibbsite in soils is usually associated with more advanced stages of weathering. Since gibbsite virtually has no cation exchange capacity, K will leach from gibbsite dominated soils with ease.

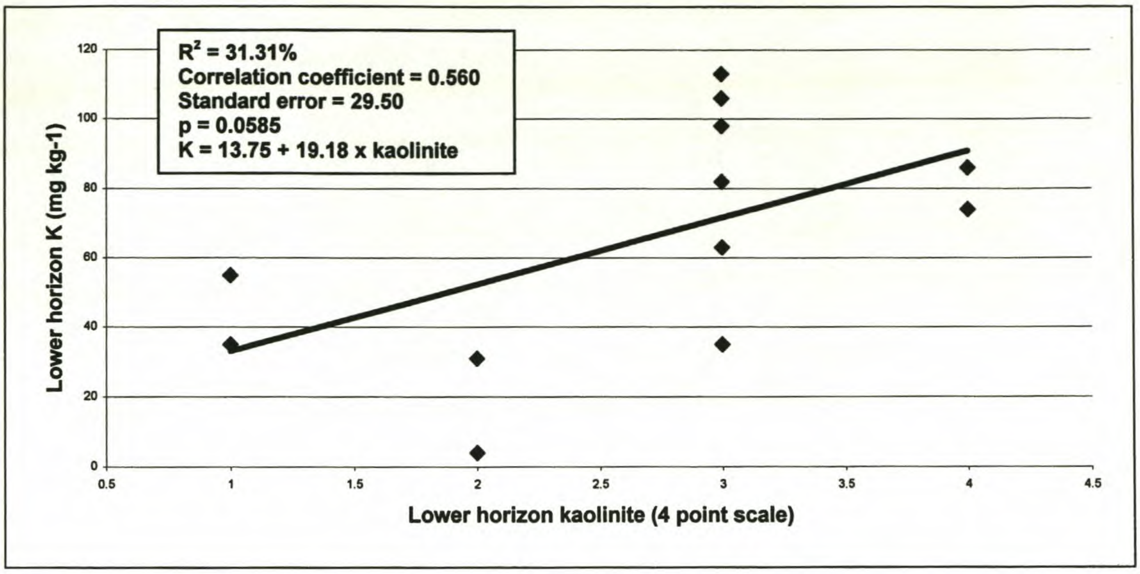


**Figure 5.2** The effect of lower horizon clay fraction kaolinite on lower horizon K .

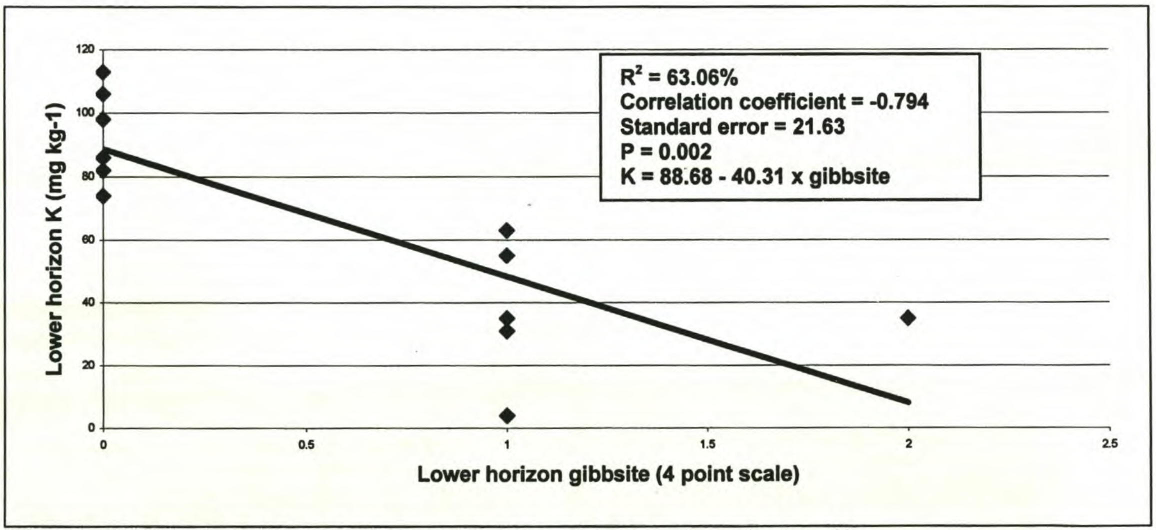


**Figure 5.3** The effect of lower horizon clay fraction gibbsite on lower horizon K.

The relationships between clay fraction quartz and clay fraction kaolinite; clay fraction kaolinite and quartz on vineyard performance as well as some geomorphologic data on clay fraction kaolinite and –quartz are discussed in Chapter 6.

## 5.7 CONCLUSIONS

The lower horizon K content of the soils in this study could not reliably be correlated with any known or predicted characteristic that might link the soil parent material with local rock types. At Durbanville, both soils contain small quantities of K in the lower horizons, reflecting the underlying phyllitic shales, but at Devon Valley and Papegaaiberg, the lower horizons contain more K than expected (when compared with underlying material only). The soils at these localities are situated on hornfels, containing low quantities of K. The large quantities of K in the soils may indicate that these soils are situated close to the granite/Malmesbury contact zone. Soils from Kuils River, Simonsberg and Helshoogte are situated on K-rich porhyritic granites and it was expected that these soils would contain relatively large quantities of K in the lower horizons. This, however, was not the case. Such material could have been derived from higher-lying sandstones, or from aeolian transport processes during the Cenozoic. Alternatively, the K content of the soil might have been depleted by long continued leaching.

The clay fraction mineralogical data indicate that all soils in the study area are in an advanced stage of weathering. It is therefore difficult to relate these minerals directly with soil parent material, because the primary minerals originating from the soil parent materials have been broken down, in some cases almost completely to form near terminal end products. In the clay fraction of both soils at Simonsberg, Helshoogte and Durbanville as well as the Tukulu soil form at Kuils River and the Hutton soil from Simonsberg, the simultaneous presence of quartz and gibbsite indicate non-uniform distribution of clay fraction minerals, indicating that different stages of weathering were present during soil formation. This could be a result of mixing of parent materials, but may also reflect different periods of weathering of the same material. The Tukulu soil form at Simonsberg, both soils at Papegaaiberg, the Vilafontes soil form at Kuils River as well as both soils at Devon Valley indicate uniform clay fraction mineralogy distribution, mainly because the absence of gibbsite is related to the presence of quartz in the clay fraction.

## 5.8 REFERENCES

DIXON, J.B. & WEED, S.B., (co-ed.), 1989. Minerals in soil environments. Second Edition. SSSA, Madison, Wisconsin, USA.

HSEUNG, Y. & JACKSON, M.L., 1952. Mineral composition of the clay fraction: Some main soil groups of China. *Soil Sci. Soc. Am. Proc.* **16**: 294-297.

JACKSON, M.L., TYLER, S.A., BOURBEAU, G.A. & PENNINGTON, R.P., 1984. Weathering sequence of clay-size minerals in soils and sediments. 1:Fundamental generalizations. J. Phys. *Colloid. Chem.* **52**, 1237-1260.

MARSHALL, E.M., 1977. The physical chemistry and mineralogy of soils: Soils in place. John Wiley & Sons.

SATYAVATHI, P.L.A., SAHRMA, J.P. & SRIVASTAVA, R., 1994. Contribution of soil organic matter, clay and silt to the cation exchange capacity of soils. *Commun.Soil Sci. Plant Anal* **26**, 1343 – 1355.

**Appendix 5.1** Chemical analysis for each diagnostic horizon of the twelve soils at the six localities.

| Locality | Soil type | Soil depth (cm) | pH (KCl) | Resistance (ohms) | P (mg kg$^{-1}$) | H (cmol$_c$ kg$^{-1}$) | Ca (cmol$_c$ kg$^{-1}$) | Mg (cmol$_c$ kg$^{-1}$) | K (cmol$_c$ kg$^{-1}$) | Na (cmol$_c$ kg$^{-1}$) | T-value (cmol$_c$ kg$^{-1}$) | C (%) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Simonsberg** | **Hu** | 0-30 | 5.87 | 1370 | 32 | 0.45 | 5.39 | 0.54 | 0.50 | 0.04 | 6.92 | 0.8 |
| | | 30-80 | 4.70 | 4000 | 6 | 1.50 | 1.79 | 0.18 | 0.34 | 0.00 | 3.81 | 0.3 |
| | | 80-120 | 4.54 | 4550 | 12 | 2.73 | 1.33 | 0.44 | 0.09 | 0.00 | 4.59 | 0.8 |
| **Simonsberg** | **Tu** | 0-25 | 5.70 | 1180 | 26 | 0.63 | 4.79 | 0.94 | 0.48 | 0.02 | 6.86 | 1.2 |
| | | 25-70 | 4.44 | 3230 | 16 | 1.88 | 1.58 | 0.40 | 0.25 | 0.00 | 4.11 | 0.5 |
| | | 70-100 | 4.16 | 3250 | 7 | 1.40 | 0.83 | 1.50 | 0.19 | 0.00 | 3.92 | 0.1 |
| **Kuils River** | **Tu** | 0-35 | 5.14 | 2260 | 86 | 1.13 | 2.53 | 0.83 | 0.42 | 0.02 | 4.93 | 0.8 |
| | | 35-65 | 4.57 | 4650 | 37 | 1.60 | 0.68 | 0.20 | 0.21 | 0.00 | 2.69 | 0.4 |
| | | 65-110 | 4.17 | 5200 | 18 | 1.65 | 0.91 | 0.39 | 0.14 | 0.00 | 3.09 | 0.1 |
| **Kuils River** | **Vf** | 0-35 | 5.30 | 2000 | 72 | 1.10 | 3.20 | 1.20 | 0.34 | 0.00 | 5.84 | 1.1 |
| | | 35-50 | 4.47 | 3900 | 6 | 0.98 | 1.43 | 0.63 | 0.16 | 0.01 | 3.21 | 0.1 |
| | | 50-70 | 4.62 | 3080 | 18 | 1.65 | 1.54 | 0.73 | 0.34 | 0.00 | 4.26 | 0.6 |
| | | 70-150 | 4.00 | 2050 | 9 | 1.93 | 1.64 | 2.09 | 0.16 | 0.02 | 5.84 | 0.1 |
| **Helshoogte** | **Oa** | 0-40 | 5.90 | 2080 | 31 | 0.50 | 7.59 | 0.49 | 0.45 | 0.00 | 9.03 | 2.3 |
| | | 40-80 | 4.63 | 5550 | 9 | 2.13 | 1.63 | 0.13 | 0.14 | 0.00 | 4.03 | 0.9 |
| | | 80-110 | 5.37 | 3920 | 10 | 0.73 | 2.54 | 0.11 | 0.09 | 0.00 | 3.47 | 0.4 |
| **Helshoogte** | **Hu** | 0-30 | 6.04 | 2870 | 68 | 0.43 | 6.04 | 1.08 | 0.46 | 0.00 | 8.01 | 1.6 |
| | | 30-70 | 4.82 | 3580 | 14 | 2.00 | 2.39 | 0.52 | 0.14 | 0.00 | 5.05 | 1 |
| | | 70-120 | 4.97 | 2720 | 5 | 0.88 | 1.46 | 0.81 | 0.27 | 0.00 | 3.42 | 0.2 |
| **Papegaaiberg** | **Av** | 0-25 | 5.48 | 2060 | 35 | 0.73 | 2.24 | 0.91 | 0.59 | 0.31 | 4.78 | 0.6 |
| | | 25-60 | 4.47 | 4010 | 6 | 1.38 | 0.80 | 0.43 | 0.43 | 0.02 | 3.06 | 0.2 |
| | | 60-95 | 4.65 | 3550 | 3 | 0.85 | 1.25 | 0.28 | 0.27 | 0.00 | 2.65 | 2 |
| | | 95-120 | 4.68 | 2520 | 9 | 0.80 | 1.54 | 0.43 | 0.25 | 0.02 | 3.04 | 1 |
| **Papegaaiberg** | **Tu** | 0-25 | 5.47 | 1660 | 40 | 0.75 | 2.73 | 1.19 | 0.67 | 0.03 | 5.37 | 0.8 |
| | | 25-50 | 5.10 | 1800 | 7 | 0.93 | 1.85 | 0.89 | 0.63 | 0.05 | 4.35 | 0.4 |
| | | 50-80 | 5.06 | 2160 | 5 | 0.60 | 1.78 | 0.48 | 0.38 | 0.06 | 3.30 | 0.1 |
| | | 80-130 | 4.47 | 1840 | 14 | 0.78 | 1.41 | 0.41 | 0.21 | 0.3 | 3.11 | 0.1 |
| **Devon Valley** | **Oa** | 0-35 | 5.66 | 2050 | 96 | 0.48 | 3.31 | 0.81 | 0.46 | 0.04 | 5.10 | 0.5 |
| | | 35-70 | 5.30 | 2560 | 5 | 0.63 | 2.41 | 0.58 | 0.35 | 0.01 | 4.27 | 0.2 |
| | | 70-110 | 5.25 | 2880 | 4 | 1.58 | 2.61 | 0.58 | 0.29 | 0.01 | 5.07 | 0.2 |
| **Devon Valley** | **Gs** | 0-30 | 5.05 | 1820 | 54 | 1.03 | 3.11 | 1.34 | 0.32 | 0.01 | 5.81 | 0.6 |
| | | 30-60 | 5.10 | 1620 | 9 | 0.88 | 2.95 | 2.25 | 0.26 | 0.05 | 6.39 | 0.3 |
| | | 60-110 | 5.52 | 840 | 20 | 0.48 | 4.20 | 5.06 | 0.22 | 0.12 | 10.08 | 0.2 |
| **Durbanville** | **We** | 0-30 | 5.57 | 1360 | 90 | 1.03 | 7.79 | 1.92 | 0.52 | 0.03 | 11.29 | 2.2 |
| | | 30-90 | 5.37 | 720 | 30 | 1.13 | 7.75 | 1.98 | 0.13 | 0.14 | 11.13 | 1.6 |
| | | 90-120 | 5.53 | 520 | 16 | 0.68 | 4.16 | 2.63 | 0.08 | 0.38 | 7.93 | 0.3 |
| **Durbanville** | **Tu** | 0-30 | 5.32 | 2840 | 94 | 1.30 | 3.74 | 0.77 | 0.31 | 0.84 | 6.96 | 1.5 |
| | | 30-80 | 5.45 | 2040 | 46 | 1.05 | 4.03 | 0.84 | 0.17 | 0.05 | 6.14 | 1.3 |
| | | 80-100 | 5.37 | 2580 | 7 | 0.65 | 2.41 | 0.56 | 0.05 | 0.14 | 3.81 | 0.2 |

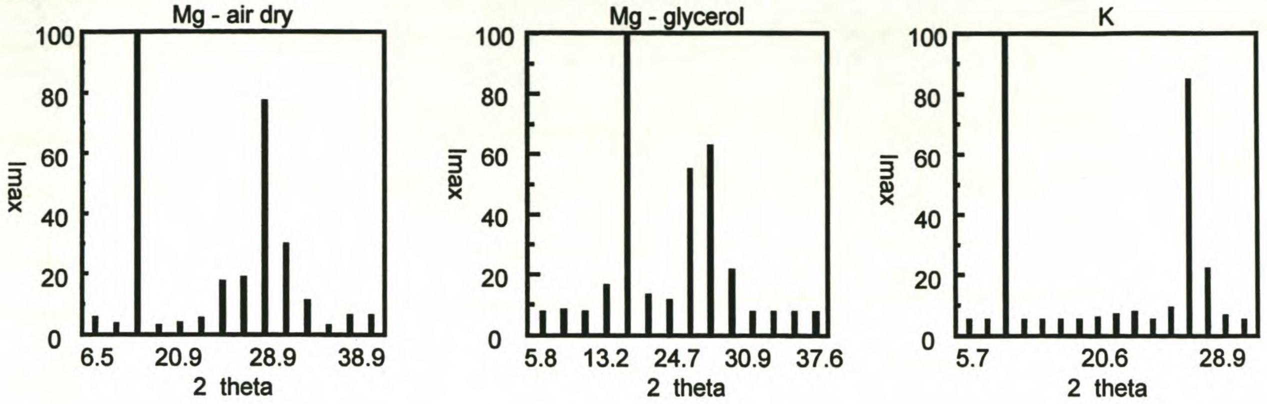
**Appendix 5.2** Total dithionite-citrate-bicarbonate (DCB) extractable Fe and Al in the clay fraction for each diagnostic horizon at the six localities.

| Locality | Soil type | Depth (cm) | Extractable Fe (%) | Extractable Al (%) |
|---|---|---|---|---|
| **Simonsberg** | **Hu** | 0-30 | 3.14 | 0.65 |
| | | 30-80 | 2.88 | 0.61 |
| | | 80-120 | 4.45 | 1.13 |
| **Simonsberg** | **Tu** | 0-25 | 3.42 | 0.75 |
| | | 25-70 | 3.48 | 1.11 |
| | | 70-100 | 3.36 | 0.65 |
| **Kuils River** | **Tu** | 0-35 | 1.98 | 0.93 |
| | | 35-65 | 1.01 | 0.80 |
| | | 65-110 | 0.56 | 0.40 |
| **Kuils River** | **Vf** | 0-35 | 1.40 | 0.69 |
| | | 35-50 | 1.05 | 0.48 |
| | | 50-70 | 1.17 | 0.61 |
| | | 70-150 | 1.67 | 0.37 |
| **Helshoogte** | **Oa** | 0-40 | 3.03 | 1.13 |
| | | 40-80 | 3.76 | 1.40 |
| | | 80-110 | 3.52 | 1.72 |
| **Helshoogte** | **Hu** | 0-30 | 4.65 | 1.33 |
| | | 30-70 | 3.62 | 1.35 |
| | | 70-100 | 2.90 | 0.61 |
| **Papegaaiberg** | **Av** | 0-25 | 2.00 | 0.44 |
| | | 25-60 | 1.73 | 0.48 |
| | | 60-95 | 2.50 | 0.59 |
| | | 95-120 | 3.02 | 0.67 |
| **Papegaaiberg** | **Tu** | 0-25 | 2.30 | 0.76 |
| | | 25-50 | 2.91 | 0.50 |
| | | 50-80 | 2.45 | 0.66 |
| | | 80-130 | 2.02 | 0.55 |
| **Devon Valley** | **Oa** | 0-35 | 2.80 | 0.61 |
| | | 35-70 | 3.58 | 0.64 |
| | | 70-110 | 3.68 | 0.90 |
| **Devon Valley** | **Gs** | 0-30 | 2.46 | 0.63 |
| | | 30-60 | 3.70 | 0.74 |
| | | 60-110 | 2.10 | 0.53 |
| **Durbanville** | **We** | 0-30 | 2.88 | 0.70 |
| | | 30-90 | 2.99 | 0.73 |
| | | 90-120 | 3.19 | 0.58 |
| **Durbanville** | **Tu** | 0-30 | 1.50 | 0.85 |
| | | 30-80 | 1.86 | 1.01 |
| | | 80-130 | 0.54 | 0.42 |

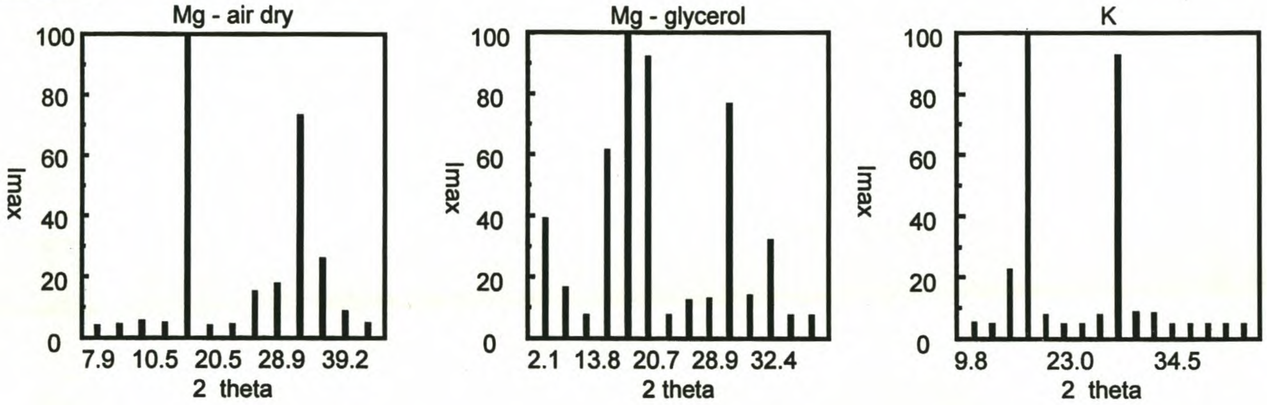
**Appendix 5.3** Generalised X-ray diffractogram patterns of minerals in the clay fraction for all soil horizons at all localities.

## Simonsberg Hu

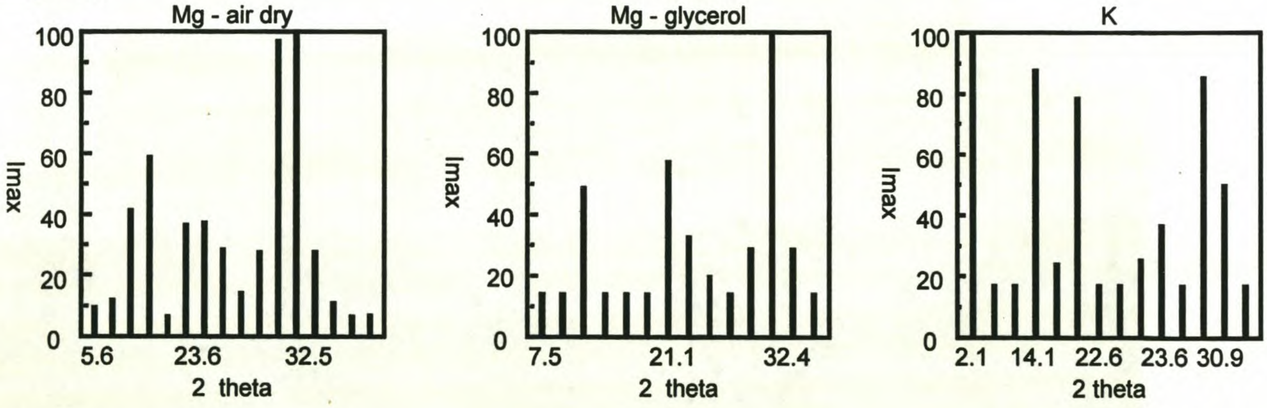
**0 - 30cm**



**30 - 80cm**



**80 - 120cm**



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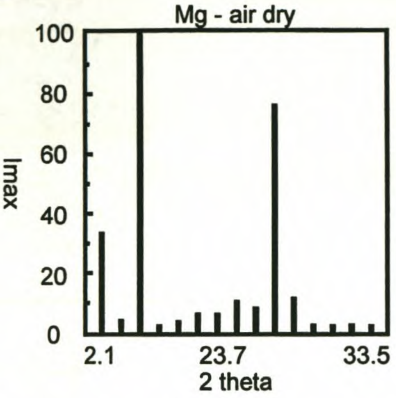
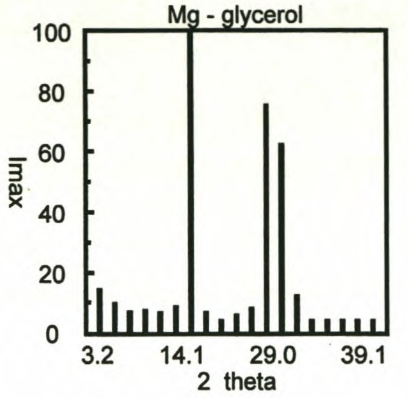
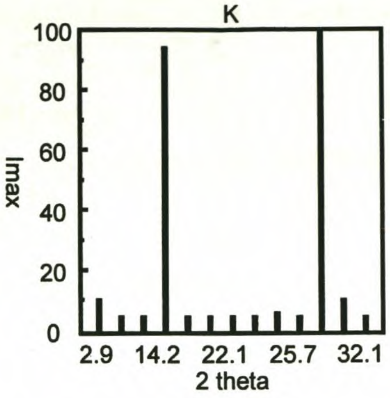
Appendix 5.3: (continued)

## Simonsberg Tu

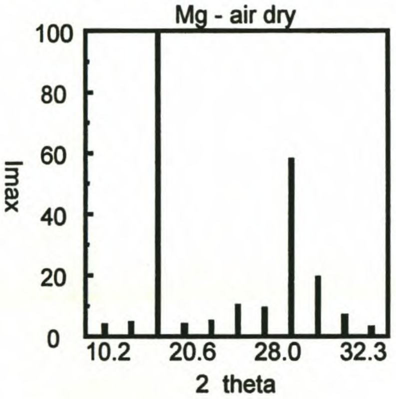
**0 - 25cm**

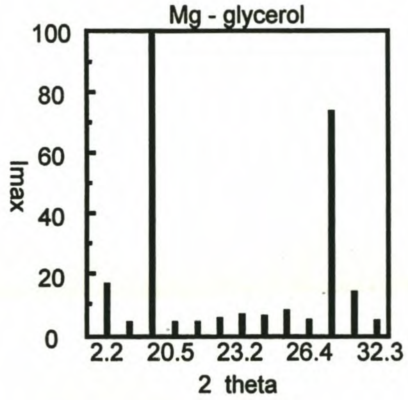


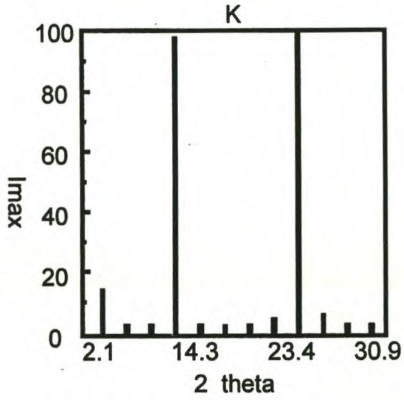




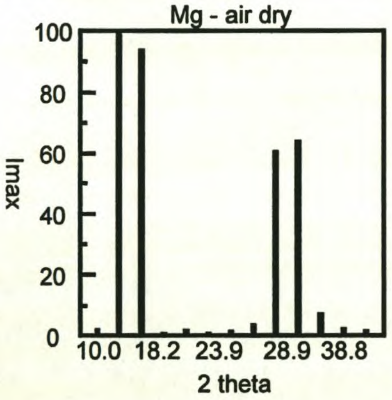
**25 - 70cm**

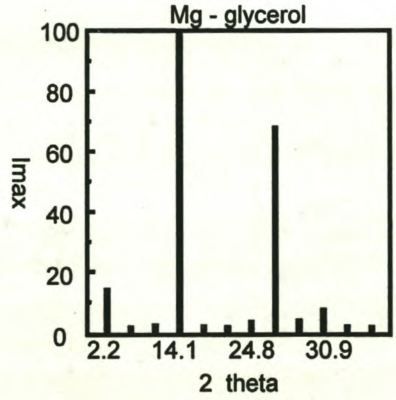


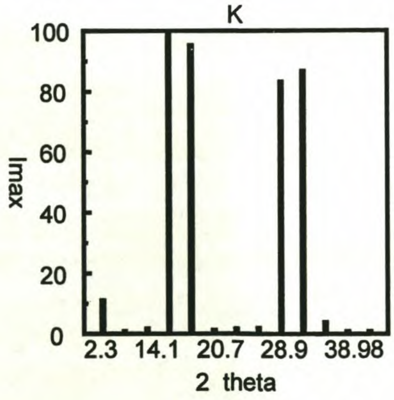




**70 - 100cm**







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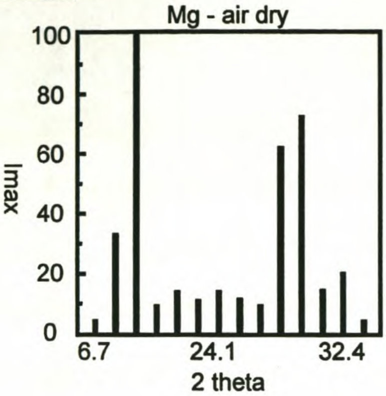
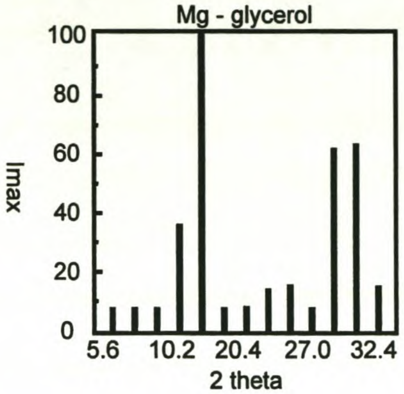
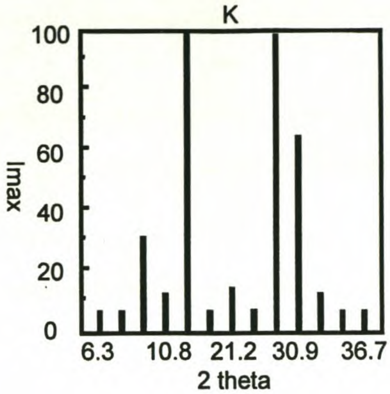
Appendix 5.3: (continued)

## Kuils River Tu

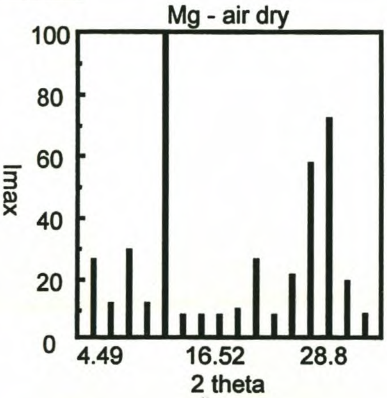
### 0 - 35cm

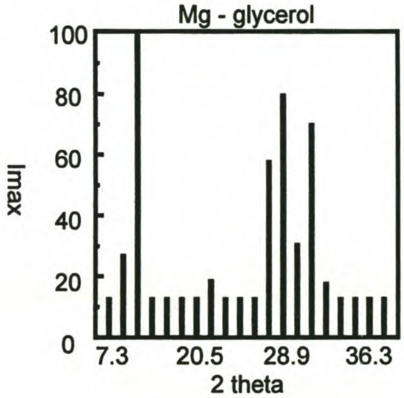


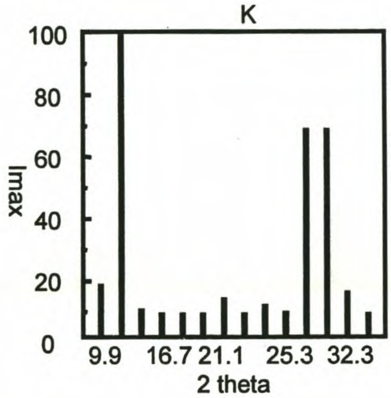




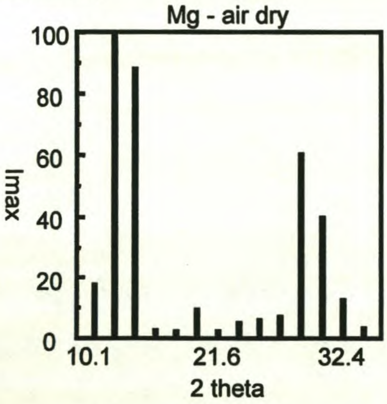
### 35 - 65cm

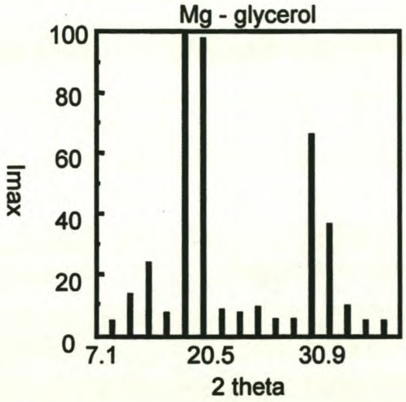


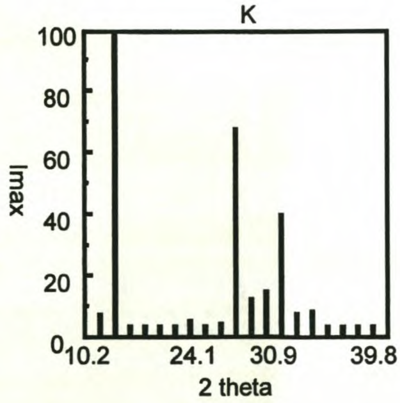




### 65 - 110cm







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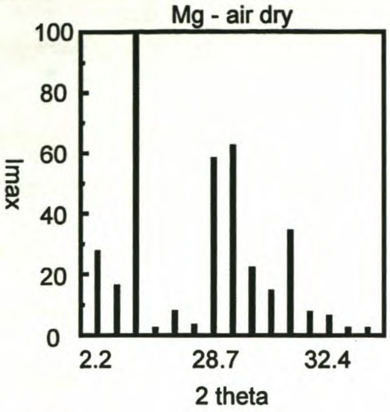
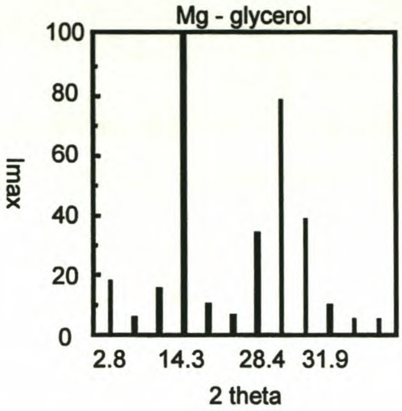
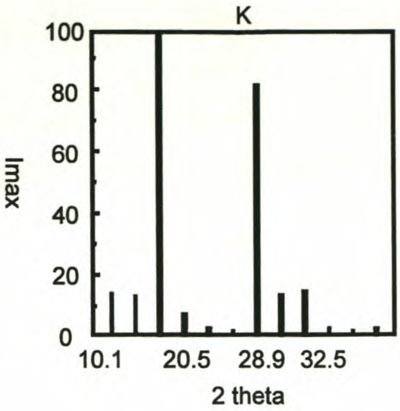
Appendix 5.3: (continued)

## Kuils River Vf

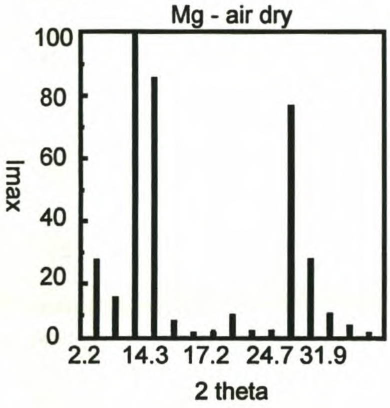
### 0 - 35cm

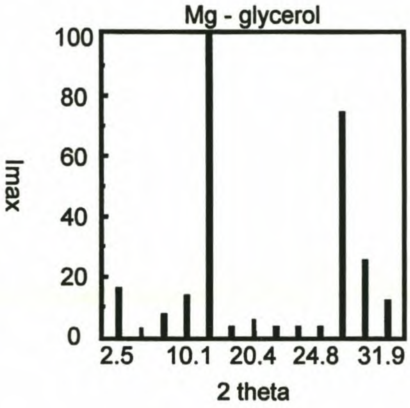


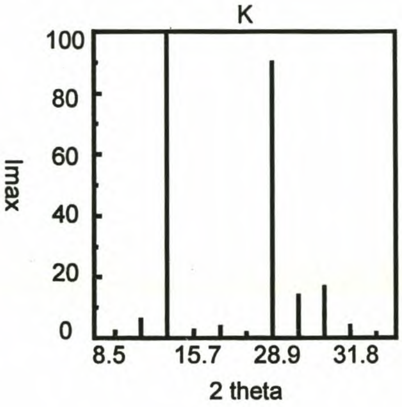




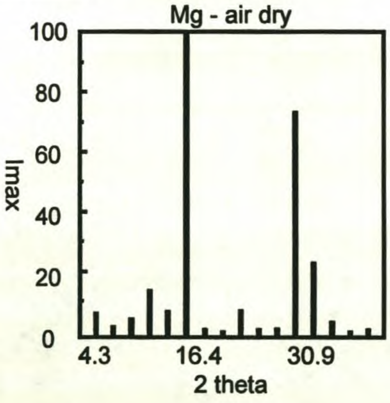
### 35 - 50cm

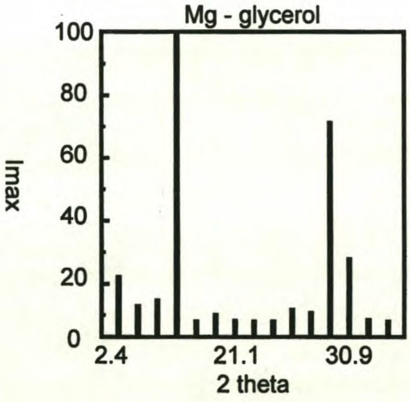


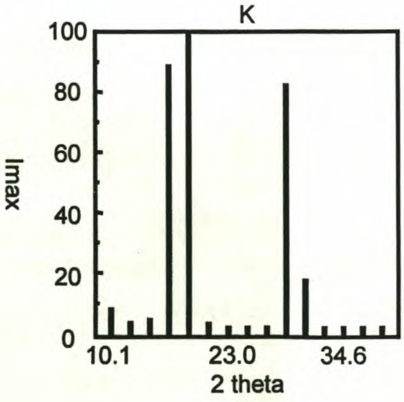




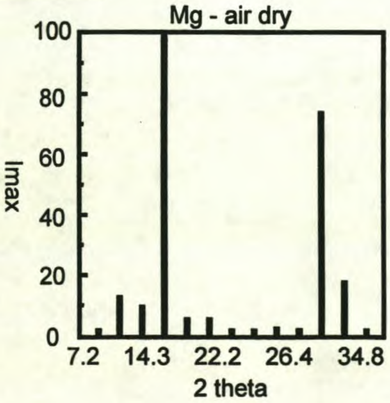
### 50 - 70cm

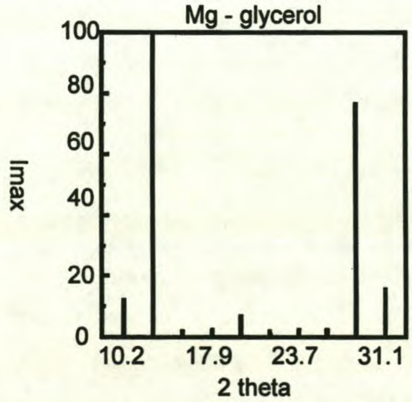


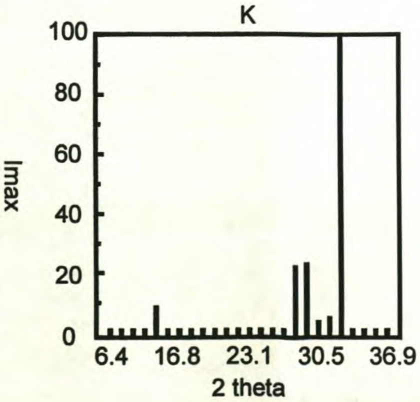




### 70 - 130cm







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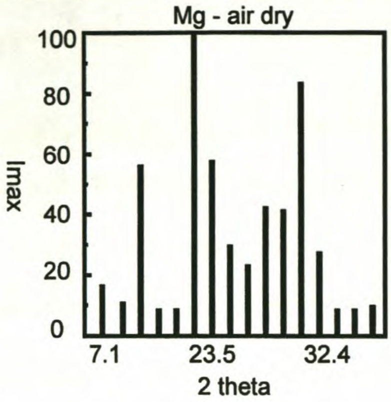
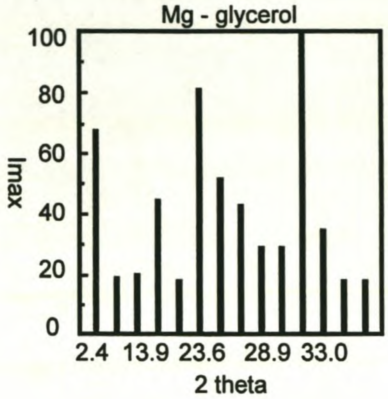
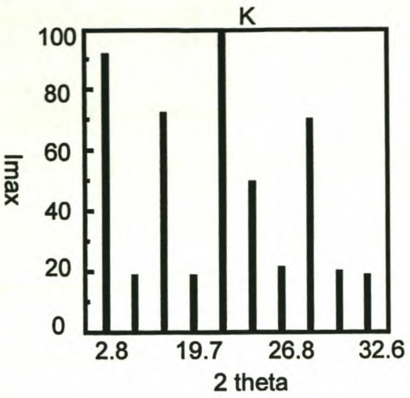
Appendix 5.3: (continued)

## Helshoogte Oa

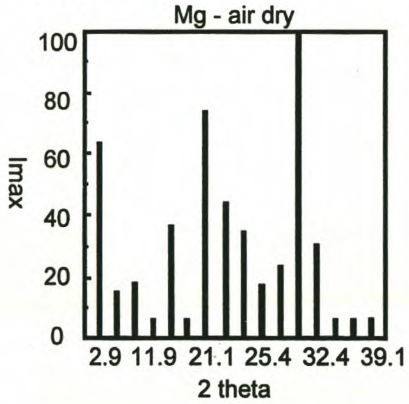
**0 - 40cm**

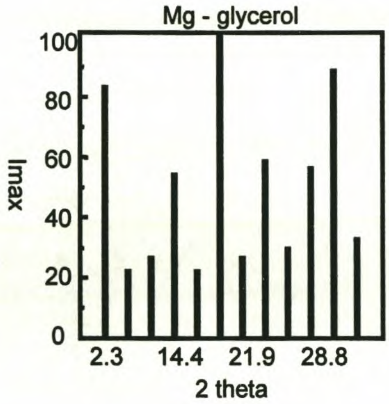


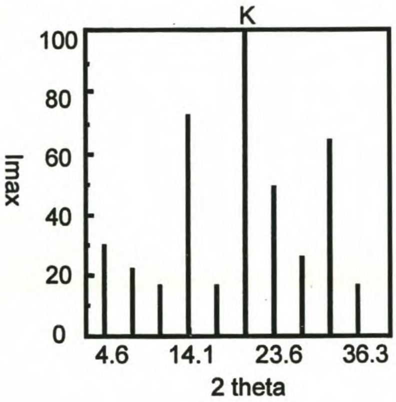




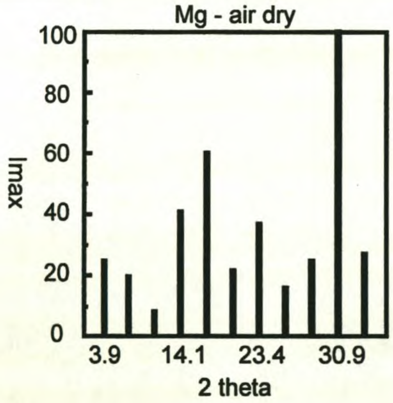
**40 - 80cm**

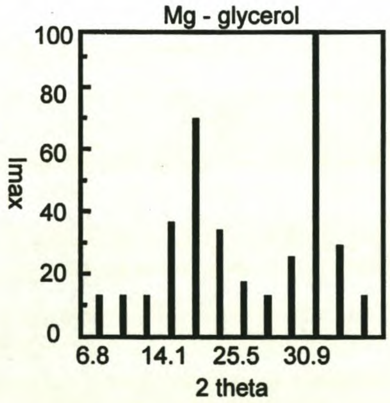


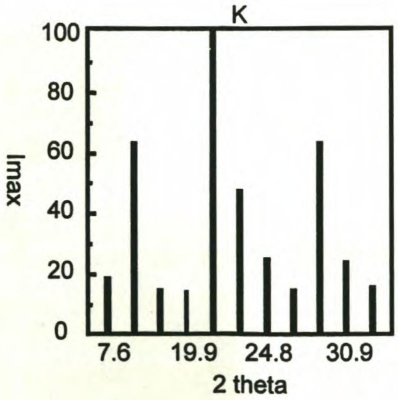




**80 - 110cm**







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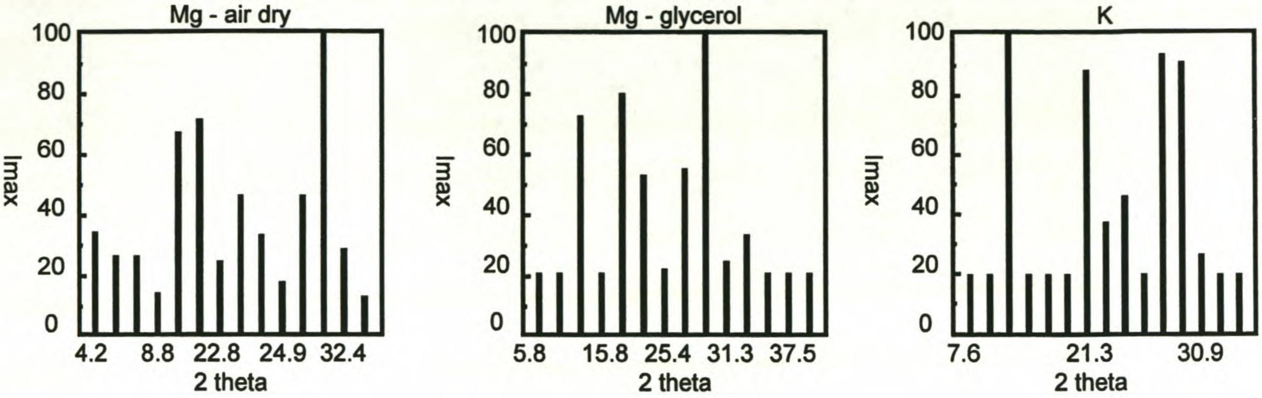
Appendix 5.3: (continued)

## Helshoogte Hu

### 0 - 30cm



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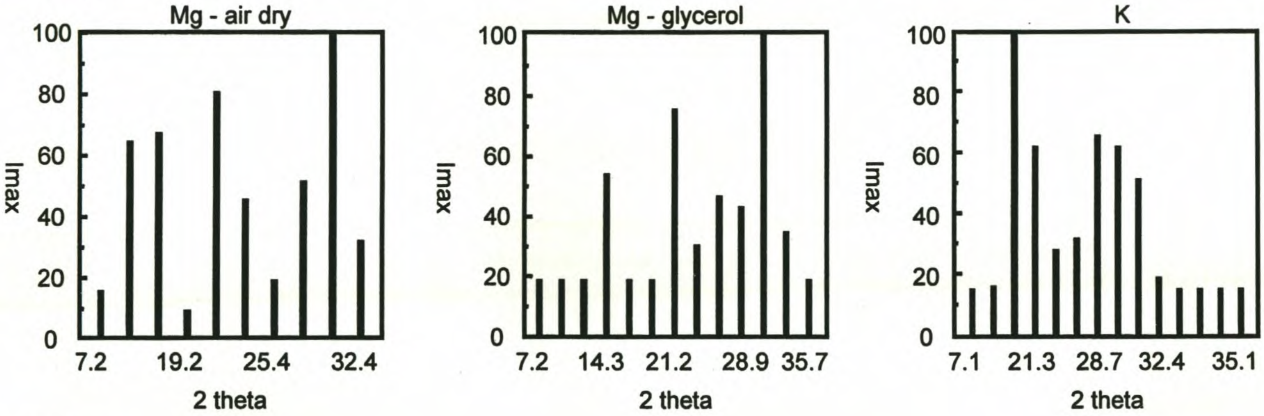
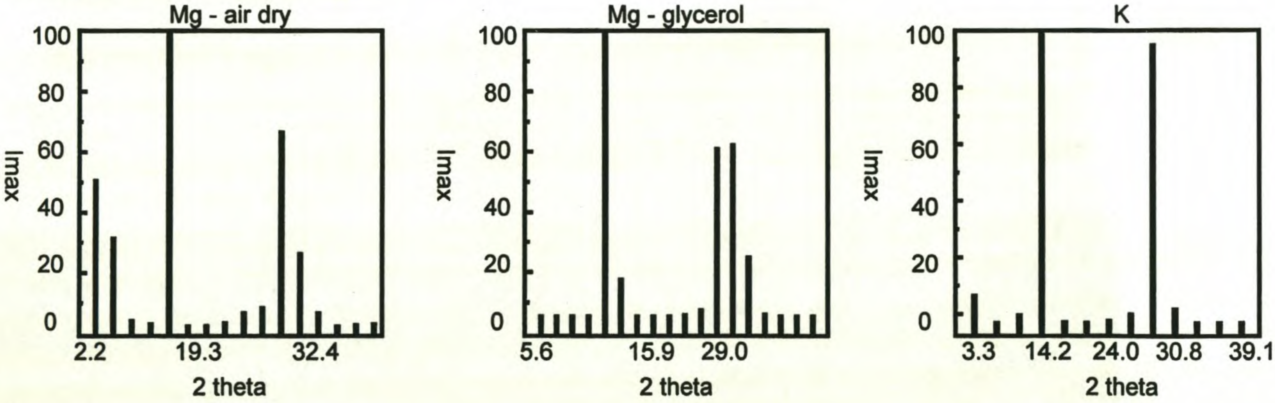


### 70 - 120cm



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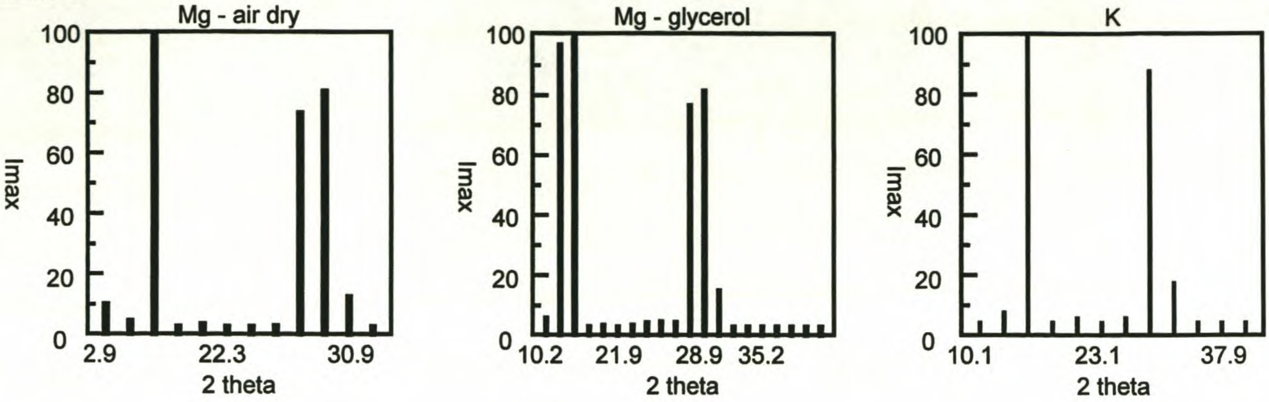
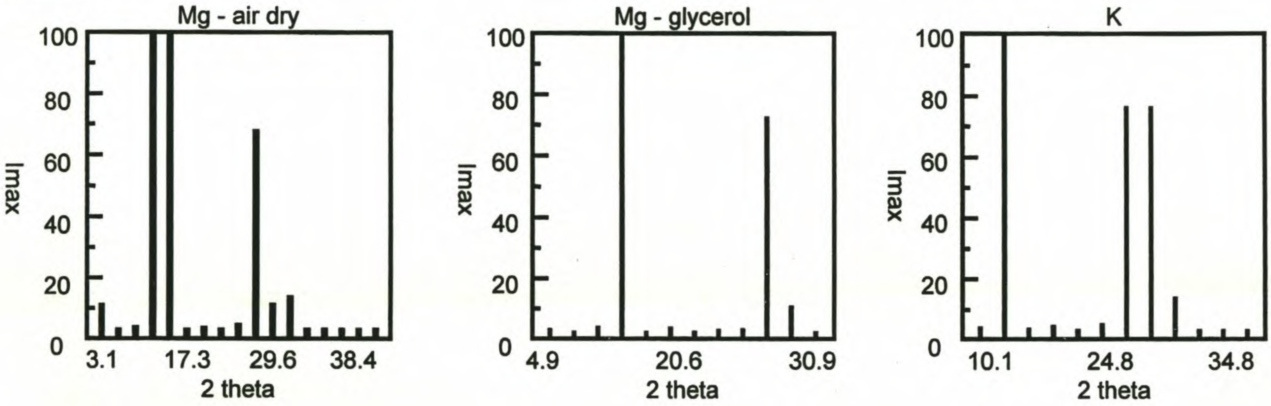
Appendix 5.3: (continued)

## Papegaaiberg Av

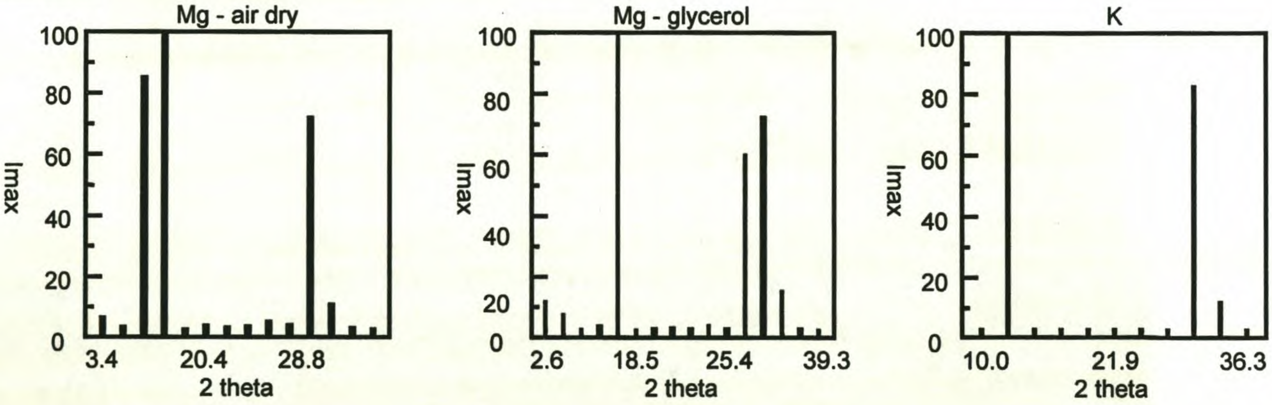
**0 - 25cm**



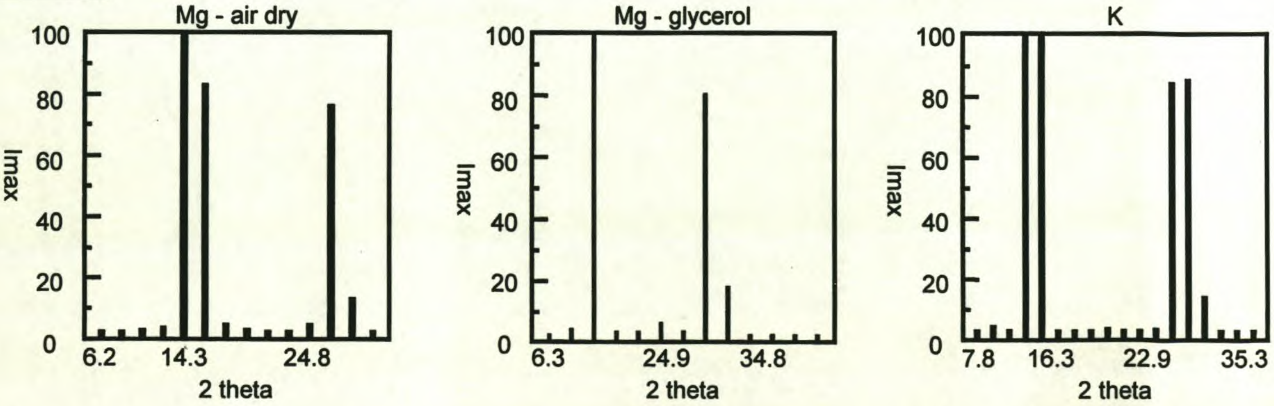
**25 - 60cm**



**60 - 95cm**



**95 - 120cm**



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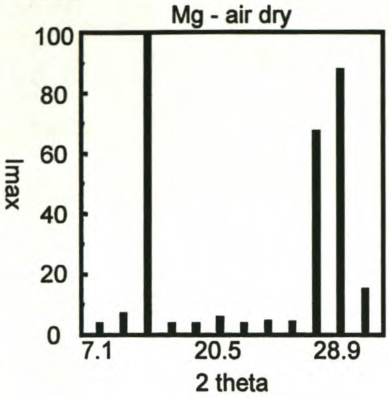
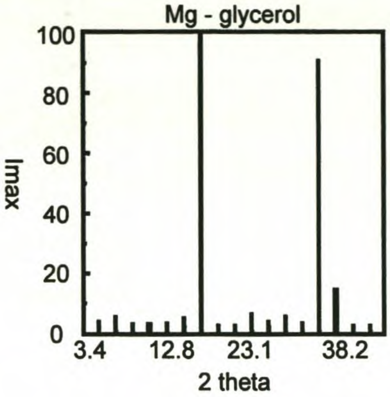
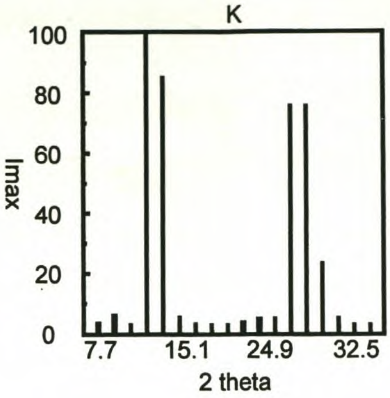
Appendix 5.3: (continued)

## Papegaaiberg Tu

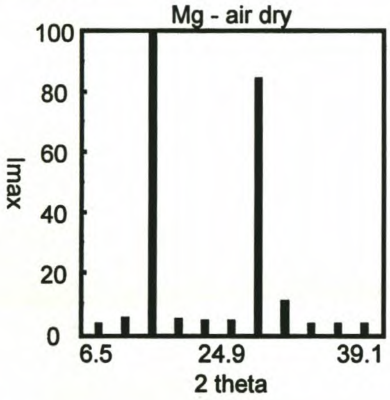
**0 - 25cm**

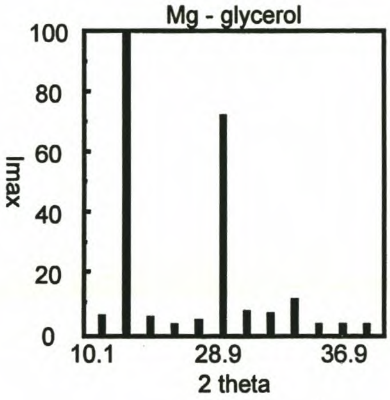


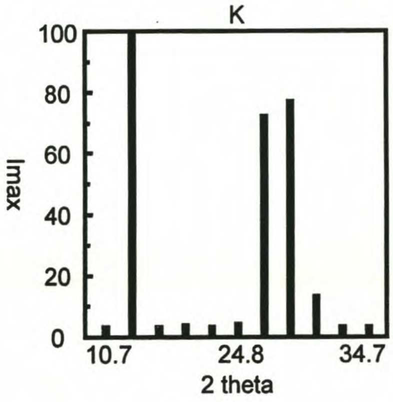




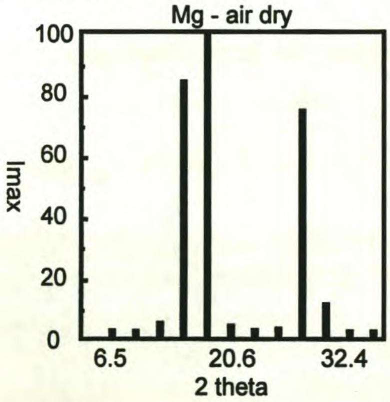
**25 - 50cm**

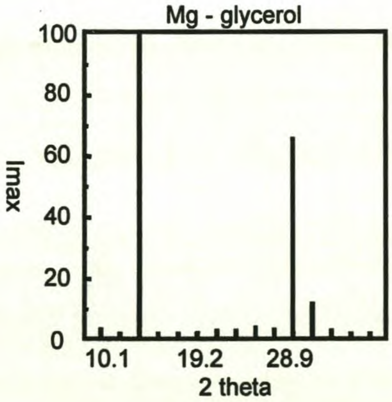


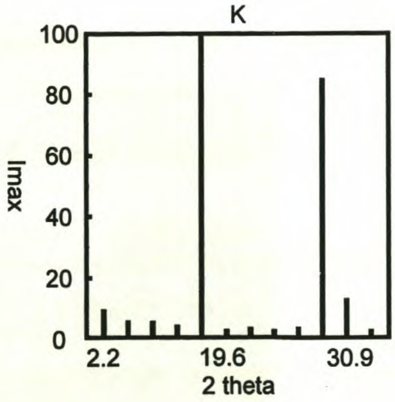




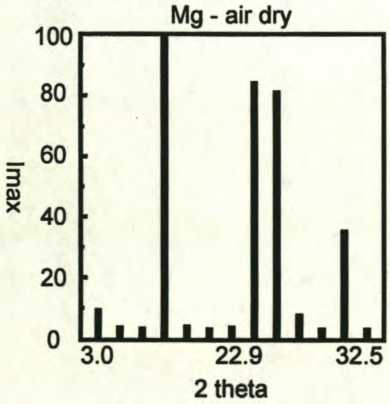
**50 - 80cm**

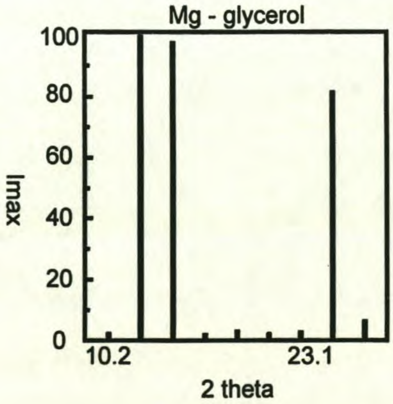


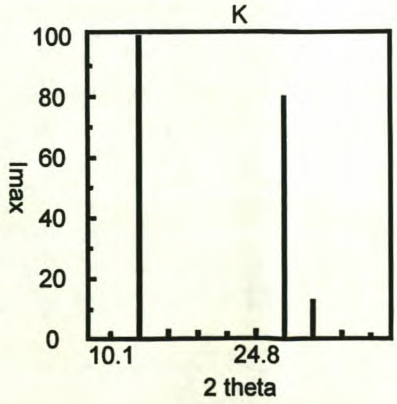




**80 - 130cm**







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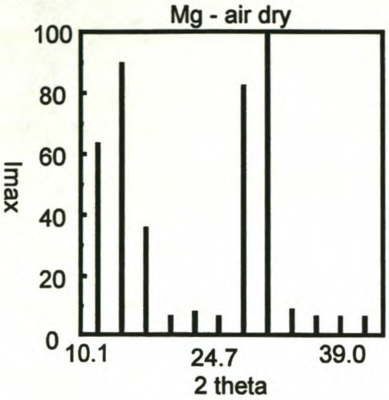
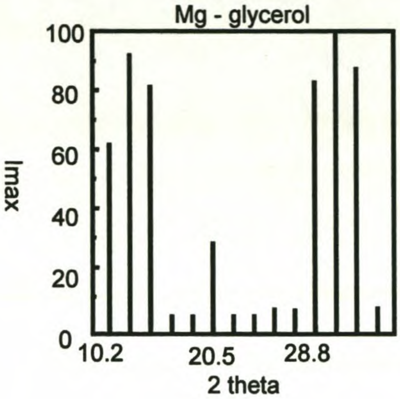
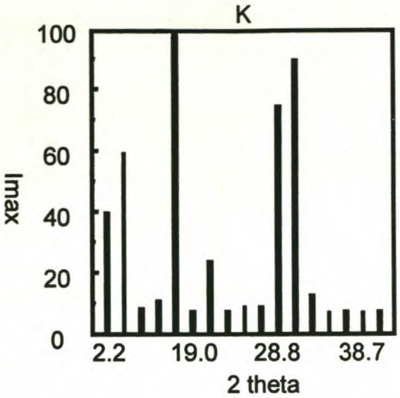
Appendix 5.3: (continued)

## Devon Valley Oa

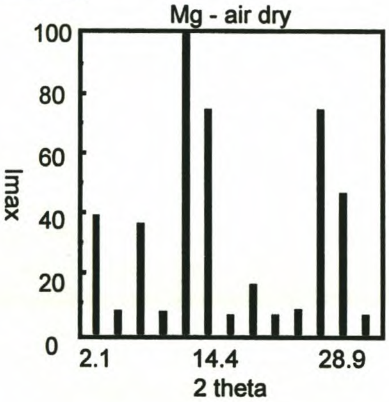
### 0 - 35cm

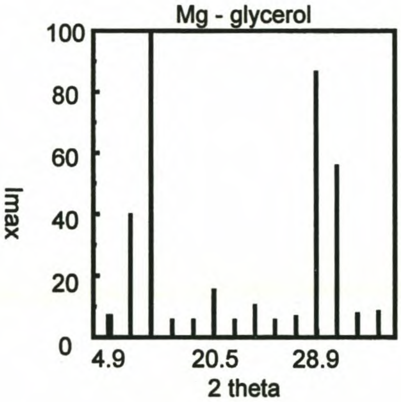

Mg - air dry

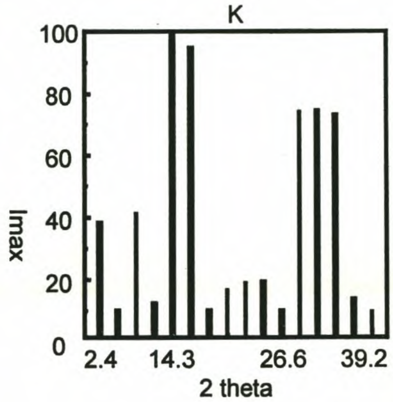

Mg - glycerol


K

### 35 - 70cm


Mg - air dry


Mg - glycerol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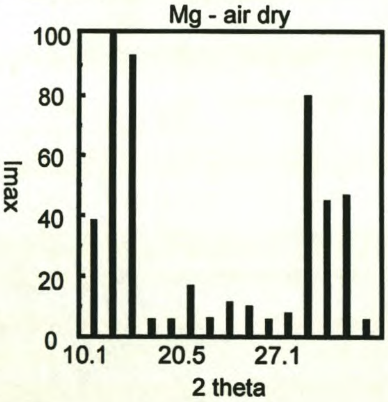
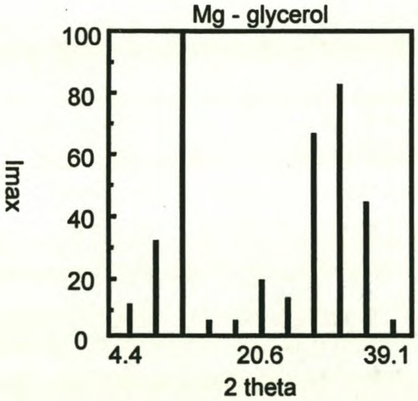
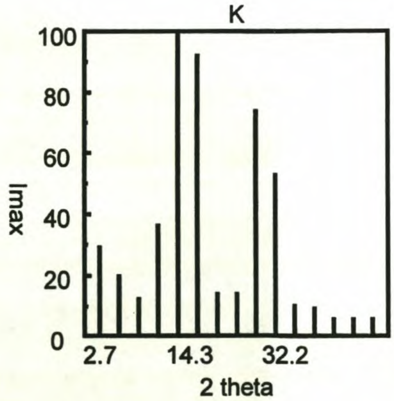
### 70 - 110cm


Mg - air dry


Mg - glycerol

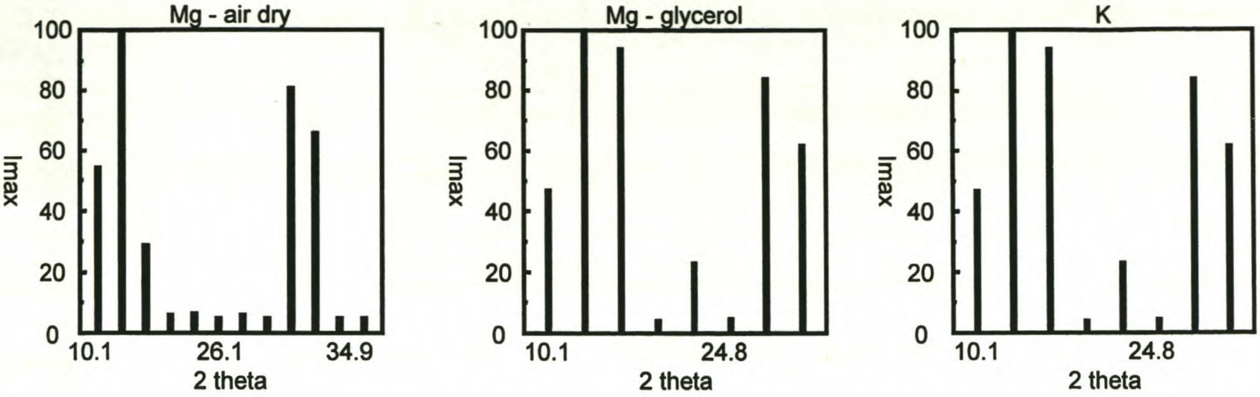

K

Continue on next page

Appendix 5.3: (continued)

## Devon Valley Gs

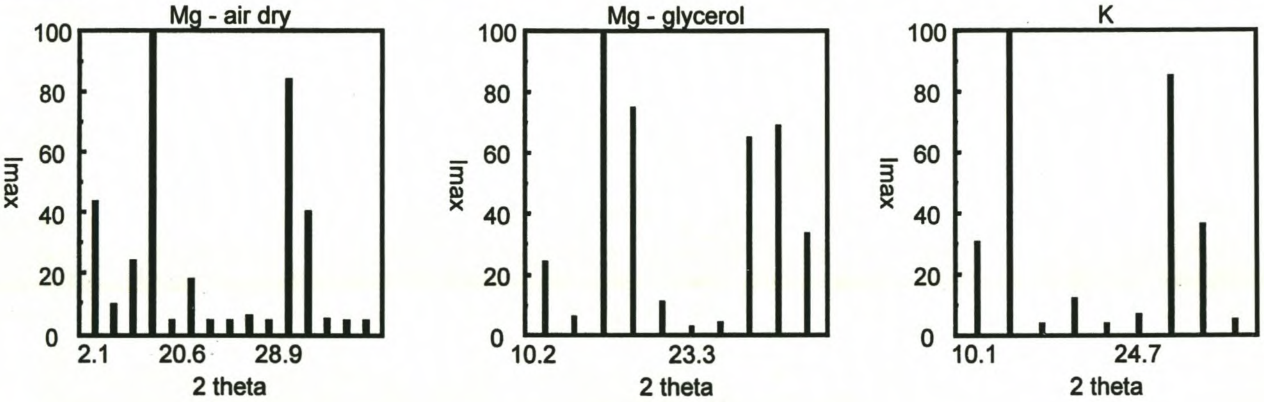
### 0 - 30cm


Mg - air dry

Mg - glycerol

K

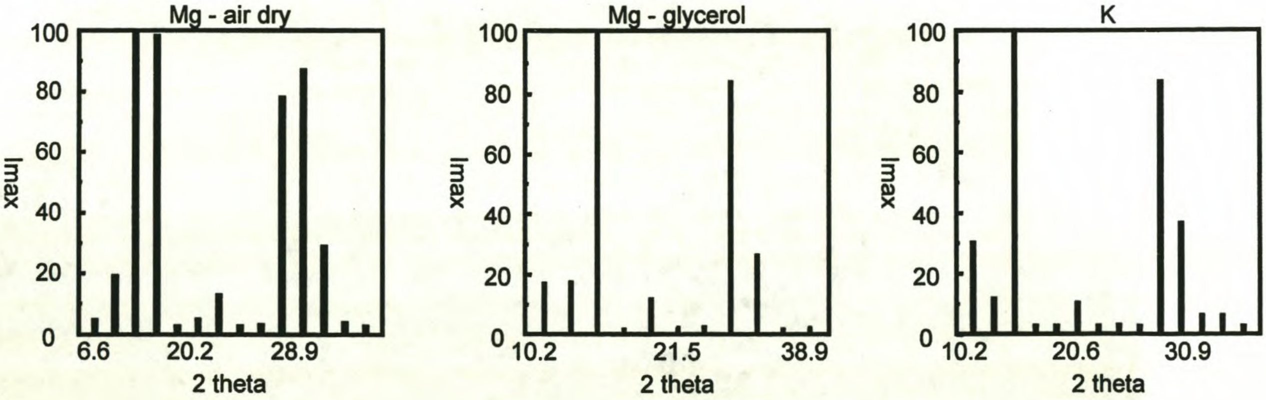
### 30 - 60cm


Mg - air dry

Mg - glycerol

K

### 60 - 110cm


Mg - air dry

Mg - glycerol

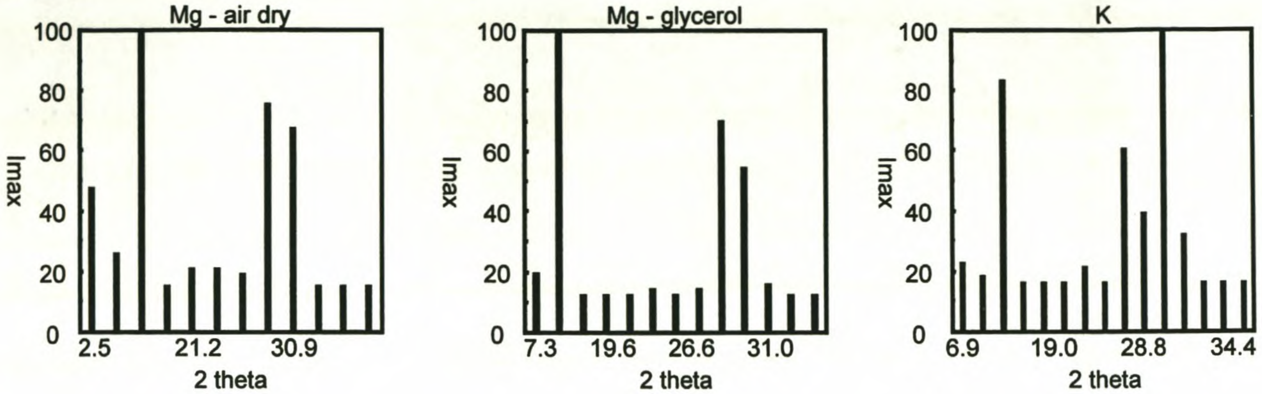
K

Continue on next page

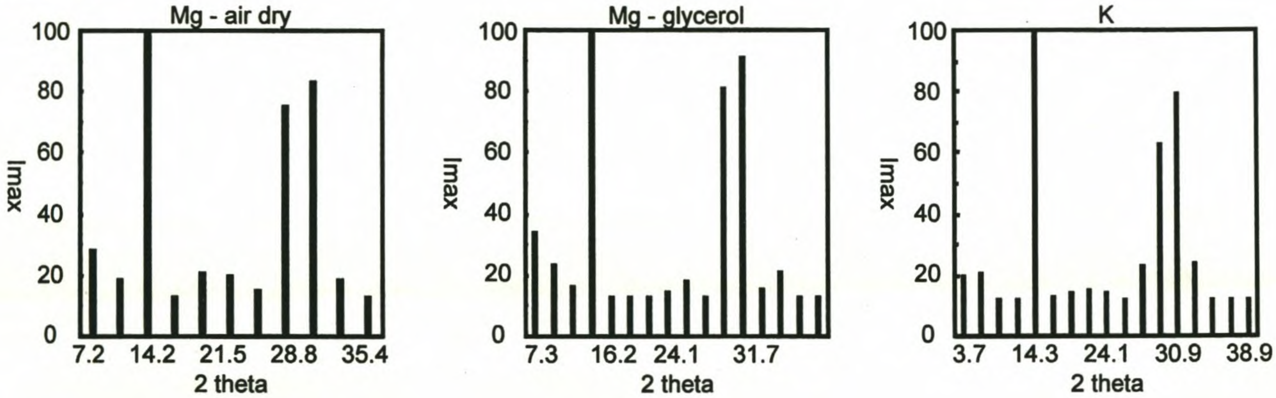
Appendix 5.3: (continued)

## Durbanville We

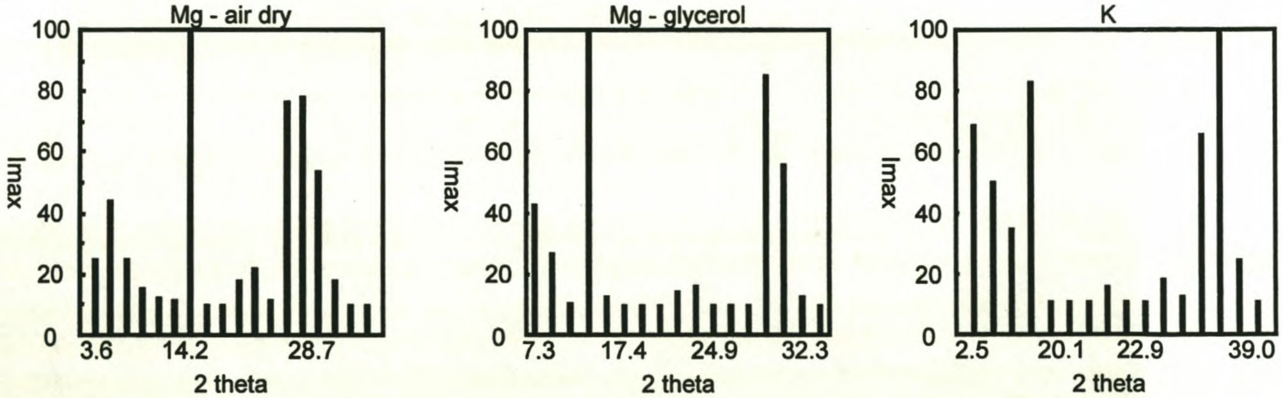
**0 - 30cm**



**30 - 90cm**



**90 - 120cm**



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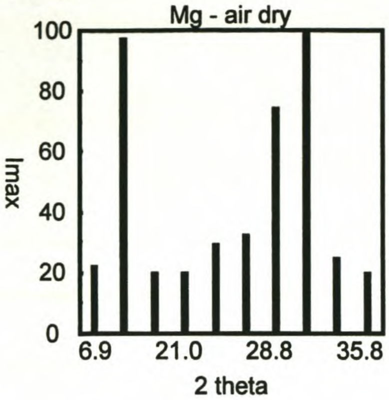
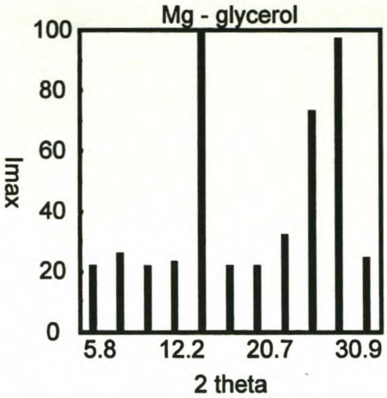
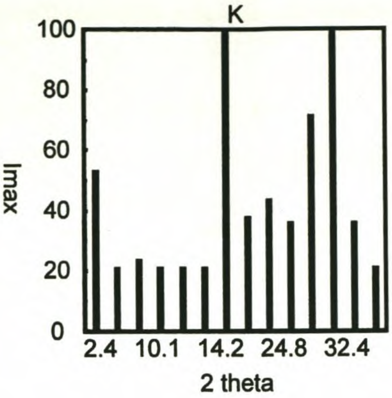
Appendix 5.3: (continued)

## Durbanville Tu

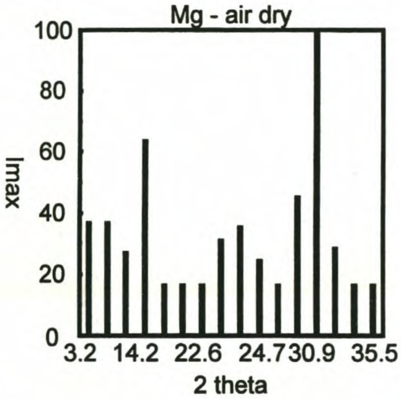
### 0 - 30cm

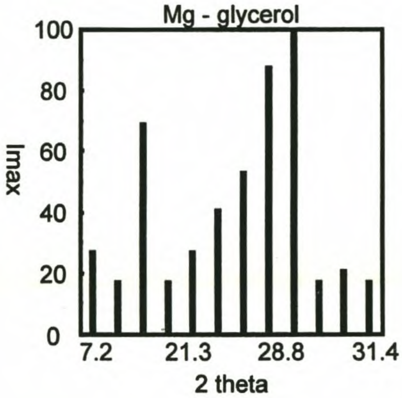

Mg - air dry

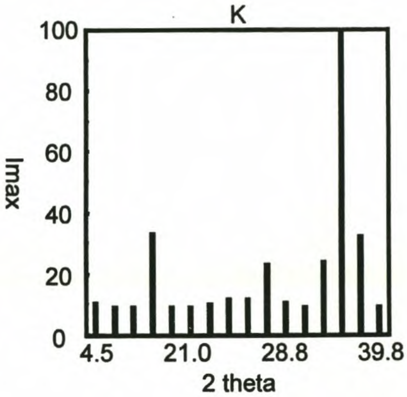

Mg - glycerol


K

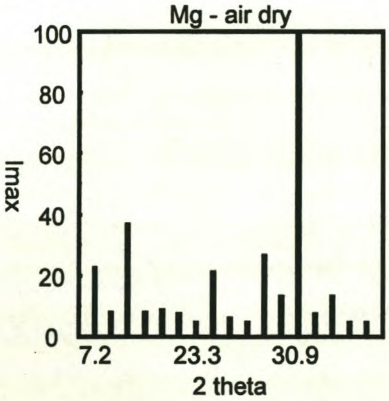
### 30 - 80cm

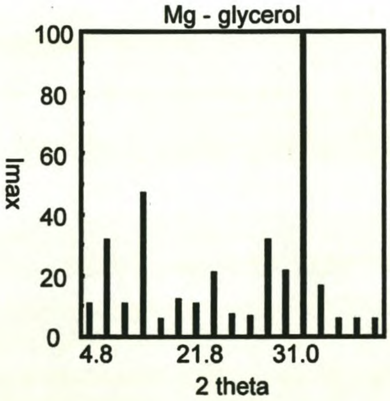

Mg - air dry

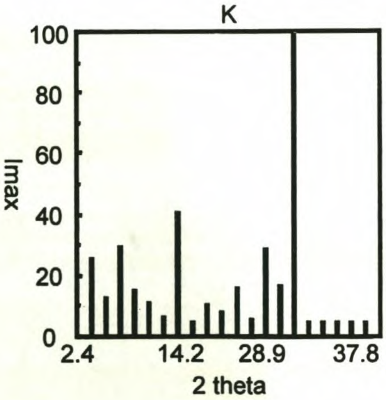

Mg - glycerol


K

### 80 - 130cm


Mg - air dry


Mg - glycerol


K

**Appendix 5.4** Weighted average (up to 100 cm soil depth) clay fraction kaolinite and quartz expressed in total soil volume.

| LOCALITY | SOIL TYPE | AVERAGE CLAY FRACTION KAOLINITE (4 POINT SCALE) IN TOTAL SOIL VOLUME* | AVERAGE CLAY FRACTION QUARTZ (4 POINT SCALE) IN TOTAL SOIL VOLUME |
|---|---|---|---|
| **Simonsberg** | Hu | 1.02 | 0.47 |
| **Simonsberg** | Tu | 1.18 | 0.36 |
| **Kuils River** | Tu | 0.12 | 0.08 |
| **Kuils River** | Vf | 0.42 | 0.14 |
| **Helshoogte** | Oa | 0.28 | 0.55 |
| **Helshoogte** | Hu | 0.44 | 0.47 |
| **Papegaaiberg** | Av | 1.15 | 0.49 |
| **Papegaaiberg** | Tu | 0.85 | 0.26 |
| **Devon Valley** | Oa | 0.58 | 0.29 |
| **Devon Valley** | Gs | 0.38 | 0.18 |
| **Durbanville** | We | 0.38 | 0.36 |
| **Durbanville** | Tu | 0.13 | 0.19 |

* Clay fraction mineral x clay (%) x [(100 – (total gravel and stone (%))/100]

# CHAPTER 6

# EFFECT OF SOIL PROPERTIES ON VINE GROWTH AND WINE QUALITY AND CHARACTER

## 6.1 INTRODUCTION

The objective of this Chapter is to investigate the relationships between soil properties, as determined in this study, and vine growth and wine quality and character, which characteristics were determined as part of the broader multidisciplinary research project. In the first part results obtained in the multidisciplinary project will be reported. Shoot mass and wine quality data are from unpublished NCVW-research reports dated 1993 to 1998, of the multidisciplinary study. The objective of the second part is to try and relate soil property parameters with wine properties and parent material.

## 6.2 VINE GROWTH AND WINE QUALITY AND CHARACTER

Average shoot mass obtained for Sauvignon blanc on the different soils during the period 1993 to 1998, are presented in Table 6.1. Shoot mass varied from 1.68 tonnes ha$^{-1}$ for Papegaaiberg Tu, to 3.61 tonnes ha$^{-1}$ for Helshoogte Hu. In view of the fact that readily available water (RAW) was higher for Papegaaiberg Tu (161 mm) than for Helshoogte Hu (145 mm) (Table 4.3), this result is unexpected. However, apart from the restrictive effect that low RAW will have on vegetative growth, other factors such as soil physical/soil chemical/climatic limitations can also play a role. For Papegaaiberg Tu, a shallow rooting depth probably restricted effective utilization of available soil water. Within a specific locality, however, shoot mass generally tended to be lower for the soil with the lowest RAW, where water stress was the highest. Highest shoot masses were obtained for Helshoogte Oa, Helshoogte Hu and Durbanville We, where organic C exceeded 1.6% (Appendix 5.1). Vegetative growth was apparently enhanced by the higher N-supplying capacities as well as improved soil structure (as a result of more organic material) of these soils. In the case of Kuils River Tu, however, shoot mass was also high, in spite of relatively low organic material (0.8% C in topsoil). Relatively luxurious shoot growth in this case can be ascribed to the soil being without any physical restrictions and to deep root distribution (Conradie, 1998).

The most representative wine aroma characteristics, as well as overall wine quality, are presented in Table 6.2. In order to interpret Table 6.2, it should be borne in mind that an aroma component should receive a score of higher than 2.5, in order to be reasonably prominent. If Sauvignon blanc grows relatively luxuriously, fresh vegetative character will be dominant. When vines are subject to water stress, fresh vegetative character usually decreases, with a concomitant increase in cooked vegetative character.

**Table 6.1** Average shoot mass for Sauvignon blanc on the different soils for the period 1993-1998 (after Conradie, 1998).

| LOCALITY | SOIL TYPE | MEAN SHOOT MASS (tonnes $ha^{-1}$) | MEAN SHOOT MASS (kg $vine^{-1}$) |
|---|---|---|---|
| **Simonsberg** | Hu | 2.46 | 0.68 |
| **Simonsberg** | Tu | 2.60* | 0.72 |
| **Kuils River** | Tu | 3.33 | 0.83 |
| **Kuils River** | Vf | 2.76* | 0.69 |
| **Helshoogte** | Oa | 3.46 | 0.96 |
| **Helshoogte** | Hu | 3.61* | 1.00 |
| **Papegaaiberg** | Av | 2.09 | 0.58 |
| **Papegaaiberg** | Tu | 1.68* | 0.47 |
| **Devon Valley** | Oa | 2.94 | 0.98 |
| **Devon Valley** | Gs | 2.50* | 0.83 |
| **Durbanville** | We | 3.32 | 1.19 |
| **Durbanville** | Tu | 2.58* | 0.92 |

* Vines on these soils showed more water stress when compared to the vines on the other soils at the same locality

**Table 6.2** Most representative wine aroma characteristics and overall wine quality for Sauvignon blanc from different soils for the period 1993-1998 (after Conradie, 1998).[1]

| LOCALITY | SOIL TYPE | WINE AROMA CHARACTER (10-point scale) | | | WINE QUALITY (9-point scale) |
|---|---|---|---|---|---|
| | | VEGETATIVE: FRESH[2] | VEGETATIVE: COOKED[3] | FRUITY: TROPICAL[4] | |
| **Simonsberg** | Hu | 1.9 | 2.3 | 1.9 | 4.5 |
| **Simonsberg** | Tu | 2.5 | 1.2 | 3.7 | 4.9 |
| **Kuils River** | Tu | 3.2 | 3.3 | 1.1 | 6.7 |
| **Kuils River** | Vf | 2.5 | 4.3 | 1.1 | 6.1 |
| **Helshoogte** | Oa | 4.0 | 2.7 | 2.8 | 6.0 |
| **Helshoogte** | Hu | 3.6 | 3.6 | 2.3 | 5.4 |
| **Papegaaiberg** | Av | 2.4 | 1.3 | 2.4 | 4.9 |
| **Papegaaiberg** | Tu | 1.7 | 2.0 | 3.1 | 3.8 |
| **Devon Valley** | Oa | 2.7 | 2.4 | 2.4 | 4.4 |
| **Devon Valley** | Gs | 1.9 | 2.8 | 2.0 | 4.8 |
| **Durbanville** | We | 1.3 | 3.2 | 0.8 | 5.7 |
| **Durbanville** | Tu | 3.4 | 4.2 | 1.8 | 6.6 |

[1] Wines were produced and tested for quality and character using standard NCVW procedures.
[2] Grass/green pepper/blue gum
[3] Green bean/asparagus/green olive
[4] Pineapple/sweet melon/banana/guava

If water stress becomes very severe, vegetative character (both fresh and cooked) may almost be entirely lost and the resulting wine may only have a slight fruity (tropical) character. Such a wine cannot be regarded as a "typical" Sauvignon blanc. However, overall wine quality is affected by many factors and cannot always be predicted from the aroma profile. The "ideal" Sauvignon blanc wine should have the correct balance (as yet undefined) between fresh vegetative, cooked vegetative and fruity character. In comparison to the cooler European countries, the fresh vegetative character of Sauvignon blanc wine from South Africa tends to be low, and experience has shown that a relatively high fresh vegetative character is usually associated with high overall wine quality. If the score for overall wine quality (9-point scale) exceeds 5.4 (equivalent to 60%) a wine may be regarded as being of relatively high quality.

At the Simonsberg locality, mean shoot mass for the two soils are very similar (Table 6.1), although vines on the Tukulu soil showed slightly more water stress (Conradie, 1998). Wines produced from these soils (Table 6.2) showed low fresh vegetative and cooked vegetative characters and low overall quality. Compared to Simonsberg Hu, the vines from Simonsberg Tu (with more water stress) showed more tropical character. In general, the tasting panel did not regard these wines as being typical of Sauvignon blanc (Conradie, 1998).

Higher shoot mass of Kuils River Tu, in comparison to Kuils River Vf (Table 6.1), indicated more luxurious vegetative growth in the case of the former. This is in agreement with vines on Kuils River Vf being subjected to higher water stress. These conditions led to a lower fresh vegetative character and a higher cooked vegetative character, in the case of Kuils River Vf. Overall wine quality was high for both soils, even though Kuils River Tu tended to be slightly superior. These results illustrated that two wines of completely different styles, albeit both of high quality, can be obtained in the same vineyard. Parent material did not differ and the two sites were only 50 m apart. The differences could be ascribed to better root distribution and a larger soil volume in the case of Kuils River Tu.

At Helshoogte, vegetative growth was similar for both soils (Table 6.1), in spite of higher water stress experienced by vines on the Hutton soil, especially during the latter part of the growing season (Conradie, 1998). The higher water stress experienced by the vines on the Hutton soil resulted in a wine with a lower fresh vegetative, and a higher cooked vegetative character. Wines from both soils showed high overall quality (with the Oa being slightly better than the Hu) and were regarded as being typical examples of Sauvignon blanc wines (Conradie, 1998).

At Papegaaiberg, vines on the Avalon soil showed more vegetative growth in comparison to the Tukulu (Table 6.1). Vines on the latter soil had a poor root distribution, leading to high water stress (Conradie, 1998). Wines from both soils showed low fresh vegetative and cooked vegetative characters, while fruity character was relatively high. As already pointed out, such an aroma profile cannot be regarded as being typical of a good Sauvignon blanc wine. Consequently, poor overall wine quality (Table 6.2) was obtained for both soils. The main reason for the poor performance may have been the low altitude (148 m) and the fact that this locality is masked from the Atlantic Ocean, thereby restricting the cooling effect of sea breezes (Conradie, 1998). This led to summer temperatures being too high for the production of Sauvignon blanc wines of high quality.

At Devon Valley, higher water stress for vines on the Glenrosa (Gs) soil, led to a lower shoot mass compared to that of vines on the Oakleaf (Oa) soil (Table 6.1). As in the case of Papegaaiberg, higher water stress led to the wine from the Glenrosa soil showing lower fresh vegetative character and higher cooked vegetative character than that of the Oakleaf soil. For both soils, however, aroma profiles could be regarded as fairly acceptable. The low overall wine quality, for both soils, was difficult to explain.

Vines from the Westleigh soil at Durbanville, showed more vegetative growth (Table 6.1) and less water stress, in comparison to the Tukulu soil (Conradie, 1998). The fact that wine from the Westleigh (vigorous growth) showed low fresh vegetative character, was difficult to explain. It is possible that actively growing shoots at harvest may have caused less aromatic compounds to be accumulated in the bunches. In spite of the aroma profile, wine from the Westleigh still received a high score for overall wine quality (Table 6.2). However, wine from the Tukulu was clearly better balanced and received a superior score.

## 6.3 RELATIONSHIPS BETWEEN SOIL PROPERTIES AND VINE GROWTH, WINE QUALITY AND CHARACTER

Readily available water, the predominant clay fraction minerals (kaolinite and quartz), and soil K, were related to vine growth, wine quality and wine character. No significant relationships between RAW and shoot mass, wine quality, or any of the aroma components were found.

Shoot mass, however, was negatively correlated to clay fraction kaolinite at the 99% confidence level (Figure 6.1).

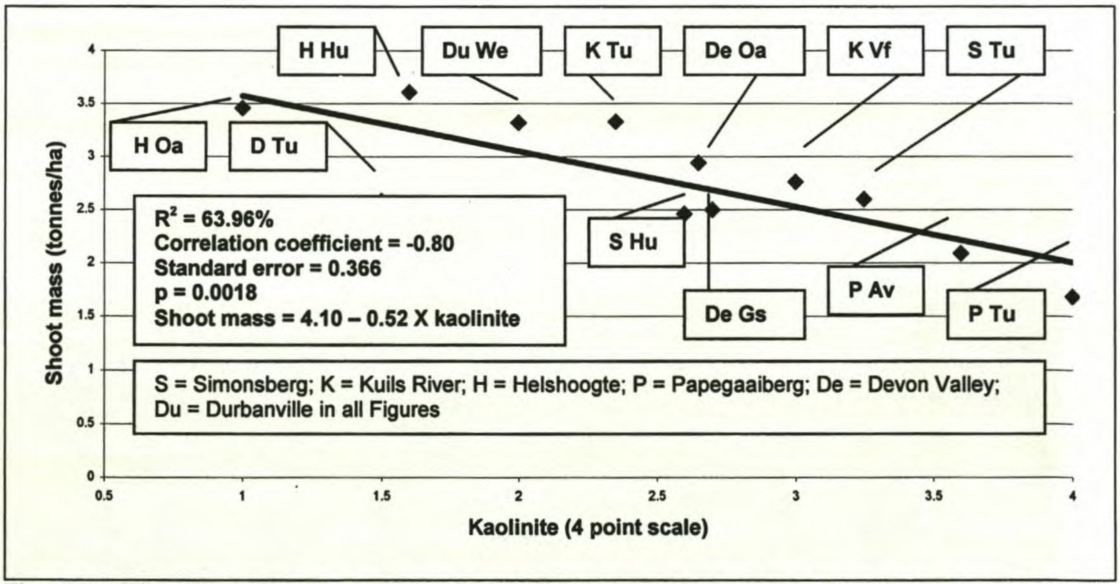


**Figure 6.1** The effect of clay fraction kaolinite (weighted average up to 1 meter soil depth) on shoot mass for the different soils in the study.

The effect of clay fraction kaolinite expressed as clay fraction kaolinite per total soil volume [clay fraction kaolinite (4 point scale) x clay (%) x (100-gravel & stone %)/100] confirmed the above relationship, where clay fraction kaolinite was negatively associated with shoot mass at the 95 % confidence level (R-square = 36.9%) (data not shown). If, as the above data suggested, an increase in clay fraction kaolinite is associated with less vigorous shoot growth, the fresh vegetative character of wine should decrease at higher kaolinite concentrations. This is confirmed by Figure 6.2.

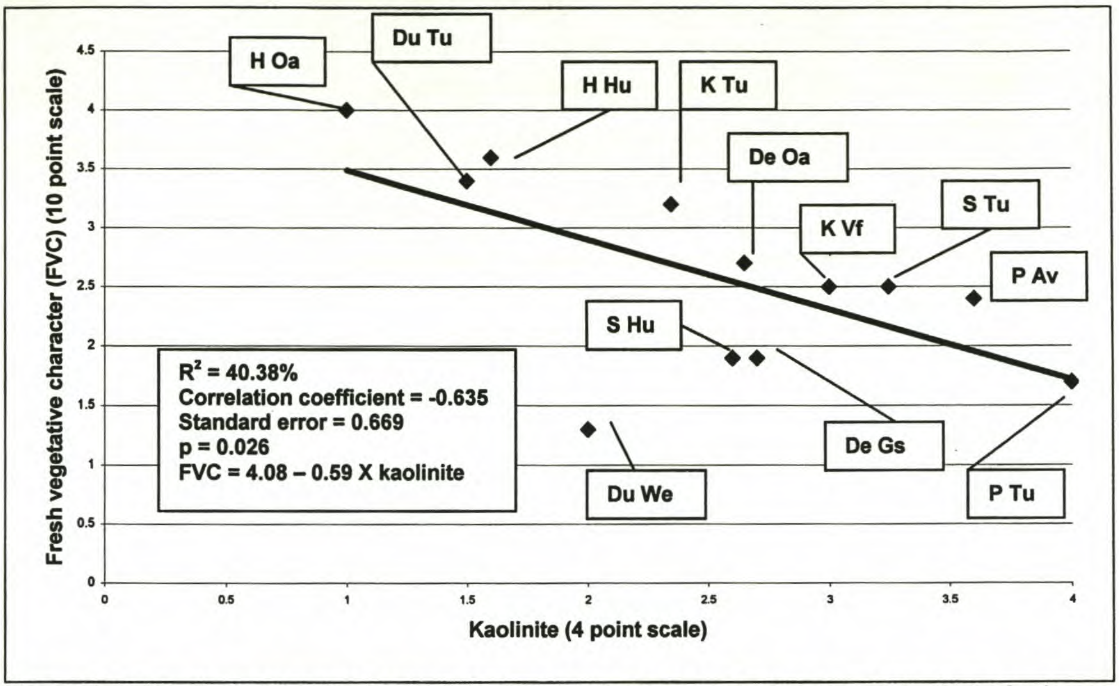


**Figure 6.2** The effect of clay fraction kaolinite (weighted average up to 1 meter soil depth) on fresh vegetative character (FVC)for the different soils in the study.

Clay fraction kaolinite expressed in terms of total soil volume (data not shown) indicated a similar trend, although the relationship was weak (R-square = 19.01%, significance level: 90 %). As already discussed, the fresh vegetative character of Sauvignon blanc wine from South Africa tends to be low. Any factor, in this case a reduction in clay fraction kaolinite, associated with an increase in fresh vegetative character should therefore also induce an increase in overall wine quality. Figure 6.3 confirms such a relationship between clay fraction kaolinite and vegetative growth.

Clay fraction kaolinite expressed in terms of total soil volume (data not shown) confirmed this relationship at the 99 % confidence level (R-square = 53.1 %).

Clay fraction quartz, however, was negatively associated with clay fraction kaolinite (Figure 6.4). If a reduction in clay fraction kaolinite is correlated with increased shoot growth and higher wine quality, the reverse may be expected for clay fraction quartz. Even though no significant relationship existed between clay fraction quartz and shoot mass or fresh vegetative character, an increase in clay fraction quartz correlated with an increase overall wine quality (Figure 6.5).

Clay fraction quartz expressed in terms of total soil volume (data not shown) showed a similar trend (p = 0.33), but the relationship was weak (R-square = 10 %). The seemingly positive

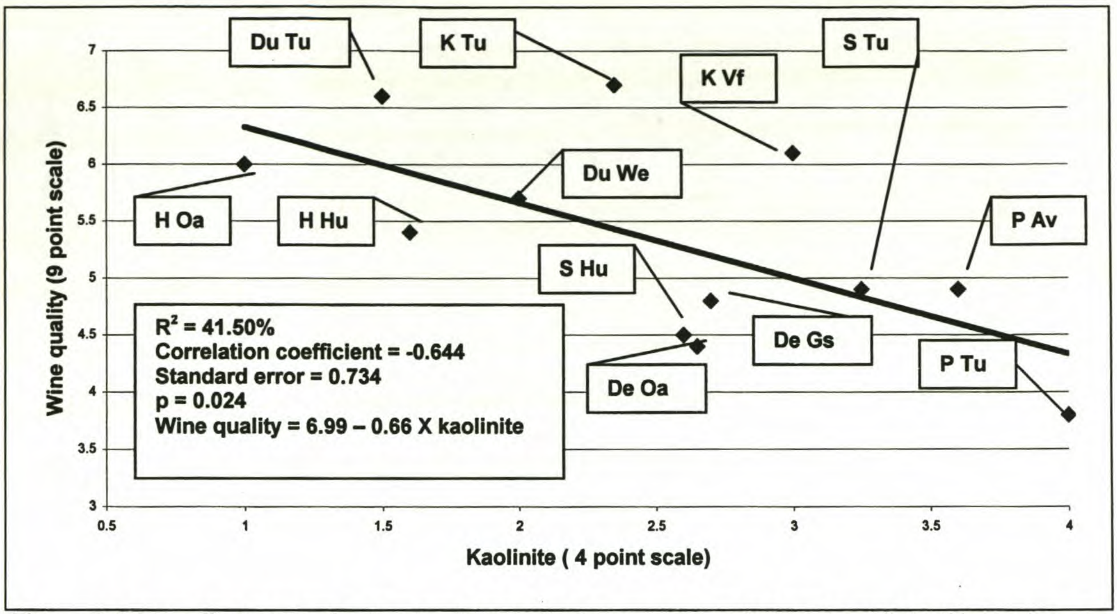


**Figure 6.3** The effect of clay fraction kaolinite (weighted average up to 1 meter soil depth) on wine quality for the different soils in the study.

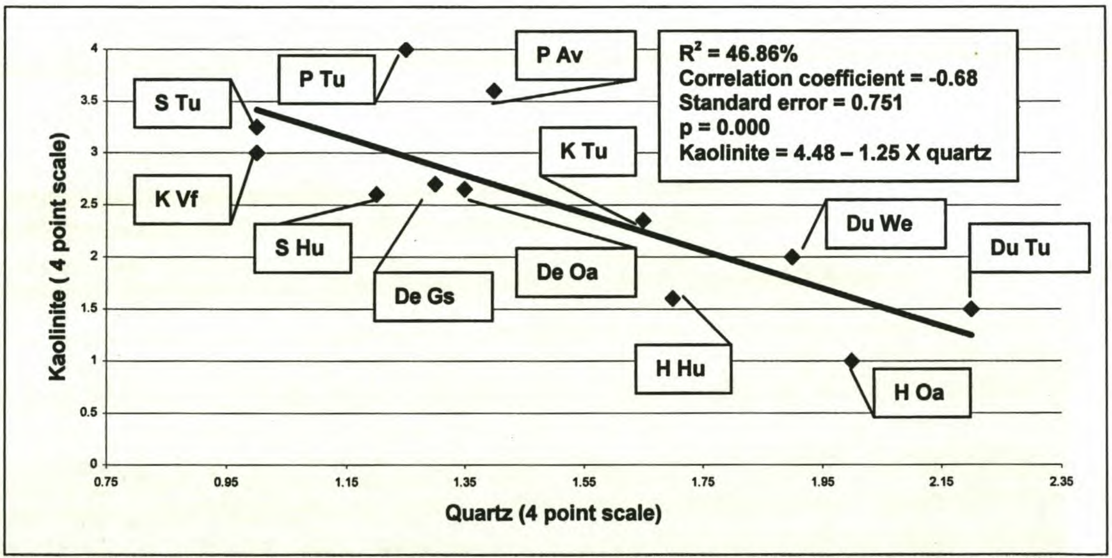


**Figure 6.4** Relationship between clay fraction quartz and kaolinite as weighted averages up to 100 cm for the different soils in the study.

effect of clay fraction quartz on overall wine quality and the negative effect of clay fraction kaolinite on vine growth, overall wine quality and fresh vegetative character is difficult to explain. As only twelve observations were used in this study, further studies regarding the effect of clay mineralogy on vine growth and wine quality should be conducted. This could include studies on the effect of low plasticity and cohesion of soil kaolinite (Brady, 1984) on soil structure and vineyard performance.

It is a well recognized fact that soil K has considerable effects on the acid balance in grape juice and on the pH of the resulting wine (Conradie & Saayman, 1989).

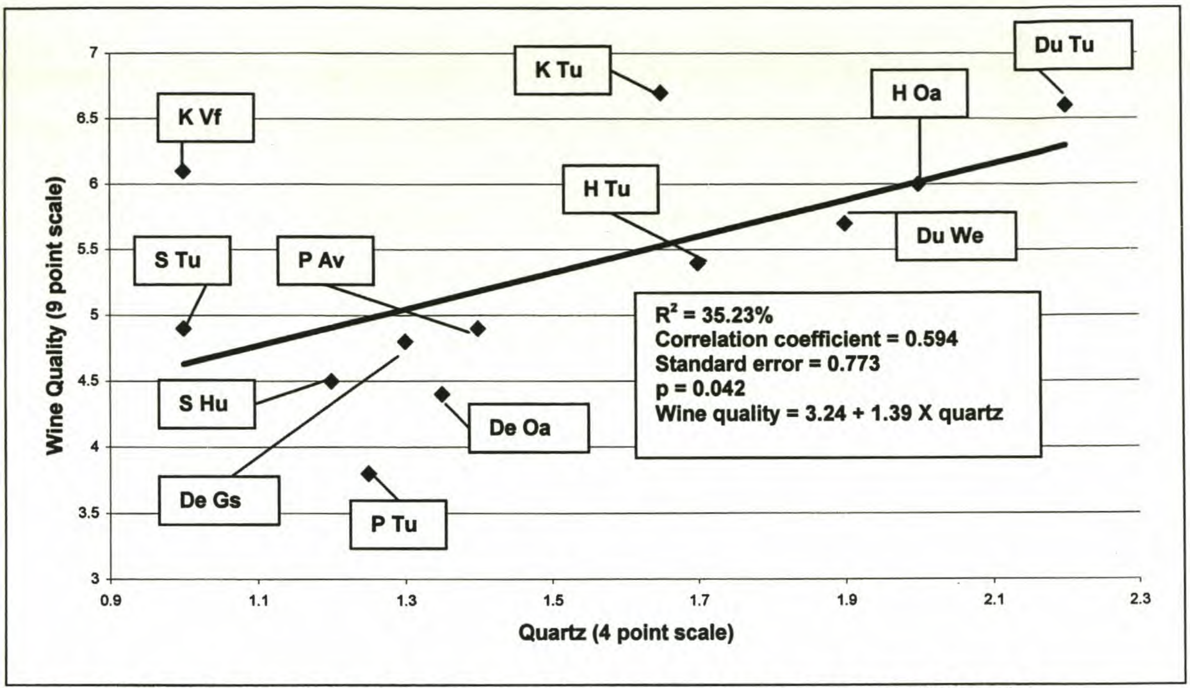


**Figure 6.5** The effect of clay fraction quartz (weighted average up to 1 meter soil depth) on wine quality for the different soils in the study.

Especially in warmer countries a high level of soil K may lead to wine with a high pH, thereby reducing quality (Somers, 1975). In other cases, however, the response of grapevines to soil K will be affected by factors such as the clay content of the soil, K-saturation of the exchange complex and K/Mg ratios in the soil (Etourneaud & Loué, 1984). In the current investigation high levels of lower horizon K was associated with high levels of clay fraction kaolinite (Figure 5.2). High levels of K may, therefore, have been partly responsible for lower wine quality obtained on soils with high levels of clay fraction kaolinite. However, levels of soil K, especially in the topsoil, will be affected by K-fertilization. As uptake of K occurs largely in topsoil, K-levels in subsoils will not necessarily be reflected in wine quality. This was probably the reason why no significant relationship between lower horizon K and wine quality could be found for the different localities in the study. Levels of soil K for the different localities are shown in Table 6.3. At each locality the rate at which K was applied as fertiliser, was the same across the entire production block. The soils at both sites at each locality therefore received the same amount of K.

The K values shown in Table 6.3 refer to weighted averages per locality, calculated to a depth of I meter. The highest value (193 mg $kg^{-1}$) was found at Papegaaiberg, where wine quality was lowest. At Durbanville, where wine quality was high, K-content (82 mg $kg^{-1}$) was lowest. Relatively low K-contents were also obtained for two other localities (Kuils River and Helshoogte) with low clay fraction kaolinite and high wine quality. In spite of soil K levels being confounded by K-fertilization, a trend towards higher wine quality at lower K-levels was, therefore, still discernible. Low levels of soil K in soils with low levels of clay fraction kaolinite may thus have been partly responsible for the high wine quality obtained on such soils.

**Table 6.3** Mean values for soil K for the different localities (weighted average per locality, to a depth of 1 meter).

| Locality | Soil K (mg kg$^{-1}$) |
|---|---|
| **Simonsberg** | 120ab[1] |
| **Kuils River** | 104ab |
| **Helshoogte** | 101ab |
| **Papegaaiberg** | 193c |
| **Devon Valley** | 123b |
| **Durbanville** | 82a |

[1] Values followed by the same letter do not differ significantly ($p \leq 0.05$)

Current results from the broader multidisciplinary research project regarding the effect of climate on wine quality have already indicated that altitude, distance from the sea, sea-breezes and aspect, amongst others, play a major role (Carey, 2001). Some of these factors were compared against clay fraction kaolinite and clay fraction quartz. Kaolinite showed a statistically significant negative relationship with altitude at the 95% confidence level (Figure 6.6).

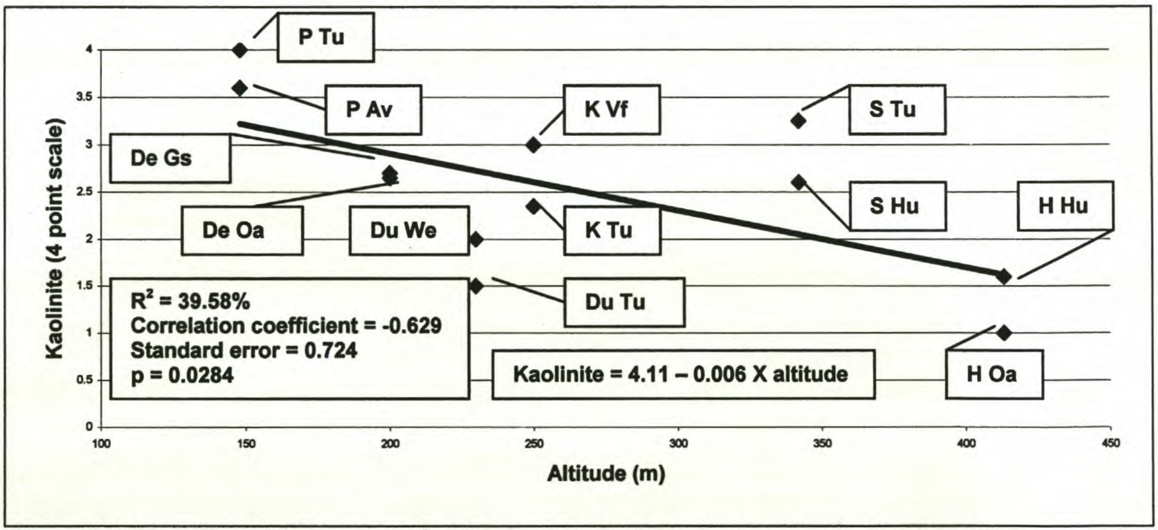


**Figure 6.6** The effect altitude on clay fraction kaolinite (weighted average up to 1 meter soil depth) for the different soils in the study.

In conjunction with the above (lower clay fraction kaolinite at higher altitudes) it may be postulated that increased shoot mass and a higher fresh vegetative character was found at higher altitudes (Figure 6.7). On lower altitude localities, where more clay fraction kaolinite occurred in soils, less fresh vegetative character was found in Sauvignon blanc wines, in comparison to higher altitude localities (Figure 6.8).

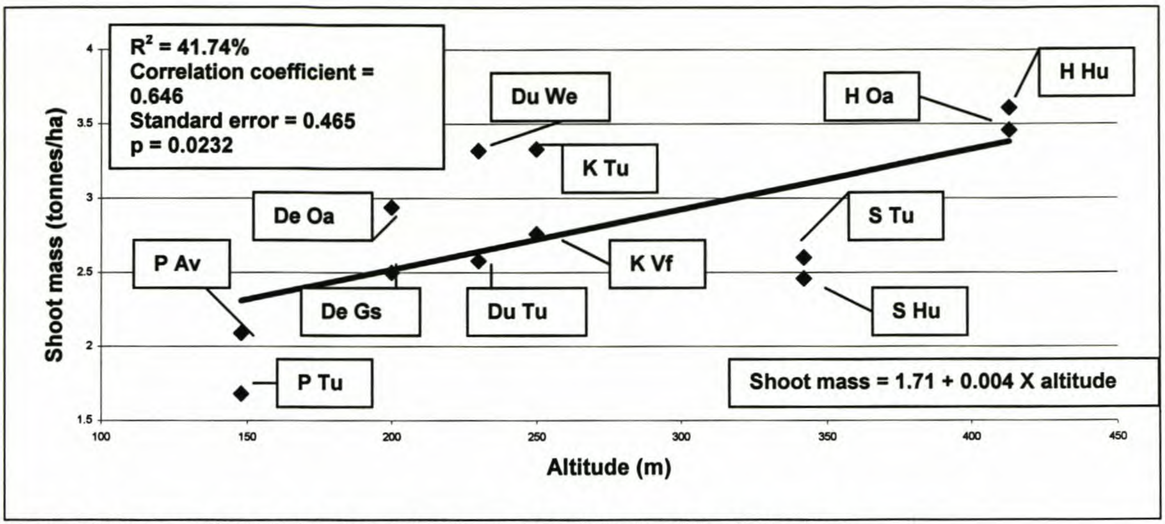


**Figure 6.7** The effect of altitude on shoot mass for all the localities in the study.

The linear relationship between distance from the sea and wine quality showed a moderately strong relationship (p = 0.075; R-square = 28.3 %). In this relationship an increase in distance from the sea resulted in a decrease in wine quality. A non-linear relationship at the 99 % confidence level was found between distance from the sea and wine quality (R-square = 82.1 %) also indicated that an increase in distance from the sea affected wine quality negatively.

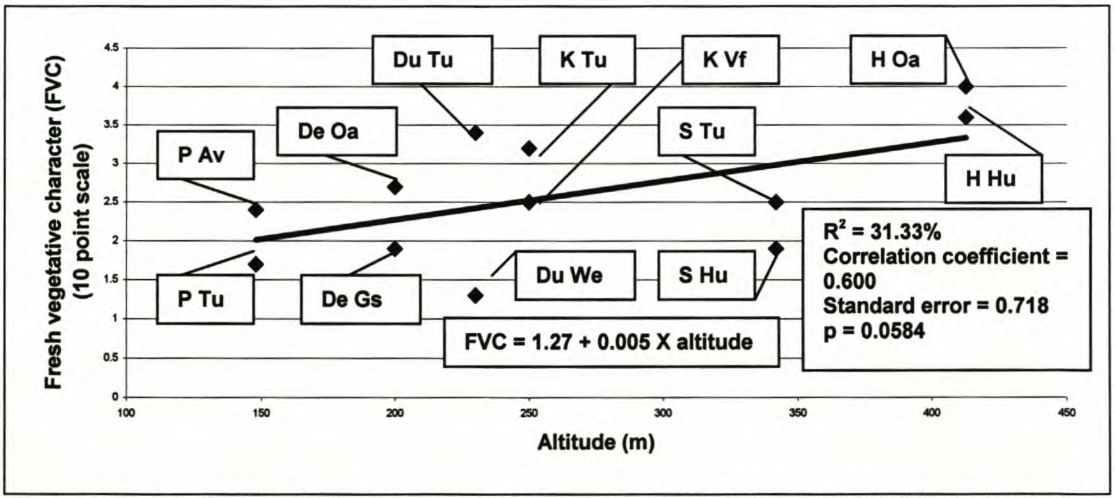


**Figure 6.8** The effect of altitude on fresh vegetative character (FVC) for all the localities in the study.

The positive relationship between fresh vegetative character and high overall wine quality also suggested that, under the conditions of this trial, a relatively high shoot mass should lead to high wine quality. This has been confirmed in Figure 6.9. In South Africa it is generally accepted that grapevines tend to grow too vigorously (mainly due to the warm climate) and that this leads to lower wine quality. In the current trial, however, the more vigorous vines yielded higher wine quality. This apparent anomaly may stem from the fact that growers normally optimise canopy microclimate through a variety of canopy management practices. In such cases high wine quality may be obtained in spite of vigorous growth. Slightly luxuriant growth conditions are, in fact, required by Sauvignon blanc. Different cultivars therefore require different levels of vegetative growth vigour.

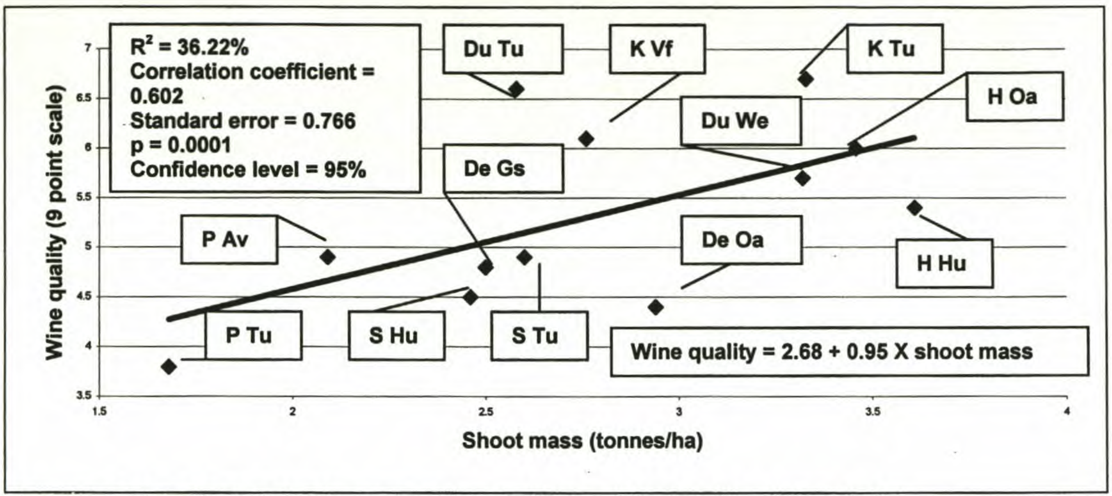


**Figure 6.9** The effect of shoot mass on wine quality for all the localities in the study.

These jointly indicated that altitude plays a major role in linking the six separate localities. Altitude, however, is correlated with temperature. Temperature decreases by about $0.3^0$C for every 100m above sea level in the South-western Cape wine producing areas of South Africa (Le Roux, 1974). This should normally lead to higher wine qualities being obtained at higher altitudes. In the present study the soil with the highest organic C (Helshoogte), was also found at the highest altitude (413m). High soil organic material will definitely affect vine growth and wine quality. Grapevine performance and wine quality are thus demonstrably affected by many factors. Amongst them clay mineralogy is particularly closely linked to wine quality. The results that were obtained during the course of this work indicate the following:

*The higher a locality is situated, the lower is the clay fraction kaolinite content. The higher the locality, the higher the fresh vegetative character in Sauvignon blanc wines. A high clay fraction kaolinite was correlated with lower clay fraction quartz, lower vegetative growth, lower fresh vegetative character and lower wine quality. More vegetative growth also resulted in more fresh vegetative character. More growth occurred at higher altitudes, and higher vegetative growth resulted in higher quality wines.*

Based on the foregoing observations it appears possible that the occurrence of predominant clay fraction kaolinite in soils may be a predictor of lower quality for Sauvignon blanc wines for specific soils. This is probably a reflection of landscape positions in that climatic factors (lower altitudes and further from the sea) are negatively associated with vine growth, fresh vegetative character and overall wine quality. Where clay fraction quartz dominates clay fraction kaolinite in a particular soil, however, the opposite may occur. One should always keep in mind, however, that soil data from only six localities were included in the data set.

## 6.4 PARENT MATERIAL AND WINE QUALITY

Various sources of parent material were identified at the different localities in this study. Wine quality and character also varied between the localities. In this section the contribution of parent material at the different localities to wine quality and character will be discussed in terms of the effects of these parameters on vine performance.

It is important to realise that other soil properties, position of the landscape and climate probably dominated vine performance and that it is suggested that clay fraction mineralogy and geology is to be used only as a tool to identify these factors.

### Simonsberg

This locality is situated on porphyritic biotite granites. Particle size distribution of the sand fractions (Chapter 4) indicated that other parent material, probably sandstone material or eolian sands, were included in the soil parent material. Granites contain high quantities of potassium, but this did not reflect when the lower horizon K was determined, confirming the dilution effect of sandy, K-poor material. Weighted clay fraction mineralogy indicated that the soils at this locality contain predominantly kaolinite. Statistical analyses showed that kaolinite decreased with an increase in altitude. Therefore, this locality (342m) does not fit in the model. The direct effect of kaolinite on wine quality and/or character is at this point unknown, but from the results obtained in this study, the relatively low wine quality obtained at Simonsberg could still be expected from the high clay fraction kaolinite content.

### Kuils River

Particle size distribution indicated that the underlying porphyritic granite dominated the Kuils River soils. A high concentration of K in the lower horizon of the Vilafontes soil confirmed granitic origin, but the Tukulu soil did not reflect the same high K content. The Vilafontes soil was also characterized by more clay fraction kaolinite. From these results it could be expected that the Vilafontes soil would produce lower wine quality, when compared to the Tukulu soil and that the fresh vegetative character from the Tukulu would be stronger. This was confirmed by data in Table 6.1 and Table 6.2. Both soils did produce high quality wines.

### Helshoogte

This locality is situated at the highest altitude (413m), when compared with all other localities. Porphyritic granites underlie the soils, but mixing of K-poor material was also suggested because both soils contained relatively low concentrations of K in the lower horizons and particle size distribution indicated additional finer sand fractions from either sandstone material or eolian processes during soil formation. The clay fraction kaolinite content in these soils was the lowest, when compared with the other localities, and quartz dominated the clay fraction mineralogy. From these data, it was expected that vines from this locality would have a high shoot mass and that wine from this locality would show high quality and strong fresh vegetative character, mainly as result of the low clay fraction kaolinite content, the high clay fraction quartz content, the high altitude and low K-content in the lower horizons of these soils. This prediction was confirmed by wine quality and wine aroma characteristics.

**Papegaaiberg**

Particle size distribution of the sand fraction in soils at this locality indicated that soils were affected not only by underlying hornfels, but also by surrounding granitic material. Both soils contained relatively high concentrations of K in the lower horizons, especially the lower horizon of the Avalon soil. The clay fraction of both soils was dominated by kaolinite, but was relatively higher in the Tukulu soil. More clay fraction quartz occurred in the Avalon soil. With these data, as well as the low altitude of this locality, resulting in high temperatures, it was expected that soils from this locality will produce low quality wines with little fresh vegetative character and poor vine growth. It was also expected that the clay fraction quartz in the Avalon soils would probably increase growth and wine quality, in comparison to the Tukulu soil. This was confirmed by overall wine quality and by wine character.

**Devon Valley**

This locality is situated on hornfels, but granite in close proximity as well as aeolian processes could have played a role in pedogenesis. C horizon potassium concentrations were relatively high. Clay fraction mineralogy analyses indicated that the two soils at this locality are very similar and contain relatively high concentrations of kaolinite (intermediate to dominant quantities). From these results, as well as the relatively low altitude (200m), it was expected that both soils would produce wines of relatively low overall quality, low fresh vegetative character and that vegetative growth would be poor. These predictions were confirmed by data for overall wine quality and for wine character.

**Durbanville**

Particle size distribution of sand indicated that the underlying phyllitic shales dominate soils at this locality. These rocks contain very little potassium and this was confirmed in the analyses of the lower horizon K, although the Westleigh soil contained a higher concentration, when compared with the Tukulu soil. Clay fraction kaolinite occurred in relatively low quantities, when compared to the other localities, except Helshoogte. Clay fraction quartz, however, occurred in significant quantities. From this data it was expected that wines from this locality would be of a high quality and dominated by fresh vegetative character. Vegetative growth would also be high, but high organic matter content probably played an important role in this regard. The Westleigh soil, however, did not fit in this model, as the fresh vegetative character was very low. This was the only soil in the study that contained a low quantity of clay fraction kaolinite, while the resulting wine showed a low fresh vegetative character. As already discussed, this may have been on account of excessive vigour, causing problems with effective ripening of grapes. In the case of the Tukulu, where grapes ripened normally, results fitted expectations.

## 6.5 CONCLUSIONS

For most soils in this study, an increase in clay fraction kaolinite was associated with a reduction in vegetative growth, overall wine quality, and fresh vegetative character. An increase in clay fraction quartz was associated with higher overall wine quality. Increased shoot growth also affected fresh vegetative character positively. Better growth occurred on higher altitudes and this resulted, for Sauvignon blanc, in higher wine quality. Wines produced from vines situated on both phyllitic shales and porhyritic granites showed high quality (Durbanville and Helshoogte), but both were related to low clay fraction kaolinite content and high altitude. It was not possible to relate parent material directly with vine growth, wine quality and/or wine character. The lowest quality wines, however, were produced from vines situated on hornfels (Papegaaiberg and Devon Valley), both containing high quantities of clay fraction kaolinite and situated on low altitudes. High levels of K in soils containing high levels of clay fraction kaolinite may have been partly responsible for low wine quality obtained on such soils.

## 6.6 REFERENCES

BRADY, N.C., 1984. The nature and properties of soils. Ninth Edition. MacMillan Publishing Co., New York.

CAREY, V.A., 2001. Spatial characterisation of natural terroir units for viticulture in the Bottelary-Simonsberg-Helderberg winegrowing area. MSc-thesis. University of Stellenbosch, South Africa. March 2001.

CONRADIE, W.J., 1998. Die kwantifisering van die invloed van grond en klimaat op wynkwaliteit en –karakter met die oog op wetenskaplike gebiedsafbakening. NCVW-1993/98 research report, unpublished, Private Bag X5026, Stellenbsoch 7599. South Africa.

CONRADIE, W.J. & SAAYMAN, D., 1989. Effects of log-term nitrogen, phosphorus, and potassium fertilization on Chenin blanc vines: II. Leaf analyses and grape composition. *Am J. Enol. Vitic.*, 40, 91-98.

ETOURNEAUD, F. & LOUÉ, A., 1984. Le diagnostic petiolaire de la vigne en relation avec l'interpretation de l'analyse de sol pour le potassium et le magnesium. Proceedings of the 6th international colloqium for the optimization of plant nutrition. Vol 2, September, Montpellier, 189-198.

LE ROUX, E.G., 1974. 'n Klimaatsindeling van die Suidwes-Kaaplandse Wynbougebiede. MSc-thesis. University of Stellenbosch, South Africa.

SOMERS, T.C., 1975. In search of quality for red wines. *Food Tech Aust.* **27**, 49-56.